Dissertation

Benchmarking Climate Change Strategies Under Constrained Resource Usage

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Doctor of Philosophy

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Introductory remarks

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Importance of the glossary. Before starting with the first chapter it is recommended to peruse the Glossary on page iii, following the Table of Contents.

Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

This doctoral dissertation presents evidence based research into climate change policy. The research technique of political economy is used to investigate policy development. A major change in the Anglo-American growth paradigm from unconstrained to constrained growth is identified. The implications of this change for climate policy are identified. The political economy of climate change policies is expressed in a new Spatial Climate Economic Policy Tool for Regional Equilibria (Sceptre). This is an innovative benchmarking approach to computable general equilibrium (CGE) that provides a spatial analysis of geopolitical blocs and industry groupings within these blocs. It includes international markets for carbon commodities and geophysical climate effects. It is shown that climate constrained growth raises local policy issues in managing technology diffusion and dysfunctional resource expansive specialisations exacerbated by the creation of global carbon markets.

Acknowledgements

Discipline in the pursuit of enlightenment

Anon. Shinto Philosopher

A doctoral dissertation that covers so many interdisciplinary subjects and takes several years to complete could not be written without the support of many colleagues at the University of Technology Sydney. I would like to thank Assoc. Professor Deepak Sharma for his wise mentorship, perspicacity, candour and friendship. Deepak introduced me to the world of Input Output analysis and general equilibrium modelling, encouraged me in the pursuit of philosophy and political economy, and kept me focused by regularly drawing the discussion back to policy implications.

Deepak's Energy Policy Program has been a jewel of the Faculty of Engineering and Information Technology for eighteen years. I was fortunate to participate in the Energy Modelling module, which provided an excellent foundation to Input Output analysis and resource infrastructure policy. This was complemented by practical studies in Policy Research through the Australian Technology Network (ATN) of Universities LEAP program.

Although my other mentors William Nordhaus and Thijs ten Raa would at present know me only from published comments in the Mathematica support group or through a few emails, they have had a profound influence on my research. William Nordhaus' 2007 book A Question of Balance showed me best practice in assessing climate change policies. Thijs ten Raa's 2006 book The Economics of Input Output Analysis provided a refreshing and exciting paradigm for computable general equilibrium modelling that elevated Input Analysis to a completely new level. My head became filled with exciting new ways to understand the world. My passion to do this led me to an almost singular obsession in implementing Thijs ten Raa's concepts in a Nordhaus-like intertemporal economic-climate model.

Daniel Lichtbau at Wolfram is another dear mentor who constantly amazed me at his knowledge of Mathematica optimisation, ability to obtain answers to esoteric questions from the mysterious halls of Wolfram and his tireless perseverance in responding to me as I pushed many of the limits of Mathematica and its algorithms.

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My colleague Ravin Bagia systems dynamics perspective and always cheerful disposition led to many interesting insights and new ideas. I sincerely hope that Ravin and I can fulfil our plan to develop critical mass in funded policy research using the methods shown in this dissertation.

Lastly, the understanding of my family has made this work possible. My thanks go to my children. To my daughter for deftly wielding her existential blade with elegance and grace and to my son for his practical demonstration of that secret of life that Herculean perseverance along with a good heart brings extraordinary success.

Above all, the patient indulgence of my wonderful partner, Julie, has been beyond the pale of duty and has made this work worthwhile and enjoyable. Julie was the first to read this dissertation and see those things my eyes passed over too quickly. I am truly grateful and humbled by her confidence and ever encouraging smile for me to persevere with yoga.

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Glossary

Abbreviations

Acronym	**Meaning**
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
APEC	Asia Pacific Economic Forum
BAU	Business As Usual
bbl	Barrel of oil (159 litres)
BP	Before (the) Present
Btu	British Thermal Unit (about 1.06 x 10^3 Joules)
C	(degrees) Celsius
CCS	Carbon capture & storage
CDM	Clean Development Mechanism
CEPII	Centre d'Etudes Prospectives et d'Information Internationales
CFCs	Chlorofluorocarbons
Computed General Equilibrium (CGE)	“Computed” means “ascertained or arrived at by calculation or computation; (also) performed or controlled by a computer; computerized” (OED, 2009). A Computed General Equilibrium (CGE) is the result, outcome, state or output of a “Computable General Equilibrium (CGE) model” following calculation or computation. This dissertation draws no distinction between models that are able to be computed and models that have been computed and are represented by their computed state. Therefore the terms “Computed General Equilibrium”, “Computable General Equilibrium” and the acronym “CGE” have the same meaning.
Computable General Equilibrium (CGE) model	“Computable” means “Capable of being computed, calculable; solvable or decidable by (electronic) computation” (OED, 2009). A Computable General Equilibrium (CGE) model is “A general equilibrium model of the economy so specified that all equations in it can be solved analytically or numerically. Computable general equilibrium models are used to analyse the economy-wide effects of changes in particular parameters or policies” (Black et. al.. 2009). See also Computed General Equilibrium (CGE) above.
CH4	Methane
CO2	Carbon Dioxide
CO2e	Carbon Dioxide equivalent see Gt CO_2
Cognitive Behavioural Therapy (CBT)	“A cognitive therapy that is combined with behavioural elements (see behaviour therapy). The patient is encouraged to analyse his or her specific ways of thinking around a problem. The therapist then looks at the

Acronym	Meaning
	resulting behaviour and the consequences of that thinking and tries to encourage the patient to change his or her cognition in order to avoid adverse behaviour or its consequences. CBT is successfully used to treat phobias, anxiety, and depression (it is among the recommended treatments for anxiety and depression in the NICE guidelines)" (Martin, 2007)
COP	Conference of the Parties (of the UNFCCC)
COP15	UNFCCC November 2009 meeting in Copenhagen, Denmark
CRS	Constant returns to scale such that production can be increased or decreased without affecting efficiency
CSIRO	Australian Commonwealth Scientific and Industrial Research Organisation
Data Envelopment Analysis (DEA)	Data Envelopment Analysis is a linear programming technique typically used to measure the technical (in)efficiency of decision making units compared to the units with best practice
DICE	Dynamic Integrated Model of Climate and the Economy
DMU	A decision making unit in Data Envelopment Analysis (DEA)
Effectiveness	The extent to which outputs of service providers meet the objectives set for them
Efficiency	The degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality. This can be assessed in terms of technical efficiency (conversion of physical inputs such as labour and materials into outputs), allocative efficiency (whether inputs are used in the proportion which minimises the cost of production) and dynamic efficiency (degree of success in altering technology and products following changes in consumer preferences or productive opportunities)
EU	European Union
EU25	Twenty five countries of the EU in 2004, prior to its 2007 expansion to Bulgaria and Romania
ETR	Ecological/ Environmental Tax Reform
ETS	Emissions trading scheme, which may be either a differential structure as introduced in European Union countries, or an absolute structure where emitters must purchase emissions permits in order to pollute the atmosphere with greenhouse gases
gg	Grammes (grams)
G5	Major emerging economies, comprising Brazil, India, China, Mexico and South Africa
G8	Group of 8, comprising Canada, France, Germany, Italy, Japan, Russia, United Kingdom, United States
G20	Group of 20, comprising Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, United Kingdom, United States,

Acronym	Meaning
	European Union. In September 2009, the G20 announced it would be the world's peak economic policy body, replacing the G8.
gC	Grams of Carbon (see GgC)
Gg	Giga-grammes (grams)
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GHG	Greenhouse Gases
Global warming potentials	CO_2 (1), CH_4 (21, although a recently detected reaction with aerosols now suggests 33), N_2O (310), CF_4 (6,500), C_2F_6 (9,200), SF_6 (23,900), HFC-143a (3,800), HFC-23 (11,700), HFC-125 (2,800), HFC-134a (1,300), HFC-143a (3,800)
GJ	Gigajoules
Gt	Gigatonnes
GtC	Gigatonnes of Carbon
Gt CO2	Gigatonne of CO_2 (3.67 Gt CO_2 has the same carbon content as 1 GtC. The factor of 3.67 represents the ratio of the molecular weight of CO_2 , which is 44.009, to the atomic weight of carbon, which is 12.011, see Oak Ridge National Laboratory (Carbon Dioxide Information Analysis Center 1990, Table 3) and Clark (1982, p467))
GTAP	Global Trade Analysis Project (Purdue University)
GTEM	Global Trade & Environment Model
HCFC	Hydro-Chloro-Fluoro-Carbon
HFC	Hydro-Fluoro-Carbon
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
IMAGE	Integrated Model to Assess the Greenhouse Effect
IPCC	Intergovernmental Panel on Climate Change, based in Geneva, Switzerland. In 2007, the IPCC and Al Gore shared the Nobel Peace Prize
IRIO	Interregional Input Output Model (see also MRIO)
Kyoto Protocol	The Kyoto Protocol stems from a 1992 United Nations Conference on Environment and Development in Rio de Janeiro (Brazil), which considered climate change regulations and a United Nations Framework Convention on Climate Change in Berlin (Germany) the same year. In 1995, a Conference of the Parties in Berlin proposed a new protocol to replace the ambiguous agreement reached in 1992. In 1997, at the 3rd session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in Kyoto, Japan, the Berlin proposal became the Kyoto Protocol. Its target was that by 2008–2012 the net emissions of 6 greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC and SF_6) would be reduced by 5.2% of the 1990 emission levels of these gases. While each signatory to the Kyoto Protocol decides how it will implement the agreements of the

Acronym	Meaning
	Treaty, the Kyoto Protocol offers mechanisms to achieve targeted reductions in greenhouse gases including international and local emissions trading schemes (ETS), emissions sinks (the development and management of forests and agricultural soils), joint implementations (where one company invests in another's facility and shares reductions in emissions), clean development mechanisms (where companies invest in reducing greenhouse pollution in developing countries), bubbling (collectively attaining targets), etc.
Linear program	Programming algorithms to maximise or minimise an objective function subject to a set of linear mathematical constraints
MAD	Mutually assured destruction
Mb	millions of bytes of random access memory (RAM) or file size
MEF	Major Economies Forum comprising Australia, Brazil, Canada, China, Germany, the European Union, France, the United Kingdom, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea and the USA.
MJ	Million (10^6) Joules or Mega Joules
MBTU	Thousand (10^3) BTU (where M is the Roman Numeral for one thousand)
MMBTU	Million (10^6) BTU
Moral Hazard	“The observation that a contract which promises people payment on the occurrence of certain events will cause a change in behaviour to make these events more likely. For example, moral hazard suggests that if possessions are fully insured, their owners are likely to take less good care of them than if they were uninsured. The consequence is that insurance companies cannot offer full insurance. Moral hazard results from asymmetric information and is a cause of market failure” (Black et al. 2009)
MRIO	Multiregional Input Output Model (see also IRIO)
NGO	Non-Governmental Organisation
N2O	Nitrous Oxide
NOAA	United States of America National Oceanic & Atmospheric Administration
NOX	Nitrogen Oxides
NPV	Net Present Value
OECD	Organisation for Economic Cooperation and Development
PCA	Principal components analysis
PJ	Peta Joule(s)
ppm	Parts per million, used here as a measure of the concentration of greenhouse gases in the atmosphere (1 ppm of CO_2 in the atmosphere = 2.123 GtC in the atmosphere, which assumes an atmospheric mass of 5.137×10^{18} kg, see references for “Gt CO_2”)
Principal -	“The problem of how person A can motivate person B to act for A's benefit

Acronym	Meaning
Agent Problem	rather than following self-interest. The principal, A, may be an employer and the agent, B, an employee, or the principal may be a shareholder and the agent a director of a company. The problem is how to devise incentives which lead agents to report truthfully to the principal on the facts they face and the actions they take, and to act for the principal's benefit. Incentives include rewards such as bonuses or promotion for success, and penalties such as demotion or dismissal for failure to act in the principal's interests" (Black et al. 2009)
Prisoner's dilemma	"A two-player game that illustrates the conflict between private and social incentives, and the gains that can be obtained from making binding commitments. The name originated from a situation of two prisoners who must each choose between the strategies 'Confess' and 'Don't confess' without knowing what the other will choose. The important feature of the game is that a lighter penalty follows for a prisoner who confesses when the other does not. The game is summarized in the pay-off matrix where the negative pay-offs can be interpreted as the disutility from imprisonment" (Black et al. 2009)
Production frontier	A curve plotting the minimum inputs required to produce a given quantity of output
Productivity	The ratio of physical output produced from the use of a quantity of inputs (see also TFP)
quad	Quadrillion BTU, equivalent to 1.055 x 10^{18} Joules
quadrillion	One thousand million (10^{15}) i.e. Peta
R&D	Research & Development
Sceptre model	Spatial Climate Economic Policy Tool for Regional Equilibria (the model of this doctoral research and described in this dissertation)
Slacks	In a linear program solution, the extra amounts by which an input (output) can be reduced (increased) to attain technical efficiency after all inputs (outputs) have been reduced (increased) in equal proportions to reach the production frontier
SO2	Sulphur Dioxide
SRES	United Nations' IPCC "Special Report on Emissions Scenarios"
tt	Tonnes
TJ	Terajoules
TFP	Total Factor Productivity is the ratio of the quantity of all outputs (weighted by revenue shares) to the quantity of all inputs (weighted by cost shares)
UK	United Kingdom
UKMO	United Kingdom Meteorological Office
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change, based in Bonn

Acronym	Meaning
USOSTP	United States Office of Science and Technology Policy
USGCRP	United States Global Change Research Program
USA or U.S.	United States of America (America)
WHOSTP	White House Office of Science and Technology Policy
WMO	World Meteorological Organisation
WWF	World Wildlife Fund

Mathematical Symbols

Symbol	Meaning
$\forall$	For each/all/any of
∂	Partial differential
Δ	Difference
$\in$	Is an element of
$\prod$	Cartesian product of
$\sum$	Sum of
$\leq$	Less than or equal to
$\geq$	Greater than or equal to

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Preface

> You must become the change you wish to see in the world.
>
> Mahatma Gandhi

Putting pen to paper on this dissertation in April 2008, it occurred to me that it has never been a more poignant time for a comprehensive review of climate change strategies, which is the subject of this dissertation. Oil had reached US$120 per barrel on its way to US$150 per barrel, the contract prices of Australian coking coal for steel smelting had just tripled to US$305 per tonne, steaming coal for power generation up 130% to US$125 per tonne, iron ore up 65% to US$120 per tonne, following a 35% rise the previous year, and third world food riots were occurring due to rice and corn production being diverted to ethanol for transport. American President George W. Bush had just taken the unusual step of invalidating vehicle tailpipe emissions controls in States like California and announced significantly lower standards.

Three wildly divergent views about the future were circulating in Western markets about the commodity price spiral. The first was that it was merely a trading bubble due to speculators and it would burst. The second view was that the emergence of a prosperous middle class in China and India had a ravenous demand for animal protein and cars. This meant the world was now in a new era of high resource demand and prices. However, the world would adapt, as always. We could be sanguine because the world had previously coped with similar dire exigencies and would produce the necessary resources, so commodity prices would fall. The third scenario was that the world had reached or passed peak-oil production and was in a new era of scarce food, energy and metals, and this meant a continuation of rapidly increasing demand and high prices.

Such questions about the impact of resource scarcity on world economic growth had not been asked since I was an undergraduate in the 1970s. Adam Smith's invisible hand had solved the crises. Western birth rates declined, economic growth in Japan and Europe subsided and the Club of Rome's dire Malthusian projections did not eventuate.

Yet in April 2008 a new dimension of Climate Change had emerged into a major market factor in my home country, Australia. In its first day in office, Australia's new Rudd Labour Government had just ratified the Kyoto Protocol.

In Australia, as in many Western countries, there is unquestioned support for local protection of air and water quality, and the control of polluting goods such as waste, noise and smoking. Support for regional level protection is considerably less overwhelming because it usually has some implication in trading-off local employment or amenity for the good of people elsewhere in Australia. For example, management of the Darling, Murray and Snowy Rivers means the environment gains and farmers lose water. Forestry workers lose jobs when old growth forests are protected in Tasmania.

Notwithstanding the increasing attention to greenhouse gas pollution at the Government level, apathy at best exists among industry and consumers. There is little respect for the scientific evidence of Intergovernmental Panel on Climate Change, released in 2007, which shows that climate change threatens the very basis of our civilisation. Nor is there respect for Al Gore's call to action to avert it.

There appears to be an overwhelming lack of consensus in Australia, or in any Anglo-American country, for carbon taxes or similar market mechanisms to increase the price of goods and processes that contribute to global warming. In fact, despite increasing evidence that Australia was in a long term drought attributable to climate change, the former Prime Minister John Howard claimed to be a “non-believer in climate change”. Perhaps even more disturbing, he legitimated uncritical scepticism amongst Australia's political conservatives and greatly empowered already strong industry lobby groups like Clean Coal to argue against any tilt in policy toward the environment.

These examples suggest that as the issues become geographically and culturally broader, citizens of Western democracies rapidly lose interest in protecting the commons from being despoiled. As a result, any change to environmental policies in Western countries is a very difficult thing. The vast majority of individuals and business ask “Why me, why should I be charged more and my business or livelihood be disadvantaged for some theoretical concept called climate change?” Indeed, following a fuel revolt in 2000, the Constitutional Court of France declared environmental taxes unconstitutional. As a result, the European Union emissions trading scheme introduced in 2004 included neither a tax on carbon nor the requirement for companies to bid for permits to pollute. To date, America has steadfastly refused to affirm the Kyoto Protocol. At the time of concluding this thesis, its pending Waxman Markey Bill is not as strong as legislation in the United Kingdom and European Union.

Nor is there understanding in Europe about combining fiscal and environmental policy into a holistic solution where environmental tax revenues are recycled into reduced labour and income taxes. Perhaps it is not surprising that people living in areas of long term structural unemployment are uninterested in the argument that recycling environmental taxes into lower labour taxes increases economic growth and creates extra jobs. People in Europe simply want fiscal and environmental policies kept separate.

In April 2008, I made a submission to the Garnaut Review suggesting a moderate carbon tax on carbon-adders as the first stage of a market based emissions trading scheme that would ultimately lead to a market for emissions trading consistent with that of other major Western democracies (see Appendix 1). My submission also proposed that a carbon-added tax be imposed on imports in the same way as a goods and services tax (GST) is applied. Between April 2008 and October 2009, European policy has come full circle to align with my proposal: France introduced a carbon tax and together with Germany was planning duties on the untaxed carbon embedded in imports.

There remains much division over policies to ameliorate and abate the consequences of global warming. As I was drawing this dissertation to a conclusion in August 2009, the opposition party in Australia used its upper house majority to vote down the Government's Carbon Pollution Reduction Scheme.

The end of my dissertation has coincided with the 80^{th} anniversary of the start of the Great Depression. I reflect on the past few years and am amazed at the dazzling panoply of world events in the period: China and India burst onto the world stage as global leaders, America became a debtor nation with multi-trillion dollar deficits, a global financial crisis of almost Great Depression proportion came and went in just one year, as did a swine-flu pandemic.

Yet climate change policy remains in disarray as the United Nations' COP15 Copenhagen meeting approaches, Governments flounder and people remain *blasé* or cognitively dissonant about scientific evidence. Climate sceptics abound and mock the melting of the Arctic, Greenland and Antarctic ice-caps that threaten many metres of sea rise, a shift in the earth's axis of rotation, widespread earthquakes, tsunamis and volcanic eruptions from shifting tectonic plates and the release of methane deposits from the sea beds and permafrost.

Every day, almost every newspaper carries the latest stories of my research topic and the policy imbroglio in climate change. It is at the same time satisfying and disturbing that my research into benchmarking climate change policies remains poignant and needed.

Chapter 1 Introduction

1.1 Background

In the 200 years from the Industrial Revolution through to the 21st century, technology, energy, the political economy of markets and democratic systems delivered abundant food production, prosperity and growth in lifestyle. It has truly been *homo sapiens*' golden age of expansion. In *Common Wealth: Economics for a Crowded Planet* (2008a), Jeffrey Sachs writes that following a millennium of static productivity, output per person jumped one hundred-fold while aggregate global output exploded from a negligible level to US$70 trillion in 2008.[i]

Facilitated by the plentiful availability of fossil fuels, rapid advances in technology and stability within economic, social and political institutions, policy makers have successfully advanced bedrock social objectives such as full employment, industrial and security self-reliance, and improving living standards. In 1800, ninety percent of world economies were subsistence. Aristocrats and even royalty lived in conditions and health that today, we would consider distasteful in many ways (Jeffrey Sachs observes that one need only consider dentistry). Average per capita purchasing power has risen from US$400-$500 in the 18th Century to a current world average of US$10,000 pa. However, great disparities in wealth distribution have left one billion people living in extreme poverty on a few hundred dollars a year while America, Australia and other western nations enjoy an average income of US$50,000-$60,000 pa.

Policy makers have never had an easy task in resolving competing priorities for increased living standards against the backdrop of increasing population. In 1800, global population was about 1 billion. This grew to 2 billion in 1930. Notwithstanding World War II, population was 3 billion by 1950. It took just ten years to rise to 4 billion in 1960, 5 billion by 1975, 6 billion by 2000 and 6.7 billion in 2008. The United Nations projects that world population will exceed 9 billion by 2050.

Today, population and standards of living based on abundant energy from fossil fuels, such as coal and oil, and its accompanying greenhouse gas pollution, are leading to major world problems due to global warming. In November 2007, scientists of the United Nations Intergovernmental Panel on Climate Change (IPCC) confirmed that runaway greenhouse gas emissions had created a situation where global warming was a real and pressing problem for the world (IPCC 2007; Karoly 2007). The IPCC scientists warned of a 2°C to 6°C increase in terrestrial atmospheric temperature between 2020 to 2080.

The unique imperative for climate policy and strategy is that decisions implemented now will determine climate and environmental damage outcomes in one hundred years time, such as impacts on biodiversity, flooding and mass human migration. These issues affect people of all nations, from those living in the poor Bangladeshi river delta to rich financial hubs like New York, London and Sydney, to name only a few.

Energy efficiency measures have been proposed as a solution, which is doing more with less. For example, better energy efficient buildings and voluntary simplicity in domestic consumption, such as fewer children, smaller houses, smaller cars and smaller bellies. While better energy efficiency in buildings is fairly obvious, neither voluntary simplicity nor the central planning of private lives has fared well in policy terms over the last century. Others feel that the trend of employing energy to support advanced standards of living will not change. Indeed, the demand for electricity is expected to double from 2009 to 2050. Advocates of increasing energy production argue that no change in energy policy is necessary other than to price in the new externalities, such as ameliorating greenhouse gas pollution.

It is realistic to hope that policy makers will deal with climate change. The world has previously united to solve similar problems of chlorofluorocarbon gases damaging the ozone layer and acid rain. In his advice to the United Nations, Jeffrey Sachs outlined that our crises have solutions but require good science and technology, population control and finding ways to live sustainedly with biodiversity and water production. He says (Sachs 2008b):

> We have within reach solutions for all of these challenges, the irony

> I should say …. is not that we are at an abyss …. its almost the opposite, we've unlocked the ability to promote economic development in all parts of the world, we have at our hand the ability to end extreme poverty, we have before us …. technologies to replace dirty fossil fuels …. we have these things, the question is whether we can bring knowledge to bear on these solutions, and then find a common purpose on the planet.

Unfortunately, until quite recently, the IPCC's message about climate change fell on deaf ears. Politically conservative governments in America, Canada and Australia continued to renege on their December 1997 commitments to the Kyoto Protocol and were embarrassed by Russia's ratification of the treaty that brought it into effect.[ii] In fact governments of most Anglo-American countries, with the exception of the United Kingdom[iii], actively discredited scientific arguments about climate change and in some cases actively subverted action (Ayres 2001; Hamilton 2006; Sachs 2008a).

New political parties have since been elected in Australia and America. It is well known that Australia's Prime Minister Kevin Rudd, in his first act of office, ratified the Kyoto Protocol on 3 December 2007. Furthermore, America's newly elected President Obama appreciates that America is facing one of its greatest ever challenges. His goal is to guide the American economy to sustainable growth. President Obama unshackled the Environmental Protection Agency (EPA) to deal with greenhouse gases as pollution and personally appealed for American Congressmen to support the 2009 Waxman Markey Bill to mitigate America's contribution to global warming.

With these political developments now behind us, the climate change debate has moved from science into economics, technology and the competitive strategies of nations, industries and businesses. If fossil fuel usage is constrained by greenhouse gas emissions, all countries face the challenge of using energy resources more efficiently. Industries and countries need to cope with new commodity and factor substitutions between industries and between countries. At the same time, national governments are still charged with stewardship of their citizens' welfare. They need to balance policies for improved standards of living, employment, utilisation of national endowments, international trade, technology and security.

Climate change is therefore a major cross-disciplinary area of strategy and policy. It involves macro and welfare economics, political economy, business and industry strategies, security and warfare strategies, finance, valuation, technology, climate science, operations research, game theory, philosophy, sociology and psychology.

1.2 Policy context

Policy issues in climate change

The key climate change policy issues are mitigating the level of future adverse effects and helping vulnerable communities cope with unavoidable consequences. At present, storms, floods, rising sea levels, drought and desertification affect approximately 211 million people. Many of these people are already living in poverty, hunger, poor health, environmental decline and insecurity. In the future global warming will impact all countries both in physical and economic terms.

The unavoidable consequences of global warming include extreme weather events (storms, cyclones and heat waves), shifting rainfall patterns resulting in disruption to crops and water supplies, environmental degradation, destruction of ecosystems and extinction of biodiversity, melting of glaciers and polar ice caps, acidification of oceans, rising sea levels, inundation of coastal cities and low-lying regions, changing of sea currents (Gulf Stream and El Niño), water table contamination, populations coming into contact with pesticides, arsenic, cyanide and heavy metals from coastal sediments and human suffering from water shortage, mass starvation, forced migration, mass sickness and pandemics, political instability and armed conflicts.

Examples may include Hurricane Katrina, aggravated El Niño effects and the Iraq and Somali wars. According to the IPCC, worldwide sea levels rose 17cm over the 20th century and are projected to rise by another 18-59 cm by 2100. If Antarctica and Greenland thaw, the sea level rise could be as large as 75 metres.

The magnitude of the problem has prompted calls for a comprehensive set of sustainability policies to address key risks across the environment, social equity, economic futures and national culture. Lowe (2009, pp.1-4 & 19-20) identifies the risks by asking questions about resources and social stability, for example:

> Are we likely to run short of critical resources or energy for heating, washing and cooking? Are we doing serious damage to the natural systems that support us, for example clean air, potable water and food? Is our society stable and equitable (implying the absence of instability based on inequity between rich and poor)? Is our economic activity viable and able to sustain our living standard under the challenges of resources and globalisation? Are our cultural and spiritual identities stable under the challenge of globalisation and imported values?

In the United Kingdom, Nicholas Stern (2007) applied the techniques of computable general equilibrium (CGE) modelling to show that the economic cost of inaction on climate change is greater than the cost of action. In Australia, Professor Ross Garnaut (Garnaut Climate Change Review 2008a; 2008b) and the Australian Treasury (2008) conducted similar investigations to Stern and found similar results.

Policy needs

Cochran & Malone (1995) define the essence of policy as: “Public policy consists of political decisions for implementing programs to achieve societal goals.”

While this definition has inherent verisimilitude, it is perhaps merely a description rather than a theory of public policy because although it can be used to explain much, in fact is has little value in predicting public policy outcomes or development. Cochran et al. (1993) better captures the scale of the behavioural complexity in policy making “The term public policy always refers to the actions of government and the intentions that determine those actions …. Public policy is the outcome of the struggle in government over who gets what.”

It is widely appreciated by the major economies of the world that they need to join together with common policies to contain emissions. However, complexity arises because equity is an important issue. Any policy response needs to address a number of fundamental issues leading to different behaviour amongst nations:

- developed economies, such as America, the European Union and Australia, have very high per capita emissions and have caused most of the current climate crisis. While the European Union has been actively limiting emissions, America and Australia do not yet have legislated climate policies. These have proven controversial and implementation has been delayed. Industries and consumers in developed countries need time to adapt, allow sunk investment to be amortised and reduce aggregate emissions rather than per capita emissions. If lifestyle, employment and security is threatened then developed countries such as America almost certainly will not participate in climate change amelioration
- developing economies, such as China and India, have not created the current issue and have comparatively low emissions per capita to date. However, China is rapidly growing and has one-fifth of the world's population. It has become the world's second largest emitter. Continuation of its present trajectory will endanger the world. For example, over the past decade China has been commissioning one new coal-fired power station each week. If growth in living standards and employment is unreasonably impacted then developing countries will not participate
- countries are coming together under the auspices of the United Nations, which is an institution that has been seriously weakened in recent years by the unilateralism of America, Australia and the United Kingdom
- at this point in time, just as climate change science and need for action has been widely accepted, the world found itself in the 2008-9 Global Financial Crisis and recession
- climate damages such as sea inundation and extreme weather will affect the infrastructure and endowments of all counties, albeit in different

ways. For example, Australia's coal industry is threatened because coal is the main polluting fossil fuel

- the world is now highly interlinked through trade. Exporting countries such as China and Germany will suffer large loss of income if the economies of their customers suffer climate change damage
- it is an unfortunate feature of international relations that countries often cheat on their joint obligations. There needs to be effective auditing of countries by the United Nations
- industries such as steel and aluminium production will move to wherever they find the lowest cost of production. This is called “carbon leakage.” Polluting industries may gravitate to those jurisdictions where there is no carbon levy and continue with undiminished pollution
- there is a need to legally protect the biodiversity of the planet because a loss of biodiversity will adversely affect all people in the long term
- there is a need to invest in technology to accelerate the development of substitution technologies (such as electric cars), supplementary technologies (such as carbon capture and storage) and new technologies that will remove CO_2 from the atmosphere.

Agreeing a set of policies to ameliorate climate change really means agreeing on a model of how these policies will work. This is because climate change treaties are in effect “alliance contracts,” where each participant shares the profits and correspondingly shares the losses. Unfortunately, as countries are well aware, immediately after an alliance contract is entered into, the conditions that applied at the time will change. Through elections, governments will change, wars will begin, countries will suffer unpredictable earthquakes and tsunamis, and the effect of the contract will work out differently than envisaged. Cultural differences will play a big part. For example, in China a contract is mainly a statement of intentions at the time and totally disregarded if new circumstances arise or new market opportunities or alliances present themselves.

As an alliance contract, a climate change treaty needs to be sufficiently flexible to cope with these changes. The people administering the alliance contract need to be able to reappraise changing situations and find other ways to achieve a win-win outcome for all stakeholders. This is not so easy to do when various countries are proceeding to change their institutions on the basis of previous commitments and arrangements.

The Indian lawyer Anuradha (2009) has identified policy and legal requirements relating to infrastructure and technology transfer that will enable developing countries such as India to join with industrialised countries in addressing global warming:

> (i) a framework for assessing economic costs of undertaking emission reductions, while at the same time investing in economic growth and development priorities
>
> (ii) predicating emission reductions by developing countries on the full adherence by developed countries to binding legal obligations for financial and technical assistance and technology transfer
>
> (iii) a mechanism for periodic assessment at the national level of programmes and activities necessary for technical and financial assistance, capacity building and technology transfer and its cost implications
>
> (iv) evolving clear benchmarks and criteria for monitoring and evaluating whether implementation of obligations relating to capacity building, technical and financial assistance and technology transfer has been effective
>
> (v) articulating any emission reduction targets as being conditional on all of the foregoing.

Evidence-based policy

In *The Policy Context for Research,* Lorman & Van Groningen (2009) provide a more comprehensive social and behavioural definition of public policy:

> Public policy is about the arrangements for social and economic life in our society. It comes out of the interaction between the different interests of stakeholders who have different views about what

> constitutes a problem that needs to be solved. These interactions are mediated through an extensive set of institutional arrangements …. This engagement is done within and between organisations with different traditions, including international organisations and processes. Within formal political processes the emphasis is on values and ideas, sustained through alliances, brokerage and compromise …. Public policy is made when people engage with others, through their interests, commitments and paid occupations in shaping social and economic arrangements. This capacity to engage and shape arrangements is greatly influenced by their command over resources. Those with the greatest command over resources have the greatest potential to influence policy outcomes.

Policy makers use many techniques in the democratic process of shaping policy amongst stakeholders. These include evidence-based policy, “dialogic” policy development (multiple ongoing stakeholder dialogue) and Lindbloom's (1959) incrementalism or “muddling through” alternative to the rationalist model. As *Chapter 3 Political economy of Anglo-American world view of climate change* demonstrates, the development of climate policy has been amongst the largest evidence based policy research projects ever undertaken. This dissertation therefore uses evidence based policy research as the underlying paradigm for its climate-economic policy research framework. As will be discussed below, the concept of evidence is more synonymous with an estimate than an irrefutable truth.

Keane (2009) had discerned a trend towards “monitored democracies,” similar to India, where government decisions will be increasingly monitored by many non-governmental organisations. In an early 1990s example of this trend, Prime Minister Tony Blair sought to reform United Kingdom government policy and corporate governance with evidence-based policy (United Kingdom Cabinet Office 1999; UK Hampel Committee 1998).

Although some would argue that Tony Blair's own Prime Minister's office did not provide a very good example of transparency and evidence-based analysis, the underlying assumption of evidence-based policy remains undisputed: better policy is achieved with research and that better policy produces better outcomes. In contrast, poor policy usually wastes money and fails its aims.

Influential deductivists such as Sir Karl Popper and Thomas Kuhn argue that confidence can only be developed in a hypothesis by attempting to falsify it through tests (see later in this Chapter). Deductivists would never agree that a clinical trial is sufficient to be sure that a drug will cure the next person tested. Popper's oft-quoted example is that no matter how many white swans are observed, the absolute theory that all swans are white is never justified (Magee 1974, p.22). However, deductivists would agree that the more tests a drug withstands without failure then the more robust is the efficacy hypothesis.[iv]

There are famous experiments where deductivists have developed tests of a hypothesis, such as testing Einstein's theories that light bends and space-time curves. However, in general it has proven extremely hard in practice to progress science and society through a rigid deductivist discipline of public criticism and falsification.

For example, modern political systems are not able to function by hypothesis falsification. Many issues dominate politics. Neither politicians nor the bureaucracy like to encourage negative criticism, even if rationality is identified with the virtues of public criticism and falsification testing. Unfortunately, people are not purely rational beings. They have emotions and tend to respond poorly to falsification attacks. Pragmatism, realism, working trade-offs and sub-optimisation are the norm rather than exception. Indeed, the working assumptions of the bureaucracy are rarely, if ever, examined. This is the reality of the messy social milieu for public policy formation.

Instead of deduction, society tends to work by induction, which is the process of using bodies of well specified information, professional systematic practice and human intuition and creativity to infer generalisations from specific observations. This creative process is not uncontrolled but subject to various measures of quality assurance such as peer and judicial review. The requirement for coherence and believability of any form of induction is the same as proving a hypothesis beyond reasonable doubt in a court of law. In this tradition, policy makers approach issues as a “historian who sees common tendencies in certain contexts, not a philosopher who seeks clear general principles that apply across contexts” (Brooks 2009).

Policy feasibility

Evidence-based techniques place a high value on evidence being consistent and rational in order for confidence to develop in the hypothesis. Historical analysis is a very important part of establishing consistency because every time more observations confirm a theory, the result becomes more believable.

For example, the scientific method has been exceptionally successful in validating drugs through clinical trials. Leonhardt (2009) observes that policy makers and doctors alike have become perplexed by the plethora of treatments available and the lobbying groups for drug companies, device makers, insurers, doctors and hospitals. He notes America's transition evidence based care where doctors and policy makers, working together and across precedent of circumstances with many nuances, are taking the next step of identifying the best treatment practices among all the alternatives:

> But there is one important way in which medicine never quite adopted the scientific method. The explosion of medical research over the last century has produced a dizzying number of treatments for different ailments. For someone with heart disease, there is bypass surgery, stenting or simply drugs and behavior changes. For a man with early-stage prostate cancer, there is surgery, radiation, proton-beam therapy or so-called watchful waiting. To enter mainstream use, any such treatment typically needs to clear a high bar. It will be subject to randomized trials, statistical-significance tests, the peer-review process of academic journals and the scrutiny of government regulators. Yet once a treatment enters the mainstream — once we know whether it works in certain situations — science is largely left behind. The next questions — when to use it and on which patients — become matters of judgment, not measurement. The decision is, once again, left to a doctor's informed intuition .... The human mind can sometimes do a better job of piecing together amorphous bits of information — diagnosing a disease, for example — than even the most powerful computer. On the other hand, human beings can also be unduly influenced by just a few experiences, like the treatment of an especially memorable patient. As a result, different doctors frequently end up coming up

> with different answers to the same question. Cardiologists in Davenport, Iowa, are quick to insert stents; cardiologists in Iowa City and Sioux City are not. They can’t both be right. Some people with heart disease are getting the best treatment, and some are not. The same is true of debilitating back pain, various cancers and even pregnancy. .... The lobbying groups for drug companies, device makers, insurers, doctors and hospitals have succeeded, so far, in keeping big, systemic changes out of the bills. And yet the modern history of medicine nonetheless offers reason for optimism. Medicine has changed before, after all. When it did, government policy played a role. But much of the impetus came from inside the profession. Doctors helped change other doctors.

This type of evidence-based policy making that relies on inter-subjectivity is called the “objective theory of evidence.” The name is somewhat controversial because the words “objective,” “theory” and “evidence” have always been challenged by one philosophical persuasion or another. For example, how could something be simultaneously objective and subjective, or be a theory when it is really an untestable hypothesis, or be evidence when it is really an observation or estimate?

Sir Karl Popper (1972) proposed that this conundrum be solved by recognising a “World III” of objective knowledge comprising statute and common laws, scientific papers, textbooks, documented procedures etc. While both Popper's “World III” and the “objective theory of evidence” remain controversial in philosophical circles, these ideas have had a profound influence on normative theories for practical professional practise as described above.

Evidence based processes are *prima facie* subjective Bayesian inductive inference due to the subjective assignment of prior probabilities. However, the “objective theory of evidence” holds that these processes have the nature of an “objective theory” because professional researchers have a concern for objectivity and independence in their work, such as undertaking professional error-statistical practices as part of their methodologies (Mayo 1996; Mayo & Spanos 2004; Staley & Cobb 2009); peer reviewers introduce an inter-subjective due diligence layer because their concern for truth means that research assumptions and results are subjected to informed criticism and repeatability testing (Achinstein 1991; 2001; Rehg & Staley 2008); and Bayesian inference conforms to the "likelihood principle" because it merely depends on prior probabilities, which have nothing to do with the experiment (Birnbaum 1962, p. 271; Sprenger 2008, pp 197 & 204).[v] Therefore, the results emerging from a process that applies the scientific method are qualified to be considered as part of an independent body of knowledge (which is Popper's "World III").

The "objective theory of evidence" relies on two primary concepts. The first is that true and false are not absolute states. In *A Treatise on Probability* (Keynes 1921, Chapters 15 & 17), Keynes hypothesised a continuum between falsity and truth. He suggested that intermediate points in this interval are associated with probabilities of truth. The legal system accepts his proposition, for example, requiring guilt to be proven beyond reasonable doubt in serious cases and on the balance of probabilities in less serious cases.

The second concept in the objective theory of evidence is associated with Thomas Bayes' theorem of conditional probability. This theorem states that the probability that a hypothesis is true at a point in time, given certain evidence, is the probability of the past evidence occurring when the hypothesis was true, multiplied by the probability of the hypothesis being true in any case and divided by the probability of the evidence occurring in any case. For example, suppose a sports drug test is 95% accurate. Assume that 1% of sports people have taken drugs. The probability that a positive result will occur in random tests regardless of whether drugs have been taken or not is 5.9%.[vi] Therefore, the Bayesian probability of a person having taken drugs, given that a test result shows positive, is only 16.1%.[vii] If the accuracy of the drug test is increased to 99%, the probability of a person having taken drugs given the test result is positive rises to 50%.[viii]

Bayes' theory demonstrates the reason why policy makers seek confirmation from economic modellers that a particular policy represents a scenario that is at least feasible. In an example analogous to the one above, we assume that economic modelling has a 90% probability of correctly showing a particular policy is feasible, if indeed it is feasible, and that say 60% of all proposed policies are feasible. The probability of economic modelling identifying that policies are feasible, notwithstanding whether the policy is or is not, is 58%.[ix] Therefore, the Bayesian probability that a policy is feasible given that modelling shows that it is feasible, is a more impressive 93%.[x]

Thus in this example economic modelling has improved a policy maker's chances of a feasible policy from 60% to 93% by simply showing that the policy is a feasible scenario. Note that in this example the policy maker is not necessarily asking the economic modellers whether the particular policy is the best policy, only whether it is feasible. However, if in addition to determining feasibility the modellers can reliably discriminate between policies and develop a better policy then the “value added” is correspondingly greater.

Policy risks

The Australian Securities and Investments Commission Practice Notes expound on the presentation of risk in financial projections (ASIC). Many elements have equal applicability in policy settings. There are two types of risk: the systemic risk of being unable to fully represent the real world in a model; and non-systemic or ordinary uncertainties associated with the economic environment.

Systemic modelling risks

As for all professionals, policy modellers' prima facie duties include integrity, objectivity, an absence of any conflict of interest, possession of the necessary skills and competence, and processes for care and due diligence. The duty of care includes an appreciation of misleading (or deceptive) assumptions, including misleading by omission.

Wise hands in policy formation recognise first and foremost that any projection or forecast is a matter of opinion and judgement. They look for reasoned and sustainable assumptions and a systematic modelling process. For their part, modellers need to appreciate that a reader's understanding of the assumptions is essential for their proper assessment of the information contained in the model. Therefore, specialists and experts preparing models need to take as much care with the formation and publication of the assumptions as they do with the model results.

Non-systemic modelling risks

As there is little verisimilitude to be found in any single-point or stand-alone scenario, there is no point looking to one or other scenario as an immutable outcome. Nevertheless, there is considerable value in understanding the differences between scenarios in order to develop a feel for the patina of intensity in economic responses to policy. This can be achieved with a narrow range of scenarios that suffice to highlight risks. Modelling can become meaningless if the range of scenarios is too wide or too narrow.

Communication risks

The way results are read by the intended audience is also important and there is a risk that the presentation of results could be misleading. Due to a human behavioural fallibility, many people act on the assumption that the middle value of a table or range is the most likely value. Rather than extensive tables, it is better to show the most probable outcomes and discuss the variables that have a significant impact on these results.

Public exposure of policy

Evidence-based policy has obvious application in clinical testing and other scientific experiments where the objective theory of evidence holds. It also has significant benefit in other areas of society where the scenarios are less experimentally clear. For example, policy areas such as economics, health, education, law and defence. Modelling is particularly useful in these areas because a great number of dependencies exist, variables can rarely be held constant *ceteris paribus* as is done in controlled scientific experiments, and the effluxion of short periods of time inevitably brings additional changes to the basis of the policy research. A further key problem in macroeconomic or climate research is that the sample size is just one.

From the above discussion it may be appreciated that a key requirement in the process of evidence-based policy is that research is assembled that maximises the probability of correctly determining that a proposed policy is both feasible and the best policy. In this, consistency of the evidence is extremely important. For example, developing a historical analysis of the political economy of the policy area along with economic modelling for future scenarios of the policy.

As the great deductivists like Popper and Kuhn surmised, exposure of expertly prepared evidence-based research to peer review and, ultimately, to an open and transparent process of public criticism provides a diligent proving ground for assuring that a proposed policy is both feasible and the best policy. In particular, it is often only at the stage of public exposure that issues of social equity and justice are appropriately weighed, for example, doing the most for the majority while at the same time looking after the least well off as argued by Rawls (1972).

Prior to public exposure, the process of developing expert opinion for evidence-based policy usually relies on normative principles of systematic practice in the respective profession, be it economics, law, engineering or another profession. Ironically, while systematically applying inductivism throughout evidence-based policy, enlightened professional practice complies with strict deductivist principles in claiming only to represent current best working hypotheses and shunning any ambit that these professional hypotheses be regarded as a science of theories and laws.

Lastly, evidence based policy is always at risk of being subverted and the "policy makers for policy making" need to be ever vigilant of degenerate policy-driven evidence. This is selective or manipulated evidence provided to justify or promote a particular policy. For example, Thomas Kuhn showed in *The Structure of Scientific Revolutions* (1962) that vested interest groups will invest large resources in defending the status quo. Bryson & Mobray (2005) highlight the need for high level impartiality and a passion for diligent governance to eliminate conflicts of interest.

Tools of policy research

One methodology rarely encompasses all that needs to be investigated in policy research. Usually, the policy issue is deconstructed into smaller, manageable pieces with an appropriate tool chosen for each research task. Policy analysis becomes the insight developed through iteratively using each tool and ensuring consistent answers.

Policy making may be understood from the research methods used for economic decision making and allocation of resources. The main categories are (expanding on Gruber 2007):

- political economy analysis to understand the fabric in which the *tétonnement* of marginal social benefit and marginal cost occurs. Lindahl pricing techniques for public goods may be applied by evaluating disclosed or expressed preferences of individuals against their willingness to pay. Expressed preferences can be determined through engaging with lobbyists, referenda and election mandates for political parties
- mathematical microeconomic models such as indifference curve-budget constraint graphs and equilibrium models for constrained utility maximisation; and supply & demand diagrams for equilibrium and social welfare efficiency
- empirical analysis of data using statistical methodologies that measure the impact of government policy on individuals and markets. For example, randomised trials and quasi experiments provided by differential changes in the economic environment, time series analysis, cross-sectional regression analysis (comparing many individuals at one point in time) and structural modelling to determine underlying drivers or factors
- budget analysis using cash and accrual accounting, static and dynamic scoring, intertemporal accounting (generational accounting & intergenerational equity), short-run, automatic and discretionary stabilisation, and IS-LM *tétonnement*
- cost-benefit analysis applying the theoretical tools of microeconomic analysis (above) in the context of a host of evidence from surveys and expert analysis
- ideological analysis in which conservative, liberal, radical and alternative ideologies are considered. Point of view analysis is a similar technique which analyses policies from prominent points of view
- influence analysis which measures the influence of the policy on target groups and evaluates the effectiveness of reaching the target.

The importance of historical analysis in developing evidence for consistent and believable hypotheses was referred to above. Discovery of the historical background through political economy analysis has become *de rigueur* for research in evidence based policy.

1.3 Equilibrium tools for policy research

From the above tools of policy research it may be noted that governments often look to the discipline of economics to help them understand complex policies. Classical economic theory and neoclassical economic models have become one of the main ways of evaluating policy proposals.

Main mathematical microeconomic research tools for developing insights into policy have included the modelling of equilibriums in competitive commodity markets and modelling that also includes the market for financial assets (Ljungqvist & Sargent 2000).

Equilibrium modelling has two variants: partial and general equilibrium. Marshall's famous microeconomic scissor curves for supply and demand are the classic representation of partial equilibrium analysis (Marshall 1890). Partial Equilibrium modelling focuses on a single commodity and assumes *ceteris paribus* that the supply and demand curves are independent of each other. This means that if demand for a commodity increases, it will not lead to a change in the supply curve because for small changes (called perturbations) supply is isolated from dynamic effects in other industries.

General equilibrium has the more ambitious goal of finding a commodity market *tétonnement* where partial equilibrium assumptions do not apply. General equilibrium seeks to explain the price and quantity effects of whole economies, which are composed of many individual commodity markets. As the production of commodities is interlinked and the raw materials of each production unit comprise the output commodities of other industries, the demand of the downstream industries is the derived demand of the upstream industry. Indeed, in practice many complex industrial feedback loops occur. Furthermore, if raw materials, labour or capital are constrained then the producers in each market need to compete for scarce resources and bid for raw materials. The *tétonnement* of each market is contemporaneously settled in concert with all of the other markets. This compound effect accounts for the upward sloping supply curve.

A review of the literature (*Chapter 4 Economic models for climate change policy analysis*) suggests that general equilibrium seems to have become the preferred “model of choice” for developing inputs required for climate change policies and strategies. A computable general equilibrium (CGE) model simulates the policy scenarios across commodity markets and consumers using a system of equations that describe the economy, international trade, technology and resource constraints of labour, capital and other critical limits such as the capacity of oceans and atmosphere to absorb CO_2. Economists, engineers and industrial ecologists use CGE models to simulate policy options by solving the complex interactions between different technological processes and labour markets across wealthy, rapidly developing and poor regions.

The crux of the climate-CGE modelling approach can be deciphered from these examples:

- William Nordhaus' DICE model was used in providing recommendations to the American Administration regarding the Kyoto Protocol and policy options for post 2012
- The United Kingdom's Stern Review relied on the Page 2002 climate-CGE model to investigate climate policy in the United Kingdom and the European Union
- The Australian Treasury and Garnaut Review modelling for Australia's Carbon Pollution Reduction Scheme (CPRS) used the Australian Bureau of Agricultural and Resource Economics (ABARE) GAIM climate-CGE model

General limitations of CGE tools

CGE is an internally consistent neoclassical paradigm. It assumes that democracy and free markets are the best form of social organisation and that at an aggregated level everyone has the same perception of utility in personal consumption and will make rational decisions. One of the paradigm's weaknesses is that the construction of synthetic market models and the evidence used to do this is embedded with assumptions.

A neoclassical paradigm may easily be (or become) delaminated from reality. Economics is not a science based on immutable laws. It can only ever be a consistent discipline of practice with working assumptions that have proven generally valid in the past. The past is not always a reliable guide to the future (Popper 1959). Quite often assumptions become invalid and sometimes the body of policy makers doesn't notice this happening. At this point the paradigm diverges from reality. As we have seen from America's recent sub-prime credit crisis and financial collapse, neither individual nor collective behaviour can be fully predicted by sets of equations. Markets are subject to failure due to behavioural factors such as the breakdown of enlightened self interest, which is an article of faith in the dogma of self-regulation, and not being fully accountable for the outcome of one's actions, which is called “moral hazard.”

One of the reasons that CGE modelling delaminates from reality is that its assumptions about utility and profit maximisation are generalisations. At times when individuals and, even more importantly, institutional stakeholders behave in different ways then these assumptions can become unjustified. Any numerical policy research needs to be supplemented with an understanding of the values and ideas, alliances, brokerage and compromise of the strongly competing stakeholder institutions that have large resources to influence policy outcomes. It is necessary to evaluate the same policies with reference to the tools of political economy, ideology, moral philosophy and influence analysis as Lorman & Van Groningen (2009) note: “This capacity to engage and shape arrangements is greatly influenced by their command over resources. Those with the greatest command over resources have the greatest potential to influence policy outcomes.”

The difficulty of achieving effective policy analysis may be gauged by the large range of stakeholder institutions in policies with national and global implications. These include international and global organisations such as the United Nations, multinational corporations, international social movements, and trade, aid and immigration policies within national political processes; national governments and domestic institutions such as Ministers of Parliament, Departments, courts, non-government organisations (NGOs) and private sector industry organisations and companies (which are often striving for self-regulation); the bureaucracy, which often features hierarchical control and coordination; the professions, which are guided by principles of autonomy, self-regulation and occupational control; and social movements which have open and fluid structures, such as Greenpeace, the World Wildlife Fund, German Watch and the David Suzuki Foundation.

Furthermore, the large range of institutions will often have just as large a range of alternative agendas, different views on the importance of key issues and even strong ideological and moral differences about the collective behaviour of how societies work and individual behaviour, for example, neoclassical rationalism, Keynesian, Monetarist, self-regulation, social democracy, capitalism, “dry-liberal”, “wet-liberal”, welfare state, green and radical views of all types. This can lead to highly contradictory contexts and pragmatic tradeoffs in negotiating multiple and conflicting objectives.

For example, countries will be the primary stakeholders entering into international treaties. However, in Western democracies, governments are voted in and out according to how citizens see their quality of life and security unfolding. As such, the ability of governments to exercise their social mandate is highly constrained by voters' perception of their future welfare and security.

It is the citizens and powerful vested interests in the country that can be the real stakeholders in international agreements. For example, oil, coal and gas producers and users, such as power stations and motorists, would be significantly affected by taxes or escalating emissions permit costs designed to switch users from using fuels that pollute to clean fuels and technologies.

Traditionally fossil fuel producer groups (or their industry associations) have exceptionally strong influence on governments. These producers are often commercialising national endowments and in doing so bringing much needed income, industry and prosperity to the country. Resource companies often control commodity cashflows with such immense magnitudes that they are singularly important to countries. Global producers, such as the “six-sisters” of the oil industry, are bigger than most national governments and on an equal or better footing in negotiating with governments. These companies can “play the employment security card” with their employees by threatening job losses. For example job losses if logging of forests, fishing or coal mining is restricted or financially impaired in any way.

Governments are almost universally committed to economic growth. Lowe (2009, pp.8 & 74) provides a good example of the popular radical belief that the cult of economic growth is invalid: "The fundamental myth of modern society, unlimited growth ….the "growth is good" idea: that growth is either inevitable or, at least, desirable as the bringer of wealth and happiness. Challenging it is tantamount to heresy, so the benefits of growth are acclaimed and the costs are ignored."

This paradox of growth has led a number of authors from John Stuart Mill to the present day to argue for a growth-less or steady state economy (Mill 1848; Daley 1992; Hamilton 2006). Even the New Scientist editor writes in the magazine's special issue *The Folly of Growth: how to stop the economy killing the planet:* "Most economists care only about growth. Where resources come from and where wastes go are largely irrelevant. If we are to leave any kind of a planet to our children, this needs to change" (New Scientist 2008).

As already noted, CGE models are rationalist models that seek to maximise growth, or at least welfare as measured by the expansion of consumption. Those who criticise the paradigm of growth are equally scathing of CGE models being tools of the cult of growth that conveniently justify growth policies. However, criticism of neoclassical economics and CGE models as promoting growth is largely misplaced. This is because constraints on resource usage from natural endowment scarcity and specific policy implementation (for example to control emissions) means that the dual solution provides the very efficiency in resource utilisation that Lowe and others seek.

Societies that restructure from unconstrained growth to constrained growth can achieve the auto-stabilising goals sought by Lowe. However, CGE modelling is a market tool that shows how this can be achieved through democratic and market means rather than through quantitative regulation and central planning mechanisms.

It can be seen that inherent conflicts in the outlooks and aims of individuals and institutions necessitate policy implementation being fine-tuned through a large number of potential instruments of intervention. Policy is often defined by the instrument that is used: “It can express itself through the clarification of public values and intentions; through commitments of money and services; by the granting of rights and entitlements” (Considine 1994, p.3).

Such instruments of interventions range through “reasoned inaction” to Research and Development, monitoring, communication and information flow, education and moral persuasion, consultative mediation, self-regulation, intergovernmental agreements and policies, new laws, control regulations and impact assessments to enforce standards and prohibit practices, institutional change and market price mechanisms.

The traditional process for policy is to set the agenda; formulate policy options; select policy instrument; implement; monitor; evaluate; review; and terminate (Sutcliffe & Court 2005, p.9; Lorman & Van Groningen 2009; Young & Quinn 2002, pp.13-4). The first phase of setting the agenda seeks to identify all aspect of the issue. For example, the reasons why the issue is important, competing definitions of the problem, potential policy instruments; the steps ahead; and the power blocs and the stakeholder engagement required for alliances, brokerage and compromise.

CGE analysis has its place in the second stage of the policy forming process, namely, research. This phase encompasses the iterative research needed to establish what needs to be done; identify potential intervention responses; potential instruments; institutions that will implement the policy; individuals and institutions that will be affected; and to provide information to help achieve stakeholder institutions support. The vast number of policy instruments required for the fine tuning of policy implementation means that high level policy research tools such as CGE models need to be carefully finessed.

In order to fulfil this role, over the last four decades CGE researchers have developed models for various influential institutional agendas and strategies. For example, to take into account developments in instruments of intervention such as carbon taxes and emissions trading.

The literature survey in *Chapter 4 Economic models for climate change policy analysis* highlights that there are now many CGE models from policy researchers investigations into different dimensions of problems and exploring advances in theory, techniques, data availability and computing power. From a climate change perspective, these CGE models have evolved from economic models into energy models, then economic-energy-emissions (E3) models and now into economic-climate models.

Inadequacy of traditional CGE modelling for developing effective climate change policies

As identified in the CGE literature study in *Chapter 4 Economic models for climate change policy analysis* the main weaknesses in traditional CGE models for climate change policy analysis is the difficulty in solving comprehensive general equilibrium with spatial disaggregation; the computational complexity in settling intertemporal CGE models, which are already optimisations, within further overall climate damage and trade deficit feedback loops; including emissions trading in each country and between countries; applying different abatement regimes in each country, which is perhaps the most important scenario outcome of an economic-climate model; and establishing the redistribution of production between countries after differential carbon pricing and abatement are introduced in each country.

The reason for this is that markets in CGE models are constructed with many equations. This is quite onerous and imbued with many assumptions such as elasticities and marginal productivities. When the number of countries and commodities is expanded, the complexity of the task increases dramatically. The rapidly multiplying assumptions become copious and manifold. The shear scope of addressing the huge set of exogenous variables means that detailed due diligence of assumptions is difficult to complete. This compares to, say, using data such as Input Output data at face value, and creating marketplaces by virtual of primal and dual formulations present in all optimisations. For example, the “Main Theory of Linear Programming” simultaneously maximises an output isoquant while minimising resources. At the same time, the resource marginal productivities are established endogenously, instead of exogenously as in traditional CGE models.

Government policy makers and private sector industry strategists need a model where their own region, country and industry equilibrium is calculated in a world context. All countries and industries want to understand their SWOT profile of strengths, weaknesses, opportunities and threats, to appreciate how this compares with that of their competitors and trading partners, and to understand intertemporal tradeoffs such as how fast we need to change now as compared to deferring action. Many strategic choices then have to be made both locally and in response to changes in the relative competitive position of nations. For example, the relocation of distribution warehouses away from areas that may be impacted by climate change.

This highlights the primary limitation in current CGE models, which can't readily provide spatial disaggregation. For example, Australia's CGE models are amongst the most sophisticated in the world. Yet none of the Australian CGE models could easily model Australia's climate change policy in the world setting. The Garnaut and Australian Treasury policy analysts need to manually assemble a system of partial equilibriums (i.e. manually create a synthetic national equilibrium in a world context). The lack of modelling flexibility appears to have been exceedingly exasperating because the modelling team ran late in its task.

A second major research gap in existing CGE models is the need to select a production function, such as the Nordhaus DICE Cobb-Douglas function, GTAP's Constant Elasticity function or a Translog function. It is difficult to justify synthetic, econometrically-estimated production functions based on calibration alone. Dale Jorgenson was the first person to use econometrics for estimating American economic parameters, giving rise to the complex task of econometric general equilibrium modelling (Johansen 1978; Hazilla & Kopp 1990).

A third research gap is present in Leontief, Nordhaus DICE and ten Raa's modelling of intertemporal performance. In intertemporal models, population and technology productivity are the only exogenous variables. Investment and capital (i.e. accumulated and depreciated investment) are endogenous because these factors have to be produced by the economy and the level of production is determined by expectations of future consumer and industry demand. Therefore, intertemporal models need a way of inherently controlling investment in an industry.

In Leontief's B matrix approach, which is a type of Markov chain, the capital at the end of the period is assumed to be zero. This implies that care needs to exercised in the use of Leontief B approaches to ensure that consumers and producers do not consume the total capital base of the industries.

In the Nordhaus DICE model, which is investigated in Chapters 4 and 5 (and Appendices 4 and 5), industry investment is any available excess of output over consumption. Capital accumulation becomes an outcome. This is the reverse of the actual situation where capital investment in industry needs to be maintained and grow with output. To many, Nordhaus' approach of preferring consumption over investment is unremarkable because it seems so much in accord with consumption-led economics, which has been the pervasive Anglo-American tenet of political economy.

In ten Raa's intertemporal formulation, which seeks equivalence with Leontief's B matrix approach, capital is determined as a convolution of investment.

A fourth research gap in traditional CGE models is communication. CGE modelling is undertaken in batch processing environments where equations are programmed in specialist modelling languages and presented to industrial optimisation solvers. The results are returned as batch files of text. The lack of a Graphical User Interfaces (GUI) for interactive model development, fast turnaround and visualisation of results is a major disadvantage for research productivity. Even more unsatisfactory is the difficulty in creating rich graphs for presentation to policy makers, which often results in bland tables, minimal graphics and poor communication. While enhanced graphics can be achieved with supplementary tools, the lack of productivity due to double handling and absence of early visualisation stifles agility and creativity.

Effect of inadequate policy tools on climate change policy makers

We are at a cusp in history that makes innovation in CGE climate modelling important and timely. In Anglo-American nations, such as America and Australia, major philosophical, economic, behavioural and security changes are taking place. The great American dream of expansion and unlimited resources, through force of arms if necessary, is evolving to a new type of sustainable dream. New regionally disaggregate policy modelling platforms are needed for these new times of heavily constrained and symbiotic global growth.

However, nations continue to vacillate about how long they can defer the decision to switch from policies of unconstrained growth to policies of constrained growth. This has led to dithering in international agreements, what some might call “policy paralysis” and to the use of Prisoners Dilemma game theory strategies to minimise losses.

All of these elements have been present at the UNFCCC Bonn meeting in June 2009, which failed to bring consensus to policy for 2012 and beyond. For example, America determinedly sought China's agreement to targets such as 40% reduction in emissions by 2020 (compared to 1990 level). China responded that this type of target is inappropriate but that China would be cooperative in reducing emissions if America provides inexpensive green technologies such as carbon capture and storage.

China's response has the merit of logic. A unique issue in climate policy is the existence of a fixed tranche of emissions, beyond which global warming is considered cataclysmic (see *Chapter 3 Political economy of the Anglo-American world view of climate change*). This stark reality forces the inescapable issue that either green technology is cheap and widely available or countries will need to face large reallocations in their domestic production and perhaps internationally. Many regions, for example the Spanish Asturias (Arguelles et al. 2006), have expressed concern that limiting emissions will have dire effects on their economies. Of course, making green technology cheap and widely available leads to other issues such as minimal or no patent protection for private technology developers.

Traditional CGE models have great difficulty in adequately coping with the plurality of climate-economic policy constraints, which multiply the complexity of models. For example, living within current income rather than borrowing to maintain lifestyle, maintaining the purchasing power of the labour force, managing energy requirements and greenhouse gas pollution, while achieving social objectives such as expanding both population and the welfare of the population.

A CGE framework for climate policy analysis is needed that captures the background of changing Anglo-American, European, Chinese, Indian and other world views, focusing on the various dimensions of the debate on climate change and looking forward to satisfactory “win-win” solutions to the issues that emerge from the interaction of such dimensions.

Resolving inadequacies in CGE climate policy modelling

A way of addressing the first and second shortcomings identified above could be to utilise the Use (U) and Make (V) tables from national accounts instead of the more synthesised Input Output tables or the equivalent Leontief (A) matrix. The U, V and A matrices are related by the equation $U = A.V^T$, where V^T is the transpose of the V matrix. As Gross Domestic Product is $V^T - U$ then many industrial relationships can be conveniently modelled by retaining the U and V format. For example, pollution, emissions trading, abatement and various energy sources can be directly modelled. Creating Leontief's A matrix (and, for this matter, Leontief's B matrix) is useful for many traditional analysis purposes but sacrifices information. In contrast to utilising techniques associated with the Leontief A matrix, ten Raa's $(V^T - U).s$ may be used as a straightforward production function, where s is the activity vector of the commodity production units.

The Use-Make model implies a Leontief production function, which is a constant return to scale formulation and special case of the Constant Elasticity of Substitution model. Applied in a multi-industry model, there is substitution between industries of the factors of production such as materials, labour and capital. The optimisation process dual solution settles the market by balancing marginal productivities and therefore marginal prices for *tétonnement*. This overcomes the usual objection to Leontief production function where there is no substitution of the factors of production within a single industry. Studies comparing data envelopment analysis (DEA) and transcendental production functions (Translog) demonstrate that there is little value in providing a more advanced econometrically synthesised production function. The long use of DEA in government and industry imparts confidence in the use of optimisation-type production functions. Therefore, the use of Use and Make table production functions within computable general equilibrium models appears to be a prospective area for investigation.

ten Raa's benchmarking using $(V^T - U).s$ is in itself a highly efficient production function across industry sectors, both for domestic substitution and international substitution through bilateral trade flows.[xi] It models the trade-off effects in policy scenarios across regions and industries. This analysis becomes insightful when intertemporal outcomes are also constrained as in climate modelling.[xii] However, the Armington assumption underlying all multiregional input output models and CGE models is still applied: that commodities in the same statistical class are substitutes, albeit imperfect substitutes (Armington 1969).[xiii] It applies to domestic industries as well as the international trade of commodities.

ten Raa's benchmarking approach has the advantage that intertemporal economic models can be readily, directly and transparently solved by fast linear programming. In contrast to current CGE models, these benchmarking models are holistic, comprehensive and highly flexible for testing new policy formulations and the turnaround is very fast. Interior point nonlinear programming brings these benchmarking models to the next level of sophistication, for example, when nonlinear climate scientific equations are used. While not nearly as fast as linear programming, nonlinear models remain holistic and flexible.

Although traditional CGE models have a long heritage and are widely used there has been no definitive testing of whether benchmarking CGE models are superior to traditional CGE models. This is because economics, strategy and policy making are all disciplines of practice rather than sciences in the strict sense of hypothesis testing. Only the use of both traditional CGE models and benchmarking CGE models over a reasonably long period will develop a deeper understanding of whether one or other formulation has compelling advantages.

A way of addressing the third research gap in intertemporal modelling of maintaining capital in an industry as a competitive endogenous variable can be bridged by using a financial modelling technique where the ratio of sales to assets in each industry is maintained. Provenance for such an approach may be found in the use of Leontief stock coefficients to provide a relationship between stocks and flows using a turnover period (Bródy 1974; 2004; ten Raa 2004; 2007).

DuPont Analysis deconstructs Return on Assets (all assets, including buildings, machinery, inventories and debtors) with equation:[xiv]

$$Return\,on\,Assets = \frac{Profit}{Assets} = \frac{Profit}{Sales} * \frac{Sales}{Assets}$$

For example, a certain level of assets is needed to support an expected economic output or sales volume. For a manufacturer this might be twice sales, while for a retailer it might be equal to sales. Therefore, capital formation in intertemporal models can be satisfied with a constraint on future economic output that limits future flows to the level of opening capital stock multiplied by a Sales/Asset ratio.

A way of addressing the fourth gap in CGE policy research, being a lack of agility and poor communication, may be to use a modern mathematical optimisation platform with a rich set of data visualisation functions. The last decade has brought considerable advances in the development of advanced optimisation techniques within visualisation environments.

1.4 Research aims

Against the above backdrop, the main aim of this research is to answer the question:

> What changes in regional and industry performance are implied by a change in the Anglo-American world view from unconstrained to climate-constrained resource usage?

The means of understanding this question is to examine climate-economic polices through the lens of a new spatial, intertemporal CGE policy research tool appropriate for situations where resources are limited by climate change.

1.5 Research methodology

The five-step methodology of achieving the research aim is:

1. Reviewing the history of the Anglo-American world view with a view to understanding the confluence between economic growth, free markets, energy security and domestic security, and global warming. The evolution of the Anglo-American world view will be contrasted to the European world view using literature survey and political commentary. This analysis of political economy will particularly focus on the cusp of change in the Anglo-American psyche from a determination to remain unconstrained to an acceptance of economic and climate constraints.
2. Reviewing the political economy of climate change in Anglo-American countries and the policy options under consideration with a view to delineating the major underlying influences from science and ecology, the policy making of major nations, environmental activism and the dynamics of international treaties.
3. Examine the history of climate-CGE modelling and the main methodological frameworks that have constituted the mainstay on the analyses required to inform policies and strategies for containing climate change. This part of the methodology will select a CGE modelling paradigm, computing environment and data source.
4. Describe a new CGE modelling approach to achieve the research aim.
5. Demonstrate the appropriateness of this new CGE model in the context of the research aim.

The research methodology is shown diagrammatically as follows:

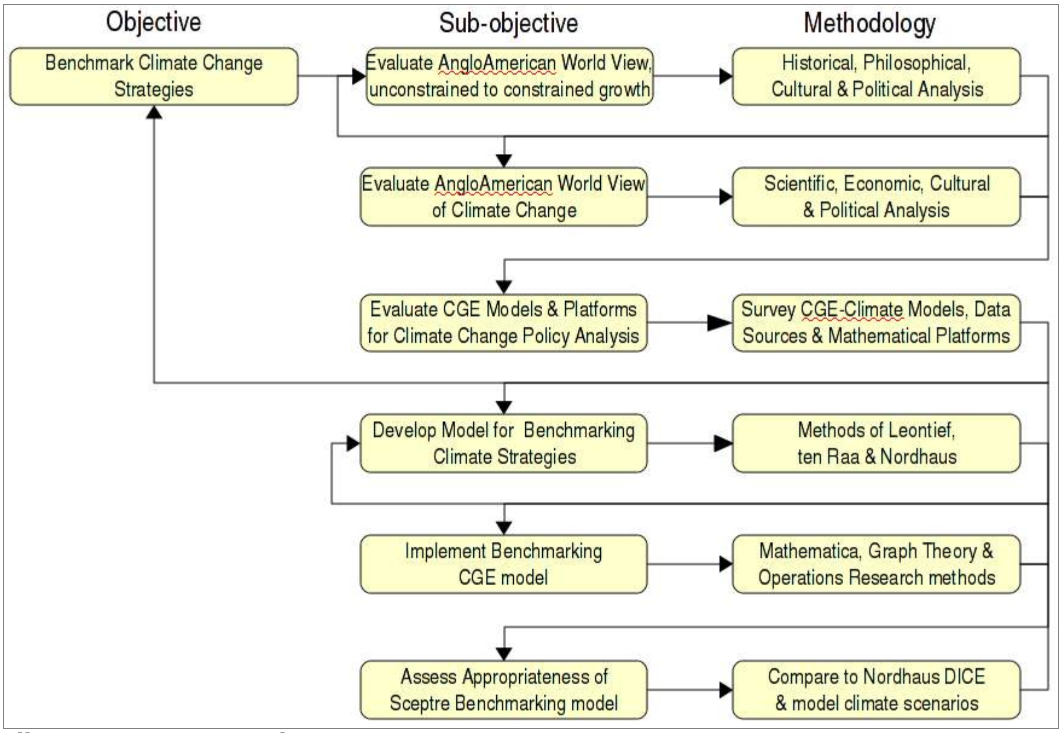

Illustration 1: Research structure

1.6 Scope of research

Time frame

This research project has been conducted during a period of intense international negotiations over climate change policy. Countries involved in these negotiations experienced many domestic and international pressures, and employed various intriguing game strategies. This dissertation investigates the political economy of these negotiations and strategies as Anglo-American countries face new constraints on both their economic growth and unilateralism.

While the political process in international relations has been in-train for thousands of years and presumably will continue for thousands of years more, bringing this research to a conclusion necessarily requires that a time scope be set. Therefore the time frame for this research is the period ending with the UNFCCC's Bangkok talks on 10 October 2009.

Data scope

The wide variety of sources of data assembled and, where necessary, purchased for this research reflects its multidisciplinary nature across economics and technology.

Significant advances have been made in the standardisation and availability of international economic data over the past fifteen years. The author personally acquired the Global Trade Analysis Project (GTAP) economic database for this research from the Purdue University Department of Agricultural Resources (2008). The GTAP 7 database, published in December 2008, provides economic data for 113 regions and 57 sectors for the base year 2004. The database is updated every three years so the next update can be expected in 2011.

The economic data in the GTAP database comprises approximately 96% of world GDP and 88% of world population. Remaining economic activity and the other 12% of world population is included in aggregated regions. This database includes 2004 country National Accounts Input Output tables, IMF and OECD bilateral trade data, CEPII and UN FAO tariff data, and World Bank economic data. The two unique and compelling advantages of the GTAP database are that the data is fully reconciled and that specific regions can be investigated with a Rest of World (ROW) sector, which is essential for regional studies using multiregional Input Output models.

The GTAP 7 database provides harmonised energy and greenhouse emissions data derived from the International Energy Agency's (IEA) extended energy balances and data from Asian Development Bank. Energy related CO_2 emission volumes are based on the Tier 1 method of the revised 1996 IPCC Guidelines, with special treatment for non-emitting activities, country-specific sectoral feedstock use ratios and energy transformation. For example, coal used to produce coal products. In addition, GTAP is preparing to issue non-CO_2 emissions volumes for, CH_4, N_2O, and F-gases emissions based on IPCC Tier 1 and Tier 2 methods and mapping emissions sources to GTAP sector activities.

While GTAP 7 doesn't provide population growth rates, the GTAP data can be supplemented with a wide range of financial and resource data, for example from the Mathematica's Country Database, which provides population growth rates for the year 2006.

The climate-economic feedback loops in climate CGE modelling require that scientific data and physical relationships accepted by the United Nation's scientific body for climate change, the Intergovernmental Panel on Climate Change (IPCC), be mapped through to economic damage multipliers. William Nordhaus' DICE model (2007; 2008) is a highly respected model and has been drawn upon for these scientific-economic linkages.

Geographical scope

The research focus of this dissertation has been to understand the policy challenges facing Anglo-American countries as they restructure from unconstrained growth to an acceptance of climate change constraints. Policy development in Anglo-American countries is contrasted to that in the European Union and to BRIC countries (primarily Brazil, Russia, India and China), which dominate the rest of the world category. Therefore, three regions of the world have been modelled to understand policy development and outcomes with reference to the two predominant trading blocs: the North Atlantic Free Trade Association (NAFTA) and the European Union (EU of 25 countries). Countries outside of these two trading blocs are aggregated into a Rest of World (ROW) category.

Commodity scope

Three basic commodities are analysed in each region: food, manufactured goods and services. The GTAP 7 economic and emissions databases are aggregated for these commodities across the geographical scope of NAFTA, EU and ROW. Additional emissions permits and carbon mitigation services commodities are appended to enable climate change policies to be evaluated.

Intertemporal scope

The climate-CGE modelling tool developed in this dissertation facilitates the study of climate change policies over projections of 130 years (13 decades) from the data's base year of 2004. This is somewhat less than the full 60 decades of the Nordhaus DICE model. While the intertemporal scope is sufficient, it is limited by the magnitude of the task in symbolically representing the whole spatial and industry disaggregation model within optimisation constraints combined with the operations research challenges of nonlinear optimisation.

1.7 Significance of research

Any new strategy or business idea requires a business plan with market analysis, economic/financial projections and risk analysis. It is no different for government policy makers and private sector planners when new constraints arise. The arrival of climate change imperatives is perhaps the first of many such new conditions in a rapidly populating world that is perhaps facing declining oil availability. Climate change brings with it new constraints and this demands a whole new paradigm of resource-constrained modelling.

Anglo-American governments are facing the extraordinary challenge of shifting their policy framework from unconstrained growth to constrained growth. There is considerable trepidation about this new uncharted future and this anxiety has been exacerbated further by the current financial crisis.

A literature review highlights the difficulty in using existing partial equilibrium models to answer economic-climate questions in the light of changing Anglo-American approaches to constraints on growth.

This research has led to an innovative methodological technique for intertemporal computable general equilibrium in the presence of international trade, emissions trading, emissions abatement and climate change resource constraints.

In its review of the role of economic modelling in the global financial crisis, The Economist (2009) concludes: “Economists need to reach out from their specialised silos: macro-economists must understand finance, and finance professors need to think harder about the context within which markets work. And everybody needs to work harder on understanding asset bubbles and what happens when they burst. For in the end economists are social scientists, trying to understand the real world.”

Multidisciplinary groups are aware of this. For example Jan Oosterhaven, President of the International Input Output Association, ends his address in the Association's 2008 Annual Report (2007, pp.1-2): “IO [Input Output] analysis is doing well because of the continuous extension of its fields of application. Also it is doing well as judged by the intensive use of IO data, social accounting data and all kind of linked satellite accounts. However, it might do better if we could include the interaction of prices and quantities - between sectors, between institutions, between regions and between countries.”

This research introduces techniques from finance and computable general equilibrium (CGE) pricing into Input Output analysis, informed by a consistent framework of political economy. A new type of neoclassical climate policy model is developed, which has been called Sceptre.

Sceptre's application is in projecting, pricing and making the most of constrained resources. From the perspective of policy analysis, it is a comprehensive approach to globalised markets with full attention to commodity production technologies and population labour dynamics. It has the compelling advantages of consistency, flexibility, transparency and the potential for ubiquity because of its underlying deployment platform.

This research has significant impact in delivering clear and compelling outcomes from policy and strategy modelling in many different climate and other scenarios. Organisations at all levels in the community are keenly interested in the answer to the research question as part of formulating their own policies and strategies.

From the literature survey we have seen the decades of effort that international organisations, such as United Nations, IPCC, IEA, IMF and World Bank, and domestic organisations, such as the Australian Productivity Commission, ABARE, Australian Treasury, CSIRO, Garnaut Review, Monash University and others have devoted to the pursuit of better models. This research is therefore timely in providing the first model of its type for multiregional, intertemporal policy analysis in growth constrained by climate change.

This research establishes a platform for further development to address additional and more specific issues in the future. In particular, it addresses a number of Australian National Research Priority Areas including an environmentally sustainable Australia (through developing strategies for transforming existing industries, reducing and capturing emissions in transport and generation, and responding to climate change and variability); promoting and maintaining good health in strengthening Australia's social and economic fabric; and safeguarding Australia's critical infrastructure including our financial, energy, communications, and transport systems; and understanding our region and the world (societies, politics and cultures).

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ii On 18 November 2004, Russia ratified the Kyoto Protocol thereby satisfying the condition precedent that at least 55% of 1990 Annex 1 country CO_2 emissions were encompassed by the treaty

iii The United Kingdom government is aware of many climate threats, such as the flooding of London

iv Ironically, deductivism is itself a hypothesis that cannot be accorded the status of a theory because any proof of deductivism is inconsistent if it relies on any axiom or proof established using deductivist principles. Deductivism is caught by the ultimate paradox that a consistent set of rules cannot establish the validity of that same set of rules. This paradox is illustrated by Kurt Gödel's incompleteness theorems in Mathematics. These incompleteness theorems prove that it is not possible to find a formal theory (i.e. a set of axioms) that can prove all theories and exclude all falsehoods; and that if a formal theory can be proven consistent from within itself, then it must rely upon itself and therefore be inconsistent (Gödel 1931, Theorems VI & XI). Despite vulnerability to these tests, deductivism is widely regarded as a useful and powerful formulation for rational scientific enquiry. The deductivist paradigm is not broken merely on account that it is unable to self-establish. To do so would have many unreasonable consequences. For example, the identity 1 + 1 = 2 is well accepted as part of the body of common knowledge that every child learns at school. Indeed, if the child does not know this rule then either the child's learning or the school's teaching would be considered grossly deficient. Nevertheless, Gödel's incompleteness theorems declares that this fundamental identity is unprovable and, by extension, render as flawed the whole set of proofs, tests and practices that depend upon it

v Although Birnbaum's “likelihood principle” is highly regarded, it remains controversial. It is stated as follows, *The likelihood principle (L)*: “In an experiment E with observed data x, all experimental information about v is contained in the likelihood function $v \to P(x|v)$. All other information can be neglected. More precisely, if E and E' are two experiments and if the outcomes x and x' generate the same likelihood function, then $Ev(E,x) = Ev(E',x')$, without reference to the structure of *E* and *E'*" Its corollary is that the probability of results that could have been observed is irrelevant to the statistical inference. The "Likelihood Principle" contains the principles of sufficiency (S) and conditionality (C). Birnbaum notes: "The fact that relatively few statisticians have accepted (L) as appropriate for purposes of informative inference, while many are inclined to accept (S) and (C), lend interest and significance to the result, provided herein, *that (S) and (C) together are mathematically equivalent to (L)*"(Birnbaum,1962, p271)

vi 5.9% is the probability of a correct positive identification plus the probability of an incorrect positive identification (i.e. 95% x 1% + (100%-95%) x (100%-1%))

vii 16.9% is calculated as 95% probability of the test being positive if the person has taken drugs x 1% probability of a person taking drugs regardless of other factors / 5.9% probability of a positive result regardless of other factors

viii If the accuracy of the test remains at the new level of 99% and the probability of drug use by sports people falls to just 0.1%, then the probability of drug use given a positive test falls to only 9.02%. This illustration of Bayes' posterior probability has been developed with reference to "Further Examples: Example 1 Drug Testing" at http://en.wikipedia.org/wiki/Bayes%27_theorem

ix 58% is calculated as 90% x 60% + (100%-90%) x (100%-60%)

x 93% is calculated as 90% probability that the modelling correctly shows a policy is feasible if it is indeed feasible x 60% probability of a policy being feasible regardless of other factors / 58% probability of a positive result regardless of other factors

xi Without modification, ten Raa's linear programming benchmarking uses a simple Leontief function for each industry, which implies a constant mix of inputs. However, it provides full substitution to other industries in the world with a better technology function and substitutes the factors of production across domestic industries. The Leontief function can be modified by increasing returns to scale and decreasing returns to scale if desired but in most situations the simplicity of constant returns to scale is intuitive and appealing

xii The 2009 case of Pacific Brands transferring its underwear factories from Australia to Asia is an example of industrial production shifting from one structure of labour and technology to another

xiii The Armington Assumption is a constant elasticity of substitution (CES) aggregate assumption for international trade

xiv DuPont Analysis was developed by the American chemical conglomerate E. I. du Pont de Nemours and Company

Chapter 2 Political Economy of the Anglo-American economic world view

The 2008-9 Global Financial Crisis, wars in Iraq and Afghanistan and deep deficits in the American economy have brought challenges and emerging changes to the Anglo-American world view. This Chapter investigates the development of the Anglo-American economic world view to establish a framework for understanding climate change policy. America's unique themes of liberty and free markets are distinct, pervasive and dominant in Anglo-American culture.

America is therefore used as a proxy for the Anglo-American group of nations, which is defined widely to include the United Kingdom, Canada, Australia and, on various dimensions, countries as diverse as Japan, South Korea, Denmark, Poland and Georgia. Many of these countries look to a “special relationship” with America. The sources of America's world view are traced from the time when American society was formed through to almost the first anniversary of President Barack Obama's election. America is compared and contrasted to Europe and in particular with Germany. This analysis concludes with an investigation of the preparedness of America to accept the decline of its exceptionalism and new reality of resource constrained growth.

2.1 Origins of the American worldview

Walt Whitman recalled in Democratic Vistas (1888):

> The old men, I remember as a boy, were always talking of American independence. What is independence? Freedom from all laws or bonds except those of one's own being, control'd by the universal ones.

Around 17 February 1775, the great ambassador Benjamin Franklin had firmly highlighted the primacy of freedom in the American psyche (B. Franklin & W. T. Franklin 1818) “ Those who desire to give up Freedom in order to gain Security, will not have, nor do they deserve, either one.”

Perhaps the most fundamental of American character traits is the belief in freedom. The tenet was bravely announced in The Unanimous Declaration of The Thirteen United States of America adopted by the Congress of the United States on July 4, 1776. It stated:

> We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty, and the pursuit of Happiness. That to secure these rights, Governments are instituted among Men, deriving their just powers from the consent of the governed. That whenever any Form of Government becomes destructive of these ends, it is the Right of the People to alter or to abolish it, and to institute new Government, having its foundation on such principles and organizing its powers in such form, as to them shall seem most likely to effect their Safety and Happiness.

However, in drafting the American Constitution approved on 17 September 1787, the fathers decided to subjugate personal liberty to order. They returned to the British concept of “order out of chaos”, legislating that the rule of law and order of society were more important than individual liberty.[i] Two years later ten amendments to the American Constitution, collectively known as the Bill of Rights (1789), reinstated the importance of individual liberty in law.

Nearly fifty years later, the French lawyer Alexis de Tocqueville visited America to critically appraise the emergent American democracy. For his pioneering work of observational political sociology *De la démocratie en Amérique* (1835) de Tocqueville was decorated as a chevalier de la Légion d'honneur (Knight of the Legion of Honour), elected to the Académie des sciences morales et politiques and subsequently to the Académie française.

De Tocqueville looked beyond the familiar elite of cosmopolitan cities of New York, Boston, Washington and New England, recognising the parochial thinking and fundamental religious values of Americans to the West. Of the business fervour across America and the social conditions in the virgin territories of the West, de Tocqueville writes (Volume 1, Chapter III, *Social Condition of the Anglo-Americans*):

> I know of no country, indeed, where the love of money has taken stronger hold on the affections of men and where a profounder contempt is expressed for the theory of the permanent equality of property .... there are but few wealthy persons; nearly all Americans have to take a profession .... in the Western settlements we may behold democracy arrived at its utmost limits .... the population has escaped the influence not only of great names and great wealth, but even of the natural aristocracy of knowledge and virtue. None is there able to wield that respectable power which men willingly grant to the remembrance of a life spent in doing good before their eyes. The new states of the West are already inhabited, but society has no existence among them.

In American society, de Tocqueville identifies pervasive traits of pragmatism and preoccupation with consumption. In Volume 2, Section 1, *Influence of Democracy on the Action of Intellect in The United States,* Chapter X, *Why the Americans are more addicted to practical rather than theoretical science*, de Tocqueville locates these traits in America's engrossment with business:

> In America the purely practical part of science is admirably understood, and careful attention is paid to the theoretical portion which is immediately requisite to application. On this head the Americans always display a clear, free, original, and inventive power of mind. But hardly anyone in the United States devotes himself to the essentially theoretical and abstract portion of human knowledge. In this respect the Americans carry to excess a tendency that is, I think, discernible, though in a less degree, among all democratic nations .... Everyone is in motion, some in quest of power, others of gain. In the midst of this universal tumult, this incessant conflict of jarring interests, this continual striving of men after fortune, where is that calm to be found which is necessary for the deeper combinations of the intellect? .... The man of action is frequently obliged to content himself with the best he can get because he would never accomplish his purpose if he chose to carry every detail to perfection. He has occasion perpetually to rely on ideas that he has not had leisure to search to the bottom; for he is much more

> frequently aided by the seasonableness of an idea than by its strict accuracy; and in the long run he risks less in making use of some false principles than in spending his time in establishing all his principles on the basis of truth. The world is not led by long or learned demonstrations; a rapid glance at particular incidents, the daily study of the fleeting passions of the multitude, the accidents of the moment, and the art of turning them to account decide all its affairs .... The greater part of the men who constitute these nations are extremely eager in the pursuit of actual and physical gratification. As they are always dissatisfied with the position that they occupy and are always free to leave it, they think of nothing but the means of changing their fortune or increasing it. To minds thus predisposed, every new method that leads by a shorter road to wealth, every machine that spares labor, every instrument that diminishes the cost of production, every discovery that facilitates pleasures or augments them, seems to be the grandest effort of the human intellect. It is chiefly from these motives that a democratic people addicts itself to scientific pursuits, that it understands and respects them. In aristocratic ages science is more particularly called upon to furnish gratification to the mind; in democracies, to the body.

Perhaps with great foresight, de Tocqueville identifies systemic risks and consequences in American's pragmatism and risk taking. In Volume 2, Section 3, *Influence of Democracy on the Feelings of Americans,* Chapter XIX, *What causes almost all Americans to follow industrial callings* he writes:

> The Americans make immense progress in productive industry, because they all devote themselves to it at once; and for this same reason they are exposed to unexpected and formidable embarrassments. As they are all engaged in commerce, their commercial affairs are affected by such various and complex causes that it is impossible to foresee what difficulties may arise. As they are all more or less engaged in productive industry, at the least shock given to business all private fortunes are put in jeopardy at the same time, and the state is shaken. I believe that the return of these commercial panics is an endemic disease of the democratic

> nations of our age. It may be rendered less dangerous, but it cannot be cured, because it does not originate in accidental circumstances, but in the temperament of these nations.

Today, most Americans hold unquestioned the core beliefs of freedom, independence and democracy. Walt Whitman's Democratic Vistas (1888), previously mentioned, provides an eloquent statement of pride in the new nation. Following is a short abridgement of Walt Whitman's first three paragraphs, which confirms the American ideal of unfettered individual social, economic and moral freedom from the State (advanced by John Stuart Mill in his 1859 essay *On Liberty*) and the pride in a nation that is forever nascent and supreme to all other social systems:

> As the greatest lessons of Nature through the universe are perhaps the lessons of variety and freedom, the same present the greatest lessons also in New World politics and progress. If a man were ask'd, for instance, the distinctive points ... he might find the amount of them in John Stuart Mill's profound essay on Liberty in the future, where he demands two main constituents, or sub-strata, for a truly grand nationality -- 1st, a large variety of character -- and 2nd, full play for human nature to expand itself in numberless and even conflicting directions … America … counts, as I reckon, for her justification and success ... almost entirely on the future. Nor is that hope unwarranted. To-day, ahead, though dimly yet, we see, in vistas, a copious, sane, gigantic offspring. For our New World I consider far less important for what it has done, or what it is, than for results to come. Sole among nationalities, these States have assumed the task to put in forms of lasting power and practicality, on areas of amplitude rivaling the operations of the physical kosmos, the moral political speculations of ages, long, long deferr'd, the democratic republican principle, and the theory of development and perfection by voluntary standards, and self-reliance. Who else, indeed, except the United States, in history, so far, have accepted in unwitting faith, and, as we now see, stand, act upon, and go security for, these things? …. I shall use the words America and democracy as convertible terms … Not the least doubtful am I on any prospects of their material success. The triumphant future of their business,

geographic and productive departments, on larger scales and in more varieties than ever, is certain. In those respects the republic must soon (if she does not already) outstrip all examples hitherto afforded, and dominate the world …. *I perceive clearly that the extreme business energy, and this almost maniacal appetite for wealth prevalent in the United States, are parts of amelioration and progress, indispensably needed to prepare the very results I demand. [Walt Whitman's emphasis]* …. Political democracy, as it exists and practically works in America, with all its threatening evils, supplies a training-school for making first-class men. It is life's gymnasium, not of good only, but of all.

2.2 International relations

National security

American shared beliefs uniquely shaped a foreign policy built on the dual premises of America as a new promised land for a chosen people of God, and an even more arrogant “bully-boy” attitude that “the most powerful player makes the rules”. These attitudes were formalised as the Monroe Doctrine, known more broadly as Manifest Destiny, that justified America attacking any country in the world (Jensen 2000, pp.86-8; Perkins 2004, pp.69-70):

> Manifest Destiny – the doctrine, popular with many Americans during the 1840s, that the conquest of North America was divinely ordained; that God, not men, has ordered the destruction of Indians, forests, and buffalo, the draining of swamps and the channelling of rivers, and the development of an economy that depends on the continuing exploitation of labour and resources …. got me thinking about my country's attitude toward the world. The Monroe Doctrine, originally enunciated by President James Monroe in 1823, was used to take Manifest Destiny a step further when, in the 1850s and 1860s, it was used to assert that the United States had special rights all over the hemisphere, including the right to invade any nation in central or South America that refused to back U.S. Policies. Teddy Roosevelt invoked the Monroe Doctrine to justify U.S. Intervention

> in the Dominican Republic, in Venezuela, and during the “liberation” of Panama from Colombia. A string of U.S. Presidents – most notably Taft, Wilson, and Franklin Roosevelt – relied on it to expand Washington's Pan-American activities through the end of World War II. Finally, during the latter half of the twentieth century, the United States used the Communist threat to justify expansion of this concept to countries around the globe, including Vietnam and Indonesia.

A notable use of Manifest Destiny in its most extended form was the American invasion of the sovereign nation Hawaii on 16 January 1893. Using a fabricated excuse, American Marines invaded Hawaii and occupied Government buildings and the Iolani Palace. On 18 December 1893, President Grover Cleveland sought to redress the invasion with an impassioned plea to the Senate and House of Representatives to not succumb to the wrongful acquisition of Hawaii (Cleveland 1893):

> Our country was in danger of occupying the position of having actually set up a temporary government on foreign soil for the purpose of acquiring through that agency territory which we had wrongfully put in its possession. The control of both sides of a bargain acquired in such a manner is called by a familiar and unpleasant name when found in private transactions. We are not without a precedent showing how scrupulously we avoided such accusations in former days. After the people of Texas had declared their independence of Mexico they resolved that on the acknowledgement of their independence by the United States they would seek admission into the Union. Several months after the battle of San Jacinto, by which Texan independence was practically assured and established, President Jackson declined to recognize it, alleging as one of his reasons that in the circumstances it became us "to beware of a too early movement, as it might subject us, however unjustly, to the imputation of seeking to establish the claim of our neighbors to a territory with a view to its subsequent acquisition by ourselves". This is in marked contrast with the hasty recognition of a government openly and concededly set up for the purpose of tendering to us territorial annexation .... I believe that a candid and

> thorough examination of the facts will force the conviction that the provisional government owes its existence to an armed invasion by the United States. Fair-minded people with the evidence before them will hardly claim that the Hawaiian Government was overthrown by the people of the islands or that the provisional government had ever existed with their consent. I do not understand that any member of this government claims that the people would uphold it by their suffrages if they were allowed to vote on the question …. But in the present instance our duty does not, in my opinion, end with refusing to consummate this questionable transaction. It has been the boast of our government that it seeks to do justice in all things without regard to the strength or weakness of those with whom it deals. I mistake the American people if they favor the odious doctrine that there is no such thing as international morality, that there is one law for a strong nation and another for a weak one, and that even by indirection a strong power may with impunity despoil a weak one of its territory …. a substantial wrong has thus been done which a due regard for our national character as well as the rights of the injured people requires we should endeavor to repair.

President Grover indeed did "mistake the American people". Instead of Hawaii being returned to Queen Liliuokalani and her Government, President Grover's successor, President William McKinley, annexed Hawaii through the Newlands Joint Resolution of 7 July 1898. President McKinley justified his action as a consequence of the Spanish-American War. One hundred years later, President Clinton apologised to the nation of Hawaii (103rd Congress 1993):

> The Congress … (3) apologizes to Native Hawaiians on behalf of the people of the United States for the overthrow of the Kingdom of Hawaii on January 17, 1893 with the participation of agents and citizens of the United States, and the deprivation of the rights of Native Hawaiians to self-determination; (4) expresses its commitment to acknowledge the ramifications of the overthrow of the Kingdom of Hawaii, in order to provide a proper foundation for reconciliation between the United States and the Native Hawaiian people.

Manifest Destiny continued to provide legitimacy for American incursions across the world, in Vietnam, South America, Panama and ultimately in Iraq (Perkins 2004, pp.181-2):

> In November 1980, Carter lost the U.S. Presidential election to Ronald Regan ... A president whose greatest goal was world peace and who was dedicated to reducing U.S. dependence on oil was replaced by a man who believed that the United States' rightful place was at the top of a world pyramid held up by military muscle, and that controlling oil fields wherever they existed was part of our Manifest Destiny. A president who installed solar panels on White House roofs was replaced by one who, immediately upon occupying the Oval Office, had them removed ... Regan … was most definitely a global empire builder, a servant of the corporatocracy ... He would advocate what those men wanted: an America that controlled the world and all its resources, a world that answered to the commands of America, a U.S. military that would enforce the rules as they were written by America, and an international trade and banking empire that supported America as CEO of the global empire.

In a visionary speech on 4 June 2009, seeking a new beginning with Iran, President Obama acknowledged America's role in the 1953 Iranian *coup d'état* of the democratically elected Prime Minister Mohammed Mosaddeq (Obama 2009c) “In the middle of the Cold War, the United States played a role in the overthrow of a democratically elected Iranian government.”

Self-authorised extraterritorial actions, justified by Manifest Destiny, including assassinations, kidnapping (known as extraordinary rendition) and torture, continued to be pervasive through George W. Bush's presidency (Schmitt & Mazzetti 2008):

> The United States military since 2004 has used broad, secret authority to carry out nearly a dozen previously undisclosed attacks against Al Qaeda and other militants in Syria, Pakistan and elsewhere ... These military raids, typically carried out by Special Operations forces, were authorized by a classified order that Defense Secretary Donald H. Rumsfeld signed in the spring of 2004

> with the approval of President Bush ... The secret order gave the military new authority to attack the Qaeda terrorist network anywhere in the world, and a more sweeping mandate to conduct operations in countries not at war with the United States … the new authority was spelled out in a classified document called “Al Qaeda Network Exord,” or execute order.

Sachs (2008, p.10) notes that American failures, including the Bush Administration's crude and violent unilateralism, are a legacy of ashes:

> The CIA-led overthrows of several governments (Iran, Guyana, Guatemala, South Vietnam, Chile), the assassinations of countless foreign officials, and several disastrous unilateral acts of war (in Central America, Vietnam, Cambodia, Laos, and Iraq). The United States has thrown elections through secret CIA financing, put foreign leaders on CIA payrolls, and supported violent leaders who then came back to haunt the United States in a notorious boomerang or “blowback” effect (including Saddam Hussein and Osama bin Laden, both once on the CIA payroll) … Like the earlier excesses during the Cold War era, the Bush administration's excesses are rooted in a perverse belief system in which American goodness can and must be defended against foreign evil by violent, covert, and dishonest means. Both the Cold War and today's war against Islamic fundamentalism are born of a messianism that sees the world in black and white, and lacks the basic insight that all parts of the world, including the Islamic world, breathe the same air …. the United States has completely failed to recognize our common links with these regions, and instead has carried on an utterly destructive war on peoples and societies that we barely understand.

Resource wars

International policy is of course about a complex set of issues involving more than wars between ideologies. Discussions of climate change and economic growth cannot be divorced from the accompanying issue of energy security. American consumer traits have, if anything, intensified further to the modern day, demanding that troops be deployed to secure energy supplies for American consumers.

Andrew Bacevich writes in *The Limits of Power: The End of American Exceptionalism*, which reached 4th place on the New York Times bestseller list (2008, pp.1-6):

> In 1991, the US began two decades of unparalleled intervention that shattered the Long Peace following the Cold War. The US invaded Panama, Kuwait, Iraq, Bosnia and Haiti. It also attacked Kosovo, Afghanistan and Sudan. The second invasion of Iraq in 2001 started the Long War of global, open-ended war on terrorism …. Americans remain convinced that they are benign and that the perpetual wars they are involved in are not of their own making …. Instead the arrogance and narcissism to believe in managing global order, the sanctimonious conviction that American beliefs are universal, and the paranoid fear of being attacked have been inculcated through progressive administrations. …. During the 1990s, US became convinced that it was an exceptional country with bountiful reserves of economic, political, cultural and military power. Many Americans firmly equated America's new position with God's divinely predetermined plan for the world. It became widely believed in the US that its dominance was indispensable to world democracy. As such, the US was entitled to tend its new Pax Americana empire, expand it through globalisation, regulate the new international order through both persuasion and military force, and patrol the perimeter of the empire. Few could argue with the apparently unassailable situation, and if they did they were regarded as unpatriotic and delaminated from reality …. As individuals, Americans never cease to expect more of everything however, they have never contributed less. Neoconservative Robert Kaplan wrote after 9/11 that America did not change on September 11. It only became more itself. Determined pursuit of life, liberty and happiness through consumption, sanguine about their country's contempt for international law; enthusiastic embrace of preventative war; and dodging moral analysis. …. If one were to choose a single word to

> characterise that US identity it would have to be “more”. For the majority of contemporary Americans, the essence of life, liberty, and the pursuit of happiness centres on a relentless personal quest to acquire, to consume, to indulge, and to shed whatever constraints might interfere with those endeavours … oil dependence is key to our weakness. America's imperial military overstretch since the 1980 promulgation of the Carter Doctrine – which holds that the U.S. will defend vital interests in the Persian Gulf "by any means necessary" – is a natural consequence of that oil dependency. Our collective refusal to conserve oil, to learn to live more sensibly within our means, requires an ever-growing military commitment to the Middle East.

Others have supported Bacevich's views. In the January 2009 Darwin Day Lecture to the British Humanist Society *Can British Science Rise to the Challenges of the 21st Century?*, former UK Chief Scientist Sir David King[ii] rejected government claims that America and the United Kingdom invaded Iraq because of weapons of mass destruction or to topple President Saddam Hussein. Sir David maintained that the invasion was solely to lessen American reliance on foreign oil (Randerson 2009):

> The Iraq war was just the first of this century's resource wars, in which powerful countries use force to secure valuable commodities … future historians might look back on our particular recent past and see the Iraq war as the first of the conflicts of this kind …. [the USA,] casting its eye around the world – [saw] there was Iraq [and its immense oil reserves for the taking] …. it was certainly the view that I held at the time, and I think it is fair to say a view that quite a few people in government held …. Unless we get to grips with this problem globally, we potentially are going to lead ourselves into a situation where large, powerful nations will secure resources for their own people at the expense of others.

Highlighting with grim irony the place of oil in America's war in Iraq, Stanford University's Professor Gretchen Daily has rhetorically asked (Lowe 2009, p.22) “How concerned would the US administration be about Iraq if it had 10% of the world's broccoli?”

A pessimistic interpretation of the traditional American approach to foreign policy is that there will be many more wars over important resources such as oil and water.

2.3 Precursors of the Anglo-American world view

How did Americans develop such an unremitting, perhaps even unbalanced, focus on consumption?

The founders of Western philosophy, Socrates (469 BCE–399 BCE) and Plato (approx. 428BCE – 348BCE) first referred to the role of commerce in organising society. However, it was Plato's student Aristotle (384 – 322 BC) that philosophically investigated commerce in the role of work.

As many men have done before and after him, Aristotle sought an explanation to the meaning of life. Consciously or unconsciously, Aristotle subscribed to the dominant Greek Stoic world view that all things had a purpose and the world was happily harmonious and in order only when objects followed their innate and predetermined purpose. The liberal Epicureans regarded humans as free to some extent but their thoughts were not to become mainstream for 2,300 years, with the German philosophers Immanuel Kant, Arthur Schopenhauer, Johann Gottlieb Fichte and Friedrich Nietzsche.

Aristotle's view that every object seeks its natural purpose or goal is called “teleology” (Saunders 1974). Theists believed that God determined this purpose for each object, while others ascribed it to nature. Whatever the source of the belief, it was understood that when humans deviated from their inherent purpose, through misfortune or lack of understanding, then they became miserable and the world was in disharmony.

After considerable contemplation, Aristotle hypothesised that the inbuilt purpose for humans was to do work and that humans were only happy when doing work. Of course, happy people led to a happy society. This was fortunate because society needed just this happy work to fulfil its consumption needs. This serendipitous and internally consistent paradigm was seemingly verified everywhere one looked (Aristotle 350BC, Book I):

Now of the Chief Good (i.e. of Happiness) men seem to form their notions from the different modes of life, as we might naturally expect: the many and most low conceive it to be pleasure, and hence they are content with the life of sensual enjoyment. For there are three lines of life which stand out prominently to view: that just mentioned, and the life in society, and, thirdly, the life of contemplation .... As for the life of money-making, it is one of constraint, and wealth manifestly is not the good we are seeking, because it is for use, that is, for the sake of something further: and hence one would rather conceive the forementioned ends to be the right ones, for men rest content with them for their own sakes .... And now let us revert to the Good of which we are in search: what can it be? for manifestly it is different in different actions and arts: for it is different in the healing art and in the art military, and similarly in the rest. What then is the Chief Good in each? Is it not "that for the sake of which the other things are done?" and this in the healing art is health, and in the art military victory, and in that of house-building a house, and in any other thing something else; in short, in every action and moral choice the End, because in all cases men do everything else with a view to this. So that if there is some one End of all things which are and may be done, this must be the Good proposed by doing, or if more than one, then these .... Now since the ends are plainly many, and of these we choose some with a view to others (wealth, for instance, musical instruments, and, in general, all instruments), it is clear that all are not final: but the Chief Good is manifestly something final; and so, if there is some one only which is final, this must be the object of our search: but if several, then the most final of them will be it .... So then Happiness is manifestly something final and self-sufficient, being the end of all things which are and may be done .... But, it may be, to call Happiness the Chief Good is a mere truism, and what is wanted is some clearer account of its real nature. Now this object may be easily attained, when we have discovered what is the work of man; for as in the case of flute-player, statuary, or artisan of any kind, or, more generally, all who have any work or course of action, their

> Chief Good and Excellence is thought to reside in their work, so it would seem to be with man, if there is any work belonging to him …. we assume the work of Man to be life of a certain kind, that is to say a working of the soul, and actions with reason, and of a good man to do these things well and nobly, and in fact everything is finished off well in the way of the excellence which peculiarly belongs to it: if all this is so, then the Good of Man comes to be "a working of the Soul in the way of Excellence," or, if Excellence admits of degrees, in the way of the best and most perfect Excellence …. And we must add, in a complete life; for as it is not one swallow or one fine day that makes a spring, so it is not one day or a short time that makes a man blessed and happy …. it is thus in fact that all improvements in the various arts have been brought about, for any man may fill up a deficiency …. Now with those who assert it to be Virtue (Excellence), or some kind of Virtue, our account agrees: for working in the way of Excellence surely belongs to Excellence …. Why then should we not call happy the man who works in the way of perfect virtue, and is furnished with external goods sufficient for acting his part in the drama of life: and this during no ordinary period but such as constitutes a complete life as we have been describing it.

In formulating his hypothesis, Aristotle charged humans with the mission to be useful to society in production in order to be happy. In more temperate words, he declared man to be a factor of production. It was but a little further extension to value a person's worth as the future value of his or her labour. It did not concern Aristotle that his hypothesis was wholly unprovable in common with all the big philosophical questions, such as “What is life?”

The concept that man's utility was his only value seemed appropriate in the societies of ancient Greece and seventeenth century USA, which depended on the exploitation of slave labour. It also matched the power and wealth structure of society thereby justifying the implicit assumption that there is a natural and defensible hierarchy (Aristotle says “degrees”) in the society of man.

In France, François Quesnay (1758) developed the *Tableau économique* to measure agriculture. His Physiocrat school of philosophy sought *Laissez-faire* regulation of agriculture at a time when the French monarchy was very repressive. As agriculture was regarded as the only true production, land was correspondingly the only scarce resource and was therefore considered the most important form of wealth. From this perspective, extractive, manufacturing and merchant services only convert material from one state to another and are considered "sterile" of wealth creation.

In 1776, Scotsman Adam Smith (1776) interpreted Aristotle's concept of human value to being useful to society in producing goods for consumption or export. However, Smith assumed that each individual was the best judge of his own welfare (Book IV):

> Every individual necessarily labours to render the annual revenue of the society as great as he can. He generally indeed neither intends to promote the public interest, nor knows how much he is promoting it… . He intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote as end which was no part of his intention.

The first extension of this principle was to a society of suppliers and consumers. According to Smith, a market of individuals pursuing their own best interest would reach the necessary equilibrium or *tétonnement* at a price to clear the market of all commodities. One further extension of the concept led him to the magical process that converts observable factors of production (being labour, money and land) into tangible goods for consumption. Famously, Smith called his magical process the "invisible hand of capitalism". As with Quesnay, Smith could not see any role for the government in regulation. Smith's work was the beginning of today's scholarly discipline of Classical Economics, which considers only markets to the exclusion of government.

Smith was ready to accept that goods included more than Quesnay's strict limit of agricultural production. It seemed obvious to Smith that the tangible goods had a value that could be readily calculated from the comprising factors from which the goods were made: land rent, labour cost, capital cost and the return for taking risk. The return for taking this risk was called entrepreneurship and had been investigated by philosophers such as David Hume (1752) and David Ricardo of the Mercantile Trading school.

Adam Smith's “invisible hand of capitalism” became the fundamentalist, unproven doctrine of American commerce and social structure as observed by de Tocqueville. Smith's book *The Wealth of Nations* became America's bible of business and philosophy. Unfortunately for many people in society, Smith categorised certain occupations as unproductive services. He included the Sovereign along with “churchman, lawyers, physicians, men of letters of all kinds, players, buffoons, musicians, and opera singers”.

Vargo and Lusch (2004), pioneers in the development of Service Sciences as an academic discipline, highlight that the classical philosophers of economics, politics and polity, Jean-Baptiste Say and John Stuart Mill, were early dissenters to the concept that humans existed to produce goods for consumption and found ultimate happiness in that work. In addition, while still accepting the concept of utility, Say and Mill sought to broaden its limits to include the poor churchman, lawyers, physicians etc. that had been excluded by Adam Smith.

Jean-Baptiste Say (1803) reasoned that production was the creation of utility rather than the creation of matter or the growing of something new. For example, a sword is still only iron ore so no matter has been created. Therefore, he held, human labour services of churchman, lawyers, physicians etc. as well as everyone else are intangible products consumed at the time of production. He developed his now famous Say's law that “Production generates an equivalent demand that in turn generates employment in production”.

John Stuart Mill was prepared to go further. In *Principles of Political Economy* (1848), Mill proposed the Aristotelian heresy that production is not the sole purpose of human existence. He also moved on from Adam Smith's concept of embedded value deriving from the factors of production to a quite revolutionary concept that the value of production is not in the objects themselves but in the attribute of their usefulness to the particular consumer.

Frederic Bastiat's *Essays on Political Economy* (1848) quickly swept forward with Mill's concepts to suggest that the value of a man's services is quite independent of any tangible goods and furthermore is not just an attribute of tangible goods as Say and Mill still accepted.

Bastiat hypothesised that the foundation of economics is that individuals who have wants seek out satisfactions and the satisfactions are obtained through: gratuitous utilities provided by Providence, such as air and water, and onerous utilities purchased by trading effort through labour. He proposed a still unprovable hypothesis as a great economic law:

> The great economic law is this: Services are exchanged for services .... It is trivial, very commonplace; it is, nonetheless, the beginning, the middle, and the end of economic science .... Once this axiom is clearly understood, what becomes of such subtle distinctions as use-value, and exchange-value, material products and immaterial products, productive classes and unproductive classes? Manufacturers, lawyers, doctors, civil servants, bankers, merchants, sailors, soldiers, artists, workers, all of use, such as we are, except for the exploiters, render services. Now since these reciprocal services alone are commensurate with one another, it is in them alone that value resides, and not the gratuitous raw materials and in the gratuitous natural resources that they put to work.

Bastiat's hypothesis has now become a widely accepted part of marketing practise. For example, Philip Kotler (1994), a major voice in American marketing education, writes that “The importance of physical products lies not so much in owning them as obtaining the services they render”.

In his book *The Structure of Scientific Revolutions* (1962), Thomas Kuhn demonstrates that theories and power structures change in waves. Those who make up the system, which they see as the legitimate one, use all means at their disposal to quash new competing forces. Change occurs when new eyes come to look at the situation and see compelling reasons for change. So it is that all fundamentalist paradigms require an enemy on which to sharpen polemic and differentiate their arguments.

America's number one ideological enemy was Karl Marx, who maintained in his book *Das Kapital* (1867) that the specialisation of labour would remove the ownership of production from individuals and introduce monotony, thereby deprive individuals happiness in producing.[iii] To Marx, the deterministic corollary of his theory of dialectical materialism would be that labour would choose to move away from organisations employing specialisation to self-producing communities. Violent revolutions occurred in his name in Russia and China, although Marx did not specifically advocate such violence.

Ironically, Vladimir Lenin and Joseph Stalin introduced specialisation into Soviet manufacturing. They were impressed with Frederick Winslow Taylor's view that managers need to motivate workers with performance pay on measured output. Taylor is known as the father of scientific management and famous for stopwatch time & motion studies. He believed that managers were the problem in stifling the productivity growth of workers. This is because managers kept raising the bar on worker performance until there was no incentive left, therefore reinforcing the attitude that management needs to force workers to be productive because they naturally slack-off.

A second enemy of classical economics and its mathematical sibling, Neoclassical Economics, was John Maynard Keynes, who published a new macroeconomic theory in *The General Theory of Employment, Interest and Money* (1936). Keynes foresaw a role for the government to invest to stimulate economies when stagnation occurred in the regular economic cycles of boom and bust. This pump-priming or demand stimulus was to get people working again in order to both alleviate human misery and reboot the income-consumption cycle. Keynes' theory appealed to governments as a way of clearing the Depression. Following World War II, governments of all persuasions adopted Keynesian stimulation to successfully rebuild their economies.[iv] Perhaps an equally impressive use of massive Keynesian stimulus has been in assuaging the 2008-9 global financial crisis in just one year.

Implicit in Keynes' theories were two key arguments that upset classical economists. The first was that the simplicity of classical economics could not cope with economic cycles. The second was that an almost total lack of government business regulation through the 1920s directly contributed to the excesses of the decade, the 1929 Wall Street crash and the ensuing Depression. At the time, as in 2009, many people lost confidence in the ability of classical and neoclassical economics to predict or to fix the market failures.

Classical economics continues to rail against its Keynesian critics. The Monetarists, Libertarians, the Chicago and Austrian Schools and more recently Leo Strauss' neoconservative philosophy all fervently believe in minimal government regulation. Monetarists are controversial for demanding that the Government keep its hands off the economy and allow the market to heal itself; cease all subsidies to agriculture, public housing and tax policy because these have done more harm than good; leave business to its sole function of making profits and require no ethical duty of corporations other than to obey the law. Its leading proponent, Milton Friedman, proudly declared that “The social responsibility of business is to increase its profits.”

Nowadays, the Gini Index measures inequality of income distribution. The index ranges from 0 (or no inequality) to 1. A small index number implies that the distribution of income in a society is fair. The Gini Index for Germany is only 0.28, compared to 0.45 for the America.[v]

America's inequality of income distribution suggested to John Rawls, Professor of Philosophy at Harvard University, that welfare in America lacked justice. In *A Theory of Justice* (1972, p.152-7), Rawls rejects Adam Smith's concept that the social welfare of an economy is simply the sum of the social welfare of each citizen, which is the underlying utilitarian assumption of classical and neoclassical economics. Assuming that the simple Pareto Optimum is unfair in welfare terms, Rawls drills into the efficiency of the price mechanism that determines producer and consumer surpluses. In order to maintain justice, he argues for a von Neumann maximin[vi] type of social utility function for the consumer, where governments look to maximise the welfare of the least well-off persons (Rawls 1972, pp.273-7):

> It is essential to distinguish between the allocative and distributive efficiency of prices. The former is connected with their use to achieve economic efficiency, the latter with their determining the income to be received by individuals in return for what they

> contribute …. The allocation branch [of government], for example, is to keep the price system workably competitive and to prevent the formation of unreasonable market power …. and correcting, say by suitable taxes and subsidies and by changes in the definition of property rights, the more obvious departures from efficiency caused by the failure of prices to measure accurately social benefits and costs … A competitive price system gives no consideration to needs and therefore it cannot be the sole device of distribution …. It is clear that the justice of distributive shares depends upon the background institutions and how they allocate total income, wages and other income plus transfers. There is with reason strong objection to the competitive determination of total income, since this ignores the claims of need and an appropriate standard of life …. But once a suitable minimum is provided by transfers, it may be perfectly fair that the rest of total income be settled by the price system, assuming that it is moderately efficient and free from monopolistic restrictions, and unreasonable externalities have been eliminated.

Americans have machinated over the potent challenges from Marx, Keynes and Rawls. In most cases, it has not responded by action but used the challenges to strengthen the defence of its core value system. For example, the defence of American democracy and capitalism, the unified concept of human existence and service value, and minimal government regulation.

This core value system is embodied in the neoclassical paradigm, which derives two major strengths from it. Firstly, that the paradigm is internally consistent and, secondly, that society has been modified to fit the paradigm. Therefore, the Neoclassical paradigm parallels the workings of Anglo-American societies, except in exceptional circumstances.

In fact, a dramatic reversal of Marx's theory of dialectical materialism has occurred in recent decades: the owners of capital have prospered to a far greater degree than the owners of labour with the proletariat meekly accepting their deteriorating position, prospects and vulnerability. Direct evidence of this can be found across the Anglo-American nations in the declining labour share of GDP and sweep of income to the most wealthy. UBS economist Martin Lueck comments "If you draw a line dividing the winners and losers [of the past 20 years], it is not between US or UK economic systems and Europe's, but rather the owners of capital vs. the owners of work. The losers are the owners of work in all parts of the world, particularly Western countries. The winners have been the owners of capital" (Herbst 2009).

In the 27 years from 1980 to 2007, Reaganomics delivered a 700% increase in the real income of the top 0.01% of Americans compared to only a 22% increase in median real income (Bucks et al. 2009; Krugman 2009a). The increase in real median income was only one-third of its increase in the previous 27 years and there was no increase at all in the otherwise golden period from 2000-2007 as President George W. Bush pursued Reagan's policies of supercharging the wealthy sector of the population.

Even proudly egalitarian nations such as Australia have seen inequality strongly rising in the same period for the same reasons. As shown in the illustrations below, Australian companies enjoy a very high and rapidly growing share of factor income. As a result, they are able to pay considerably higher dividends than companies in the rest of the world. However, this has resulted in the labour share of factor income falling steadily over the last 30 years. This has been exacerbated by the compulsory alienation of individual incomes for retirement superannuation contributions.

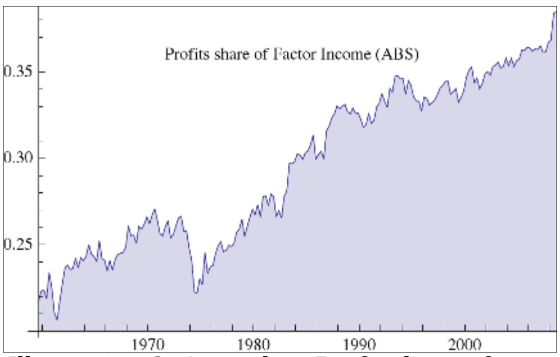


Illustration 2: Australian Profit share of Factor Income (Source: Australian Bureau of Statistics 5206.0 Australian National Accounts: National Income, Expenditure and Product, Table 7. Income from Gross Domestic Product (GDP), Current prices)

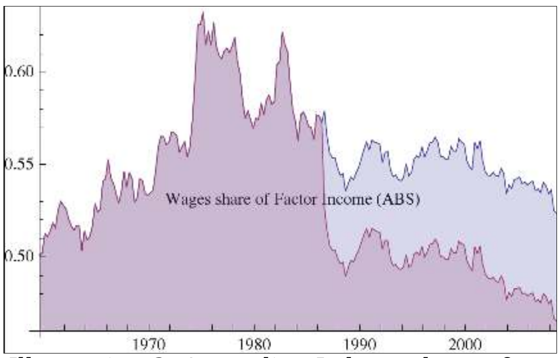


Illustration 3: Australian Labour share of Factor Income, before (blue) and net of (purple) superannuation (Source: Australian Bureau of Statistics 5206.0 Australian National Accounts: National Income, Expenditure and Product, Table 7. Income from Gross Domestic Product (GDP), Current prices)

It may be noted in the illustrations below that the Australian income share of labour is significantly less than international benchmarks (Krämer 2008).

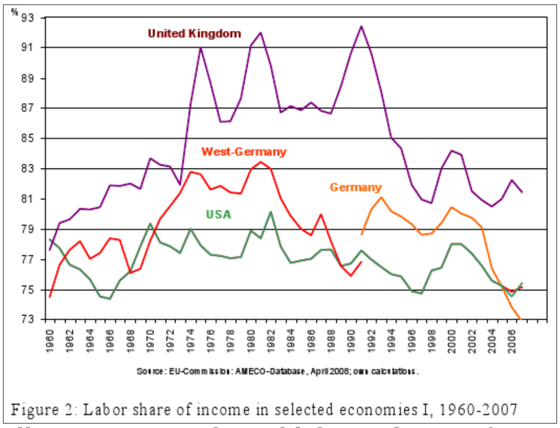


Illustration 4: Selected labour shares of advanced economies (Source: Krämer 2008)

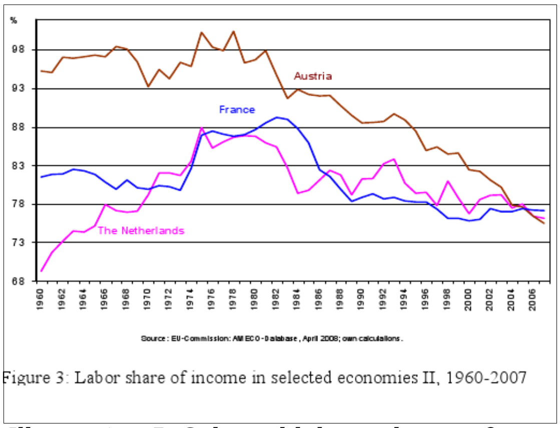


Illustration 5: Selected labour shares of advanced economies (Source: Kramer, 2008)

Similarly as in America, the depression of labour share of income has been accompanied by a sweep of income to the top 1% as shown in the right hand illustration (Atkinson & Leigh 2006). There could only be one result from the pressure on labour share and sweep of income to the most wealthy. As in America, easy money coupled with these financial pressures led to recurrent living expenditure being financed from debt: Australian average private debt to income has risen four-fold from 40% in 1980 to 160% in 2008.

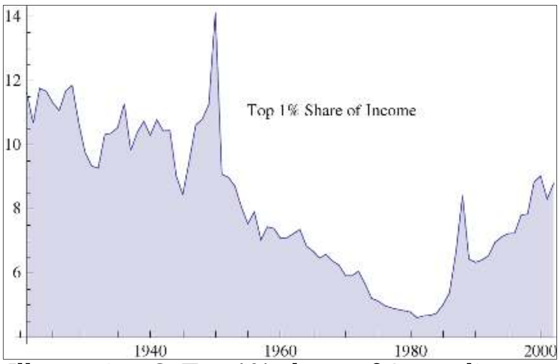


Illustration 6: Top 1% share of Australian Income (Source: Atkinson & Leigh 2006, Appendix 6, Table 1)

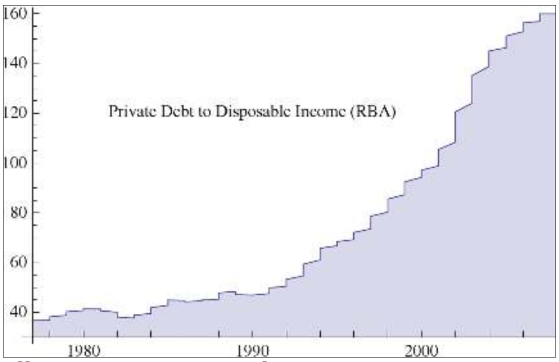


Illustration 7: Australian average private debt to income (Source: Reserve Bank of Australia, Statistical Bulletin B21 Household Finances Selected Ratios)

The phenomena of ordinary people financing their current expenditure from debt instead of income has led economists to conclude that this effect was one of the largest contributors to the 2008 global financial crisis.

Peter Self, a trenchant critic of the American market system, summarises in his book *Rolling Back the Market* (Self 2000, pp.xi, 6 & 12):

> The prevailing market system is supported by a very influential set of economic dogmas which have come to occupy a dominant place in the lives of modern societies. These include the high importance attached to market-led economic growth; the value of complete free trade in money and capital as well as in goods and services; the need to subordinate social welfare to market requirements; the belief in cutting down or privatizing government functions; the acceptability of profit as a test of economic welfare; and others as well … Neoclassical economics provides a comprehensive model for a market economy based on the exchanges between economic actors to maximise their utilities … [However,] Neoclassical economics cannot be subjected to Popperian falsification (Blaug 1992) because a controlled experiment in human behaviour cannot be performed with the holding of other factors constant (*ceteris paribus*) … [and] is best understood as a Weber's ideal type theory.

While the neoclassical paradigm has served America's preoccupation with consumption as the measure of happiness and has successfully repelled external criticism, we will see in the next sections that the paradigm has aged and come to face its greatest test from within. In the face of major and unexpected systemic risks, it has delaminated from reality across many facets of society. Like a patient lurching from spasm to spasm, economic doctors seek to cure the symptoms by bandaging the wounds, while being unprepared and mostly opposed to addressing the fundamental causes.

Philosophy & psychology diverge from the paradigm

Americans have been strongly attracted to Aristotle's notion that human happiness is to be found in work. Government, business and social pressure has reinforced this assumption. Perhaps with an economy of thinking, individuals in Anglo-American societies have accepted the need to work hard, notwithstanding their scepticism about the workplace as being the font of happiness. This resigned perseverance is known as the Protestant Work Ethic.

However, European philosophers have been less convinced. Arthur Schopenhauer observes that if human existence demonstrates a purpose then for the vast majority of people in the world this purpose would be suffering, woe and pain. His point raises the prospect that Aristotle's cult of happiness is merely a social fiction of the elite, who have the means to afford.

Another German philosopher, Friedrich Nietzsche decisively rent the veil of socially imposed value systems. Nietzsche identified the important principle that humans are a “will to power,” which is the seemingly insatiable urge on the part of some people to exert their will over others (Nietzsche 1887). Once people understood this, they could reassert control over their own lives.

Max Weber, another important German philosopher, took this idea forward into organisations, arguing that power structures take precedence over structures of authority (Weber 1904). Uncloaked from its Aristotelian ideology of work as a place of virtue, the workplace began to be perceived as a place of power struggles.

Friedrich Nietzsche bluntly repeated Max Stirner's assertion that “God is dead,” by which he meant there was no organising principle or “author” of the universe (Nietzsche 1882; 1887).[vii] His classic statement of egotism invalidated all inherent Aristotelian purpose in humans. Furthermore, a corollary of there being no universal morality or purpose is that every value must be self-created.

The French existential philosopher Jean-Paul Sartre extended Nietzsche's concept of self-creation. Sartre (1943) developed the theory that a person's existence precedes essence, which means that humans are born in a biological process and proceed to develop their being. This opposes the Judeo-Christian dogma that humans enter the world with a soul.

Sartre perceived that a person's self-created values can lead to psychological situations such as anxiety. He argued that the fundamental human condition is freedom and that this is both the greatest prize and greatest burden of man: “Man is nothing else but that which he makes of himself” (Sartre 1946).

Of course, Aristotle and pragmatic American philosophers would agree entirely with this, the first of Sartre's principles of existentialism. Sartre rejects more than the existence of God, he rejects any exogenous meaning or reason for mans' existence. Sartre argues that we all need to find our own reason for existence and meaning. However, the path to defining one's own essence is extraordinarily difficult.

Individuals make decisions in unpredictable ways, some may feel personal decisions lack rationality. For example, recently Brooks (2009) highlighted that American economists have underestimated the complexity of human behaviour:

> Reason is not like a rider atop a horse …. each person’s mind contains a panoply of instincts, strategies, intuitions, emotions, memories and habits, which vie for supremacy. An irregular, idiosyncratic and largely unconscious process determines which of these internal players gets to control behavior at any instant. Context — which stimulus triggers which response — matters a lot …. This mental chaos explains how people can respond so quickly and intuitively to so many different circumstances. But it also entails a decision-making process that is more complicated and messy than previously thought.

The onerous task of making decisions and being fully accountable for the outcome can be a lonely pursuit because humans individually need to make decisions and live with the results. At times when the very foundation of existence is challenged, humans usually begin to contemplate our own finite mortality. Sartre writes of this time when our values are disturbed (Sartre 1946, Chapter 4):

> Everything is indeed permitted if God does not exist, and man is in consequence forlorn, for he cannot find anything to depend upon either within or outside himself. He discovers forthwith, that he is without excuse. For if indeed existence precedes essence, one will never be able to explain one's action by reference to a given and

> specific human nature; in other words, there is no determinism--man is free, man *is* freedom. Nor, on the other hand, if God does not exist, are we provided with any values or commands that could legitimise our behaviour. Thus we have neither behind us, nor before us in a luminous realm of values, any means of justification or excuse. We are left alone, without excuse. That is what I mean when I say that man is condemned to be free. Condemned, because he did not create himself; yet is nevertheless at liberty, and from the moment that he is thrown into this world he is responsible for everything he does.

Moral hazard is present where individuals are in a position to make decisions for themselves, their economy and their country when they are not fully accountable for the outcome. This concept is discussed later in this Chapter. In one of the major differences between pragmatism and existentialism, pragmatism accepts moral hazard as part of conservative moral philosophy while existentialism emphasises taking personal responsibility for one's own actions.

Perhaps the greatest anxiety in life comes from loneliness and the realisation that one's assumptions are invalid. Sartre dealt with the anxiety of confronting emptiness in his first novel *Nausea* (1938). He later explained the experience of anxiety in an essay, *The Look* (1992, p.347), as follows:

> What I apprehend immediately when I hear the branches crackling behind me is not that there is someone there; it is that I am vulnerable, that I have a body which can be hurt, that I occupy a place in which I am without defence – in short, that I am seen.

Free choices are always prey to one's sense of angst and anxiety. The loneliness and magnitude of the tension between freedom and responsibility often leads to despair. Sartre argues that for the most part this reveals that a person's decisions are often in *mauvaise foi* (self-deception or bad faith) that lack authenticity due to *angst*, which is irrational anxiety over a perceived need for security. Therefore, we give in and exchange our authenticity for things like belongingness.

Sartre's solution is twofold: firstly, to simply accept the situation that existence is absurd because there is no “big picture” that gives it meaning; secondly, to get on with life and be as authentic as possible to oneself in choices. He says “Man’s task in life is to authenticate his existence. Approach your existence creatively, and do something with it.”

Sartre chose to balance his personal life on the fulcrum of disruption, rather than succumb to a conventional life. He was convinced that to be conventional was bad faith. Sartre believed his only authentic choice was to remain in the state of uncertainty, perpetually at the point where a man was not only free but conscious of his total freedom.

Another influential existential philosopher, Albert Camus, won the 1957 Nobel Prize in Literature at the age of 44.[viii] Camus claimed to have found meaning within himself as a great outcome from a bleak and stressful experience. He wrote of it in his essay *Return to Tipasa*: “In the depth of winter, I finally learned that within me there lay an invincible summer” (Camus 1952).

Camus employed the myth of Sisyphus to illustrate that Aristotelian happiness in working is absurd and, by extension, that all purpose in life is absurd (Camus 1942, Chapter 4):

> The gods had condemned Sisyphus to ceaselessly rolling a rock to the top of a mountain, whence the stone would fall back of its own weight. They had thought with some reason that there is no more dreadful punishment than futile and hopeless labour …. You have already grasped that Sisyphus is the absurd hero. He is, as much through his passions as through his torture. His scorn of the gods, his hatred of death, and his passion for life won him that unspeakable penalty in which the whole being is exerted toward accomplishing nothing. This is the price that must be paid for the passions of this earth …. The workman of today works everyday in his life at the same tasks, and his fate is no less absurd …. One does not discover the absurd without being tempted to write a manual of happiness. "What!---by such narrow ways--?" There is but one world, however. Happiness and the absurd are two sons of the same earth. They are inseparable …. One must imagine Sisyphus happy.

In 1974, the esteemed philosopher Isaiah Berlin[ix] concurred with Sartre (Saunders 2009a):

> If you aren't fully responsible for your own acts, if you can say, "I am as I am because my parents maltreated me; I am as I am because the nature of the universe is such", and then you put the responsibility on the back of the universe and shuttle it off your own. And people don't want to be all alone, lonely persons responsible for their own actions, they want some justification of what they do from the nature of something greater, more stable in a way than themselves. And people can do all sorts of things in the name of history, in the name of progress, in the name of "my class", in the name of the church, which they might hesitate to do if it was entirely up to them individually.

In a perceptive reflection on the human condition, Harrison (2008 pp.111-2) observes that Aristotle's virtues are but a single facet of a multidimensional moral paradigm. He writes “vices are every bit as cultivatable as virtues. The cultivation of envy, spite, pride, greed can be taken to exquisite levels. But this does not transform those vices into virtues; on the contrary, by submitting them to extremely regimented rules and protocols, it gives them a style that renders them more sublime while leaving their vicious essence intact.”

Indeed, virtues are the least part of this moral paradigm. Drawing on his unique perspectives from Italian Medieval and Renaissance literature, Harrison concludes that the Western human condition is fundamentally restless and disconsonant (pp151-8). He compares the hero knights in Ludovico Ariosto's *Orlando's Furioso* (1516) to the pilgrims of Dante's *Divine Comedy* (circa 1310), suggesting that the existential boredom and aimless path of the former characterises the modern Western journey:

> They wander the earth laterally in search of action and distraction. Desire is a principle of motion with neither master plan nor final destination. The knights merely desire “more”, more of their own dynamism, an intoxication with and more of the same circulating energies. They are archetypal modern consumers in a tumultuous world of digressive compulsions where they court adventure, pursue elusive erotic objects and strive to measure up to their rivals. It feeds on its need for ever-new challenges and exploits. Remaining in motion becomes an end in itself. There is neither a higher personal or historical purpose nor a redemptive goal. The knights craving for action is at bottom a craving for distraction, what Blaise Pascal called divertissement, without which the modern male (according to Pascal) quickly succumbs to melancholy. That craving for diversion arises from the pointlessness of their mode of being – the pointlessness of being knights in a post-chivalric world, men of action in an age when action has lost its normative or underlying meaning …. The modern differential in Ariosto's knights is not so much their aversion to [the peace of] Eden as their existential boredom. Boredom indicates a certain deficiency or blockage of care. Boredom can bring about the conditions for desperation and

> lead to a constant search for diversion, a constant “turning-away” from oneself … Orlando goes on to commit a mindless devastation of what others have carefully cultivated, laying waste to farmers' fields, the well-husbanded countryside, the quiet forests and rivers. He particularly directs his rage against gardeners and shepherds. This nihilistic vortex of pathological agitation and ravaging destruction is the hero of the age of which he is the harbinger. Herein lies the knights quintessential and even contemporary modernity, for this is precisely the spiritual condition of the age today: driven and aimless, we are under the compulsion of an unmastered will to destroy whatever lies in our way, even though we have no idea where the way leads or what its end point may be.

When Orlando roams with such unpredictable intent the safety of society is compromised. In order to be happy, a society needs shared attitudes and sanctions that promote trust. Weiner (2008, pp.234-6 & 405)found that the deeper the trust ethos in society, the happier the society reports that it is:

> Aristotle said more or less "Happiness is your state of mind and the way you pursue that state of mind." How we pursue the goal of happiness matters at least as much, perhaps more, than the goal itself. The means and the end are the same. A virtuous life and a happy life are the same thing. … Nietzsche says that a society cannot avoid pain and suffering but the measure of a society is how well it transforms this pain and suffering into something worthwhile …. Trust - or to be more precise, a lack of trust - is why Moldova is such an unhappy land .... Moldovians don't trust the products they buy at the supermarket .... they don't trust their neighbours .... they don't even trust their family members. ... For years, political scientists assumed that people living under democracies were happier than those living under any other form of government ... but the collapse of the Soviet Union changed all that. Most (although certainly not all) of these newly independent nations emerged as quasi-democracies. Yet happiness levels did not rise. In some countries they declined, and today the former Soviet republics are, overall, the least happiest places on the planet …. It is not that democracy makes people happy but rather that happy people are

> much more likely to establish a democracy …. The institutions are less important than the culture. And what are the cultural ingredients necessary for democracy to take root? Trust and tolerance. Not only trust of those inside your group - family, for instance - but external trust. Trust of strangers. Trust of your opponents, your enemies, even. That way you feel you can gamble on other people ….Money matters, but less than we think and not in the way we think. Family is important. So are friends.

Harrison (2008 p.33) identifies the catalytic component of Weiner's ethos of trust as Karel Čapek's basic ethical principle of proactive care that “you must give more to the soil than you take away” (K. Capek et al. 2002 p.88) Harrison extends this principle to “nations, institutions, marriages, friendships, education, in short for human culture as a whole” and rejects Aristotle's grand vision of work as a virtue (pp.166 & 170-1):

> I have insisted throughout this study that human happiness is a cultivated rather than a consumer good, that it is a question of fulfilment more than of gratification. Neither consumption nor productivity fulfils. Only caretaking does …. A gardener does not exalt the work ethic …. He does not espouse the cause of labour. He espouses the cause of what he cultivates …. The gardener is not a labourer, regardless of how much real labour cultivation entails …. The gardener, in short, is not committed to work, and even less to “productivity”. He is committed to the welfare of what he nourishes to life in his garden …. This self-extension of the gardener into care is an altogether different ethic from the one that drives the present age to crave more life and to escape what Heidegger calls the emptiness of Being through a jacked-up productivity. Nothing is further from the gardeners mind, nothing motivates him less than self-perfection, the value of work, or the virtue of his deeds.

American psychologists Aaron Beck and Albert Ellis are each credited with independently originating Cognitive Behavioural Therapy to assist individuals deal with distress about the vicissitudes of life, such as Harrison's unpredictable Orlando and Sartre's *angst*. The therapy seeks to reorientate an individual's thinking toward recognising and controlling their own demandingness about needing happiness, authenticity and an environment of trust, mutual care and peace. Over many decades the therapy has been very successful in its objective of helping individuals think about their own thinking and make accountable choices to move away from unremitting stressors.

Cognitive Behavioural Therapy is now highly influential and even the dominant form of psychological therapy. It draws upon the same fundamental concepts as does existentialism, for example, the unquestioned existential statement of existence that “I am”. However, a key difference from existential philosophy and therapy is that Cognitive Behavioural Therapy specifically circumvents the major imponderables of life, such as whether life has meaning, if there is a God etc., as answers are unlikely to be forthcoming. Existentialism emphatically maintains that the answer to each of these questions is “no”. Cognitive Behavioural Therapy also avoids Aristotle's idea that people find their happiness solely or principally in work, or that human value or happiness can be measured by work in any intrinsic way.

Although corporate human resources departments would prefer otherwise, nowadays it is considered quaintly misplaced to equate happiness with economic or work behaviour. Humans do not correspond to formulae, except when they choose to. Individuals have the unique, nonlinear and disruptive capacity to critically reflect by thinking about their own thinking. In this respect we are children of Plato rather than Aristotle.

Furthermore, we commonly work in systems where power and lies coexist, which was adroitly understood by the Renaissance political philosopher Niccolò Machiavelli (1513) in his advice to Lorenzo Di Piero De’ Medici the Magnificent. For example in Chapter 15, *Concerning things for which Men, and especially Princes, are Praised or Blamed* he writes “It is necessary for a prince wishing to hold his own to know how to do wrong, and to make use of it or not according to necessity.”

Americans value leaders with proactive plans and an inner impetus or passion to move forward. The American proclivity for actions over words is legendary. Nike Inc. registered the ubiquitous slogan “just do it” as a trademark. In his inauguration speech, President Obama sought to motivate Americans and draw the nations together using the mantra of the cartoon character Bob the Builder, “Yes we can”.

American business practices and character traits surprise Europeans who tend to be more methodical. For example, Americans prefer “learning by doing” to extended planning and specification. They have a greater respect for doing than thinking, or action over words. This is sometimes expressed as the tracer bullet strategy “ready, fire, aim”. For Americans, tracer bullets are cheap so the best way of locating a target is just to start shooting. Feedback mechanisms quickly correct mistakes to provide the way forward.

In business, this means that Americans prefer projects with small investments, very short payback periods and near term exit strategies. When starting a project they look to do a “half, not half-assed” job (37 signals 2006, p.48). It also means that instead of planning a comprehensive project that will provide for contingencies and future growth, they prefer to limit a project to the smallest essential element that will just satisfy current requirements. If expansion is required, then it can be done as another project in the future. This maximises value by creating “real options” for future stages. However, it can also result in band-aid policies, shabby urban architecture and massive cumulative liabilities for infrastructure refurbishment.[x]

Perhaps above all, Americans respect leaders that develop bold strategies and have the charismatic personality to carry them forward. They share the reverence given to Homer's heroes and also the forgiveness given to the often misplaced, reckless and capricious acts of the Greek Gods. However, these old legends do not shape their future.

Each individual is free to choose their own path. It is a truism that each person learns through their own mistakes. The French novelist Marcel Proust neatly expressed this concept in *Remembrance of Things Past,* Volume II *Within a Budding Grove* and Chapter IV *Seascape, with a Frieze of Girls* (1913) where he writes “We don't receive wisdom; we must discover it for ourselves after a journey that no one can take for us or spare us.”[xi]

Open and closed institutional philosophies

It wasn't only personal psychology and philosophies that were emerging from the tyranny of top down paradigms. There was equivalent friction taking place in institutions between the European tradition of open establishment groups in Science and American closed groups.

Steve Fuller provides an interesting retrospective on the great *Popper versus Kuhn* encounter sponsored by Imre Lakatos as part of the International Colloquium in the Philosophy of Science at the former Bedford College, University of London on 13 July 1965 (Fuller 2003, p.10). Five years later, Lakatos wrote of the diametrically opposed views (Lakatos 1970):

> The clash between Popper and Kuhn is not about a mere technical point in epistemology. It concerns our central intellectual values, and has implications not only for theoretical physics but also for the underdeveloped social sciences and even moral and political philosophy.

Thomas Kuhn

In his famous book already referred to above, *The Structure of Scientific Revolutions* (1962), Thomas Kuhn examines with the way science was conducted in cold-war America. He characterises the dominant form of behaviour as a heads-down or monkish approach.

Rather dispiritingly, heads-down describes organisations where any challenge to orthodox views is an anathema to the organisational culture. Therefore, people are advised to keep their head down and focus on processing the work at hand rather than promoting new ideas. If a person unwisely raises a controversial idea, the organisation can be expected to eliminate the challenge as quickly as possible.

It may take ten or even thirty years or more for a new paradigm to be accepted in the scientific community. Perhaps, the person who had the original idea will not even be alive to see its fruition. Kuhn found that it was wise not to raise one's head before the time had come or else the person may be forever tarred as a failure because of the idea (whether or not it subsequently turns out to be a better theory) and many times a brilliant career could die with the idea.

This is analogous to the way a whistleblower may be treated today for highlighting problems, injustices or fraud in a company. Kuhn’s organisation man would be expected to deal with such organisational failures internally within himself, without any upsetting publicity or revolution. Such failures are expected to exist and even persist in the organisation for periods of time. Therefore, Kuhn would maintain that failures are never fundamental and an organisation is not considered broken just because it has such issues. While the practices may not be acceptable, an effluxion of time and circumstance will slowly remedy the situation.

It may even require generational change over twenty or thirty years to bring in new people that are able to make the needed changes because they do not have their careers and reputations invested in the old paradigm. This personal interest factor is known as an “agency conflict” and arises from what Nietzsche identified as the “will to power” (discussed above). All in all, it is expected that the failures will be quietly corrected over time and there is no hurry because institutions have plenty of that resource.

Of course, one is no doubt amazed by the fact that a new scientific idea could have been placed in the same category as an injustice or a fraud. Kuhn correctly identifies that the establishment's ferocious defence leads to changes in the scientific paradigm coming in waves, rather than linearly. It is thought that the paradigm will naturally switch with new circumstances in the organisation.

Fortune magazine editor William H. Whyte Jr. was on the same track in his book The *Organization Man* (1956). He identified a puzzling dichotomy between conformity and individualism in American 1950s society. Whyte found that corporation men willingly subordinated to unquestioned cooperation in exchange for the security of belongingness. They were prepared to become “yes men,” leaving their personalities at the door as they entered the office or factory.

Fifty years later, Ehrenhal wrote of the impact of Whyte's book “By the following spring, it was hard to find a college commencement speaker who didn’t devote his remarks to the conformity crisis and its implications. “We hope for nonconformists among you,” the theologian Paul Tillich told one audience of graduates, “for your sake, for the sake of the nation, and for the sake of humanity.” The president of Yale, A. Whitney Griswold, talked about a “nightmare picture of a whole nation of yes men” (Ehrenhal 2006).

Ehrenhal goes on to observe that the waxing and waning of demographic groups, such as the baby-boomers and the X- and Y-generations, has provided no better understanding of the dichotomy “The first decade of the 21st century is now more than two-thirds over, and we are still waiting for a convincing explanation of what it is all about ... It is the era of cell phones, BlackBerries and iPods, and we sense that these technologies are changing the nature of social interaction — but it seems too early to say exactly how.”

Fuller (2003, p.129) argues that Kuhn's findings arise from the three forms of authority created by Roman Law, which operated until the twelfth century: Gens, the transmission of the family status and wealth across generations; Socius, goal based ventures such as business activities and military expeditions, which were seen as temporary organisations for specific purposes; Universitas, the enduring public service corporations of craft guilds, universities, religious orders and city-states.

The important character of Universitas was that it gave certain groups niche monopolies to perpetually decide what constitutes a worthy pursuit and who is qualified to pursue it. These organisations are now the institutions of society.

For individuals in these institutions, the practicality is almost unchanged from the days of Roman Law: that to be against the establishment is to be against the activity – for example, to be against the position of the scientific establishment on a particular theory is perceived as being against science itself. A pervasive risk is that one's research funding will be cut. Therefore, the enormous pressure to conform with the establishment and keep one's head-down remains deeply entrenched.

Fuller (p46) notes of Kuhn's findings that public institutions which manage science are "A politically social formation that combined qualities of the Mafia, a royal dynasty and a religious order. It lacked the constitutional safeguards that we take for granted in modern democracies that regularly force politicians to be accountable to more people than just themselves."

Most people in organisations, whether Socius or Universitas, whether private or public, see the autonomy of the institution as self-evident and are reluctant to see any of its authority taken away. There is a strong belief that the organisation will always do the right thing.[xii]

Any organisational failures are explained away as because the leaders need to take risks and it is argued that in the absence of a pattern of fraud they should be protected or indemnified from the consequences of these risks. This is arguably one of the two key reasons for the slow and difficult implementation of corporate accountability and systems of corporate governance in boardroom and at the level of Government.

Sir Karl Popper

Sir Karl Popper's theory of falsification as the demarcation between science and pseudo-science is set out in *The Logic of Scientific Discovery* (1959), originally published in German in 1934 and translated into English by Popper himself in 1959. Popper is regarded as one of the first existentialists in science. In Britain, he was knighted for his liberalist, rational and anti-authoritarian values.

Popper treats falsification as the cornerstone of the scientific ethic and challenges scientists to test their theories by simultaneously making predictions and undertaking empirical tests that actively seek to falsify their own theories. Fuller (p102) notes that Popper found Kuhn's heads-down model abhorrent.

Popper maintains that the best theory is the one that has withstood the greatest number of falsification attempts. According to Fuller (pp. 24-5) he departs from the logical positivists on this very point: Popper requires that logic be used to challenge rather than bolster scientific authority.

Of course, this is diametrically opposed to Kuhn's finding that scientific institutions, far from submitting theories to falsification, go to extraordinary lengths to defend their theories against falsification. Also, in the real world the number of confirmations of success is regarded as more important than the number of times a theory has failed or even survived falsification. For example, an Australian Court of Law will accept widely used rules of thumb as compelling evidence.

The approaches of Popper and Kuhn have been presented as being completely opposed. However, in the 1965 debate, Popper readily accepted that Kuhn's approach best described the way organisations operated and how science advances in waves. Nevertheless, he says it is an inferior system that should be replaced by critical thinking; proactively falsifying theories; and passionately providing new ideas for peer review and receiving in return positive criticism. Furthermore, that new ideas may die but the careers of the people who have them should not. Indeed, an individual is even to be respected for sensibly moving on to new and hopefully better ideas.

Critics of Popper's falsification theory argue that it is itself subject to falsification, so it cannot be an absolute principle or scientific law warranting a special position in the core of the scientific paradigm. For example, O'Hear (1989) argues that the falsification tests are themselves just theories, so they cannot be true tests of another theory. Curd & Cover (1998) explain the Quine-Duhem Thesis (Duhem 1906) that it's impossible to isolate a single theory for testing from the environment of theories that surround it. So if a cluster of theories is falsified it is not possible to identify the defective element.

Ironically, this criticism turns against Popper his favourite quote from Xenophanes of Colophon (570 – 480 BCE):[xiii]

> The gods did not reveal, from the beginning,
> All things to us, but in the course of time
> Through seeking we may learn and know things better.
> But as for certain truth, no man has known it,
> Nor shall he know it, neither of the gods

Nor yet of all things of which I speak.
For even if by chance he were to utter
The final truth, he would himself not know it:
For all is but a woven web of guesses.

Even more ironically for Popper, Kuhn's empirical research finding that in practice science doesn't proceed by falsification became widely accepted as a test that falsified Popper's theory. The highly regarded anarchist philosopher, Feyerabend (1975), one of Popper's greatest critics, concluded that the theories of both Popper and Kuhn had failed and this left only the pluralist approach of “anything goes” in Science.

Unfortunately, the same ignominious fate awaited Popper's concept of objective knowledge, which Popper calls World 3, a third dimension of existence following the objective and the subjective (Popper 1972). Few were prepared to admit the existence of knowledge (for example the knowledge within books contained within a library) and institutional structures (for example laws and the police force) are independent of the knowing subject.

Perhaps this is because Poppers World 3 breaks the simple Cartesian dualism of matter and soul[xiv] and demands an answer to the old phenomenological chestnut “Does a tree make a noise when it falls in a forest and there is no-one to hear it?”

In some ways it is surprising that Popper's theory of falsification remains so controversial as the technique has always been used in academic peer review. In addition, since 2000, falsification became the fundamental principle for the way software is developed. In test driven development, tests are written before the application code is started and then only sufficient software code to pass the test is actually prepared.

The following discussion of an instance where Popper's world view has been implemented allows conclusions to be drawn on Popper's influence from the boardroom to international democracy.

Perhaps the only institutional environment where open criticism was encouraged was the classical democracy of Athens, which was greatly influenced by Solon (594 BC). However, it is best known for its golden age under the leader Pericles (c. 495 BCE - 429 BCE). The Athenian democracy existed for at least 186 years from the time of Cleisthenes (508 BCE) until its suppression by the Macedonians in 322 BCE.

Fuller (p. 105) notes that: “Athens expected its citizens to speak their minds. Indeed, failing to speak was worse than failing to persuade.” Not only was criticism encouraged in Athens, it was actively demanded to protect society from political capriciousness, or *stasis*. This is the Athenian term for the agency conflict between the public interest of politicians and officials in positions of authority and their private interests of staying in power and enriching themselves through their position. The duty of public criticism was designed to empower citizens and remove the mythology, superstition and institutionalised dogma that accompanies Platonic stratification of knowledge and authority in a society.

Following Bergson (1932), Popper uses the term open society to describe a classical democracy that is predicated on debate, accountability and the testing of ideas (Popper 1945). Fuller (p. 160) explains that Popper was particularly concerned with what is nowadays called the “spiral of silence.” This is the tendency in democratic societies for politicians to allow public opinion to drift towards a minority position that has repeated exposure and little formal opposition and for a culture of self-censorship to develop amongst scientists, journalists and bureaucrats in order that to avoid career victimisation.

In modern society it represents a failure by the media, which is expected to represent the third estate, to give public expression to the majority view and not assume it to be simply self-evident. The third estate of the realm in medieval Europe comprised all members of society, excluding the first estate (King and clergy) and the second estate (nobility). Today, it is mainly seen as the public voice represented by investigative journalists.

However, Popper's principle of falsification can appear to be a paradigm that encourages passionate individuals to rail against institutions. As Fuller (pp. 32 & 162) notes, active falsification was a complete about-face for the logical positivists at the core of America's post World War II big-science phase and had the alarming potential to cross the line from criticism of that pragmatism approach to nihilism, which is Nietzsche's term for without meaning, purpose or value.

Undeniably, the ideal of falsification has a place in science, companies and democracies. However, it appears to be an unattainable perfection and the dichotomy between open and closed organisations remains as a continuing tension. As the democracy of Athens proved to be too pure in its principles to stand the test of time against powerful elites, so Popper's open society is considered by the institutions of society to be insufficiently stable for social cohesion.

Nevertheless, it appears to be a valid hypothesis that the closer falsification can be approached and transparency is valued, the more open and successful economies and business will be. Thus organisations and countries that strive for open principles will not just demonstrate their ethical commitment but maximise economic welfare in their society by providing the conditions of transparency and trust in which people can make their greatest achievements.

2.4 Unexpected failures in the Anglo-American world view

Agency conflict

Agency conflict and corporate excess in the 1980s became the first indication that something was really wrong with post World War II Anglo-American capitalism. Perhaps the major deficiency in an elementary paradigm of competitive markets is that of principal agent conflict. Much of the regulation of markets has focused on the issues between both shareholders and directors, and between directors and management.[xv]

As a result of prominent failures in agency conflict, economic stability in America and in the world became increasingly threatened by American business practices. The American Congress, and governments around the world developed Corporate Governance as a major theme.

The need for specific Corporate Governance regulations arises because directors do not have a legal responsibility to individual stakeholders such as shareholders, creditors or employees.[xvi] Prior to the need for Corporate Governance being recognised, much of directors' duties regulation was merely to ensure that directors carried out their fiduciary duties honestly and in good faith for the benefit of the shareholders as a whole. For example, a fiduciary duty was described by the UK High Court in *Aberdeen Railway Co v Blaikie Bros.* (1854, 1 Macq 461) as “A duty to act with fidelity and trust to another, to act honestly, in good faith and to the best of one’s ability in the interest of the company.” This simple fiduciary duty leads to imperfect accountability of directors and managers, which has been exploited in every possible way.

Based on Nietzsche's analysis (above) we might expect that directors and chief executive officers of companies and organisations, would be reluctant to see demands for accountability and governance impact on their personal “will to power.”

Agency conflict is obviously a very big opportunity space for directors and managers. They would prefer to leave it unresolved and flexible for exploitation. For example, Duffner (2003, p.34) notes that an agent has the opportunity to maximise their own utility, utilising better information about the business, and perhaps pass over obligations such as contracts, laws and moral standards. Kaplan & Stromberg (2004) emphasise that principal-agent conflicts are ever present due to these information asymmetries.

One attempt to address the moral hazard of imperfect accountability was to appeal to the supposed enlightened self interest that Adam Smith assumed to be a prominent feature of capitalist behaviour. Smith assumed that capitalists would readily respond to the demands of society to protect their extremely valuable right to operate under the social mandate granted by society. Directors associations therefore assiduously prepared Codes of Conduct that exhorted directors and managers to “act honestly, in good faith and in the best interest of the company as a whole; not make improper use of information acquired as a director; and not allow personal interests, or the interests of any associated person, to conflict with the interests of the Company.”

However, these Codes of Conduct could only provide unenforceable statements of good intent and the mission was flawed from the outset because the social mandate extended by society was such a nebulous concept. In addition, forfeiture of the mandate to operate is a very big issue, requiring such gravity of circumstances, that it had rarely been invoked. Therefore, directors and managers nodded in due deference to their vague accountability and unenforceable obligations but were confident that in practice all these lofty principles are inevitably subject to considerable interpretation in ambiguous situations. As a result, Codes of Conduct did little to address moral hazard, which continued to be an imperative because exploitation of company positions for personal advantage continued unabated as a major ethical problem.

In the late 1990s and early 2000s, a number of prominent American and Australian companies began to fail after Corporate Governance abuse. More than any other example, the American company Enron showed what happens when Corporate Governance goes awry. Bala Dharan, Professor of Accounting at Rice University, noted in his testimony to the American House of Representatives Committee on Energy and Commerce that the Enron debacle will rank as one of the largest securities fraud cases in history. He noted that many people were confused as to how this tragedy could have happened while the company's management, board of directors and outside auditors were supposedly watching over for employees and investors. Dharan testified (Dharan 2002):

> My analysis of the Enron debacle shows that Enron's fall was initiated by a flawed and failed corporate strategy, which led to an astounding number of bad business decisions. But unlike other normal corporate failures, Enron's fall was ultimately precipitated by the company's pervasive and sustained use of aggressive accounting tactics to generate misleading disclosures intended to hide the bad business decisions from shareholders. The failure of Enron points to an unparalleled breakdown at every level of the usual system of checks that investors, lenders and employees rely on – broken or missing belief systems and boundary systems to govern the behaviour of senior management, weak corporate governance by

board of directors and its audit committee, and compromised independence in the attestation of financial statements by external auditor.

When gross deficiencies of Corporate Governance and breach of duty by auditors such as Arthur Anderson were discovered, Congress took a firm black letter approach to Corporate Governance in the Sarbanes-Oxley Act of 2002. This regulated agency conflict and set standards in accountability and risk management.[xvii]

In Australia, after failures of prominent companies such as HIH and OneTel, Justice Owen was appointed to lead a Royal Commission into the failure of insurance company HIH. For the purposes of the Royal Commission, Justice Owen defined Corporate Governance as (Owen 2003, p.xxxiii) “The framework of rules, relationships, systems and processes within and by which authority is exercised and controlled in corporations.” Justice Owen held that Corporate Governance encompasses the mechanisms by which companies, and those in control, are held to account (Owen 2003a, p.2).

With the HIH Royal Commission underway, the Australian Stock Exchange's Corporate Governance Council acted to address Corporate Governance. Sadly, under pressure from a political conservative government, it introduced an undemanding and predominantly voluntary set of Corporate Governance Guidelines (ASX Corporate Governance Council 2003; 2005; 2006; 2006; 2007). The Committee persevered with the now defunct assumption that directors and managers would step-up to their responsibilities out of “enlightened self-interest”. Perhaps predictably, the Governance Council was to be embarrassed in its naive assumption by a lack of *bona fide* commitment “Overall, the quality of exception reporting in 2004 annual reports was lower than expected. Motherhood statements were commonly used, providing insufficient disclosure to investors” (ASX Corporate Governance Council 2005).

In 2006, the Committee was forced to move to the previously threatened sanction of a black letter approach, similar to Sarbanes-Oxley (ASX Corporate Governance Council 2006)

One might be forgiven for assuming that the moral hazard had finally been addressed by tough Corporate Governance rules across Anglo-American economies. Unfortunately, this is not the case.

Daily, Dalton & Cannella (2003, p.371) found that Corporate Governance has degenerated into a set of check the box requirements that do not meet expectations of *bona fide* behaviour change: "The field of corporate governance is at a cross roads. Our knowledge of what we know about the efficacy of corporate governance mechanisms is rivalled by what we do not know."

In other words, measurements based on structure (such as the number and diversity of directors, the mix of executive and independent directors, the separations of chairman/chief executive officer roles) have run their course. Of course, no-one in industry, academia or government doubts the value of Corporate Governance in keeping agency conflicts at bay. However, the problem is now board performance, which is behavioural and much harder to quantify.

In *What's wrong with corporate governance* (2004) Leblanc concludes: "[the link between financial performance and the board's strategic decision-making effectiveness] cannot be measured from the outside, e.g., when a board says "no" to a CEO, how do you measure this?" Leblanc suggests that the way forward for research that connects with financial performance, rather than compliance, is direct observation of board behaviour: "The only possible way to know whether boards operate well is to observe them in action – to see and understand the processes by which they reach decisions. The missing link in establishing the relationship between board governance and corporate performance may be an understanding of that elusive activity called board process. Uncovering "how boards work" has tremendous practical significance. We are just beginning a very important journey."

In *What makes great board great*, Sonnenfeld characterises the ingredient that continued to be missing as "the human side of governance" (Sonnenfeld 2004, p.109). Two years earlier, he had concluded that the key to strong performance is a social attitude of accountability rather than compliance where the focus had been placed to date “So if following good-governance regulatory recipes doesn’t produce good boards, what does? The key isn’t structural, it’s social. The most involved, diligent, value-added boards may or may not follow every recommendation in the good-governance handbook. What distinguishes exemplary boards is that they are robust, effective social systems” (Sonnenfeld 2002).

Petre (2003) found that exceptional organisations seek to become transparent and heads-up in giving recognition at all levels for good ideas. The people with the ideas are allowed to follow them through across multidisciplinary borders. She also found that organisations that can't quite cope with multidisciplinary management still pursue multidisciplinary projects but each member of a given domain (for example, mechanical engineers and industrial designers) remains within their own department.

However, Petre noted that exceptional performance is still rare and corporate culture has a complex balance of contributing factors that means it is always at risk to subversive behaviour:

> It should be remarked how fragile this cooperative, communicative culture can be. It requires energetic, high-quality personnel, with high levels of expertise and creativity, capable of assimilating and evaluating high-quality information. It requires trust, sharing and open-minded communication. It requires careful management of resources, workload, practices, and team dynamics. It is a complex system of factors, easily perturbed by a dissonant element or by a lapse in momentum.

We may conclude that Governments were successful in extending directors' fiduciary duties into formal Corporate Governance compliance. However, we have seen that human decisions and behaviour remain discretionary, outside the net of compliance, and subject to incomplete accountability. Therefore, regulators failed to effectively address the moral hazard inherent in Anglo-American capitalism. Shortly we will see that this accumulated to dire consequences in the 2008-9 global financial crisis.

Excessive speculation in markets

While business practices had been out of control, attention had not been focused on the rampant speculation occurring in commodity markets. By 2008, American investment practices had become a major issue in world commodity prices, particularly oil and food prices.

Due to the large amount of surplus capital in America, investors looked to hedge funds for high returns. Hedge funds along with pension funds and investment bank trading desks found a source of abnormally high profits in the commodity markets. So they shifted their hedge capital from share, bond and currency markets, distressed or scarce agricultural real-estate, to dabble in commodities while there is high profit to be made from ramping the market. When the market ultimately corrects and there is no longer abnormal profit to be made, the hedge funds will depart leaving the production and consumption players like farmers, miners, refineries, other people in these industries like airlines and most important of all consumers, to lick their wounds.

Prior to 2000 there was negligible managed capital in commodity markets. From 2000 to 2007, about US$200 billion in managed financial assets was invested. This rose a further US$30 billion in the first four months of 2008.

Diana Henriques (2008) reviewed the increasing concern of the American Congress and President George H. W. Bush's Administration about excessive speculation in commodity markets exacerbating and even manipulating oil and food prices. This speculation came at a time when commodity prices were already under upward pressure from global supply and demand forces such as unfavourable weather, the decline of the American dollar, economic growth in India and China economies and increasing standards of living.

The fundamental dichotomy in commodity markets is the need for liquidity and therefore for speculators. The contrary view of the hundreds of billions of dollars that has flowed into the commodity markets from 2000-2007 is that without this capital liquidity would have been far less and prices may have been far higher and more volatile than they are now.

On the other hand, too much money causing excessive speculation leads to massive bubbles in the price of basic commodities, which hurts ordinary people and the economy. Commodities market regulations to prevent excessive speculation were withdrawn in the final year of the President George H. W. Bush Administration.

The ability of firms to consistently make abnormally high profits in a market usually has its roots in poor government policy. In America, the legal pursuit of market profits had become a form of market manipulation. For example, new speculators piling in on the buy-side in the belief that prices will rise is self reinforcing and prices rise.

Measures to curb excessive speculation range from outright bans to raising the capital requirements for futures trades. For example, in America, futures trading in onions has been banned since 1958. A Congressional report at the time stated “Speculative activity in the futures markets causes such severe and unwarranted fluctuations in the price of cash onions as to require complete prohibition of onion futures trading in order to assure the orderly flow of onions in interstate commerce.”

In July 2008, just before the global financial crisis, Congress contemplated raising margin requirements. Following World War II, President Harry Truman had raised the deposit on margin trades to an unprecedented level of 33% of the contract value saying “The cost of living in this country must not be a football to be kicked about by gamblers.” However, increasing margin requirements may not be effective since prices do not appear to be affected by margin requirements, although volume of contracts certainly is.

Another bias in American markets is the well-known “Enron loophole,” also called the “investment bank loophole”. Speculative investors such as commodity index funds can dramatically increase the size of their commodity bet in excess of normal limits by working with an investment bank. Operating in a back-to-back way, both the investor and the investment bank avoids regulation. For example, the investment banks sells a swap to the commodity index fund for a commodity like corn. The investment bank then writes many times the swap as a hedge in the commodity futures market. This technique limiting speculators.

In addition to this new speculation that tilts the market toward higher prices, there is always secret and collusive trading activity to produce illegal profits. These things are often below the radar of the regulators due to the massive volumes and sizes of transactions in the commodity market. However, major commodity market manipulation scandals have become public, such as J. R. Simplot's fixing of the Maine potato market, William Herbert Hunt's 1979 manipulation of the silver market to over US$50 per ounce before it collapsed to US$10.80, Enron in the California energy market and British Petroleum's 2007 settlement of charges that it rigged the propane market.

Collusive trading is not limited to covert communication. It can also occur through open mechanisms where large institutional investors signal their intentions through the press or take turns in increasing prices.

The immensity of the hedge fund capital in a relatively small market has led to a change in the nature of speculators from commodity traders and facilitators to massive financial betting institutions. These financial institutions have at their disposal highly sophisticated techniques to achieve extraordinary profits from price volatility. For example, they are able to react faster to new information than everybody else. It is a zero-sum game. In aggregate terms, the profit taken by speculators is a major loss to the market.

Two main issues seem to have been highlighted by the failure of the commodities market due to excessive speculation. The first is that the continued existence of loopholes allowing massive speculation is inappropriate. A free economy needs to facilitate speculation in a way that is pro-public interest. Regulating markets at the point of market failure is not incompatible with being pro-market. Secondly, in the end the market is just a mechanism and is not a policy instrument. The market can only operate successfully in the public interest where government provides a strong sustainable policy for the commodities.

Sub-prime crisis

In October 2009, a decade of American consumers binging on Chinese imports and gorging on Middle East oil came to a shuddering end as Americans could not continue to borrow for their current consumption.[xviii]

According the Bacevich, the roots of the sub-prime credit crisis lie in the Regan era (Bacevich 2008, p.36):

> Regan portrayed himself as a conservative. He was, in fact, the modern prophet of profligacy, the politician who gave moral sanction to the empire of consumption. Beguiling his fellow citizens with his talk of morning in America, the faux conservative Regan added to America's civic religion two crucial beliefs: Credit has no limits, and the bills will never become due. Balance the books, pay as you go, save for a rainy day – Regan's abrogation of these ancient bits of wisdom did as much to recast America's moral constitution as did sex, drugs and rock and roll.

However, the sub-prime crisis was merely a symptom of many economic exigencies. On 11 September 2001, when the American economy was on the brink of recession, Al Qaeda attacked the New York World Trade Centre and Pentagon. The American Federal Reserve sprung into action, aggressively easing monetary policy. It reduced interest rates from 6.5% in May 2000 to 1% by June 2003. Already preparing for economic stimulus, the American Government then started large public deficit spending to prop up the economy.

The Federal Reserve's low interest rates and vastly over-expanded money supply fuelled a boom in property lending. Investment bankers who used every avenue of unfettered financial innovation to maximise profits supercharged the already huge volume of risky debt. One major innovation was bundling mortgages into new unregulated collateralised debt obligations (CDOs). These securitised debt products were sold to other banks, superannuation funds and overseas investors. In this new model of business, banks transformed from boring mortgage lenders into fee-for-service earners.

The new role of banks was to originate mortgages through their sales channels and sell these mortgages in parcels, taking a fee for the transaction. Parcels of mortgages had mixed credit quality, just as DeBeers has traditionally sold parcels of diamonds with variable quality in the parcels. Ultimately, banks ceased focusing on the credit quality of the mortgages in the parcel, which was seen as a mortgage insurer risk. In America, Fannie Mae, Freddie Mac and investment banks provided trillions of dollars of mortgages. AIG insured many trillions of dollars of these loans against credit risk default. Then the sub-prime mortgage crisis began as Bear Stearns failed on 13 March 2008.[xix]

The American Government had begun to believe in its own illusion that there could be a new world economic order having growth without savings. This became accepted in many advanced economies such as Australia. A compliant American government and Federal Reserve became very confident and permitted high risk lending to borrowers with doubtful credit histories. One of the now infamous acronyms for such lending was the “NINJA loan,” a loan to people with “No Income, No Job, no Assets”. In America, Australia and the United Kingdom, there were regular advertisements for 110% mortgages and urging existing house owners to withdraw equity from the rise in the value of their house to spend on a car, boat or holiday.

Buyers with easy money chased properties so house prices began rising in 2000. Continued appreciation of house prices ensured attractive returns for all involved. In concert, equity prices continued their bull run as the bellboys (people that heard rumours in the lift) were making big money. Wise heads knew that this meant a recession but the concerted and massive economic stimulus meant that the recession just didn't come.

In 2006, China burst onto the world stage, supplying huge volumes of cheap capital goods to America and the world. This supercharged the already overheated equity and commodity markets.

In June 2004, the American Federal Reserve became very concerned about runaway inflation. It began to increase interest rates from 1% to 5.25% by June 2006. This discouraged investors who stopped investing in new mortgage loans and led to a build up in unsold homes. The oversupply of houses led to a steep collapse in prices from their peak in 2006. By November 2008, American metropolitan city house prices had fallen approximately 25%.

Bubbles are a massive Ponzi (pyramid) scheme. Each increase in price of houses or shares requires a new fool to believe that markets will rise further. At a crucial point, for a myriad of reasons, expectations about future income growth falter. At this so-called “Minsky moment,” the unbridled greed turns abruptly to fear and the bubble collapses.[xx]

Moral hazard

The 2008 sub-prime debt crisis was a watershed in attitudes and a turning point in history. Given the topicality of this section, perhaps it could have been placed at the start of the chapter rather than in here its linear place as part of the development of shared American attitudes.

Over the past 200 years the USA has endured frequent recessions accompanied by asset bubbles and banking failures.[xxi] Yet the 2008 recession has been special for the reason that America forfeited much more than its global industrial competitiveness and accumulated a huge foreign debt. As Paul Krugman winner of the 2008 Nobel Prize in Economics “for his analysis of trade patterns and location of economic activity,” writes “The financial crisis has had many costs. And one of those costs is the damage to America’s reputation, an asset we’ve lost just when we, and the world, need it most” (Krugman 2009b).

Along with abusing and subsequently forfeited its most precious asset of all, its reputation, America lost its preeminent position as the leader of the Western world. For at least thirty years, American national arrogance in being different and exceptional, led by God, and above the law justified increasing hubris and led to burgeoning moral hazard. The President of France, Nicolas Sarkozy, concisely summarised the issue as “This crisis is not the crisis of capitalism. On the contrary, it is the crisis of a system that has drifted away from the most fundamental values of capitalism. It is the crisis of a system that drove financial operators to be increasingly reckless in the risks they took, that allowed banks to speculate instead of doing their proper business of funding growth in the economy; a system, lastly, that tolerated a complete lack of control over the activities of so many financial players and markets” (Sarkozy 2009).

Moral hazard is the tendency to excess when a person is unaccountable or only partially accountable for the consequences of their action (for example, in taking risks, consumption, borrowing and military and covert activities). In this context, the terms moral hazard and systemic risk are being used in a generic sense, which is broader than American Treasury Secretary Henry Paulson's use of the terms. At the time of the Bear Stearn's bailout, Paulson used the term moral hazard in the context of directors, managers and shareholders receiving the massive benefit of bailouts when their own choices and actions had led to their own predicament. The reason for the bailouts was to avert systemic failure, by which Paulson was referring to the web of derivative and credit insurance transactions that might fail if Bear Stearns failed in meeting its trillions of dollars of counterparty obligations.

However, in America, the moral hazard that led to the economic collapse of 2009 was not confined to any single sector or to consumers. Americans engaged root and branch, as a people and as a nation, domestically and internationally. Every institution of government, military, business and finance, not excluding the Federal Reserve, was involved and culpable. The pervasiveness of moral hazard in government was further compromised by national and organisational psychopathy, deceit and agency conflict.

Other Anglo-American countries such as the United Kingdom and Australia had enjoyed a goldilocks decade of abundance rooted in America's intoxication with consumption. These Anglo-American nations enthusiastically followed America down the path of moral hazard. In July 2007, the new Governor of Australia's Reserve Bank stated of the Australian economy (Stevens 2007, pp.3-4):

> International financial markets remain remarkably supportive of

> growth. Long-term interest rates are not far above their 50-year lows of a few years ago, even though short-term rates have risen in most countries to be much closer to normal levels, the main exception being Japan. Share prices have been rising steadily, appetite for risk is strong, and volatility in prices for financial instruments has been remarkably subdued. To some extent, these trends in financial pricing may well reflect a genuine decline in some dimensions of underlying risk. Variability in economic activity, and in inflation and interest rates, has clearly diminished over the past 15 years in a number of countries, including Australia …. The associated prolonged period of attractive, steady returns on equity investment and low cost of long-term debt funding certainly seems to have set the stage for a return to somewhat higher leverage in the corporate sector. This is most prominent in the rise in merger and acquisition activity and the re-emergence of leveraged buyouts around the world. Corporate leverage had been unusually low after the excesses of the 1980s, so some increase is probably manageable. Nonetheless, after more than a decade in which the main action in many countries has been in household balance sheets, this trend in corporate leverage will bear watching. For the time being, at any rate, financial conditions are providing ample support for both corporate investment and household spending around the world.

By 2009, four of the six pillars of American capitalism, the American investment banks, had collapsed. Taxpayer funds had been used to save many banks and bankrupt companies like General Motors and Chrysler, formerly doyens of America's industrial heartland.

America is arguably facing its greatest ever challenge. Ironically its bailouts and budget deficits have been funded from China's foreign reserves and the children and grandchildren of current American consumers. This has confronted the undisputed dogmas of the market system: “The prevailing market system is supported by a very influential set of economic dogmas which have come to occupy a dominant place in the lives of modern societies. These include the high importance attached to market-led economic growth; the value of complete free trade in money and capital as well as in goods and services; the need to subordinate social welfare to market requirements; the belief in cutting down or privatising government functions; the acceptability of profit as a test of economic welfare; and others as well” (Self 2000, p.ix).

Americans had reduced Adam Smith's “invisible hidden hand of capitalism” to little more than a crude and unprovable, therefore both unchallengeable and unjustifiable, excuse for ubiquitous greed and reckless risk-taking. Abroad and increasingly at home the great American dream of unregulated capitalism became hotly debated and even held in disdain.

At the 2009 G-20 London Summit, President Barack Obama quietly took responsibility for the world's economic crisis (Hujer et al. 2009):

> Something was missing and Italian Prime Minister Silvio Berlusconi wasn't about to accept it .... Barack Obama, the president of the United States of America, the most important man at the G-20 summit in London, had remained silent for some time now .... Berlusconi now spoke to him directly: "I would like to extend my congratulations to Barack Obama," he said, adding that the economic crisis had begun in the US. "Now he has to address it," he said and looked towards Obama. "We wish him all the best for the citizens of the US and the entire world.".... [Barack Obama] then lowered his voice: "It is true, as my Italian friend has said, that the crisis began in the US. I take responsibility, even if I wasn't even president at the time.” .... The others couldn't believe their ears. Was that really a confession of guilt from the US? Was it a translation error, or at least an inaccuracy? Afterwards, this sentence fuelled long discussions among the members of the German delegation. German Chancellor Angela Merkel was so impressed by Obama's statement that she rushed to tell her finance minister, Peer Steinbrück. Japanese Prime Minister Taro Aso reacted immediately: The proposal to hold the next summit not in Japan, but rather in the US, is something that he no longer rejects, he says, "now that the US has shouldered responsibility." .... Obama's confession may go down in world history as one of the greatest statements ever made. The US president is accepting responsibility for the beginning of one of the worst economic crises of the last

> century. By doing so, he has admitted that one of the excesses of the American way of life -- the insatiable craving for huge profits -- has brought the world to the brink of disaster. The others may have played their part, but the origins lie in the US. The fact that Obama has now admitted this sends a strong signal of hope to the world, perhaps the strongest to emerge from the G-20 summit in London last Wednesday and Thursday. Such an admission could begin to pave the way towards rectifying the situation.

Challenges to the legitimacy of neoclassical economics

Shouldering the responsibility is an important first step. However, the next step is a recognition that the underlying models are broken. Over the last 80 years, neoclassical economists have seemingly led the world into two serious economic collapses. Many economists have asked if rational frameworks of policy testing and analysis are seriously flawed. Mark Dodgson & Eric Beinhocker criticise the fundamental assumption of rationality in CGE models (Slattery 2008):

> The intellectual field of economics is on the cusp of a big transformation. Mainstream economics is increasingly being seen to be detached from reality. Its assumptions about equilibrium, rationality in human behaviour and the primacy of market forces that are mysteriously asocial make its predictive power extremely limited. New approaches, such as evolutionary economics and the study of economies as complex adaptive systems, are much more useful in addressing big economic challenges of generating growth and productivity through innovation in ways that are sustainable and equitable. The discipline is suffering, in effect, from the challenge to neoliberal economic doctrine brought on by the [2008] sub-prime crisis in the U.S. and its repercussions across the global financial system. Feeding the mood of despair across financial markets is the perception that mainstream economics was unable to predict the crisis, or to manage it, and has been intellectually

> enfeebled by the Gordian knot of peak energy prices, planetary overheating and global debt.

The financial crisis has also led David Brooks to a certainty that neoclassical models are overly linear and rational, lacking psychological dimensions. He writes (Brooks 2008):

> Economic models and entire social science disciplines are premised on the assumption that people are mostly engaged in rationally calculating and maximizing their self-interest …. But during this financial crisis, that way of thinking has failed spectacularly. As Alan Greenspan noted in his Congressional testimony last week, he was "shocked" that markets did not work as anticipated. "I made a mistake in presuming that the self-interests of organizations, specifically banks and others, were such as that they were best capable of protecting their own shareholders and their equity in the firms." …. My sense is that this financial crisis is going to amount to a coming-out party for behavioral economists and others who are bringing sophisticated psychology to the realm of public policy. At least these folks have plausible explanations for why so many people could have been so gigantically wrong about the risks they were taking.

Brooks continues his criticism of neoclassical economics (Brooks 2009):

> Once, classical economics dominated policy thinking. The classical models presumed a certain sort of orderly human makeup …. the market rewards rational behavior …. The invisible hand forms a spontaneous, dynamic order .... Economic behavior can be accurately predicted through elegant models …. This view explains a lot, but not the current financial crisis — how so many people could be so stupid, incompetent and self-destructive all at once …. This crisis represents a flaw in the classical economic model and its belief in efficient markets …. For years, Republicans have been trying to create a large investor class with policies like private Social Security accounts, medical savings accounts and education vouchers. These policies were based on the belief that investors are

> careful, rational actors who make optimal decisions. There was little allowance made for the frailty of the decision-making process, let alone the mass delusions that led to the current crack-up …. Democrats also have an unfaced crisis. Democratic discussions of the stimulus package also rest on a mechanical, dehumanized view of the economy. You pump in a certain amount of money and “the economy” spits out a certain number of jobs …. But an economy is a society of trust and faith …. This recession was caused by deep imbalances and is propelled by a cascade of fundamental insecurities …. The economic spirit of a people cannot be manipulated in as simple-minded a fashion as the Keynesian mechanists imagine …. Mechanistic thinkers on the right and left pose as rigorous empiricists. But empiricism built on an inaccurate view of human nature is just a prison.

Brooks has not dug down to the bedrock of the American economic paradigm founded on Aristotle's analysis of human happiness. Nevertheless, his questioning of the existing models is poignant for a number of additional reasons. The most important of these is that models based on consumption growth as society's main goal do not react well in low or volatile growth situations.

The once heretical school of behavioural economics is an alternative path to “rational man” hypothesis of neoclassical economics. This thesis was championed by Daniel Kahneman, who shared the 2002 Nobel Prize in Economics “for having integrated insights from psychological research into economic science, especially concerning human judgement and decision-making under uncertainty.”

However valuable the insights from irrationalist theories, an implicit reductionism to individuals does not lead to a social future. Perhaps both Kahneman and Brooks are seeking assurances in the wrong place. What is more likely is that individual human psychology, whether of the rational or irrational, will not turn out to be durable guide for government policy.

Indeed, it may be recalled from the discussion of Evidence Based Policy in *Chapter 1 Introduction*, that policy makers would prefer that economic models are always completely correct. However, policy makers seek confirmation of feasibility from modellers to improve the probability that their policy will be feasible, not seer-like predictions of the future and iron-clad guarantees of policy outcomes. Policy makers are well aware that the future will unfold quite differently to that forecast in economic models. This is why policy makers chuckle in good humour at John Kenneth Galbraith's quip that “economists were invented to give fortune tellers a good name.”

In 2008, President Sarkozy of France commissioned eminent economists including Nobel Prize winners Joseph Stiglitz, Amartya Sen, Kenneth Arrow and Daniel Kahneman to "set aside the religion of figures" and investigate whether there was a better measure of national welfare than growth in Gross Domestic Product (Stiglitz et al. 2009). Like Aristotle, the economists concluded that the best measure of welfare is an index of well-being, or the aggregated individual happiness of populations across all aspects of life. The Commission proposed a new index of Net National Product (NNP), which is Gross Domestic Product less depletion of natural and human capital.

In highlighting the pluralist role of economics in policy, Krugman (2009c) sees that “the more it changes, the more it stays the same” because only those seeking deterministic mathematical solutions have lost. He concludes that policy formation will always be “messy” rather than neat and mathematical:

> As I see it, the economics profession went astray because economists, as a group, mistook beauty, clad in impressive-looking mathematics, for truth …. Until the Great Depression, most economists clung to a vision of capitalism as a perfect or nearly perfect system. That vision wasn’t sustainable in the face of mass unemployment, but as memories of the Depression faded, economists fell back in love with the old, idealized vision of an economy in which rational individuals interact in perfect markets, this time gussied up with fancy equations …. It’s much harder to say where the economics profession goes from here. But what’s almost certain is that economists will have to learn to live with messiness …. In practical terms, this will translate into more cautious policy advice — and a reduced willingness to dismantle economic

> safeguards in the faith that markets will solve all problems …. flaws-and-frictions economics will move from the periphery of economic analysis to its center …. they'll have to do their best to incorporate the realities of finance into macroeconomics …. It will be a long time, if ever, before the new, more realistic approaches to finance and macroeconomics offer the same kind of clarity, completeness and sheer beauty that characterizes the full neoclassical approach.

It remains to be seen if policy analysis can be improved by innovations in behavioural economics, the new index of happiness or reminders that policy formation is a rough and tumble area of politics.

Despite deft oratory from President Obama and such profound reflection amongst economists and policy makers, it seems that lessons may not have been learned from the financial crisis. President Obama's most senior chief economic adviser, former Harvard University President Lawrence Summers, changed the definition of the crisis from moral hazard to over-exuberance and over-confidence leading to too much debt. Astounding everyone at a June 2009 conference of Deutsche Bank's Alfred Herrhausen Society in Washington, Summers' only solution was to rebuild confidence by making credit more widely available (Steingart 2009a).

Perhaps even worse, two months later pre-crash "casino capitalism" had returned in America, the United Kingdom and Germany (Herbst 2009). German Finance Minister Peer Steinbrück criticised exorbitant bonuses to bank executives in the following terms “Some executives didn't hear the bang …. They are responsible for the fact that approval of our system of doing business is waning …. Taxpayers are continuing to completely finance big bonuses” (Spiegel Online 2009b).

A loss of confidence in the American economy has been taking place since 2000 with the American dollar depreciating 40% against the Euro over the period 2000-2009. Even before the 2008 financial crisis, fewer investors in China and Japan were prepared to finance the growing American deficit. The Federal Reserve's response over the three years to 2009 was to increase the money supply by 45%. Repurchasing Government securities has flooded money into the economy to finance consumption rather than productive assets.

The American consumptive binge is accelerating with the greying and medical insurance needs of the population. America's 2009 budget forecasts US$9 trillion additional debt for the decade 2010-2020. This imbalance of wild growth in money supply to finance Americans living well beyond their means is seen by many as a precursor to massive inflation and a collapse in the dollar.

2.5 Evolution of a new Anglo-American world view

Decline of American exceptionalism

Sir David King questions whether we have seen a passing of the era of consumerism “Consumerism has been a wonderful model for growing up economies in the 20th century. Is that model fit for purpose in the 21st century, when resource shortage is our biggest challenge?” (Randerson 2009).

Andrew Bacevich's *The Limits of Power: The End of American Exceptionalism* (2008) makes a compelling case that current American consumerism has reached a crisis of American profligacy (p17) but only after having been doomed for decades. He writes (p22):

> The virtuous cycle of abundance and expansion made the United States the *land of opportunity*. From expansion came abundance; from abundance came prosperity; from prosperity came substantive freedom, the means to safeguard freedom and the means to secure further abundance. The cycle of consumption and investment built a prosperous society …. Frederick Jackson Turner wrote that American democracy was possible was due to *Not the Constitution, but free land and an abundance of resources open to a fit people* …. The American dream was fulfilled. Unseen hands like self interest and a free market that would efficiently settle or clear economic utilities worked well in times of growth and prosperity …. At the end of WWII, the USA was the strongest, richest and freest nation in the world. It possessed two-thirds of the world's gold reserves, half the world's manufacturing capacity. The US produced the most oil, steel, aeroplanes, automobiles and electronics. The US exported one third of all world trade and its exports were double imports. The Bretton

> Woods agreement replaced the pound sterling with US dollar as reserve currency and made the US the manager of the world's money. The US had unquestioned air and sea superiority, a nuclear monopoly. In 1948, US per capita income was four times the combined sum of Britain, France, Germany and Italy.

America built success on success with huge patent and copyright empires across pharmaceuticals, computers (Intel, AMD, IBM), software (Microsoft, Oracle, Sun), music, movies, publishing, food and beverage (Coca Cola, MacDonald's, Kentucky Fried Chicken) and many other industries. It scooped a margin from the majority of third world development by a form of economic extortion. America owns 40% of IMF and World Bank and it used its dominant ownership to control lending to third world countries, requiring that these countries spend their loans to buy American manufactured equipment and to employ American contractors (such as Bechtel). America also deployed the CIA and Marines to coerce investment in American goods and services if economics didn't work.

However, this miracle was not to last. The extended patent empires have matured and third world countries such as Indonesia and in South American no longer need or want International Monetary Fund loans with strings attached. Bacevich writes (p29):

> By 1950, the US had begun to import oil. Then came the crushing defeat in Vietnam, oil shocks, a destabilised economy, inflation, stagflation and currency devaluation. Following Vietnam, American efforts to expand abundance and freedom have become increasingly problematic … In the name of preserving the American way of life, President Bush and his lieutenants committed the nation to a breathtakingly ambitious project of near global domination. Hewing a tradition that extended at least as far back as Jefferson, they intended to expand American power to further the cause of American freedom. Freedom assumed abundance. Abundance seemingly required access to large quantities of cheap oil. Guaranteeing access to that oil demanded that the United States remove all doubts about who called the shots in the Persian Gulf. It demanded oil wars.

Bacevich's point is that America has reach a low point in becoming the world's biggest debtor nation and demonstrated its moral bankruptcy in having thousands of American soldiers die in Iraq merely to secure oil for profligate American consumers (pp 62-3 &155):

> While soldiers fought, people consumed. With the United States possessing less than 3 percent of the world's known oil reserves and Americans burning one out of every four barrels of petroleum produced worldwide, oil imports reached 60 percent of daily national requirements and kept rising. The personal savings rate continued to plummet. In 2005, it dropped below zero and remained there. Collectively, Americans were now spending more than they earned. By 2006, the annual trade imbalance reached a whopping $818 billion. The following year, public debt topped $9 trillion, or nearly 70% of gross national product …. In February 2006, the New York Times Magazine[xxii] posed the question *Is freedom just another word for many things to buy?* …. To anyone with a conscience, sending soldiers back to Iraq or Afghanistan for multiple combat tours while the rest of the country chills out can hardly seem an acceptable arrangement. It is unfair, unjust and morally corrosive.

Bacevich concludes that the end of American exceptionalism has arrived. Americans are now normal people, just like people in Europe and Japan. The great challenge for Americans is that they now need to live within their means.

New international symbiosis

The Prisoner's Dilemma game is considered to be an ultimatum game for economic and political relationships. It is a combination of neoclassical economics, fierce competition and primitive Darwin's survival of the fastest and fittest. Such assumptions regularly occur in many real circumstances as diverse as nuclear deterrence, the Tour de France bicycle race, project management and cigarette advertising.

Antecedents for game theory can be detected in Niccolò Machiavelli's *The Prince* (1513) and Sun Tzu's *The Art of War*, 500 BC (Tzu 2006).[xxiii] However, Claude-Henri de Rouvroy, Comte de Saint-Simon, the father of Positivism, was perhaps the first person to clearly perceive that economic progress would change the world. He fervently believed that the future could be accurately predicted by the application of sound mathematical principles. Following mixed fortunes during the 1794 French Terror, Saint-Simon developed the seeds of modern game theory (Strathern 2002, p.142-3). He accurately foresaw that humans would choose science to civilise society because this would minimise our maximum loss and any other strategy would cause a greater loss.

In 1838, Antoine Augustin Cournot's *Researches into the Mathematical Principles of the Theory of Wealth* (Cournot 1838) provided the first formal proposition of game theory.

In 1944, at Princeton, John von Neumann formulated modern game theory concepts (von Neumann & Morgenstern 1953). This followed von Neumann's early work on minimax optimisation (Von Neumann 1928). Von Neumann's game theory was further developed at RAND by Merrill Flood & Melvin Dresher in 1950 (Dresher 1981). Albert W. Tucker (1980)later introduced prison sentence pay-offs, which led to the game's current name of the “Prisoner's Dilemma”.[xxiv]

In August 1949, during the early days of the cold war, Russia detonated a nuclear device that broke America's monopoly on nuclear weapons. It was early days of the Cold War and America saw itself facing the stark choice of being red or dead (Bacevich 2008, p.164) America's xenophobia was exacerbated by Mao Zedong's Communist Revolution of 1 October, 1949. In what Dick Cheney later called the “one-percent doctrine,” America stood ready to protect its Manifest Destiny against any tangible threat. The nuclear hawks sprung into action claiming that America could avoid the choice of “red or dead”. Using his minimax game theory, Von Neumann vigorously lobbied Presidents Harry Truman and Dwight D Eisenhower[xxv] to launch a first strike nuclear conflagration at the Soviet Union.

Von Neumann became head of the Atomic Energy Commission in 1954 until his death on 8 February 1957, aged 53. Following his death, Life Magazine's obituary reported that von Neumann said of his 1950 game theory strategy “If you say why not bomb them tomorrow, I say why not today? If you say today at five o' clock, I say why not one o' clock?” (Blair 1957, p.96).

Unfortunately for von Neumann, President Truman's key adviser Paul Nitze thought the argument for preventative war was absurd. In the top secret National Security Council document NSC68, promulgated in early 1950, Nitze wrote that the idea of preventative war was “repugnant and morally corrosive”.

With the onset of the Korean War in June 1950, President Truman agreed to NSC68's dogma of mutually assured destruction (ironically with the acronym MAD) and permanently investing in military capability. NSC68 optimistically claimed “The economic effects of the program might be to increase the gross national product by more than the amount being absorbed for additional military and foreign assistance purposes …. [such as] fomenting and supporting unrest and revolt [in the Soviet bloc]” (Bacevich 2008, pp.108-11). Since this time, weapons manufacture for defence and export has underpinned America's economic growth.

At Princeton, von Neumann belittled John Nash's theory of Equilibrium (Nash 1950) as merely a corollary of von Neumann's own theory. Nash's equilibrium is a game solution, which may not be a Pareto Optimum, but where all players have perfect information and no player can gain by changing their strategy. For example, the dominant strategy for a simple two player game is for each player to not trust the other and therefore betray the other. Of course, the Pareto Optimum solution would be where each player is better off by trusting the other and therefore not betraying. John Nash, John C. Harsanyi and Reinhard Selten subsequently shared the 1994 Nobel Prize in Economics “for their pioneering analysis of equilibria in the theory of non-cooperative games.”

In 1968, Garrett Hardin (1968) proposed a “Tragedy of the Commons,” which is the situation that when each person maximises their own interest then, in aggregate, people will despoil a commons, for example a common grazing area each person.

Elinor Ostrom (1990) found Harden's hypothesis to be true in many situations of common property. She showed the “Tragedy of the Commons” is a case of multiple Prisoners Dilemmas. Together with Edella Schlager, Ostrom subsequently developed the concept of property rights (Schlager & E. Ostrom 1992; E. Ostrom & Schlager 1996).

Ostrom's work now provides the necessary conceptual framework for managing international commons, such as the globally shared resources of clean air and moderation of atmospheric temperature rise and ocean acidification. Her work was recognised with the 2009 Nobel Prize in Economics for “her analysis of economic governance, especially the commons”.[xxvi] The Royal Swedish Academy of Sciences (2009) noted:

> Elinor Ostrom has demonstrated how common property can be successfully managed by user associations …. [She] challenged the conventional wisdom that common property is poorly managed and should be either regulated by central authorities or privatized. Based on numerous studies of user-managed fish stocks, pastures, woods, lakes, and groundwater basins, Ostrom concludes that the outcomes are, more often than not, better than predicted by standard theories. She observes that resource users frequently develop sophisticated mechanisms for decision-making and rule enforcement to handle conflicts of interest, and she characterizes the rules that promote successful outcomes.

Robert Aumann extended the Prisoner's Dilemma to a repeating game called the “Iterated Prisoner's Dilemma,” which is also known as the Peace-War Game. Aumann showed that a cooperative outcome could be sustained (Aumann & Shapley 1974). Robert Aumann and Thomas C. Schelling subsequently shared the 2005 Nobel Prize in Economics “for having enhanced our understanding of conflict and cooperation through game-theory analysis.”

Robert Axelrod (1984) put Aumann's theory to the test in a world-wide competition for computer simulated Iterated Prisoner's Dilemma strategies. Axelrod found that if the game has a defined end then the best strategy is to cheat all the time. The logic behind this strategy is that if the best choice on the last iteration is to cheat, then the best alternative on the second last iteration is also to cheat, which agrees with von Neumann's analysis.

However, the outcome is different if the game continues with no foreseeable end such that there is no last iteration. In this case the best strategy was a simple *tit-for-tat* rule submitted by Anatol Rapoport (Rapoport & Chammah 1965). Rapoport's *tit-for-tat* algorithm had just 4 lines. The rule is to trust other players unless they cheat, in which case the next iteration is retaliation followed by forgiveness and a return to the trust rule. Furthermore, it was found that the more that people play the Iterated Prisoner's Dilemma, the more they recognise that trust strategies maximise everyone's welfare.

There was another winning strategy submitted by Professor Nicholas Jennings of Southampton University. This was a multi-agent group predator strategy using sixty players that could recognise each other through a little dance. These players always trusted each other and cheated on the non-predators. This multi-agent strategy easily defeated individuals and resulted in predators taking the top three positions, while their sacrificed losers were at the bottom.

Axelrod's game shows that way out of the Tragedy of the Commons and the Prisoner's Dilemma game is for people to raise themselves from risk, despoilment and despair by banding together for the greater good and thereby together achieving increased individual welfare for all.

The symbiosis that creates this environment of trust is usually found by creating a high level institution with enforceable powers to sanction members of the collective group. For example, English Common Law was originally created to bring to an end a vicious tradition of blood feuds. This has evolved into national systems of judiciary and police, as well as United Nations agencies such as the International Monetary Fund and World Bank, and institutions such as the International Criminal Court.

America has traditionally been a loner, selectively choosing between international organisations and treaties that it will join. For example, it has chosen to dominate economic agencies but has neither ratified the Kyoto climate change agreement nor submitted to the jurisdiction of the

International Criminal Court, avoiding the latter in case Americans were tried for foreign war crimes.

In order to move forward in concert with other major economic blocs in a spirit of trust, America is beginning to recognise that it must rely less on cherry-picking international agreements and more on trust strategies for a democracy of nations. Jeffrey Sachs points out that America's attitude following World War II was just this, which gave considerable guidance and hope to all peoples: “Great acts of U.S. cooperative leadership include the establishment of the UN, the IMF and World Bank, the promotion of an open global trading system, the Marshall Plan to fund European reconstruction, the eradication of smallpox, the promotion of nuclear arms control, and the elimination of ozone-depleting chemicals” (2008, pp.8-10).

Sachs sees the finest hour of the American Presidency as October 1962, when President John Kennedy led the Soviets and the world away from nuclear Armageddon. In a secret agreement, American removed nuclear missiles from Turkey at the same time as Russia removed its missiles from Cuba.

In his now famous *Peace Address at American University* in June 1963, Kennedy urged all nations to use peace as the process of finding solutions to man-made problems:

> Let us focus on a more practical, more attainable peace, based on … a gradual evolution in human institutions – on a series of concrete actions and effective agreements which are in the interests of all concerned …. Genuine peace must be the product of many nations, the sum of many acts. It must be dynamic, not static, changing to meet the challenge of each generation. For peace is a process – a way of solving problems …. So let us not be blind to our differences – but let us also direct attention to our common interests and to means by which those differences can be resolved. And if we cannot end now our differences, at least we can make the world safe for diversity. For, in the final analysis, our most basic common link is that we all inhabit this planet. We all breath the same air. We all cherish our children's future. And we are all mortal.

Nikita Khrushchev, the Russian President, responded that this was the finest American Presidential speech since those of Franklin Roosevelt. Six weeks later he joined America in a Partial Test Ban Treaty for nuclear weapons.

New constrained growth model

The foregoing suggests that America needs to transition to a new economic model that remains consistent with its strong ideals of individual freedom and democracy.

Joseph Stiglitz, a former Senior Vice President and Chief Economist of the World Bank who shared the 2001 Nobel Prize in Economics with George Akerlof and Michael Spence “for laying the foundations for the theory of markets with asymmetric information,” writes that America needs to migrate from failed economic models and look to successes like the German social model (Stiglitz 2009):

> For years the US was the economic powerhouse of the world. It imported more goods from abroad than it exported, to the joy of manufacturers in Asia or Europe. But this model no longer works. The Americans are completely over-indebted. They can't increase their consumption, instead they have to save. This is why other global growth has to be increased …. The fall of the Berlin Wall really was a strong message that communism does not work as an economic system. The collapse of Lehman Brothers on September 15th again showed that unbridled capitalism doesn't work either …. Besides the two extremes of communism and capitalism, there are alternatives, such as Scandinavia or Germany. The Chinese model has succeeded very well for their people, but at the price of democratic rights. The German social model, however, has worked very well. It could also be a model for the US administration.

The German social model was developed by Economics Minister (later Chancellor) Ludwig Erhard, who guided Germany through a post World War II boom. He inculcated a culture of stability based on hard work, low gearing and free markets. At a time when Franklin D Roosevelt was expanding America's economy with massive borrowing, Erhard kept Germany's gearing low. His success has recently been reflected upon as follows (Steingart 2009b):

> His plan shuns excessive debt. His argument was that people would first make an effort when money became tight and, thus, more valuable. You get the best results, he found, if, in the tried and true manner of our forefathers, you work hard and don't forget to save. "The state can't afford anything that doesn't come from the strength of its own people," was the message. He also could have said: No pain, no gain .... His key words were not consumption and credit, but pay and performance. He insisted, practically to the point of stubbornness, that work and only work is the foundation of prosperity: "We must either make do with less or work more." He felt that the third way, which leads to the vault of the next best bank, was a dead end .... His record is impressive, even from today's perspective. He gave Germany the longest economic boom in world history, from 1949 to 1966. During this period, the country, still recovering from the war, rose up to become a leading exporter. It overtook first the French, then three years later the British and as of 1976 the Americans. Germany's currency remained stable and its level of debt low. From the late 1950s onwards, there was full employment in Germany .... Even the term "Wirtschaftswunder" [economic miracle], coined by an admiring populace, was repugnant to him. Anyone who used the expression in his presence was snubbed. "There are no miracles," he liked to say.

However there are many geopolitical and cultural differences between Germany and America that mitigate against convergence of their economic or political systems. For example, America lost interest in Germany after the fall of the Berlin Wall when city ceased to be the front line of the Cold War.

Separation, rather than convergence, accelerating. Europeans are beginning to take note that America no longer wants the role of Europe's patron. The European Council on Foreign Relations notes “We are now entering a 'post-American world'. The Cold War is fading into history, and globalisation is increasingly redistributing power to the South and the East. The United States has understood this, and is working to replace its briefly held global dominance with a network of partnerships that will ensure that it remains the 'indispensable nation' …. Seen from Washington, there is something almost infantile about how European governments behave towards them -- a combination of attention seeking and responsibility shirking” (Witney & Shapiro 2009).[xxvii] The authors note that there are “no more special relationships” and that “governments in the EU must shake off illusions about the transatlantic relationship if they want to avoid irrelevance on the global stage.”

America's disinterest in Germany may be further distinguished from the growing relationship between Russia and Germany. Nowadays, Russia's biggest trading partner is Germany and Germany depends on Russian gas for its energy security. In recent times Germany is has shown that it is more interested in this Russia than its dealings with the European Union, NATO and America (Cohen 2009). Furthermore, Germans now attribute the collapse of the Berlin Wall and Communism to German *détente* rather than American force. Indeed Germany and Russia have moved beyond self-denial and see their new geopolitical alignment as underpinned by common experiences and learning from equally horrendous mistakes in the past. In marked contrast to American conservative beliefs, the humiliation of Russia following the collapse of the Soviet Union is now seen as an American error of judgement.

At a cultural level, Americans and Germans have different collective and primal emotions (Malzahn 2009):

> Today, we believe in Obama. We don't actually know what that means yet. What's interesting in this context is not so much the nature of Obama and his administration but the nature of German political beliefs, and how they have developed over time …. For many Germans, the Americans have always been simply too extreme. They are either too fat or too obsessed with exercise, too prudish or too pornographic, too religious or too nihilistic. In terms of history and foreign policy, the Americans have either been too isolationist or too imperialistic. They simply go ahead and invade foreign countries to only, in the end, abandon those countries the way they did in Vietnam and will soon do in Iraq …. When Obama

> gave his speech at Berlin's Victory Column last summer, he talked about the post-war airlift during the blockade of Berlin and about the care packages the Candy Bombers distributed. And then he asked, buried in a subordinate and somewhat cloudy clause of one of his sentences, that Germans start thinking about how to pay back this moral debt. However, if I know my countrymen, then this type of *nudging* just isn't going to work .... When Obama says that the US is about to change but that the U.S. cannot be the only one to change, he should not overestimate the innate feelings of personal responsibility in the German populace or assume that they will fill in the unspoken subtext .... The difference being: Americans live in a society which of course celebrates commerce and selfishness -- but behind the bluster, a mere inch beneath the surface, there are often huge reservoirs of idealism and selflessness in individual Americans. We Germans, however, live in a world which in ways is much fairer and more organized for the public good. Yet, so many of our experiences from the Thirty Years War onwards have contributed to a hard egotistical core which lurks just beneath the dutiful surface of the national psyche.

The America consumer economy has a perverse economic feedback that Germans don't understand: consumption begets consumption. The robust saving and belt tightening so embedded in the German psyche has precisely the opposite effect in America. As the American savings rate rises, house prices fall, unemployment rises and the consumer sector can't lift out of its lethargy. Therefore, the individual and national psyches of America and Germany have profound differences.

This is evidenced in a fundamental difference between the American and German models of growth. Prima facie both are identical in the policy to maximise welfare, which is identified with consumption growth. The difference is that the American model is one of unconstrained maximisation and continued extension to economic growth while the German model is one of constrained maximisation.

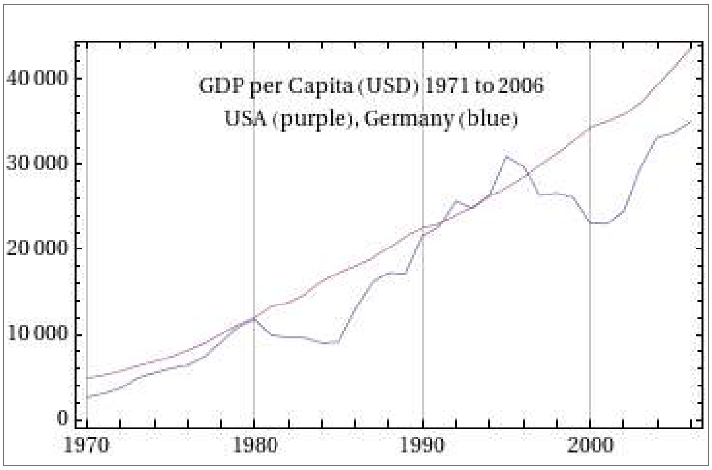
For the American consumer economy, the quality of that growth is not so important. For example, short term consumer growth through hollowing out of the manufacturing industry is just as valuable as any other sort of growth. It matters little that national income inequality is extraordinarily high and huge differentials in consumption exist between ethno-cultural groups.

We have seen above that America has traditionally removed constraints by active measures, including covert and military actions to secure resources. This includes the morally corrosive attitude of American soldiers dying in Iraq to secure oil for American consumers while they “chill out” at home.

In stark contrast to the Anglo-American model, the German model focuses on the quality of growth as much as, or more than, the quantum of growth. Production growth must be knowledge based and export led. Consumption growth must be based on a broad equality in income so all citizens more or less equally share in the benefits of the good times and impacts of the bad times.

Prime in the German psyche are the constraints of money and resources. While the German model still seeks to maximise consumption growth, this is subject to two main constraints. The first is efficiently satisfying money and resource limitations. Consistent with the previous discussion of Rawls' *A Theory of Justice*, (1972) the second constraint is that society's stability be maintained by automatic stabilisers that protect the weakest members. For example, government subsidies that compensate employees when their hours are cut, called “Kurzarbeit,” is credited with preserving hundreds of thousands of job losses in the 2008 global financial crisis.

Constrained growth will often be lower than unconstrained growth. For example, the European Union introduced carbon trading to control emissions and global warming. This resulted in lower consumption growth over the last decade compared to the America (excluding the 2008 Global Financial Crisis), as shown in the following illustration.



Source: Mathematica Country Data 9 April 2009 (note that the graph is denominated in American dollars so the blue line for Germany incorporates all exchange rate variability)

Eilenberger (2009) speculates that the world has seen the end of old models of globalisation, including post-WWII American economic and military imperialism. He sees the globalisation in a down-cycle, moving down a world historical optimum:

> We are -- at this moment -- experiencing a European utopia that has been cultivated for millennia .... The dogma-free, democratic marketplace of ideas, for which Socrates gave his life in Athens, is today a communicative reality in which hundreds of millions of citizens are actively taking part. The spirit of scientific methodology and veracity embodied by Bacon, Descartes, and Newton as a measure of the collective interpretation of the world is driving a community of researchers that is unique in its diversity. The federal confederacy based on fundamental human rights that Erasmus and Kant envisaged as the "kingdom of ends" is now our political order. The collective safeguarding of physical and intellectual basic rights that Aristotle recognized as the foundation of every polity, and the ethically concerned liberalism of Adam Smith are guiding the logic of our economic activity. And finally, the vision of a secular, active, multilingual life elevated by Shakespeare, Cervantes, and Goethe as the core of what it means to be human accurately describes our cultural existence today as nascent Europeans .... We are not dealing here with poetry or philosophical pipe dreams, but rather an

> empirically demonstrable reality. The European Union in the year 2009 represents a world-historical optimum. Never before have 500 million people united under a single political order been better off. Never before have they been as free, as healthy, or as well educated; and never before have they been as peaceful. To be sure, it is the systemic improbability of this state of affairs that lends a certain credence to the current pessimism about the future.

Eilenberger hypothesises that the Global Financial Crisis of 2008-9 is merely a symptom of the new logic of scarce resources and a fundamental change in globalisation. In particular, a change from old British and European models of imperialism and modern day Anglo-American models of economic and military imperialism.

According to Eilenberger, the new paradigm is one where Europe and all regions of the world will become inwardly focused: “The age of globalization is over. The coming 30 years will be shaped by the logic of scarcity, resulting in a turn away from global trade and the creation of self-reliant geopolitical zones.”

He sees the European tradition of wisdom as serendipitously being mature and capable of transferring proven modes of governance under resource scarcity to Anglo-American nations and new regional unions, such as an enlarged European Union including Russia, Turkey and Ukraine. He is less certain of the path of China, Middle Eastern nations and India.

Interestingly, Eilenberger observes that the journey of industrialised democracies through internationalism, globalisation and finally to domestic resilience and sustainability parallels the path of self-awareness and wisdom of Voltaire's hero Candide in *Candide, ou l'Optimisme* (1759):

> After the adventurous hero Candide, inspired by the notion that he lives in the best of all possible worlds, has circled the globe and thus directly experienced the deep *misère du monde* in all its conceivable forms, he returns to a fenced garden, the fruits of which at least guarantee him and his own an agreeable livelihood. Now and again dreadful news from other parts of the world penetrates the walls and leads to discussion about responsibility and the possibility of a

> new departure, to which the now wise Candide responds, *Cela est bien dit, mais il faut cultiver notre jardin*. (That is well said, but we must cultivate our garden) …. Tending to one's own garden, ensuring its sustainability, and continuing to cultivate it innovatively: this is Europe's future -- behind walls.

These generic themes are suggested as potential applications for further policy research in *Chapter 7 Conclusions and suggestions for further research.*

Policy reboot

The Global Financial Crisis of 2008-9 may well mark the end of a 30-year bubble in finance and impending transition of world governance from America to a group of major nations. Upon the election Barack Obama in November 2008, President Nicolas Sarkozy of France, who held the European Union's rotating presidency, wrote to Barack Obama requesting that the world governance granted to America at the end of World War II, at Bretton Woods, be redistributed to other countries including the European Union.

In a further serious challenge to America's waning economic leadership, Zhou Xiaochuan, Governor of China's central bank, suggested on 26 March 2009 that a supra-currency, such as IMF Special Drawing Rights (SDRs) replace the American dollar as the world's reserve currency (Xiaochuan 2009):

> The outbreak of the current crisis and its spillover in the world have confronted us with a long-existing but still unanswered question,i.e., what kind of international reserve currency do we need to secure global financial stability and facilitate world economic growth, which was one of the purposes for establishing the IMF? There were various institutional arrangements in an attempt to find a solution, including the Silver Standard, the Gold Standard, the Gold Exchange Standard and the Bretton Woods system. The above question, however, as the ongoing financial crisis demonstrates, is far from being solved, and has become even more severe due to the inherent weaknesses of the current international monetary system …. The acceptance of credit-based national currencies as major international reserve currencies, as is the case in the current

> system, is a rare special case in history. The crisis again calls for creative reform of the existing international monetary system towards an international reserve currency with a stable value, rule-based issuance and manageable supply, so as to achieve the objective of safeguarding global economic and financial stability …. The desirable goal of reforming the international monetary system, therefore, is to create an international reserve currency that is disconnected from individual nations and is able to remain stable in the long run, thus removing the inherent deficiencies caused by using credit-based national currencies …. The IMF also created the SDR in 1969, when the defects of the Bretton Woods system initially emerged, to mitigate the inherent risks sovereign reserve currencies caused. Yet, the role of the SDR has not been put into full play due to limitations on its allocation and the scope of its uses. However, it serves as the light in the tunnel for the reform of the international monetary system …. The basket of currencies forming the basis for SDR valuation should be expanded to include currencies of all major economies, and the GDP may also be included as a weight. The allocation of the SDR can be shifted from a purely calculation-based system to a system backed by real assets, such as a reserve pool, to further boost market confidence in its value.

President Barack Obama's 20 January, 2009 inauguration speech shifted the America's lexicon from growth to renewal, humility and peace. He did not allude to a new bigger brighter future. Instead, he spoke of Americans dusting themselves off and setting about re-achieving domestic and global respect and stability: “With a spirit of service in a new era of responsibility ….The world has changed — and we must change with it …. [America must] play its role in ushering in a new era of peace …. our power alone cannot protect us; nor does it entitle us to do as we please …. our security emanates from the justness of our cause, the force of our example, the tempering qualities of humility and restraint.”

He rejected the pervasive Christian fundamentalism of the previous Administration and substituted a commitment to the rationality of sciences and law: “[We are] a nation of Christians and Muslims, Jews and Hindus — and nonbelievers …. we will restore science to its rightful place …. we reject as false the choice between our safety and our ideals.”

While reaffirming America's commitment to defeat those who seek to advance their aims by inducing terror, President Obama distanced tomorrow's America from President Bush's mantras such as “the war on terror.” In an olive branch to America's adversaries Iran, Korea and the Taliban he reiterated the campaign idea that “We will extend a hand if you are willing to unclench your fist.” On 8 March 2009, President Barack Obama declared that America was not winning the Afghanistan war (Cooper & Stolberg 2009). Mirroring General David H. Petraeus' rapprochement with Sunni militias in Iraq, he suggested a new policy in both Afghanistan and Pakistan of America's military reaching out to moderate elements of the Taliban.[xxviii]

In an address to the Congress on 24 February 2009, President Obama reaffirmed his commitment to excise the pervasive rot in America's leadership that had led to broken promises, delayed reform and a culture of reckless spending by Americans as a whole (Obama 2009a):

> Now, if we're honest with ourselves, we'll admit that for too long we have not always met these responsibilities, as a government or as a people. I say this not to lay blame or to look backwards, but because it is only by understanding how we arrived at this moment that we'll be able to lift ourselves out of this predicament. The fact is, our economy did not fall into decline overnight. Nor did all of our problems begin when the housing market collapsed or the stock market sank. We have known for decades that our survival depends on finding new sources of energy, yet we import more oil today than ever before. The cost of health care eats up more and more of our savings each year, yet we keep delaying reform. Our children will compete for jobs in a global economy that too many of our schools do not prepare them for. And though all of these challenges went unsolved, we still managed to spend more money and pile up more debt, both as individuals and through our government, than ever before. In other words, we have lived through an era where too often short-term gains were prized over long-term prosperity, where

> we failed to look beyond the next payment, the next quarter, or the next election. A surplus became an excuse to transfer wealth to the wealthy instead of an opportunity to invest in our future. Regulations - regulations were gutted for the sake of a quick profit at the expense of a healthy market. People bought homes they knew they couldn't afford from banks and lenders who pushed those bad loans anyway. And all the while, critical debates and difficult decisions were put off for some other time on some other day. Well, that day of reckoning has arrived, and the time to take charge of our future is here.

The Rev. Thomas Robert Malthus is mainly remembered for his courageous albeit erroneous conviction that population would growth in a geometric sequence and therefore overtake food production, which he thought could only grow in an arithmetically progression (Malthus 1798). His notable achievement of modelling with geometric and arithmetic progressions is seen as an important precursor to neoclassical economics.[xxix] While he was completely incorrect in his conclusions, it is ironic and at the same time very interesting that the base case of the *Club of Rome's* 1972 Malthus-like projections has indeed been borne out (Turner 2008).

Modelling aside, Malthus' greatest contribution to economics was his proposition, in *Principles of Political Economy* (1820), that general gluts emerge periodically and that these gluts cannot be cleared by normal market mechanisms because the downward spiral of unemployment and falling consumption is too rapid. His views directly challenged Jean-Baptiste Say's assertion that gluts could only be local and temporary because a major virtue of capitalism was its automatic clearing of markets, which he provided as Say's Law (1803) that supply created its own demand.[xxx] Malthus saw that even if prices fall, the market may not clear because ordinary people have insufficient income to afford consumption. Prefiguring Keynes by a century, Malthus proposed that the government should intervention to fund consumption by landowners and the employment of the poor in roads and public works.

In an important change in American political philosophy, President Obama has acted on this Malthus-like insight. In continuing to outline his vision of reducing America's consumerism, notwithstanding that it has been America's main source of economic growth, President Obama has strongly advocated the importance of substituting investment and saving for excess consumption, while simultaneously removing the policy distortions of previous Administrations that have exacerbated America's inequality of income by diverting middle class wealth to the rich and played a major part in America's financial collapse (Obama 2009e):

> And most of all, I want every American to know that each action we take and each policy we pursue is driven by a larger vision of America's future – a future where sustained economic growth creates good jobs and rising incomes;a future where prosperity is fuelled not by excessive debt, reckless speculation, and fleeing profit, but is instead built by skilled, productive workers; by sound investments that will spread opportunity at home and allow this nation to lead the world in the technologies, innovations, and discoveries that will shape the 21st century. That is the America I see. That is the future I know we can have …. Even as we clean up balance sheets and get credit flowing; even as people start spending and business start hiring – we have to realize that we cannot go back to the bubble and bust economy that led us to this point …. It is simply not sustainable to have a 21st century financial system that is governed by 20th century rules and regulations that allowed the recklessness of a few to threaten the entire economy. It is not sustainable to have an economy where in one year, 40% of our corporate profits came from a financial sector that was based too much on inflated home prices, maxed-out credit cards, over-leveraged banks and overvalued assets; or an economy where the incomes of the top 1% have skyrocketed while the typical working household has seen their income decline by nearly $2,000.

In the overview of the fiscal 2010 budget *A New Era of Responsibility: Renewing America’s Promise*, the President was just as categorical (Obama 2009b):

> This crisis is neither the result of a normal turn of the business cycle nor an accident of history. We arrived at this point as a result of an era of profound irresponsibility that engulfed both private and

public institutions from some of our largest companies' executive suites to the seats of power in Washington, D.C. For decades, too many on Wall Street threw caution to the wind, chased profits with blind optimism and little regard for serious risks - and with even less regard for the public good. Lenders made loans without concern for whether borrowers could repay them. Inadequately informed of the risks and overwhelmed by fine print, many borrowers took on debt they could not really afford. And those in authority turned a blind eye to this risk-taking; they forgot that markets work best when there is transparency and accountability and when the rules of the road are both fair and vigorously enforced. For years, a lack of transparency created a situation in which serious economic dangers were visible to all too few …. This irresponsibility precipitated the interlocking housing and financial crises that triggered this recession. But the roots of the problems we face run deeper. Government has failed to fully confront the deep, systemic problems that year after year have only become a larger and larger drag on our economy. From the rising costs of health care to the state of our schools, from the need to revolutionize how we power our economy to our crumbling infrastructure, policymakers in Washington have chosen temporary fixes over lasting solutions …. The time has come to usher in a new era of responsibility in which we act not only to save and create new jobs, but also to lay a new foundation of growth upon which we can renew the promise of America …. This Budget is a first step in that journey …. Our problems are rooted in past mistakes, not our capacity for future greatness. We should never forget that our workers are more innovative and industrious than any on earth. Our universities are still the envy of the world. We are still home to the most brilliant minds, the most creative entrepreneurs, and the most advanced technology and innovation that history has ever known. And we are still the Nation that has overcome great fears and improbable odds. It will take time, but we can bring change to America. We can rebuild that lost trust and confidence. We can restore opportunity and prosperity. And we can bring about a new sense of responsibility among Americans from every walk of life and from every corner of the country.

However, the President was still appealing to the great American dream of unrestrained economic growth. In contrast, the European Union and Japan have shown that growth can occur in sustainability and quality of life without extraordinary growth in GDP. In addition to GDP growth, environmental and social considerations need to be included in all scenarios for sustainable development.

In April 2009, President Barack Obama surprised the world with his understanding of the new *realpolitik* across international economic, security, energy and climate relations (Scherer 2009):

> Most of the hallmarks of the foreign policy of George W. Bush are gone. The old conservative idea of "American exceptionalism," which placed the U.S. on a plane above the rest of the world as a unique beacon of democracy and financial might, has been rejected …. Obama has made clear that the U.S. is but one actor in a global community. Talk of American economic supremacy has been replaced by a call from Obama for more growth in developing countries. Claims of American military supremacy have been replaced with heavy emphasis on cooperation and diplomatic hard labor …. after the G-20 summit ended … two American reporters asked Obama for his response to the claim by Brown that the "Washington consensus is over." Obama all but agreed with Brown, noting that the phrase had its roots in a significant set of economic policies that had shown itself to be imperfect. He went on to talk about the benefits of increasing economic competition with the U.S. "That's not a loss for America," he said of the economic rise of other powers. "It's an appreciation that Europe is now rebuilt and a powerhouse. Japan is rebuilt, is a powerhouse. China, India — these are all countries on the move. And that's good." …. At a town hall in Strasbourg, France, Obama stood before an audience of mostly French and German youth and admitted that the U.S. should have a greater respect for Europe. "In America, there's a failure to appreciate Europe's leading role in the world," he said before offering other European critical views of his country. "There have been times where America has shown arrogance and been

> dismissive, even derisive." …. French President Nicolas Sarkozy addressed the issue directly, speaking through an interpreter. "It feels really good to be able to work with a U.S. President who wants to change the world and who understands that the world does not boil down to simply American frontiers and borders," he said. "And that is a hell of a good piece of news for 2009.

On 4 June 2009, President Obama made a visionary speech to the Muslim and Jewish worlds about international ethics and peace (Obama 2009c). This speech linked directly to President John F. Kennedy's transformative and enduring Peace Speech at American University in 1962 (Kennedy 1993). It was to prove just as historic. President Obama said:

> So long as our relationship is defined by our differences, we will empower those who sow hatred rather than peace, those who promote conflict rather than the cooperation that can help all of our people achieve justice and prosperity. And this cycle of suspicion and discord must end …. I've come here to Cairo to seek a new beginning between the United States and Muslims around the world, one based on mutual interest and mutual respect …. Unlike Afghanistan, Iraq was a war of choice that provoked strong differences in my country and around the world …. events in Iraq have reminded America of the need to use diplomacy and build international consensus to resolve our problems whenever possible. Indeed, we can recall the words of Thomas Jefferson, who said: "I hope that our wisdom will grow with our power, and teach us that the less we use our power the greater it will be." …. In the middle of the Cold War, the United States played a role in the overthrow of a democratically elected Iranian government. Since the Islamic Revolution, Iran has played a role in acts of hostage-taking and violence against U.S. troops and civilians .... I've made it clear to Iran's leaders and people that my country is prepared to move forward …. No single nation should pick and choose which nation holds nuclear weapons. And that's why I strongly reaffirmed America's commitment to seek a world in which no nations hold nuclear weapons. And any nation -- including Iran -- should have the right to access peaceful nuclear power if it complies with its

> responsibilities under the nuclear Non-Proliferation Treaty .... all of us must recognize that education and innovation will be the currency of the 21st century and in too many Muslim communities, there remains underinvestment in these areas .... On education, we will expand exchange programs, and increase scholarships .... On economic development, we will create a new corps of business volunteers to partner with counterparts in Muslim-majority countries .... On science and technology, we will launch a new fund to support technological development in Muslim-majority countries, and to help transfer ideas to the marketplace so they can create more jobs. We'll open centers of scientific excellence in Africa, the Middle East and Southeast Asia, and appoint new science envoys to collaborate on programs that develop new sources of energy, create green jobs, digitize records, clean water, grow new crops .... eradicate polio .... And .... expand partnerships with Muslim communities to promote child and maternal health .... Americans are ready to join with citizens and governments; community organizations, religious leaders, and businesses in Muslim communities around the world to help our people pursue a better life .... All of us share this world for but a brief moment in time. The question is whether we spend that time focused on what pushes us apart, or whether we commit ourselves to an effort - a sustained effort - to find common ground, to focus on the future we seek for our children, and to respect the dignity of all human beings.

Three months later, in September 2009, President Obama cancelled America's middle-European “Star Wars” missile shield project (Levy & Baker 2009). President Obama's breathtakingly bold reversal of President George W. Bush's security policy is analogous to President Kennedy pulling the world back from the brink of nuclear war in the Bay of Pigs incident. Prime Minister Vladimir V. Putin responded to President Obama as his predecessor Nikita Khrushchev had to President Kennedy, calling President Obama’s decision “correct and brave”.

President Obama's policy reversal could be said to be pragmatic. President Reagan's policy of intimidating Russia into reducing its nuclear arsenals had brought no success. Nor had George W. Bush's policy of ”prodding the bear” by intervening in Russia's sphere of influence across the former satellite states of

Poland, Romania, the Czech Republic and the client war in Georgia (Spiegel Online 2009a).

However, this policy reversal is more than merely pragmatic on the one hand and a Kennedy-Obama vision of reducing nuclear weapons on the other. It puts in place a new platform for sweeping change to Anglo-American international relations. Firstly, looking to a new international consensus across all aspects of security including nuclear weapons, terrorism and climate change. Secondly, a de-escalation of harsh words and threats that lead to anxieties, high defence costs for every country and see weapons systems across the globe placed on hair triggers. Secondly, a recognition of the new financial reality that America is unable to remain the world's policeman. Thirdly, a reorientation to domestic issues, such as health over military spending, or “butter instead of guns.”

United Nations Security Council Resolution 1887

In September 2009, President Obama became the first American President to chair the United Nations Security Council (United Nations Security Council 2009). In his opening remarks to the 6191st meeting, President Obama pledged that “the United States would host a Summit in early 2010 and pursue deeper cuts in its nuclear arsenal, as well as agreements with the Russian Federation towards the total elimination of nuclear weapons.”

The Council reaffirmed its strong support for the Treaty on the Non-Proliferation of Nuclear Weapons by adopting Resolution 1887 (2009) to end nuclear weapons proliferation. The Meeting also called on States parties “to comply fully with their obligations and to set realistic goals to strengthen, at the 2010 Review Conference, all three of the Treaty’s pillars - disarmament of countries currently possessing nuclear weapons, non-proliferation to countries not yet in possession, and the peaceful use of nuclear energy for all.”

In addressing the United Nations General Assembly on the previous day, President Obama made an extraordinary commitment to eradicate extreme world poverty. The President said (Obama 2009d; Bono 2009):

> We will support the Millennium Development Goals, and approach next year’s summit with a global plan to make them a reality. And

> we will set our sights on the eradication of extreme poverty in our time.

2009 Nobel Peace Prize

In October 2009, President Obama was recognised with the 2009 Nobel Peace Prize. The Norwegian Nobel Prize Committee (2009) commented:

> The Norwegian Nobel Committee has decided that the Nobel Peace Prize for 2009 is to be awarded to President Barack Obama for his extraordinary efforts to strengthen international diplomacy and cooperation between peoples. The Committee has attached special importance to Obama's vision of and work for a world without nuclear weapons …. Obama has as President created a new climate in international politics. Multilateral diplomacy has regained a central position, with emphasis on the role that the United Nations and other international institutions can play …. The vision of a world free from nuclear arms has powerfully stimulated disarmament and arms control negotiations. Thanks to Obama's initiative, the USA is now playing a more constructive role in meeting the great climatic challenges the world is confronting …. The Committee endorses Obama's appeal that "Now is the time for all of us to take our share of responsibility for a global response to global challenges."

Nobel Committee chairman, Thorbjorn Jagland, said after the announcement (Gibbs 2009):

> It’s important for the Committee to recognize people who are struggling and idealistic but we cannot do that every year. We must from time to time go into the realm of *realpolitik*. It is always a mix of idealism and *realpolitik* that can change the world …. The question we have to ask is who has done the most in the previous year to enhance peace in the world …. and who has done more than Barack Obama? …. There is great potential. But it depends on how the other political leaders respond. If they respond negatively, one might have to say he failed. But at least we want to embrace the message that he stands for … [West Germany's Chancellor Willy]

> Brandt[xxxi] hadn't achieved much when he got the prize, but a process had started that ended with the fall of the Berlin Wall …. The same thing is true of the prize to Mikhail Gorbachev in 1990, for launching *perestroika*. One can say that Barack Obama is trying to change the world, just as those two personalities changed Europe.[xxxii]

The news of the award was applauded around the world. French President, Nicolas Sarkozy, congratulated President Obama saying: "It sets the seal on America's return to the heart of all the world's peoples." The Editor of The New York Times (2009) noted that President Obama's Nobel Peace Prize failed to resonate in America:

> Mr. Obama's aides had to expect a barrage of churlish reaction, and they got it. The left denounced the Nobel committee for giving the prize to a wartime president. The right proclaimed that Mr. Obama sold out the United States by engaging in diplomacy. Members of the dwindling band of George W. Bush loyalists also sneered — with absolutely no recognition of their own culpability — that Mr. Obama has not yet ended the wars in Afghanistan and in Iraq …. Americans elected Mr. Obama because they wanted him to restore American values and leadership — and because they believed he could. The Nobel Prize, and the broad endorsement that followed, shows how many people around the world want the same thing.

2.6 Threats to the evolution of a new Anglo-American world view

A new symbiosis of world nations across the multifaceted dimensions of economics, trade, security and energy requires Americans to discard prejudices entrenched over hundreds of years and to rapidly move-on from the religious fundamentalism and racial rhetoric that characterised the era of George Bush, which always appeals to the worst bigotry of human attitudes.[xxxiii] As the German Foreign Minister, Frank-Walter Steinmeier, said on 5 November 2008:

> Don't expect a radical change in US climate policy after Barack Obama takes over as president … America as a whole is not ready for the contribution it needs to make in order to lessen the negative affects of global warming … Washington will take pains to ensure climate protection measures do not harm the US economy ... the dominant issue in the US has always been energy security.

America's new direction of Democrat politics raises some issues about the underlying attitudes of Americans and President Obama's ability to change direction of policy. The discipline of moral psychology, established by Kohlberg (1969), seeks to understand the difference in these conservative and liberal attitudes.

Haidt & Graham (2007) have provided a behavioural model based on five underlying psychological factors that characterise emotional reactions in politics. These are harm-care, fairness-reciprocity, ingroup-loyalty (i.e. protect the group or traditions), authority-respect, and purity-sanctity (i.e. religion).

According to Haidt's model, political conservatives are broadly pluralist and eclectic across all these factors. Political liberalism exists in nations when the social milieu permits a sort of switching off of the last three dimensions of conservatism. This leaves the moral intuitions of political liberals mainly or even solely based on harm-care and fairness-reciprocity.

Clarke (Saunders 2009b) explains that conservatives usually demand conformity and respect of authority. For example, many Americans who endorsed George W. Bush did so because they believed he upheld morality. These voters were completely oblivious to his immoral acts, such as torture. Haidt believes that this is because political conservatives see no inconsistency in decisions being made on intuition and implemented expediently with scant regard to individual rights.

Kass (1997) explains why this occurs. He argues that political conservatives rely on their gut feel for moral principles and identify any violation as repugnant and, by extension, a pernicious threat to the establishment. This is Kass' well know “yuck factor.” Abortion, euthanasia and gay marriage are but a few of the issues repugnant to political conservatives on the hard right. By further extension, individuals involved with a violation of the moral principles are characterised as foul, sub-social individuals who deserve no rights and to whom torture may be an appropriate response.[xxxiv]

Furthermore, political conservatives see no need to explicitly articulate their intuition and prejudices. Haidt notes that conservatives will often change the subject to avoid explaining the basis of their views. Any debate is often minimised by identifying their decisions with the will of God and requesting prayer for God's help. George W. Bush's rhetoric ably exemplified this. Indeed, Tony Blair and George W. Bush each claimed that God had spoken to them recommending war on Iraq (a nation that had never threatened America).

In stark contrast to the attitudes of political conservatives, political liberals see no intrinsic importance in moral values such as loyalty, authority and sanctity. Clarke explains of Haidt's ingroup-loyalty factor: "Conservative morality is the default morality that occurs in most parts of the world .... so most people consider patriotism to be a moral virtue, but a liberal will not consider patriotism to be a moral virtue; they might concede it to be an interesting character trait, but they don't consider it to be a natural morality."

Political liberals call for freedom, autonomy and the right of individuals to express their own preferences. In decision making, political liberals usually seek principles of equality, natural justice, rational accountability and transparent, evidence based debate.

Haidt suggests that conservatism is the default political attitude in the world. Conservative reasoning exists across a wide spectrum of ideology outlooks as diverse as conservative democracy, conservative Islam and conservative Marxist-Leninist. In this respect, American Republican democracy and conservative Islam have more in common than do the American Republicans and Democrats.

Arguably, throughout George W. Bush's presidency, Americans exhibited stronger fundamental political conservative values than at any other time in America's history and far in excess of any other Western democratic nation. Ebullient from the collapse of the Berlin Wall on 11 November 1989 and break down of Soviet Communism in 1991, American conservatives turned their energies toward environmental scientists, whom they believed to be the next threat to Anglo-American sovereignty and unilateralism. In reviewing the failure of the 1992 Rio Earth Summit, German Finance Minister Klaus Topfer noted “I am afraid that conservatives in the United States are picking 'ecologism' as their new enemy” (Greenhouse 1992).

In stark contrast to their European counterparts, Anglo-American conservatives continue to equate the right to pollute the atmosphere with individualism and free markets (Conason 2009). The strength and resilience of conservative political values in America represents a major weakness in President Obama's strategy to re-engage with the world on major issues such as resource scarcity and greenhouse gas pollution of the common atmosphere.

Waleed Ally, an Australia academic and columnist in Washington as guest of the State Department to President Obama's inauguration, in a live television interview on the day observed that President Obama's technique is to provide themes from history and current affairs to illustrate his points but then to leave the listener to fill-in the tapestry for themselves. As a result, almost everyone hears what he or she wants to hear in his speech. Many Americans would have heard references to 'renewal” in President Barack Obama's Inauguration Speech as targets for return to “growth” as it was from the 1950s to 2005.

While America allows its presidents considerable influence in international policy, it remains to be seen what the reaction will be to the realisation that “renewal” is developing a viable lifestyle with greater responsibility in a resource and growth curtailed world.

Tuckman's model of group development is known as “forming-storming-norming-reforming -performing” (Tuckman 1965). America's new Administration is fresh from forming the new team and being mercilessly buffeted by “storming” from vested interests across many issues such as the economy, markets and regulation, health care and climate change. It is questionable whether “norming”, which is consensus and mutual cooperation, can take place in the first term of the Administration. This means that “reforming” and “performing” may be some time in coming, if ever.

Yale historian, Paul Kennedy (1993) sees America muddling through its challenges but provides a word of caution. He observed that those people who succeed in democratic political systems usually do so by managing to avoid antagonising powerful interest groups. In this sense President Barack Obama has a large challenge because as we have seen above, the set of issues confronting him and the schisms in political values are enormous. Perhaps the American financial crisis and peak-oil realisation will serve in his favour. However, it remains to be seen if the broad base of Americans will be capable of accepting a new humbleness of sustainable living where unilateral action to secure resources is an international and punishable war crime.

2.7 Conclusion

The political analysis of the Anglo-American economic worldview in this Chapter has identified a number of key themes.

Origins of the Anglo-American worldview are found in America's drive to protect individual freedom. Since the sixteenth century this has manifested itself in the removal of obligations and constraints to independent action.

In the early eighteenth century, Alexis de Tocqueville commented on the other overwhelming preoccupations of Americans, that of making money and conspicuous consumption. He identified that the lack of pluralism and diversity in American's single-mindedness exposed their society to “unexpected and formidable embarrassments.” One hundred and fifty years on, his observation proved prophetic and the consequences are still playing out.

With virgin territories for the taking, America's population grew rapidly and with it the wealth of the *nouveau riche*. It became a powerful society. As shown in the analysis of America's national security, the fiction that its domestic success had been divinely ordained and was part of a Manifest Destiny became entrenched in its dealings with the world. Such idiosyncratic beliefs defy testing and encourage polemic. Therefore, it is unsurprising that Americans accepted their own predetermined destiny while expressing outrage at another equally untestable vision of pre-determined economics, that of dialectic materialism.

Notwithstanding this, in the name of Manifest Destiny Americans justified resource grabs from Hawaii to Iraq. In the majority of instances, America's interventions led to a legacy of ashes. However, as shown in the analysis of resource wars, it might be expected that powerful nations such as America will continue to use military force to secure resources.

In precursors of the Anglo-American world view, American beliefs in the concept of happiness through work and consumption were traced from Aristotle's virtues through to classical and neoclassical economics. It was shown that Adam Smith's “invisible hand of capitalism,” explained how the equilibrium of markets is settled by everybody pursuing their own happiness in an Aristotelian paradigm. Aristotle's hypothesis, taken for a fundamental economic law or truth, remains controversial since the late eighteenth century. Great political economic philosophers including David Hume, David Ricardo, John Stuart Mill, Jean-Baptiste Say and Frederic Bastiat refined the human interface of markets and drew from it the principles of classical economics. Their work is now recognised in the new discipline of service sciences.

However, these philosophers of political economy were unable to resolve the paradox that truly free markets fail in unexpected ways. It was shown that John Maynard Keynes and “Keynesian” economists up to the present day remain at loggerheads with fundamentalist free marketeers. Nevertheless, weaknesses in a paradigm do not invalidate it and both classical economics and its mathematical sibling, neoclassical economics, have served America's preoccupation with consumption as the measure of happiness for over two hundred years.

The systemic risk observed by Alexis de Tocqueville was to threaten the very foundations of classical and neoclassical economics. Societies were rescued from the Great Depression and the Global Financial Crisis of 2008-9 by Keynesian lifelines. From this behavioural economics has assumed a great importance.

In “Philosophy and psychology diverge from the paradigm” it was shown that behaviourist philosophers began to invalidate the Aristotelian hypothesis that humans find happiness through work. This started with the great European philosophers Kant, Nietzsche, Stirner, Weber, Sartre and Camus. This bubbling stream became a broad river with the engagement of the great deductivist institutional philosophers, Popper and Kuhn.

The analysis of “Unexpected Failures in the Anglo-American world view” concluded that an unravelling of the classical and neoclassical economic paradigms came firstly with the recognition of “agency conflict” in the 1980s. After the gnashing of teeth for two decades, black letter law such as the Sarbanes-Oxley Act emerged to set standards of accountability and thereby regulate agency conflict. Unfortunately, the regulation did not achieve its desired result and became an exercise in ticking boxes. The real problem was in the heads of the company directors. Adam Smith's “enlightened self interest” was merely a quaint fiction for directors of companies that were driven to enrich themselves and did so by taking huge risks with other peoples' money, completely disregarding their social mandate and seeking to profit from every weakness in deregulated markets.

In “Excessive speculation in markets” it was shown that hedge funds extracted massive profits from commodity markets by financial manipulation. Commodity markets are by definition thin because they involve real producers and consumers in their daily business of satisfying society's needs for commodities like food and energy. While markets benefit from a little speculation for liquidity, they became easy fodder for hedge funds with overwhelming resources. The global chaos that resulted from the Bush Administration's policy of diverting grain from food to fuel was never resolved because it was overtaken by the 2008-9 Global Financial Crisis. However, these failures of free markets and classical economics provide a salutary lesson that any national or global carbon commodity market will need appropriate regulation and not rely on flawed concepts of totally deregulated markets.

In analysing the “Sub-prime crisis” it was concluded that this unexpected failure was due to a cumulative build-up in many critical factors. From 2000, easy money, massive asset appreciation and gorging on cheap Chinese imports were seen as rewards for American success. However, the economic success of American society had long since sown its own seeds of failure. America had become corpulent and happier to be a financial dealer and profiteer than to produce and innovate. The turning point had been passed sometime in the 1970s.

In discussing “Moral hazard,” it was found that America's unifying value system had failed. A system of ethics is necessary for the fabric and social cohesion of every society. America's loss of its value system was accompanied by the loss of its reputation and world leadership of the world.

“Challenges to the legitimacy of neoclassical economics” investigated whether neoclassical economics and the American policy founded upon it will emerge from the furnace of these challenges as a reborn phoenix with a new behavioural perspective. Indications are that it will continue as before. The fact that neoclassical economics has internal conflicts and occasional spectacular failures does not mean the paradigm is broken. In fact, as Thomas Kuhn showed, this sort of thing is expected in real economies.

The major investigation into “Evolution of a new Anglo-American world view” began with an appraisal for the “Decline of American exceptionalism”. It concluded that the future outlook for Americans is that they will need to regain economic and financial stability and then live within their means like everybody else on the planet.

A “New international symbiosis” extended this concept beyond America's borders into its dealings with the rest of the world. Game theory was applied to understand how America needs to become a normal responsible citizen of the world and raise itself from the “Tragedy of the Commons.” The award of 2009 Nobel Prizes to President Barack Obama and Elinor Ostrom has sent a message to the world that this is the new way multilateral cooperation will evolve across issues of trade, nuclear proliferation and climate change.

The new economic model confronting America was investigated in a “New constrained growth model.” The American and German social models were compared and contrasted. It is concluded that there are fundamental differences in the national psyche that lead to a lack of optimism that America will adopt a European Union governance model. In fact, the risk is that

America and other Anglo-American countries will not rise to the opportunities of international symbiosis but turn inward to “tend their own gardens.”

The fresh Presidency of Barack Obama, his candid *mea culpa* on behalf of America and exhortations for America to engage with international symbiosis are discussed in “Policy Reboot.” It was found that world nations have not been comfortable with American policies since the days of President Reagan and this reached its most objectionable apogee during the term of President George W. Bush. However, world leaders of all persuasions, including Russia, have expressed the desire to help President Obama rebuild America's standing in the international community and as a valued member of a new power sharing of nations. The investigation of “United Nations Security Council Resolution 1887” on the elimination of nuclear weapons showed how this new cooperation might operate.

However, the analysis of President Barack Obama's award of the 2009 Nobel Peace Prize, with special reference to his multilateralism and policy of action on nuclear non-proliferation, showed that President Obama does not carry the goodwill of a large number of Americans and that this may defeat his attempts to reconcile America with other leading nations and power blocs such as the European Union, Russia, India, China and South America.

An investigation into “Threats to the evolution of a new Anglo-American world view” found that political conservatism in America is exceptionally strong and strongly polarised. Very few political conservatives support President Obama's domestic and international rebuilding. The far right continue to believe in the traditional American world view of exceptionalism and America's Manifest Destiny.

Many of America's future problems and opportunities have international dimensions, such as international competitiveness, trade, security, nuclear proliferation and the environment. The polarisation between the old and new world views has led to a gulf of credibility on the issue of whether America will have the bipartisan political fortitude to make the transition to a new future of international symbiosis, or if it will slide backwards into its traditional world view of yesteryear.

The next Chapter examines Anglo-American political economy at the cusp of change from unconstrained growth to climate constrained growth.

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i Napoleon put into practice the principle of “order over chaos” on 5 October 1795 when he turned his cannons on a putsch of thirty thousand royalists marching to the Tuileries Palace to overturn the Convention of the revolutionary government. Napoleon's grape-shot killed more than 200 royalists and is still visible in the walls of the Church of St. Roch at 286 Rue St.-Honore. In gratitude, the government promoted the twenty-six year old hero of the Revolution from brigadier general to commander-in-chief of the Army of the Interior.

Similarly, in 1968 violent student protests against the Vietnam War took place at the Paris Sorbonne. These protests erupted into France’s second revolution as ten million French people went on strike over industrial conditions. In June, President de Gaulle called an election to establish a mandate for reform and it was granted. However, instead of reform, de Gaulle violently quashed the protest and in response the people dismissed him in April 1969.

America experienced a similar incident. Following an April 1970 riot by reportedly six thousand students at Harvard Square in Massachusetts at the time of the Vietnam War, the American government became extremely nervous about anti-war protests. One month later, in May, a terrible incident occurred at Kent State University. National Guardsmen fired on demonstrators for 13 seconds, killing four students and badly wounding nine others

ii Sir David King, director of the Smith School of Enterprise and the Environment at Oxford University, who was the British Government's Chief Scientific Adviser at the start of Iraq war in March 2003

iii In 2005, a BBC Radio 4 poll found Karl Marx to be the world's greatest philosopher by a wide margin (Critchley 2008, p.212)

iv Examples following World War II include the Marshall Plan to rebuild Western Europe and the rebuilding of Japan in the 1950s and 1960s v Mathematica Country Database (accessed 10 April 2009). Gini Indexes for some other countries are: Australia 0.305, Canada 0.321, China 0.47, Denmark 0.24, France 0.28, Russia 0.413, United Kingdom 0.34

vi In 1928, at the age of 25, John von Neumann developed the *minmax* (*minimax*) and equivalently the converse *maximin* as part of formulating game theories that would minimise one's maximum possible loss. Von Neumann said of his strategy *defeat is inevitable if you aim to win rather that avoid losing*

vii Nietzsche uses this statement in *The Gay Science* (1882): section 108 (New Struggles), section 125 (The Madman) and section 343 (The Meaning of our Cheerfulness). Max Stirner was born Johann Kaspar Schmidt

viii In 1960 Albert Camus tragically died in a car accident at the age of 47. He had earlier written that the point of life was to live and he could conceive of no more meaningless death than in a car accident (Critchley 2008, p.262)

ix Isaiah Berlin (1909-1997) was an Oxford liberal humanist scholar of Russian-Jewish descent

x For example, in 2005 the American Society of Civil Engineers calculated that US$9.4 billion per year for 20 years is needed to refurbish America's collapsing bridges

xi *On ne reçoit pas la sagesse, il faut la découvrir soi-même après un trajet que personne ne peut faire pour nous, ne peut nous épargner*

xii Winston CHurchill's humorous version applied to US foreign policy is that “the US always does the right thing, when all alternatives are exhausted”

xiii Translated by Karl Popper

xiv *cogito ergo sum* (I am thinking therefore I exist, which is the inverse to Existentialism's existence before essence)

xv For example, in Australia, Section 198A of the Corporations Act (2001) gives directors all powers in a company, except those reserved for a general meeting. As the principle of *ultra vires* (acting beyond mandate) has been removed, nothing is beyond the powers of the company so a company may in fact do anything. The directors also have common law duties to act honestly, in good faith, with good faith and due diligence. However, these common law duties are met by complying with the statutory Duty of Care and Due Diligence set out in Section 180(1) of Corporations Law, which is commonly known as the “business judgement rule.” It requires that directors act in good faith and for proper purpose; have no personal interest in the outcome; take steps to inform themselves on all issues; and rationally believe their decision is in the best interests of the company

xvi The United Kingdom case *Percival vs. Wright* (1902) established that directors do not have a general duty to individual shareholders. In Australia, the High Court decision of *Spies vs. R* (2000) decided the issue that directors do not have a duty to creditors, except where a company is insolvent or near-so. This also resolves the position in respect to employees and other stakeholders, to whom directors owe no duty except subject to specific laws that may apply. A similar principle was embodied in the UK *Hampel Committee Report on Corporate Governance* (1998)which is arguably the best encapsulation of the concept: the Committee recommended that directors be accountable to shareholders for preserving and enhancing the shareholders' investment and be responsible for relations with stakeholders as part of this accountability

xvii The *Sarbanes-Oxley Act* of 2002 (Pub. L. No. 107-204, 116 Stat. 745, also known as the Public Company Accounting Reform and Investor Protection Act of 2002) is a United States federal law that addresses director responsibilities and criminal penalties

xviii Bacevich (2008, p181) says of Americans' future: *They will guzzle imported oil, binge on imported goods, and indulge in imperial dreams*

xix As the traditional providers of mortgage finance became increasingly nervous through 2007, Bear Stearns continued to sell mortgages, providing the finance itself by rolling 24-hour borrowings with Federated, Fidelity Investment and

European lenders. On 6 March 2008 the first European lender, Rabobank, said it would not renew its credit lines to Bear Stearns. On 11 March, ING followed. Finally, on 13 March, when Bear Sterns was seeking to roll-over US$75 billion, Federated and Fidelity Investments said they would no longer accept the sub-prime mortgages as collateral security. The Federal Reserve requested J. P. Morgan to review Bear Stearns' accounts and on 14 March, J. P. Morgan used US$30 billion of Federal Reserve funds to provide Bear Stearns with unlimited credit to avoid meltdown of the financial system

xx The "Minsky Moment" is named in honour of Russian economist Hyman Minsky. The term was inspired by the 1998 Russian sovereign debt default. The Minsky Moment is the point when investors doubt that cashflow can sustain debt obligations, which leads to a panic sell-off as investor greed abruptly turns to fear

xxiAmerican recession years: 1807, 1837, 1857, 1873, 1893, 1907, 1929, 1973, 1987, 2001 and 2009

xxiiSee Schwartz et al. 2006

xxiiiSun Tzu (544 – 496 BCE) wrote *The Art of War*, an immensely influential ancient Chinese book on military strategy. Sun Tzu argued strongly for military intelligence, claiming a general must have full knowledge of his own & the enemy's strengths and weakness. His book was known for thousands of years but a full copy was discovered only in 1972 on a set of bamboo engraved texts in a grave near Linyi in Shandong

xxivThe Prisoner's Dilemma is a two person, non-zero sum game. Consider the oft seen television police drama where two suspects are put in separate rooms for questioning. Each suspect knows full well that if they both remain silent then the police will have a hard task proving them guilty. In this case, the unsatisfactory police evidence means that each prisoner will receive a nominal sentence of only one year. However, the police keep fermenting the prisoners' anxiety to turn "Queen's evidence." This will result in a reduced or commuted sentence in return for incriminating the accomplice. If only one confesses then that prisoner will escape sentence and the other will receive a sentence of ten years. If both prisoners confess, each will be sentenced to five years in prison. The old maxim of "no honour amongst thieves" mostly holds true because their agreements are neither binding nor enforceable. So each prisoner cannot trust the other to remain silent. Each prisoner therefore looks at the situation from a self-interested point of view and seeks to maximise his own benefit without regard for what the other may do. Therefore, the dominant outcome is for each to "rat" on the other in order to be released. However, because both do the same thing, the separate strategies have the effect of resulting in a sentence of five years for each. They have foregone the Pareto Optimum outcome of trusting each other, which would have resulted in sentences of only one year each

xxvDwight D Eisenhower served as the 34th President from January 1953 to January 1961, when he was succeeded by John F. Kennedy

xxviElinor Ostrom shared the 2009 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel (often referred to as the Nobel Prize in Economics) with Oliver E. Williamson "for his analysis of economic governance, especially the boundaries of the firm"

xxviiThe European Council on Foreign Relations is a pan-European think-tank established by George Soros

xxviiiWhile successful at the time, Shiite Government secret police, aided by the American military, arrested various Sunni Members of the Sunni Awakening Councils in late March 2009, notwithstanding that these people were helping the American military

xxixEconomics was first formally taught as a discipline after the Great Depression

xxxInstead of supply creating its own demand, supply is now seen to be a function of demand xxxiReferring to the controversial 1971 award of the Nobel Peace Prize to West Germany's Chancellor Willy Brandt for his “Ostpolitik” policy of reconciliation with Communist Eastern Europe

xxxiiTwenty-one prominent American recipients of the Nobel Peace Prize include President Theodore Roosevelt (1906) for his role in international dispute arbitration, which led to peace between Russia and Japan; President Woodrow Wilson (1919) for his role in ending World War I, the Treaty of Versailles and facilitating the League of Nations; Martin Luther King (1964) for his commitment to non-violent protest of African American civil rights; former US Secretary of State Henry Kissinger (1973) for his role in negotiating a cease-fire that ended the Vietnam War; Jimmy Carter (2002) for tireless efforts to spread peace, democracy, human rights and development; and former Vice President Al Gore and the IPCC (2007) for climate change leadership

xxxiiiIn politics, this is colloquially known as “playing the race card”, where race includes racial origin or colour of the skin, religious belief, sexual persuasion, physical or mental disability etc. Political parties usually tacitly agree not to “play the race card” in campaigns because it inflames the worst of human bigotry and often escalates to riots and murders

xxxivAuthoritarian, oppressive regimes and conservative democracies alike can exhibit a kind of national psychopathy, for example, spying on their own citizens, imprisonment without charge, suspension of *habeas corpus,* torture and public lies. This can be extended to international relationships, for example, America's so-called Coalition of the Willing comprising thirty members including United Kingdom, Australia and Denmark. Australia forfeited its proud innocence and that it had never used military force except in self-defence.

On 4 September 2009, the Chinese Ambassador Zhang Junsai responded to Australia's criticism of China's military build-up with a diplomatic caution, reminding Australia that China had never occupied one inch of foreign territory. However, this assertion needs to be qualified by China's interpretation of occupation. China considers itself to be peaceful, humble and providing omnipresent rationality throughout its widespread provinces. Many in the West have the opposite view. China is perceived to be aggressively expansionist because of its 1950 so-called “peaceful liberalisation of its province of Tibet”, 1962 war with India over China's strategic occupation of the uninhabited region of Aksai Chin, ever-present threats to reintegrate Taiwan by force, continued repression of nationalist Uighurs in its province of Xinjiang Uyghur (East Turkestan or Uyghuristan) and human rights abuses.

Chapter 3 Political Economy of the Anglo-American world view of climate change shows how China and India formed an uneasy alliance to successfully resist America's “might is right” approach in climate change negotiations.

Organisational psychopaths, whether individuals in the office or national leaders, are difficult to identify because they adopt an overtly "conservative" disguise (Clarke 2005). They thrive on the excitement of the chase, seeing "who blinks first" and they will throw any amount of other people's money at a campaign or litigation to create hysteria, chaos and confrontation.

Often they will lie without compunction - truth, nonsense, disinformation and barefaced lies are all the same because the end justifies the means. For example, the Australian Government's infamous “children overboard” lie about refugee boat people. Usually, organisational psychopaths are not concerned in the least about being found out for their lies. In fact, their main distinguishing characteristic is an utter absence of remorse. They use accusations, lying, bluffing, bullying and character assassination to advance their aims.

They become expert at casting "Fear, Uncertainty and Doubt" (FUD) by offhandedly making allegations that are without merit to divert attention from real issues and to put those seeking to route them out onto the defensive. A FUD smear tactic is often used where the initial publicity surrounding claims vastly overshadow any subsequent retraction or where the assertions cannot be checked with third parties to whom the assertions are being attributed.

Makers of Kool, Viceroy, Raleigh and Belair cigarettes, Brown & Williamson (1969) elucidate the “FUD” attack: “We have chosen the mass public as our consumer for several reasons: - This is where the misinformation about smoking and health has been focused. - The Congress and federal agencies are already being dealt with - and perhaps as effectively as possible - by the Tobacco Institute. - It is a group with little exposure to the positive side of smoking and health. - It is the prime force in influencing Congress and federal agencies - without public support little effort would be given to a crusade against cigarettes. Doubt is our product since it is the best means of competing with the "body of fact" that exists in the mind of the general public. It is also the means of establishing a controversy. Within the business we recognize that a controversy exists. However, with the general public the consensus is that cigarettes are in some way harmful to the health. If we are successful in establishing a controversy at the public level, then there is an opportunity to put across the real facts about smoking and health. Doubt is also the limit of our "product". Unfortunately, we cannot take a position directly opposing the anti-cigarette forces and say that cigarettes are a contributor to good health. No information that we have supports such a claim.”

Organisational psychopaths also use any technique they can to create pressure, such as incessant delay, preventing routine things being finished and determinedly side-tracking discussions. Brown & Williamson (1969) also exemplify the often used diversionary tactic of setting up “straw men”, or alternative subjects that are easily controlled: “Truth is our message because of its power to withstand a conflict and sustain a controversy . If in our pro-cigarette efforts we stick to well documented fact, we can dominate a controversy and operate with the confidence of justifiable self-interest …. we would want to be absolutely certain that there is no damage to our advertising or to the consumer acceptance of our brands . So the first step for the immediate future would be research . We are recommending basic research to unearth specific problems in smoking and health that we can deal directly with.”

It is estimated that 1% to 3% of adult males and 0.5% to 1% of women exhibit some degree of psychopathy. These people range from murderers, serial rapists, con artists to predators at work and in social situations. Unfortunately, they are attracted to positions of power in politics and public institutions, where they can rise through ruthlessness rather than leadership. However, all have the same profile of self gratification and excessive sexually promiscuity can be a strongly identifying trait. Many of the finest sportsmen and women are found to be at least mildly psychopathic.

There are common features for organisational psychopaths in political, social and corporate environments. An organisational psychopath is difficult to identify at first but indications become increasingly clear. Fro example, inconsistent lies that don't match, amorality, defamation, enjoying ruthlessness and a total lack of remorse. They can be very difficult to ferret-out because that employ multi-agent predator strategies to amplify their tactics (Axelrod 1984).

Psychopathy is not to be confused with merely subjective behavioural choices by people. Recent scientific evidence supports the fact that pathological liars cannot control their habitual impulse to lie, cheat and manipulate others. Yang et al. (2005a; 2005b) of the University of Southern California showed that pathological liars had pre frontal cortex abnormalities. They found a 22% increase in white matter and 14% decrease in grey matter compared to normal controls. Autistic children were found to have the opposite characteristics. When people are asked to make moral decisions, they rely on the pre frontal cortex of the brain and it has long been associated with the ability in most people to feel remorse or learn moral behaviour. In normal people, it's the grey matter (the brain cells connected by the white matter) that help to keep the impulse to lie in check. The results of this study are consistent with previous studies on autistic children, who find it extremely difficult to lie and have an opposite but complementary combination of white and grey matter. The University of Southern California researchers suggested that lying takes a lot of effort and the 22% more white matter in the brains of pathological liars provides them with enhanced verbal skills to master the complex art of deceit. In addition, the 14% less grey matter means they don't have the same moral disinhibition as normal people do for misrepresentation.

Yang et al. commented that there is quite a lot to do in suppressing the truth. Lying is almost mind reading in so far as the liar needs to understand the mindset of the other person and the liar needs to suppress his or her own emotions so as not to appear nervous. Their practical observations were that pathological liars could not always tell truth from falsehood and would contradict themselves in an interview; that they were manipulative and admit to preying on people; and that they are very brazen in terms of their manner, but very cool when talking about this. Aside from having histories of conning others or using aliases, habitual liars also admitted to malingering, or telling lies to obtain sickness benefits.

Whilst corporations and democracies ultimately recognise the psychopathic behaviour for what it is, in the very existence of organisational psychopaths there is a classic case of drama. Society suffers a permanent loss. Everyone with whom an organisational psychopath comes in contact with has lost. A particular victim is the company or country that mistakenly supports the organisational psychopath.

As China chided Australia, in the Coalition of the Willing attacking Iraq, a country that had never threatened them, the Anglo-American societies of America, United Kingdom and Australia conspired to violate international conventions on national sovereignty and in the process brought shame on the institutions of Western democracy and in the process lost their most valuable asset of all, their reputation.

Chapter 3 Political Economy of the Anglo-American world view of climate change

3.1 Background

The previous chapter examined the changing Anglo-American world view and emerging renaissance in constrained resource policy. This Chapter examines the development of Anglo-American climate change policy and how the change in Anglo-American world view is now influencing this policy.

To preface, some observations by William J. Antholis, Managing Director of The Brookings Institution, draw together world views with climate change policy. Antholis' fifteen years experience in climate change negotiations lead him to call for America and Europe to build a new bridge in time for the final climate change meeting of the UNFCCC's “Bali Roadmap”, CoP15, in Copenhagen from 7 to 18 December 2009 (Antholis 2009):

> Political systems don’t account for all the difference between the United States and Europe. European private citizens, NGOs, and corporations also have moved the needle. These Europeans have not viewed climate change as a technological or an economic issue. They have viewed it as a matter of basic common sense morality, politics, economics and culture …. In contrast to Europe, where the political system has created an opening for activism on behalf of protecting the climate, the structure of American politics has been an obstacle to action on this issue. That is, our federal system - and particularly the United States Senate - empowers minorities to block action. Beyond that, or perhaps as a result, our politics tend to prioritize economic performance - at times almost entirely to the exclusion of other policy priorities. Moreover, “low-expectation pragmatism” can lead to half-measures …. while it is clear to everyone that Europe, in particular, has led America to the point of passing a real climate change law [Waxman Markey], this will be sold in the United States as an example of American leadership and independence …. chances are good that the U.S. will live up to

> Winston Churchill’s famous quip that "America can always be counted on to do the right thing, after it has exhausted all other possibilities." After a decade of learning, the upside of American pragmatism appears to be rising …. The new bridge that the U.S. and Europe need to build together …. must be built on Europe’s historic role as a leader on the issue, and must take advantage of the United States’ self-centered “following-by-not-following” conceit …. In short, we need to combine forces. We need to mobilize Europe’s leadership on the issue: its moral vision, its emphasis on lifestyles, its empowered minorities, its two millennia of experience in constitutional construction, its technological elegance, and its long-standing ties in key places around the world - from Russia to Africa to Latin America to Southeast Asia. We also need to mobilize America’s entrepreneurialism, imagination, regulatory uniformity, and complimentary long-standing ties in other key places around the world, such as East Asia, South Asia and Latin America.

Through the challenges and confusion of climate change, futurists like Antholis are perceiving the gradual commencement of humanity's third industrial revolution. It is important to understand the political economy underpinning this momentous transition. McNeil, a scientific adviser to the Australian Government, writes in *The Clean Industrial Revolution* (2009, p.6) :

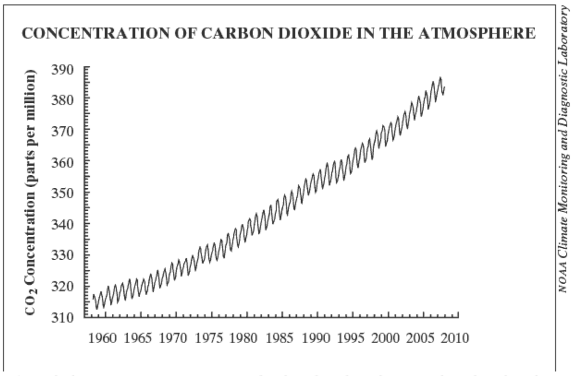
> Climate change has given all fossil fuels the knockout blow …. The clean industrial revolution this century is one where the fuel is free and infinite, and the materials grown or recycled. …. the power of the sun, wind, ocean and earth is infinite …. Fostering clean technological innovation and a low carbon economy cannot be initiated from market forces alone because, for the time being, the market doesn't account for the cost of carbon emissions or the inevitable longer-term transition beyond fossil fuels. Slashing greenhouse gas emissions by governments is needed to kick-start the revolution.

3.2 Climate change science development

Precursors in science and policy

In 1859, Tyndall showed the world's natural greenhouse effect was due to CO_2 and water vapour, which contributed 33°C of warming.

In 1957, Roger Revelle, a scientist at the Scripps Oceanographic Institute in La Jolla, California, linked increases in CO_2 in the atmosphere with global warming and first referred to CO_2 as a greenhouse gas (Revelle & Suess 2002).[i]



A graph showing rising concentrations of carbon dioxide in the atmosphere, based on the measurements of the scientist Charles David Keeling at Mauna Loa, Hawaii. As Freeman Dyson explains, the wiggle in the graph gives us 'a direct measurement of the quantity of carbon that is absorbed from the atmosphere each summer north and south by growing vegetation, and returned each winter to the atmosphere by dying and decaying vegetation.' The fact 'that the exchange of carbon between atmosphere and vegetation is rapid is of fundamental importance to the long-range future of global warming.'

Another researcher at the Scripps Oceanographic Institute, Charles Keeling, recorded atmospheric CO_2 and showed that about 50% of the CO_2 emitted by humans remains in the atmosphere (Keeling & Whorf 2005).[ii] Keeping in mind the old maxim that "correlation doesn't mean causation," the Keeling Curve is considered the most fundamental relationship of global warming. It shows a 20% increase in CO_2 concentration from 315 ppm in 1958 to 385 ppm in 2008, and continues rising at a rate of about 2 ppm per year.

The characteristic wiggle on Keeling's trajectory is attributed to the seasonal growth and decay of vegetation, which absorbs about 8% of atmospheric CO_2 every year and returns it to the atmosphere.

Sampling air trapped in Antarctic ice, Tripati et al. (2009) recently determined that the last time a 387 ppm atmospheric CO_2 concentration had occurred was "during the Middle Miocene, when temperatures were [approximately] 3 to 6°C warmer and sea level 25 to 40 meters higher than present." At this time there was no permanent Arctic ice-cap and only a thin Antarctic polar cap. Tripati et al. found the atmosphere's CO_2 concentration decreased synchronously “with major episodes of glacial expansion during the Middle Miocene (~14 to 10 million years ago; Ma) and Late Pliocene (~3.3 to -2.4 Ma)”.[iii]

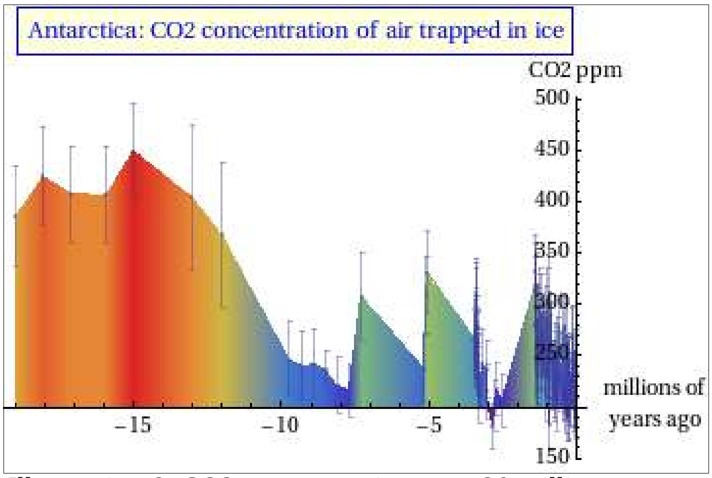


Illustration 8: CO2 concentration over 20 million years up to the present (Source: Tripati 2009)

The Jason group

The Jason Group of scientists was established in 1960 by nuclear physicists that wanted to develop new national defence frameworks within the realm of classified information. Over the last 40 years, there have been only one hundred Jasons including 11 with Nobel prizes and 43 U.S. National Academy of Sciences fellows. The group conducts a workshop for six weeks each year in San Diego, California.

Oreskes & Renouf (2008) describe two confidential Jason Group reports into the effect of climate change on the planet and the fabric of society. These reports were prepared for the U.S. Department of Defence and provided to President Jimmy Carter.

In 1977 the Group focused on climate change. Drawing upon information from the National Centre for Atmospheric Research (NCAR) in Boulder, Colorado, the group developed a climate model called “Features of Energy-Budget Climate Models: An Example of Weather-Driven Climate Stability”.[iv]

In 1979, the Jason Group published a remarkably foresighted report JSR-78-07 *The Long Term Impact of Atmospheric Carbon Dioxide on Climate* (MacDonald 1989). This report predicted that the atmospheric CO_2 concentration would double by 2035 [which the IPCC now expects to occur by 2050]; the planet would warm by 2-3°C [which accords with the IPCC's projections]; polar regions could warm by up to 10-12°C and quickly melt; the world's crop-producing capacity and productivity could significantly decline, particularly in marginal areas.

President Carter's Office of Science and Technology Policy sought a second opinion from the National Academy of Sciences' climate committee headed by the MIT meteorologist, Jule Charney. Charney's report confirmed the Jason Group's conclusions.

James Hansen

In 1988, James Hansen, Director of NASA's Goddard Space Center, testified to the US Senate Committee on Energy and Natural Resources that CO_2 pollution would lead to dramatic damage from global warming. He noted that the earth was warmer in 1988 than in any time in the 100 year history of measurement; global warming could be ascribed to the greenhouse effect with 99% confidence; and that computer simulations showed the greenhouse effect will cause extreme climatic events such as summer heat waves. Hansen outlines three policy scenarios that he had modelled, ranging from "business as usual" to "draconian emission cuts" that would eliminate trace gas growth by 2000. Courageously, he predicted that over the period from May 1988 to May 2008, the earth would become "warmer than it has been in the past 100,000 years".

In the event, Hansen's prediction was technically wrong. With the benefit of hindsight it became apparent that Hansen's base year of 1988 was an anomaly in being extraordinarily warm. Indeed, all the years since 1988 have been cooler. Nevertheless, the substance of Hansen's prediction is correct and temperatures have been monotonically rising with a superimposed oscillation.[v] In 2007, almost twenty years after Hansen's testimony, the world governments of the Intergovernmental Panel on Climate Change (IPCC) concurred with him.

Hansen's current belief is that the only safe course of action is to urgently lower the level of atmospheric CO_2 from 385 ppm to 350 ppm (Pilkington 2008). Hansen is a member of the Tällberg Foundation, which published a full page advertisement in the Financial Times, the International Herald Tribune and the New York Times on 23 June 2008 to "Call upon all nations in the ongoing climate negotiations to adopt 350 as the target to be reached peacefully and deliberately, with all possible speed" (Tällberg Foundation 2008).

350 is the Tällberg's appellation. It is the atmospheric concentration level of 350 ppm of CO_2 that the Foundation believes is the upper limit of safe CO_2 concentration in the earth's atmosphere. It is 35 ppm below the current level of 385 ppm and represents about 17 years at the current rate of increase of 2 ppm per year.

The Tällberg Foundation claims that the current discussion target of 450 ppm and global mean temperature rise to 2°C above pre-industrial levels is the wrong target and will have truly terrible consequences:

> The oft-stated goal to keep global warming less than two degrees Celsius (3.6 degrees Fahrenheit) is a recipe for global disaster, not salvation .... the simple, yes shocking, truth is that we have gone too far. We are going in the wrong direction and we have put planetary systems, all inhabitants and generations to come in grave peril. It is uncertain how long the planet can remain above the level of 350 ppm CO_2 before cascading catastrophic effects spin beyond all human control .... therefore, we must go back. We must cut carbon emissions and draw down CO_2 below the level of 350 ppm. If we are to preserve the planet upon which civilisation has developed, we have no choice but to make bold decisions that will change the way the world works – together .... to avoid a world at 450 ppm CO_2 is the greatest challenge humanity has ever had to face.

In June 2008, on the 20th anniversary of his seminal 1988 testimony, the US Senate Committee on Energy Independence and Global Warming again heard James Hansen's testimony (2008a). Hansen criticised the goal to keep global warming less than 2°C, saying:

> Warming so far, about two degrees Fahrenheit over land areas, seems almost innocuous, being less than day-to-day weather fluctuations. But more warming is already "in-the-pipeline", delayed only by the great inertia of the world ocean. And climate is nearing dangerous tipping points. Elements of a "perfect storm", a global cataclysm, are assembled .... The disturbing conclusion ... is that the safe level of atmospheric carbon dioxide is no more than 350 ppm (parts per million) and it may be less. Carbon dioxide amount is already 385 ppm and rising about 2 ppm per year. Stunning corollary: the oft-stated goal to keep global warming less than two degrees Celsius (3.6 degrees Fahrenheit) is a recipe for global disaster, not salvation.

In his testimony, Hansen furthermore called for:

- a moratorium on new coal-fired power plants that do not capture carbon, because ceasing coal burning is the primary requirement in solving global warming
- the introduction of a direct carbon tax at the first point of sale of coal, oil and gas, with 100% of the proceeds to be returned to consumers as equal monthly deposits into their bank accounts.[vi] An increase in this tax as necessary to allow the market place to choose winners by simultaneously weaning energy users from the bad habits developed due to the availability of cheap subsidised fossil fuels and promote clean energy sources
- promotion of renewable energy generation by a grid of underground cables across America, analogous to the interstate highway system. This would allow America's western states to have clean energy by 2020 and the rest of America by 2030
- where necessary, import duties to be placed on products from uncooperative countries in order to level the playing field, with the import tax added to the dividend pool returned to American consumers
- changed utility regulations to reward increased efficiency rather than increased assets and sales
- changed building code and vehicle requirements to improve efficiency

- an end to using China and India as scapegoats for non-action. Western countries still have by far the highest emissions per capita and have been (again, by far) the greatest source of accumulated emissions leading to the current climate exigencies.

Hansen also expressed his personal opinion that the chief executives of large energy companies such as Exxon Mobil and Peabody Coal should be tried for crimes against humanity because they used disinformation to discredit the link between global warming and burning fossil fuels. He likened this to the disinformation campaign by tobacco companies such as R. J. Reynolds that sought to bring the link between smoking and cancer into disrepute.

In March 2008, Hansen wrote in a personal capacity to Prime Minister of Australia, Kevin Rudd[vii], Angela Merkel, Barack Obama and other leaders, requesting their leadership in "Aggressive forward-looking actions to mitigate dangerous climate change …. [including a halt] to plans for continuing mining of coal, export of coal, and construction of new coal-fired power plants around the world, including in Australia …. that do not capture and sequester the CO_2" (Hansen 2008b).

Al Gore

Former Vice President Al Gore (2008) tirelessly campaigns for the rise of another *hero generation* with a sense of historic mission to solve the climate crisis by changing the political will in America and laying a bright and optimistic future for the world. He sees the mission of this new generation of inspired activists to be singularly momentous as the actions of the fathers of the Declaration of Independence, the people that ended slavery and the people that gave women the vote.

Unfortunately, the younger generation appears to suffer from collective cognitive dissonance on the issue. Gore is despondent that Americans who have the opportunity to make a difference still see global warming as a low priority. They have little sense of urgency about the planetary emergency. He feels that people today have a culture of distraction and a sclerosis in good citizenship. The result is that little is being done, despite two thirds of

Americans accepting that human activity causes global warming and that the earth is heating up in a significant way.

Gore has concluded that the solution to climate change is a revenue neutral carbon emissions tax with the proceeds replacing the employment taxes, first introduced in Germany by Bismarck in the nineteenth century. Similarly to James Hansen, Al Gore also flatly says “No new coal plants that do not capture and store their own CO_2.”

Gore says a few concerned people doing things themselves like changing light bulbs, driving hybrid vehicles, digging geothermal wells and installing photovoltaic panels on their roof is well and good but we need to change the laws and solve the democracy crisis in good citizenship behaviour.

He advocated the expanded use of large scale geothermal concentration, advanced photovoltaic technology and conservation. For example, renewable energy plants like Germany's proposal for a super-grid of solar energy plants across Saharan Africa to supply Europe.

By July 2008, Gore had sharpened his focus even further. He boldly challenged his fellow Americans to take an environmentally radial perspective and become completely green in electricity generation “I’m going to issue a strategic challenge that the United States of America set a goal of getting 100 percent of our electricity from renewable resources and carbon-constrained fuels within 10 years …. We need to make a big, massive, one-off investment to transform our energy infrastructure from one that relies on a dirty, expensive fuel, to fuel that is free” (Broder 2008; Herbert 2008). Gore also proposed that payroll tax be cut to offset the inevitably higher prices for fuel and electricity.

Following Barack Obama's election as President, Gore reiterated his plan to produce 100% of American electricity from carbon-free sources within 10 years. Its five key features have been adopted by President Obama:

- incentives for the construction of concentrated solar thermal plants in the South-west deserts, wind farms in the corridor stretching from Texas to the Dakotas and advanced plants in geothermal hot spots

- a national smart grid for the transport of renewable electricity from where it is generated to consumers in cities and smart ways for consumers to control usage
- help for automakers to move production to plug-in hybrids
- the retrofit buildings with insulation and energy efficient windows and lighting
- a cap on emissions that puts a price on carbon.

Intergovernmental Panel on Climate Change

The United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that global warming, if left unchecked, had the potential to materially impact the planet and the welfare of its peoples.[viii] It found that accelerating greenhouse gases from 2001 to 2007 were in large part due to China's booming economy. The acceleration of economic growth and fossil fuel emissions has led to the very difficult situation that global emissions are tracking worst estimates.

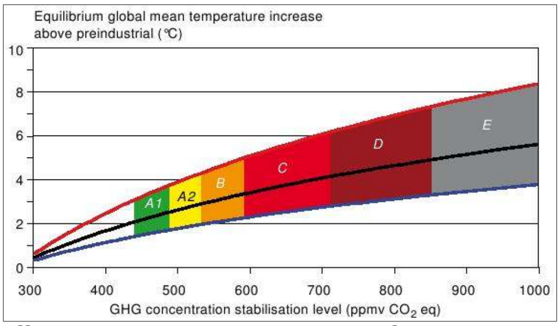


Illustration 9: IPCC Report Working Group III Figure SPM.8: Stabilisation scenario categories

Cat.	Concentration	Global mean temperature increase	Peaking year	CO_2 emission change
	ppm CO_2-eq	ºC	Year	Percent
A1	445 – 490	2.0 – 2.4	2000 - 2015	-85 to -50
A2	490 – 535	2.4 – 2.8	2000 - 2020	-60 to -30
B	535 – 590	2.8 – 3.2	2010 - 2030	-30 to +5
C	590 – 710	3.2 – 4.0	2020 - 2060	+10 to +60
D	710 – 855	4.0 – 4.9	2050 - 2080	+25 to +85
E	855 – 1130	4.9 – 6.1	2060 - 2090	+90 to +140

Illustration 10: IPCC Report Working Group III Table SPM.5: Characteristics of post-TAR stabilisation scenarios

In May 2007, member governments of the IPPC permitted for the first time the display of a graph of greenhouse gases in parts per million versus expected temperature rise as shown in Illustration 9 above (IPCC 2007). Coloured shading shows the concentration bands for stabilisation of greenhouse gases in the atmosphere corresponding to the stabilisation scenario categories in Illustration 10 above.

Illustration 10 summarises the actions and consequences of various CO_2 reduction policies. For example, stabilisation scenario A2 from Illustration 9 implies a mean temperature rise of 2.4°C to 2.8°C, with a reduction in emissions on 1990 levels of between 50% and 85%, and the CO_2 concentration will peak between 490 ppm and 535 ppm, sometime between 2000 and 2020.

The black line in the middle of the band in Illustration 9 is the best estimate climate sensitivity of 3°C. For example, a greenhouse gas concentration of 450 ppm will produce a mean temperature rise of about 2°C. The red line provides an upper bound of likely range of climate sensitivity of 4.5°C, while the blue line shows the lower bound of 2°C.

Based on the research of some 4,500 scientists and 2,500 peer reviewers, the IPCC agreed that limiting global temperature rise to 2°C (3.6°F) was necessary to avoid severe climate change damage. However, the IPCC conceded that we are already on a path that will cause more than 2°C warming so policy might need to be set around 3°C rise and to be prepared for quite large consequences such as species loss, lack of rainfall in Australia, an increasing frequency of high force tornadoes in America and nonlinear feedback loops exacerbating global warming, such as methane release from ocean beds.

In April 2008, the U.S. National Oceanic and Atmospheric Administration (NOAA 2008) released measurements of greenhouse gas concentrations in the atmosphere from 60 sites around the world. This data confirmed the IPCC's conclusions that greenhouse gas concentrations are rising faster than initially expected and the rate of increase is accelerating. In 2007, the concentration of CO_2 had already reached nearly 385 ppm, up 2.6 ppm from 2006.[ix] It attributed the rise mainly to burning of coal, oil and gas.

The next IPCC Assessment Report (AR5) is due in 2014 and will consider risk-reduction strategies. However, scientists met in Copenhagen in March 2009 to undertake an interim update of the IPCC's 2007 Fourth Assessment Report (AR4). The conference concluded that global warming is already 50% greater than expected. This places the world on track for the worst-case scenario of the Fourth Assessment Report and a global temperature rise of between 3°C and 5°C is now expected.

Non- CO_2 greenhouse gas pollution

CO_2 emissions constitute only half of greenhouse gas emissions. The other greenhouse gases are black soot, nitrous oxide, methane and man-made gases such as hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (SF_6). The emission of many of these gases is easier and cheaper to control than the emission of CO_2. As a fall-back position to a successful international agreement in Copenhagen, policy makers see non- CO_2 gases as a policy deliverable.

Black carbon soot is quite important because its particulates blacken snow and ice, causing the surface to absorb radiation and directly contributing to melting of glaciers and polar caps. In addition, millions of human deaths each year are attributed to soot pollution. Fortunately, soot can be readily and cheaply abated using diesel filters and more efficient cooking stoves.

Harmful man-made gas emissions are also relatively easy to abate. For example, under the Montreal Protocol to protect the ozone layer America and industrialised countries have addressed 97% of chlorofluorocarbon emissions (see below). A major new challenge is the emission of hydrofluorocarbons (HFCs) from refrigerators and air conditioners, which continues to grow strongly, and has 11,000 times the global warming effect of CO_2.

Stockholm Network of Scientists

In June 2008, the Stockholm Network of Scientists investigated what would happen if governments agreed to address global warming but deferred effective action (Lynas 2008).

The scientists examined three policy scenarios for global temperature rise using data from the United Kingdom's Met Office Hadley Centre:

- governments agree but ignore emissions until 2045[x] – this results in a temperature rise of 4.85°C by 2100. The consequences of such a rise are that much of the earth becomes uninhabitable, billions of people are displaced by desertification of the Mediterranean Sea and the oceans rise by 7 metres from the melting of the Greenland ice cap and 50%-80% of all species on the earth are rendered extinct

- Kyoto plus - a new round of Kyoto-type targets at Copenhagen in December 2009 that leads to rising emissions until 2030 with a global temperature rise of 3.31°C by 2100
- immediate strong policy measures including emissions permits subject to a cap set by the United Nations[xi] - emissions would peak in 2017 and the temperature rise would be 2.89°C by 2100. This exceeds the European Union's target of 2°C, which has been set as the danger threshold for extreme weather conditions, floods, spreading of deserts, sea rise, and perhaps releasing methane from Siberian permafrost.

These results led many scientists to conclude that global temperature rise cannot be contained even with the strongest policies.

American Association for the Advancement of Science

At the Association's Annual Meeting on 14 February 2009, scientists involved in the IPCC's investigations tabled recent observations that greenhouse gas emissions from burning fossil fuels in developed countries, coal in particular, had increased more quickly than expected in the IPCC's 2007 Reports (Lydersen 2009). They attributed this to higher temperatures that had triggered self-reinforcing feedback mechanisms, thereby speeding up natural processes. For example, the unexpected release of hundreds of billions of tons of CO_2 and CH_4 from melting Arctic permafrost.

The scientists noted that earlier estimates of CO_2 absorption by marine and terrestrial ecosystems are overly optimistic because oceans are becoming more acidic and the deeper layers of water, which are being exposed by stronger winds due to warmer weather, are already saturated with carbon; Northern Hemisphere land is absorbing more heat than expected, which reduces CO_2 sequestration by plants; and wildfire incidence increasing significantly, contributing about a third as much carbon to the atmosphere as burning fossil fuels. In conclusion, the scientists suggested that the rate of global warming is likely to be much faster than recent predictions.

A fixed tranche of atmospheric emissions capacity

The IPCC concluded that atmospheric temperature rise needed to be limited to 2°C in order to minimise adverse effects of climate change. However, the various feedback mechanisms of the carbon cycle governing the relationship from emissions to carbon in the atmosphere and sea, atmospheric temperature rise and thence to both physical and economic damages remain uncertain.

The atmospheric temperature rise from accumulating carbon emissions has been independently estimated by two teams (M. Meinshausen et al. 2009; Allen et al. 2009). Their probabilistic models capture risks and uncertainties in establishing limits to atmospheric emissions capacity. The results are consistent and have exceedingly important ramifications for policy makers in terms of concepts of natural justice and normative frameworks to deal with global warming. These proved to be major topics of policy debate at the UNFCCC Bonn meeting in June 2009 (below).

In the cross compared studies of M. Meinshausen et al. and Allen et al., the authors deal with two issues. The first is the tranche of emissions from pre-industrial times that will cause 2°C temperature rise. The second is the remaining part of this tranche available from 2000-2050.

Allen et al. (2009) found that 3670 Gt CO_2 (1,000 GtC) emissions from the time of the Industrial Revolution c1750 would lead to a 2°C rise in about 2070, assuming emissions peak in about 2020 at 44 Gt CO_2 (12 GtC) per year and decline sufficiently to limit the atmospheric concentration of CO_2 in 2100 and beyond to 490 ppm. The 2°C temperature rise occurs at 470 ppm and has a 5% to 95% confidence band of 1.3°C to 3.9°C.

Of the 3,670 Gt CO_2 (1,000 GtC) aggregate, about 1,615 Gt CO_2 (440 GtC or 44%) occurred before the year 2000. This led to CO_2 attributable warming by the year 2000 of 0.85°C, with a 5–95% confidence range of 0.6°C to 1.1°C.

From 2000, a further 2,055 Gt CO_2 (560 GtC or 56%) of emissions would lead to the IPCC limit of 2°C rise over the pre-industrial temperature. Of this post 2000 tranche of 2,055 Gt CO_2, it is expected that only 1,550 to 1,950 Gt CO_2 could be emitted over the years 2000 to 2049. Of the total 3,670 Gt CO2 from the time of the Industrial Revolution leading to a 2°C rise in temperature, 2,050 to 2,100 Gt CO_2 emissions would occur after the year 2000.

In reviewing the dynamic performance of their model, the authors noted that the relationship between cumulative emissions and peak warming is robust and insensitive to the timing and rate of emissions. They suggest that policy makers adopt Cumulative Warming Commitment (CWC) as a policy definition. CWC is defined as the peak warming response to aggregate CO_2 emissions and has a normalised value of 1.9°C per TtC (i.e. per 1,000 GtC), with a 5–95% confidence range of 1.4°C to 2.5°C per TtC.

In the second study by M. Meinshausen et al.(2009) limiting the probability of a 2°C temperature rise to 25% requires emissions in the period 2000 to 2050 to be capped to 1,000 Gt CO_2. This is the much discussed remaining tranche of 1,000 Gt of CO_2. Emissions of 1,440 Gt CO_2 leads to a 50% probability of causing temperature rise to exceed 2°C, which is similar to the 1,550 Gt CO_2 found in the Allen study. Alternatively, if M. Meinshausen et al. allow for non-CO_2 Kyoto gases, their 25% probability cap of 1,000 Gt CO_2 increases to 1,500 Gt CO_2 equivalent, which is almost the same as in the Allen study.

Of the remaining tranche of 1,000 Gt CO_2, approximately 234 Gt CO_2 has already been drawn in the period from 2000 to 2006 and about one third in the overlapping period from 2000 to 2008. Assuming flat emissions at the current rate of 36.3 Gt CO_2 per year and probabilities of exceeding 2°C of 20%, 25% or 50%, the CO2 emission capacity of 1,000 Gt CO_2 would be exhausted in 2024, 2027 or 2039 respectively.

The study finds that the G8's vision of a 50% reduction in world emissions by 2050 (compared to 1990 levels) has a 12% to 45% probability of exceeding 2°C. If abatement is delayed such that in 2020 emissions remain more than 25% above 2000 levels, the probability of exceeding 2°C rises to 53% to 87%.

Drawing on Meinshausen et al. (2009), the German Government's independent Advisory Council on Global Change (WBGU) has since concluded that no more than 750 Gt CO_2 may be emitted globally between 2009 and 2050 for a two-thirds probability of meeting a target of 2°C temperature rise (Schellnhuber et al. 2009; Spiegel Online 2009; Schwägerl 2009a) This declines to 600 Gt CO_2 for a three-in-four chance.

Schellnhuber et al. (2009) propose that the 750 Gt CO_2 "emissions resource" be allocated to countries on a per capita basis. The aggregate per capita entitlement would be 110 tonne CO_2 for the period 2010-2050. The following table sets out a CO_2 Budget by share of global population in 2010. The table also shows the number of years of "emission resource" that each nation would have at 2008 emissions levels.

	Population Share est. 2010 %	**Budget 2010–2050**		**Emissions est. 2008 Gt CO_2**	**Years @ 2008 emissions**
		Total Period Gt CO_2	**Per Year Gt CO_2**		
Germany	1.2	9	0.22	0.91	10
USA	4.6	35	0.85	6.1	6
China	20	148	3.6	6.2	24
Brazil	2.8	21	0.52	0.46	46
Burkina Faso	0.24	1.8	0.043	0.00062	2.89
Japan	1.8	14	0.34	1.3	11
Russia	2	15	0.37	1.6	9
Mexico	1.6	12	0.29	0.46	26
Indonesia	3.4	25	0.62	0.38	67
India	18	133	3.2	1.5	88
Maldives	0.0058	0.043	0.0011	0.00071	61
EU	7.2	54	1.3	4.5	12
World	100	750	18	30	25
Australia*	0.32	2.4	0.06	0.83	3

*Table: "Future responsibility": the period 2010-2050, 67% probability of achieving the respected 2°C safety barrier (Source: Schellnhuber et al. 2009, p.28 Table 5.3.2 Option II, * Appended Australian Department of Climate Change 2009, Table ES.1* [xii]*)*

It may be noted in the above table that the "emission resources" for Australia, America, Russia, Germany, Japan and EU are only 3, 6, 9, 10,11 and 12 years, respectively. China's "emission resources" and the World average are 24 and 25 years respectively, all far short of the 40 year period. Brazil, Indonesia and India have "emission resources" of 46, 67 and 88 years, respectively.

The implication for high emissions countries are extraordinary. For example, Germany has a target of reducing emissions by 40% by 2020 (compared to 1990 levels). This has been considered exemplary but to meet the above CO_2 Budget would need to be increased to a 60% reduction by 2020 (compared to 1990 levels) with a total emissions moratorium by 2030.

Economic damage

Climate change undermines economic progress through a feedback loop from economic activity and emissions to temperature rise, which causes socio-economic damages. However, the damage function is an area of major uncertainty due to our lack of previous experience and a lack of understanding of other complex effects that act both directly and mutually.

The cost of climate change has historically been seen as deaths resulting from extreme weather events, such as flooding and cyclones. This is because approximately 97% of losses relate to weather events, whilst the other 3% of losses are due to earthquakes, tsunamis or volcanic eruptions. Over the last decade the countries affected by such extreme weather-related disasters have included China, India, Bangladesh, Indonesia, Japan, Philippines, Dominica, Vanuatu, Samoa and Myanmar.

President of the Geneva-based Global Humanitarian Forum, former United Nations Secretary Kofi Annan, estimates that climate change already affects 325 million people each year, costing US$125 billion and leading to the death of 315,000 people. The Forum estimates by 2030 this will rise to 600 million people affected, US$340 billion in costs and 500,000 deaths.

Another consequence of climate change is the impact on water resources. The IPCC estimates that by 2020, water stress is expected to affect up to 1.2 billion people in Asia, 81 million people in Latin America and 250 million people in African countries.

The International Organisation for Migration forecasts that 200 million people will be displaced by environmental pressures by 2050.

Climate change sceptics

This doctoral research assumes that climate change policies need to be investigated because the governments of the world, under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), have agreed to address climate change. Underlying their decision is acceptance by the Intergovernmental Panel on Climate Change (IPCC) of three decades of scientific research demonstrating that global warming is predominantly a man-made phenomenon.

Prior to the June 2009 UNFCCC meeting in Bonn, American President Obama described the climate change situation as a “potentially cataclysmic disaster” (see below). A report released by the United States Whitehouse and the United States Global Change Research Program shortly thereafter underscored the IPCC's conclusions “Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping gases. Warming over this century is projected to be considerably greater than over the last century. The global average temperature since 1900 has risen by about 1.5°F. By 2100, it is projected to rise another 2 to 11.5°F In the U.S.” (Karl et al. 2009, Executive Summary).[xiii]

Additional necessary albeit not sufficient arguments for addressing climate change as an important area of policy relate to consistency with other inherently desirable goals, such as limiting pollution; increasing forests, decreasing desertification and protecting species; and fulfilling the 2000 Millennium goals of developed nations to assist nations in poverty.[xiv]

However, the science of climate change remains controversial. This has major implications for policy makers who need to incur great cost and inconvenience to fundamentally change the technologies of production and consumption in economies. Therefore, the issue of climate scepticism is addressed here, in the context of policy rather than in the context of a discussion about the scientific basis of climate change.

Nierenberg report

Oreskes & Renouf (2008) have established the inception or birth date of climate scepticism.[xv] In 1980, President Ronald Reagan commissioned a third opinion from the U.S. National Research Council: Carbon Dioxide Assessment Committee (Nierenberg 1983) using Congress funding appropriated in 1979. The chair of the committee was William Nierenberg, a member of President Reagan's transition team, director of the Scripps Institution of Oceanography Climate and a member of the Jason Group. He had been part of the Manhattan Project team creating the atomic bomb.

The Nierenberg Report shunned contributing researchers' scientific consensus in lieu of Nierenberg's own conservative intuition, based on unarticulated assumptions. This deftly derailed the issue and delivered President Regan's preferred policy outcome of “reasoned inaction”. The Report suggested that everyone should calm down and concentrate on research and monitoring “[The] knowledge we can gain in coming years should be more beneficial than a lack of action will be damaging; a programme of action without a programme for learning could be costly and ineffective. [So] our recommendations call for *research, monitoring, vigilance and an open mind* [Report's emphasis]”.

To drive home the case, Nierenberg even argued that global warming was benign and nothing new, that it would take many years to significantly affect the planet, that humans had a successful capacity to adapt to new challenges and that there was a good chance of finding new technological solutions.

His executive summary denies the importance of CO_2-induced climate change and merely recommends more research and development into alternative fuels:

- Research and development should give some priority to the enhancement of long-term energy options that are not based on combustion of fossil fuels (Chapters 1, 2, 9)
- We do not believe, however, that the evidence at hand about CO_2 - induced climate change would support steps to change current fuel-use patterns away from fossil fuels. Such steps may be necessary or desirable at some time in the future, and we should certainly think carefully about costs and benefits of such steps; but the very near future

would be better spent improving our knowledge (including knowledge of energy and other processes leading to creation of greenhouse gases) than in changing fuel mix or use (Chapters 1, 2, 9)

- It is possible that steps to control costly climate change should start with non-CO_2 greenhouse gases. While our studies focused chiefly on CO_2, fragmentary evidence suggests that non-CO_2 greenhouse gases may be as important a set of determinants as CO_2 itself. While the costs of climate change from non-CO_2 gases would be the same as those from CO_2, the control of emissions of some non-CO_2 gases may be more easily achieved (Chapters 1, 2, 4, 9)

Nierenberg's report gave rise to the term “climate change sceptic.” One year later Nierenberg cofounded the George C. Marshall Institute think tank, which denies climate change is anything more than normal and natural fluctuation. Nierenberg himself continued as an entrenched climate change critic.

Modern climate change denial

In a heavily polarised debate, the underlying science continues to be trenchantly disputed by contrarians called sceptics, or denialists, depending what side of the debate one accepts. Amongst the sceptics are many in the American Republican Party and an American group of 31,478 scientists who signed a petition over the decade 1997-2007 urging the American government to reject the basis of global warming. Prominent scientists refuting the IPCC's scientific conclusions include Professors Richard Lindzen of MIT and Fred Singer of the University of Virginia. In a good natured jest, their 30-scientist team from 16 countries is referred to as the “Non-Governmental International Panel on Climate Change.”

Criticisms and refutations from climate sceptics include:

- much of the global warming debate is alarmist because of its "tipping-point" focus
- there is considerable scepticism that human activity plays any role in global warming because human activity contributes only 5% of CO_2 emissions

- James Hansen's 1988 prediction was technically wrong. There is no evidence that emission of CO_2 is driving up global temperatures. Statistics from the Hadley Centre and University of East Anglia show that carbon emissions have been rising while global temperatures have been stable or trending down
- there is no way of knowing whether the temperature and economic modelling outcomes are realistic because the changes are based on assumptions having large differences to our direct experience. Thus there is a great deal of uncertainty between cause and effect
- temperature rise models generally only extend to 2100 when other dynamic effects may ameliorate the problem in longer time frames, such as the sea absorbing CO_2
- NASA's solar cycle 24 for increased sunspot activity has not commenced as expected so the planet may face a cooling cycle (in which a bit of human induced global warming would be appreciated)
- there is considerable scepticism that humans can do anything about global warming because of CO_2 emissions that have nothing to do with human activity.

In addition, many people not necessarily classified as “sceptics” hold divergent opinions such as:

- at the bottom of whatever problem that may exist is human population growth and not emissions. In support of this it may be noted that a key feature of IPCC's less calamitous forecasts in its later report was due to reduced United Nations estimates of human population
- while global warming is not proven, all agree pollution is bad. Therefore, we should continue to clean up pollution on a regional level but not require worldwide action or devote enormous resources to it
- we are addressing the wrong problem altogether. Oil will run out long before climate change is a problem.[xvi]

The U.S. Chamber of Commerce has intensively lobbied against the Clean Air Act, calling for climate change science to be put on trial.[xvii] Its strident sceptical position led Exelon (America's largest nuclear utility), Pacific Gas & Electric, PNM Resources (New Mexico's electricity utility) and Apple Computer to resign their memberships (Krauss & Galbraith 2009). In addition, General Electric, Johnson & Johnson and Nike issued statements distancing themselves from the Chamber's position.

In Australia, Donald Aitkin (2008) is among the prominent Australian scientists that reject the IPCC's hypothesis of global warming.[xviii] He claims quasi-religious climate change activists have diverted Australians from the key issues of water and being an energy-dependent society whose resources are depleting. Aitkin claims that carbon trading will be futile, expensive and will lead to rorts; that the European Union's attempts have been laughable; and that China and India are unlikely to reduce their use of carbon fuels in any case.

3.3 Climate change policy development

IPCC's Kyoto Protocol

In 1997, the member governments of the IPCC agreed the Kyoto Protocol treaty, which commits all signatory countries to introduce policies by 2010 to reduce greenhouse gases, limit greenhouse gas concentration to 450 ppm and temperature rise to 2°C above pre-industrial levels. In particular, the Kyoto Protocol binds its thirty-seven industrialised signatories to cut emissions by at least 5% through 2008-2012 (below 1990 levels).

In a practical example of Pareto's 80/20 rule, the top 12 greenhouse gas emitters produce 82% of all CO_2 emissions. America and China lead the list and together emit 40% of all greenhouse gases in 2009. The reduction of emissions by these two countries is of critical importance.

Australia is in a particularly exposed position because it exceeds America in terms of per capita emissions even though it ranks only 12th in total emissions with 1.3% to 1.5% of gases. Australia is able to meet its emissions reduction targets because of a special concession it received to cease land clearing. A précis of Australian climate change history is provided in *Appendix 1 Climate change engagement in Australia*.

However, in what is now seen as one of its key failings, the Kyoto Protocol avoided granting the same land conservation concession to other nations. As a consequence, about 30 million acres of rainforest continued to be cleared annually, which constitutes about 20% of all man-made emissions.[xix] European countries argued at the time that paying poor countries to refrain from rainforest deforestation was an improper way for wealthy counties to meet their climate change obligations.

The IPCC has emphasised that it is essential that by 2010 all Governments introduce policies to reduce greenhouse emissions. The IPCC estimates that if member governments do act quickly, climate change can be brought under control at a reasonable cost. It suggests that this will require a high level of energy conservation, active investment in renewable energy and new technologies, and emissions trading with a price on carbon based energy of US$20-50 per tonne of CO_2.

United Kingdom's Climate Change Act

The United Kingdom's approach to climate policy is one aspect in which it is at odds with the traditional generic Anglo-American world view. The Government is quintessentially uncompromising on global warming abatement and its impact on domestic consumption. In April 2001, the Government introduced a climate change levy to help meet its interim target of 12.5% reduction in emissions by 2010.[xx]

In December 2008, the United Kingdom Parliament passed the Climate Change Act by 463 votes to three. The United Kingdom became the first country in the world to unilaterally legislate to an 80% reduction in emissions by 2050 (compared to 1990 levels). An important feature of this legislation is that it self-entrenches to irrevocably bind future governments.

An independent Climate Change Committee (CCC) will review progress and emerging climate science to advise the Government on the five yearly carbon budgets. The CCC's first report recommends an increase of the 2020 greenhouse gas reduction target from 26% to 34%, and potentially to a 42% reduction if a global agreement on climate change is reached. It also addresses the sectors to be targeted for emission reductions and the technologies to use.

The CCC is seeking a 40% emission reduction by 2020 from the power sector, using wind, nuclear, carbon capture and storage and increased energy efficiency. It is widely understood that implicit in this is the complete decarbonisation of electricity generation and switching large parts of the economy such as cars and gas home heating to electricity.

European Union targets

Prior to the Kyoto Protocol, European and Scandinavian countries experienced considerable constitutional difficulty with environmental taxes through the 1990s. Of key importance in these countries was the debate about revenue neutral environmental taxes and double dividends. This is an issue still dramatically shaping the carbon price debate in Anglo-American countries.

Revenue neutral environmental taxes and the double dividend hypothesis

Hourcade & Robinson (1996) first suggested that revenue neutral environmental taxes can have a “double dividend”. The first dividend is the reduction in pollution. The second dividend arises out of the positive economic and employment growth that may be expected from the reduction of distortionary Bismarckian taxes on labour.

Theoretically, there is an optimal level of pollution where the marginal cost of pollution damage equals the marginal cost of avoiding pollution. Hourcade & Robinson note (p.867) “We can say that a double dividend occurs when the marginal distortionary effect of a carbon tax is lower than the distortionary effect of the taxes for which it is substituted and when the amount of overall fiscal burden remains constant. An important point is that the existence of these conditions depends on parameters far beyond the energy field.”

Bosquet (2000) surveyed 139 models with environmental taxes and concludes that in the short to medium term a double dividend can exist if emissions reductions are significant and environmental tax revenues are used to reduce distorting taxes such as payroll tax (and wage-price inflation is prevented). Bosquet also found that energy-intensive industries may be impacted but this is unavoidable if the environmental goals are to be achieved. Also, revenue recycling and support of vulnerable elements of society are able to overcome harm to households that spend a greater share of their income on goods which produce emissions.

Bayindir-Upmann & Raith (2003) found that only in low tax countries does a revenue neutral green tax reform yield the effects of better environmental quality and higher employment. In high tax countries, it is the positive economic effect, which helps employment, that in turn leads to the environmental dividend component of the double dividend being lost. The authors suggest that this may be addressed by abandoning revenue neutrality, pursuing more drastic tax reforms and using revenues for public works rather than reducing payroll and income taxes.

Using a computable general equilibrium model, McKibbin, Shackleton & Wilcoxen (1999) demonstrated that international trade and capital flows significantly alter projections of the domestic effects of emissions mitigation policy. The Ricardian comparative advantage of nations that underpins international carbon trading is strongest if countries have different marginal costs of abating carbon.

In 1809, David Ricardo proposed that the rent of a resource (such as a piece of land or a person's labour) is equal to the economic value of the best use of that resource compared to using the best rent-free resource for the same purpose. In other words, the resource owner appropriates the value of any excess production because of the more advantageous resource. For example, the value of marginal land for agriculture would be nil so the rent of that land would be nil. Rent would increase with the fertility of the soil, irrespective of any contribution by the landowner.

Bento & Jacobsen (2007) also disagree with the growing number of studies that suggest fiscally-neutral swaps of environmental taxes for labour taxes increase costs and eliminate the double dividend. It is claimed that the positive welfare effect of revenue-recycling (i.e. reducing marginal tax rates) doesn't offset the negative welfare effect arising from promoting alternative products with pre-existing labour taxes that already distort factor-markets.

The authors criticise the underlying assumptions in these models: that labour is a unique input and the production of all goods has a constant return to scale. They argue that it is well established in public finance literature that a uniform commodity tax system fails to adequately tax the rents from a fixed factor of production. The quantity of a fixed factor of production cannot be changed in the short-run, for example, land & buildings, plant & equipment and key personnel. In the long run there are no limitations on scale.

Bento & Jacobsen criticise simplistic models that do not take into account that rents on fixed factors are not fully exhausted. They claim that these models are in fact beginning with flawed, non-optimal tax systems. Contrary to these models, the authors hypothesise that it is possible for a double dividend to occur where there are partially untaxable Ricardian rents for fixed factors in the production of dirty goods.

The authors generate Ricardian rents in a static model economy where residents allocate their time between leisure & labour supply. This labour is used with the exhaustible natural resource coal to produce a dirty good. By allowing the production of polluting goods to have a fixed-factor, the authors find a double dividend of up to 11% of the reduction in pollution emissions and conclude that environmental taxes both improve environmental quality and increase the efficiency of the tax system.

However, the presence of the fixed factor means that part of the environmental tax falls on the fixed factor so the price of the dirty good does not increase by the whole of environmental tax. This reduces the welfare gain from improving environmental quality. Fortunately, this reduction in benefit is mitigated by a correspondingly lower tax-interaction effect because the environmental tax moves the tax burden from labour to the fixed factor.

Traditional models suggest a second-best optimal environmental tax should be set below the Pigouvian (first-best) tax. Bento & Jacobsen found to the contrary that an optimal environmental tax is greater than the Pigouvian tax. In contrast to other studies, the authors also found very high cost savings from using revenue neutral emissions taxes instead of non-auctioned pollution emissions permits.

Experience with environmental taxes in Germany

Beuermann & Santarius (2006) find that five years after Germany introduced ecological tax reform in 1999, Germans still regarded environmental policy and economic policy as separate issues. There is both massive criticism and unconditional support for environmental policies. As with all fiscally neutral environmental taxes, the two virtuous macroeconomic effects were meant to orient production towards energy efficiency and innovation and create additional jobs due to reduced labour costs. Despite public concern that long term unemployment was increasing, Germans neither understood nor welcomed the linking of environmental taxes with employment objectives. German's general distrust of politics and perceived information asymmetries led the coalition of the Social Democrats and Greens to stop increasing environmental tax rates beyond 2003.

Experience with environmental taxes in France

Deroubaix & Leveque (2006) investigated the political difficulty of introducing controversial environmental policy instruments. Using focus groups, they sought to understand France's fuel revolt in 2000, which led the Constitutional Court of France to declare the French Government's Ecological/ Environmental Tax Reform (ETR) project unconstitutional in December of that year. The ETR project had commenced in 1993 following a decade of failure in seeking to limit industry's greenhouse gas emissions through voluntary agreements.

The ETR had sought to be fiscally neutral by recycling taxes on labour to taxes on pollution. It had also sought to achieve the double dividend proposed by Hourcade & Robinson (1996).

Deroubaix & Leveque found that the government did not disseminate information and develop consensus to build acceptance among key groups. They also found that the distributive effects of a tax such as the ETR led to different perceptions in different groups. In unexpected outcomes, businesses that received a net benefit from ETR were the ones not exposed to environmental issues. These businesses remained uninformed and relatively ambivalent. However, the industries that were required to pay the tax strenuously objected to ETR. These were energy intensive companies and those companies with small highly skilled workforces that would not benefit from lower labour taxes. The issue of whether or not to tax the energy used in industrial processes was never resolved and remained a highly contentious issue within the Government's own policy makers.

Deroubaix & Leveque's key finding on the acceptance of environmental tax economic redistribution was that (p.948):

> There is outright hostility to economic instruments among the general public (independent of class and geography). The link between environmental protection and employment incorporated in the ETR concept was incomprehensible for the focus groups participants .... Under these conditions, the quest for social acceptability appears a false problem. The social acceptability issue only makes sense in a rational choice paradigm, taking for granted that every agent has an obvious perception of the signal price. On the contrary, the analysis of policy implementation process shows that there is no optimal tax design. There was no solution to the paradox of the political feasibility of the tax.

Carbon leakage

Hill (2001) notes that environmental taxes encourage companies to relocate industrial facilities from Kyoto Protocol Annex 1 (developed) countries to Annex II countries (developing). World Trade Organisation (WTO) rules would then prevent countries using tariffs to protect their own industries against the imports from these new offshore, lower cost, profligate greenhouse gas producers. Hill also notes that it is uncertain whether the Kyoto Protocol could provide access to the exceptions allowed for multilateral agreements.

“Carbon leakage” is the migration of carbon intensive production from a mitigating country to surrounding countries. It is calculated by taking the increase in emissions in the surrounding countries divided by the reduction in the emissions of the mitigating country. The IPCC's Third Assessment Report (2001) suggested leakage rates of 5% to 20%, although its Second Assessment Report (1995) proposed a wider range of 0% to 70%.

Environmental regulations create higher production costs for source emitters of CO_2 and other greenhouse gases. The usual assumption is that these higher production costs will flow through into downstream producers in the form of higher prices. However, the source emitters or the downstream direct and indirect emitters may not be able to pass on price increases. This provides the incentive for large industries to relocate to other jurisdictions where carbon pollution is unregulated. This is called “carbon leakage migration.”

Asturias region of Spain

Arguelles, Benavides & Junquera (2006) studied the Asturias region of Spain where Arcelor produces iron and steel using energy from coal-fired generation. Low cost, coal-fired electricity has traditionally secured the region's position as a low cost producer in the global iron and steel industry, which has been suffering from competitiveness problems for many years.

A large part of Arcelor's production in Asturias is exported to the rest of Spain and to international markets. There is considerable concern that buyers could turn to other sources or Arcelor could relocate its plants if costs increase in Asturias. This could arise by the requirement to purchase emissions permits or introduce emissions control measures when firms in non-signatory countries do not face similar imposts; or if other regions or countries develop cheaper electrical energy, for example, from gas-fired or renewable generation.

It is quite apparent that environmental policy has the potential to change the comparative advantages of regions and nations. This will favour some nations and industries and reduce, perhaps fatally, the competitiveness of others. Governments are unable to stand in the way of very significant pressures such as companies relocating internationally for lower cost production.

Where changes are not in the global or international theatre, national government policies can be effective in providing special treatment for sectors that are impacted at a regional level. The principle embodied in nations voluntarily adopting environmental policy is that companies should not be subjected to undue economic or social hardship. So called “horizontal-actions” are envisaged to provide special treatment where jobs are impacted.

Arguelles, Benavides & Junquera found that sector accountability for CO_2 emissions is radically modified if Input-Output analysis is applied to allocate responsibility for direct, indirect and induced emissions. At the local scale, the authors found the anomaly that certain sectors will bear the economic costs of CO_2 emissions while other sectors will be exempt, even though these downstream sectors use outputs from sectors that are most effected by the regulations.

Carbon leakage from the European Union

Barker et al. (2007) used computable general equilibrium (CGE) models of historical data in the decade to 2005 from six European Union member states to undertake an ex-post study of emissions relocation. The authors found that the member states probably recorded CO_2 reductions but that output does not appear to be relocating away except in highly competitive export driven markets such as basic metals industries of Germany and the United Kingdom. Otherwise, local production is favoured by transport costs and local market conditions and customised products. Leakage is minor "and in some cases negative". This is attributed to low energy taxes not significantly impacting costs.

The authors confirm the empirical analysis in Sijm et al. (2004, Section 5.2.2, p.20) that found environment policies have, to date, not been influential motives for relocation of energy-intensive processes investments like iron & steel plants to developing countries. Instead, factors like growth in regional demand and wage levels have been more important.

European Union targets: Kyoto and post 2012

On 31 May 2002, the European Union and it's then fifteen member countries ratified the Kyoto Protocol. The European Union set a “20/20/20” target of reducing emissions by at least 20% by 2020 (compared to 1990 levels).[xxi] In addition, the European Union committed to increasing the proportion of energy from renewable sources (solar, wind, hydro and nuclear) from 8.5% to 20% and reducing energy consumption by 20%. The 2050 target for CO_2 was a reduction of between 60% and 80% (compared to 1990 levels).

In December 2002, the European Union introduced an emissions trading system with quotas across the six industries of energy, steel, cement, glass, brick making and paper/cardboard. Chastened by the failure of French and German environmental taxes, the European Union introduced a differential system where emitters received emissions permits free of charge and could sell surplus permits to those emitters which require additional permits. This led to widespread profiteering with companies such as France's EdeF and Germany's E.On passing on the price of permits to consumers regardless of the fact that the companies had received the permits for free.

A second major error was allowing too many permits in the earliest phase of the scheme from 2005 to 2007. This led to glut. The price of excess permits initially rose to €30 ($42) in May 2006 and crashing to 2 euro-cents (3¢) by the end of 2007. This eliminated all incentive for companies to ameliorate or abate their emissions. As a result, the policy miserably failed to achieve any of its objectives or reduce emissions over the first three-year phase. The only winners in the emissions trading scheme were banks such as Barclay and Goldman Sachs that traded CO_2 permits in a market estimated at €62.7 billion (US$90 billion) in 2008 (Scott 2009).

A third major error in the scheme was to create a double cost for industries such as metal makers, chemical plants and paper mills. These industries have their own carbon quotas and in addition were forced to pay higher power prices.

In November 2008, the European Union (which had now expanded to twenty-seven countries) extended the same targets to post 2012, when the Kyoto Protocol no longer applies. A major feature in achieving the “20/20/20” objectives in 2013 and thereafter will be that the differential system where emissions permits are granted for free becomes an absolute system with all emissions permits auctioned.

The effect of auctioning permits on unemployment and carbon leakage (the loss of industries to less regulated countries) remains highly contentious. In order to achieve consensus, the European Union acceded to concessional exemptions demanded by Germany and Italy for their steel, chemicals, cement, aluminium and automobile manufacturing industries.

However, all industries in the European Union will need to reduce emissions each year. Polluting power producers will receive subsidies and firms that face international competition, which is estimated to be more than 90% of European Union firms, will receive free emissions permits until 2020 if their costs rise more than 5% due to buying permits.

The nine Eastern European countries that threatened to veto the post-Kyoto “20/20/20” deal because of their highly polluting coal and lignite-fired power stations were assuaged by free permits. When auctions commence in 2013, countries with per capita income under half of the European Union average and with more than 33% of their power from coal fired plants will receive free permits equal to 70% of their average annual emissions from 2005-2007. This will decline to zero at 2020.

The United Kingdom was compensated with an extra €3 billion for carbon capture and storage development, increasing the total subsidy to €9 billion.

The European Union agreement also allows countries to earn emissions credits by clean development mechanisms (CDMs), which are projects for emissions amelioration in developing countries. This remains a controversial provision in the lead-up to the UNFCCC's December 2009 meeting in Copenhagen.

The European Union also hopes that America will join with Europe to create a global carbon market. As emissions permits in developing countries are expected to be cheaper than in industrialised countries, European Union members will be able to buy a proportion of their permits from foreign countries. Those that meet the power and per capital income test will be able to buy a higher proportion of permits.

Non-Kyoto Protocol action by governments

Over the past two years, the world's largest polluters, America, China and India, which are not parties to the Kyoto Protocol, have discussed a new protocol to be agreed at the United Nations climate meeting in Copenhagen in December 2009.

APEC Sydney Conference

The indifference of politically conservative Anglo-American nations to climate change was evident at the Asia Pacific Economic Forum (APEC) Conference in Sydney in September 2007. The 21 member economies merely agreed to a non-binding, so-called “aspirational goal” of slowing, stopping and eventually reversing greenhouse gas emissions. They put aside Kyoto Protocol targets to cut greenhouse gas emissions and merely undertook to plant more trees and increase energy efficiency by one quarter between 2005 and 2030.

America's view, espoused at the Conference, was that this declaration represents the emerging parameters of a climate change arrangement to become effective when the Kyoto Protocol expires in 2012.

In placing the best spin on this lack-lustre outcome of APEC, the host nation's then Prime Minister, John Howard, noted that it marked the first time that large polluting countries such as the United States, Russia and China had agreed that they each have to make commitments to stop human activity from causing dangerous changes to the climate. Commentators noted that the wealthy Anglo-American nations regarded climate change as a "hundred year agenda" and so there was no imperative to do anything immediately.

The Sydney conference also nimbly sidestepped the growing divide between wealthy and developing nations over the Kyoto Protocol. Wealthy nations like the USA and Australia had not ratified the Kyoto Protocol, claiming possible adverse effects on economic and social growth. Most wealthy countries that did sign, such as Canada, have failed to meet their targets.

Developing countries such as China, Indonesia and poorer APEC members favour the Kyoto Protocol because it calls on richer countries to a higher standard for minimising greenhouse gases and exempts developing countries from emissions targets. Several smaller developing countries at the APEC Forum reacted angrily to developed nation bullying to endorse a declaration that would actually undermine the Kyoto Protocol (DeSouza 2007). Papua New

Guinea's Prime Minister Sir Michael Somare told fellow leaders “While we recognise that Kyoto Protocol has its flaws, it needs to be improved and strengthened - not weakened.”

China remained strongly of the view that developing nations have a lesser role to play and should be allowed to get on with economic growth and improve lifestyle to Western standards. It has adopted targets, albeit rather low and unclear, to reduce the energy intensity of economic activity by 20% by 2010 (compared to 2005 levels) and to sharply increase the contribution by renewable energy to total energy supply.

China's President Hu Jintao chided developed nations over the need for them to strictly abide by their targets under Kyoto to compensate for years of booming economic activity that has produced copious CO_2 emissions. Hu said industrialised countries have polluted for longer and thus must take the lead in cutting emissions and providing money and technology to help developing countries clean up. He reminded the wealthy countries that (Yeoh & Gosh 2007) “In tackling climate change, helping others is helping oneself.”

Although the Anglo-American nations didn't have the ears to hear, Hu's theme increasingly haunted them for almost another two years. America remained intransigent in its dogged insistence that China adopt binding and equal targets to America. The issue finally boiled over at the UNFCCC Bonn meeting in June 2009, resulting in American negotiators desperately seeking a face-saving solution to appease their own Senate.

Group of 8 Hokkaido meeting

In July 2008 the Group of 8 met in Hokkaido, Japan. The countries continued their negotiating pressure on China. President George W. Bush dominated the Group's *communiqué*, making it an agreement to a target of 50% reduction of greenhouse gases by 2050 (base unstated) on the condition that China, India and other developing nations participated (Stolberg 2008).

Environmentalists had hoped for an interim target of 25% reduction by 2020 (compared to the standard 1990 levels) to provide incentive for clean technologies. In the event, there was considerable disquiet amongst environmentalists that the lacklustre outcome signalled a lack of *bona fide intentions amongst developed nations.* South Africa's minister of environmental affairs, Marthinus van Schalkwyk, observed "Without short-term targets the long-term goal is an empty slogan."

President George W. Bush also suggested a series of meetings with a group of major emitters he dubbed the "Outreach Five": China, India, Brazil, South Africa and Mexico. The label Outreach Five became deprecated almost as soon as it was first mentioned.

China and other developing nations at a separate but concurrent meeting in Hokkaido again re-emphasised that America and other developed countries would need to first solve the problem they had created and then contribute capital to the developing nations.

The G8 nations, together with the so-called Outreach Five, together with South Korea, Indonesia and Australia subsequently issued a statement suggesting, rather self-evidently, that developed countries should share the biggest portion of the climate change burden.

United Nations 2008 Poznan climate change conference

During his Presidential election campaign, Senator Obama, outlined his belief that: "None of the numbers on the table - the EU's 20% by 2020, the US return to 1990 levels, the Chinese pledge of a 40% reduction in carbon intensity [the amount of carbon produced per unit of Gross Domestic Product] - was enough to stave off dangerous climate change."

Consistent with this position, in November 2008 Senator John Kerry, brought UN Secretary-General Ban Ki-moon the message from then President-elect Barack Obama that he would personally lead coordinated global action in Copenhagen.[xxii] Kerry also noted his personal view that "Without a new global deal temperatures could be between 3°C and 5°C higher by mid-century than they are now."

With America intransigent on committing to any targets, the European Union, China and India also declined to consider targets. As a result, the Poznan conference became another vacuum in policy development. The leaders merely deferred commitments until the November 2009 meeting scheduled for Copenhagen.

Nevertheless, upon learning of the contemporaneous European Union ratification of its “20/20/20” objectives for the period beyond 2012 when Kyoto has expired, delegates expressed relief and immediately released funds to assist poor nations protect themselves from the impact of climate change. The Adaptation Fund is expected to provide US$300 million per year by 2012, through a 2% levy on United Nations' green investments in developing nations.

At the Poznan conference, German Watch, a German environmental group, released the 2009 Climate Change Performance Index of 57 countries covering 90% of energy related CO_2 emissions (Burck et al. 2008). It found that no country engaged sufficiently in the battle against a 2°C temperature rise to win one of the top three positions. Sweden, the 2007 winner, ranked 4th, followed by Germany and France. The worst three countries were America, ranking 58th, followed by Canada and Saudi Arabia. China was 51st out of 60, however rising due to its expanded environmental initiatives. In 2007, Australia ranked in the bottom three.

3.4 American climate policy development

It is well known that President Bill Clinton never sent a Kyoto Climate Bill to Congress for ratification due to its certain defeat and President George W. Bush was openly contemptuous of the Kyoto Protocol.

Byrd Hagel resolution

Jacoby & Reiner (2001, p.300) note that in advance of the 1997 UNFCCC Kyoto meeting, the U.S. Senate had already passed, by a majority of 95-0, the non-binding Byrd-Hagel resolution to oppose any climate treaty that would either harm the American economy or omit matching commitments from developing countries. The authors note that (pp 303-4): “The US Senate acts as a high barrier to ratification of international treaties: not only is a two-thirds vote required, but Senate rules and practices give blocking power to small coalitions (or even key individuals) ... the most visible Senate critics of Kyoto, Senators Byrd and Hagel a conservative Democrat and Republican respected in foreign affairs, represent precisely those views that will have to be won over to reach the two-thirds majority.”

William Nordhaus

William Nordhaus, a senior policy adviser to the American Government over many years, takes an economist's approach to climate policy in his book *A Question of Balance: Weighing the Options on Global Warming Policies* (2008). He assumes the science of climate change and long term consequences are given and focuses only on policies of resource allocation to maximise the financial benefit of the planet.

Nordhaus' model is called Dynamic Integrated Model of Climate and Economy (DICE). It has two parts: the first part calculates the effect of reduced emissions in ameliorating climate damage, and the second calculates the net value of gains and losses to the world economy over 100 and 200 years, discounted at a rate of 4%[xxiii].

Dyson (2008) summarises the six major global warming policy alternatives examined by Nordhaus:

- “Business as usual", which results in damage to the environment of US$23 trillion by 2100. US$23 trillion is approximately $70,000 per capita of US population. This is the base case against which all other policies are compared
- “Tax worldwide carbon emissions" at a rate gradually increasing with time to provide the maximum aggregate economic gain. This is the optimal policy according to Nordhaus. The net value of this over the base case is US$3 trillion
- "Continue the Kyoto Protocol" with or without American participation. The net value of this over the base case is US$1 trillion with American participation and zero without
- "Sir Nicholas Stern's policy", which is Kyoto plus additional strict limits on emissions. The net value of this over the base case is negative US$15

trillion. In other words, this case has an additional cost over the base case of $15 trillion

- "Al Gore policy" of reducing emissions gradually to 10% of current levels by 2050. The net value of this over the base case is negative US$21 trillion
- "Low cost backstop technology", which is a hypothetical atmosphere scrubbing technology to sequester the Keeling carbon wiggle, such as pyrolation or genetically engineered carbon eating trees, or a low-cost solar or geothermal energy technology that at present might only be imagined in the realm of science fiction. It might be noted that the IPCC does not give any credence to such highly speculative miracle-technologies. The net value of a low-cost backstop technological breakthrough over the base case is US$17 trillion, which is almost the equivalent of a free solution to global warming.

Nordhaus concluded that the Stern and Gore policies would be prohibitively expensive, while the "low-cost backstop technology" is enormously attractive. Other policies like taxing carbon emissions and continuing the Kyoto Protocol (with or without American involvement) are similar to the base case of "business as usual".

Based on these findings, Nordhaus strongly recommended against American ratification of the Kyoto Protocol and that America should actively avoid all ambitious proposals such as those of Stern and Gore. The way ahead, according the Nordhaus, was to vigorously pursue low-cost backstop technologies and, as a safety-net for the planet, seek an international treaty binding all nations to a progressively more expensive carbon tax.

Environmental taxes on imports

In September 2009, French President Sarkozy noted that France and Germany were preparing a “border adjustment tax” on the assessed greenhouse gas pollution content of goods imported from countries with climate control measures that were inferior to the European Union (Butler 2009). India had earlier observed that it could respond to any such duties with a 99% tax on goods imported from countries that had created the CO_2 pollution problem.

While America has been tardy in setting greenhouse gas pollution reduction targets for industry, producers themselves had sought Government protection against “carbon leakage”. This is the loss of emissions intensive industry to overseas locations and resulting in the import of formerly manufactured products.

In February 2008, the Environment and Public Works Committee passed a bill called “America's Climate Security Act (S. 2191)” requiring importers of emissions intensive goods such as steel and aluminium to provide the Government with emissions credits.

The bill was supported by American Electric Power, together with the International Brotherhood of Electrical Workers. Steel producer Nucor Corp., also proposed that a tariff be imposed on goods imported from countries with no carbon cap.

US Congress House Energy and Air Quality Subcommittee

In April 2008 the Chairman of the U.S. Congress House Energy and Air Quality Subcommittee, Richard Boucher, confirmed that the Committee was developing legislation to reduce carbon emissions 60% to 80% by 2050 (compared to 2008 levels) (Boucher 2008). However, the key feature of this target was that there would be no American action until 2025, followed by a higher levels of emissions amelioration if and only if carbon capture and storage (CCS) had become feasible.

Boucher noted that three carbon capture technologies were in development in America: integrated gasification combined cycle (IGCC), chilled ammonia carbon capture application and combustion of coal in an oxygen rich environment. He suggested that one of these could be commercially available by 2025, although the integrity of storage locations for carbon dioxide sequestration would need to be mapped and monitored.

Following these unsatisfactory revelations, in June 2008 environmentalists requested the Senate to address a proposal to cut greenhouse gases by 70% by

2050 (compared to 1990 levels). However, the Senate declined to address the matter.

President Obama's emergent policy

Senator Obama's November 2008 election policies for climate change were:

- to reduce CO_2 emissions by 80% by 2050 (compared to 1990 levels)
- to introduce a cap-and-trade scheme that would cap American CO_2 emissions and require companies to buy permits to pollute at a specified carbon price
- to invest US$150bn in renewable energy over ten years as part of plan to reduce American dependence on foreign oil, tackle America's carbon emissions and create jobs
- increase production tax credits for the wind industry from one year to seven years

In dealing with the global financial crisis that began shortly after his election, President Obama included some of these climate change policies in the American Clean Energy and Security Act of 2009. This was not universally well received. Notwithstanding calls for a 40% cut in emissions by 2020 (compared to 1990 levels), America's new clean energy project provides only for a reduction in greenhouse emissions of between 6% and 7%. European Union countries expressed dismay at this perceived lack of American leadership in the lead-up to the United Nation's December 2009 climate change meeting in Copenhagen.

President Obama later defended the American Clean Energy and Security Act in a speech at Georgetown University (Obama 2009):

> The investments we made in the Recovery Act will double this nation's supply of renewable energy in the next three years. And we are putting Americans to work making our homes and buildings more efficient so that we can save billions on our energy bills and grow our economy at the same time …. But the only way to truly spark this transformation is through a gradual, market-based cap on carbon pollution, so that clean energy is the profitable kind of

> energy. Some have argued that we shouldn't attempt such a transition until the economy recovers, and they are right that we have to take the costs of transition into account. But we can no longer delay putting a framework for a clean energy economy in place. If businesses and entrepreneurs know today that we are closing this carbon pollution loophole, they will start investing in clean energy now. And pretty soon, we'll see more companies constructing solar panels, and workers building wind turbines, and car companies manufacturing fuel-efficient cars. Investors will put some money into a new energy technology, and a small business will open to start selling it. That's how we can grow this economy, enhance our security, and protect our planet at the same time.

American Clean Air Act

In 2007, the U.S. Supreme Court ruled that Congress had intended the Clean Air Act to cover greenhouse pollution and that the Environmental Protection Agency (EPA) had a mandatory obligation to regulate greenhouse gas pollution. However, the Bush Administration opposed this and disenfranchised the EPA of this obligation.

President Obama subsequently expressed the opinion that it would be better for Congress to prepare custom regulation for emitters like electricity generators and factories. Nevertheless, in a move that was seen as the first step of the Obama Administration in taking global warming seriously and building its credibility in preparation for the United Nations' Copenhagen meeting in December 2009, President Obama released the EPA from its previous administrative restraints.

On 17 April 2009, this resulted in the EPA issuing a report labelling CO_2 and five other greenhouse gases a significant threat to public health and therefore subject to its regulation under the Clean Air Act.

American fuel standards

Despite a policy vacuum at the Federal level during the Bush Administration, many American States adopted their own targets. For example, California legislated to return State emissions to the 1990 level by 2020 with an 80% reduction by 2050 (compared to 1990 levels). California also required a reduction in new vehicle emissions of 14% by 2011 and 30% by 2016 (compared to 2008). However, these regulations were immediately blocked by the Bush Administration. On 3 July 2009, President Obama overturned this situation with the Environmental Protection Agency granting California the right to enforce its own standards.

Earlier, in May 2009, President Obama had introduced America's first ever measure to reduce greenhouse gases by placing an obligation on automobile manufacturers to increase car and light truck average fuel efficiency by 40% from 25 miles per gallon to 35.5 miles per gallon by 2016 and to decrease greenhouse gas emissions by approximately one-third by 2016. The measures will commence in 2012 and be overseen by the Environmental Protection Agency and Department of Transport.

President Obama's initiative was widely seen as reversing the previous Administration's indifference to America's extraordinarily high level of oil imports and its rebuff of California’s clean car program.

Washington Climate Summit April 2009

At the Washington Climate Summit, China and India reiterated their position that industrialised nations needed to lead with major CO_2 emissions reductions or developing countries would not commit to any binding reductions.

America and Australia were discussing such small targets in the order of 5% to 7% (compared to 1990 levels) that they could hardly criticise this policy stance by developing countries. It was left to Russia, Japan and, ironically because of its widely criticised duplicity, Canada to object that China and India were already among the world's top emitters and should engage with the issue.

American recognition of domestic climate change impacts

As noted in the section on Climate Change Sceptics (above), in June 2009 the White House Office of Science and Technology Policy and the United States

Global Change Research Program issued a comprehensive report on how global climate change was impacting America (Karl et al. 2009). Thirteen Federal agencies contributed to the report.

This is notable as it is the first time American policy makers have moved the debate from hypothetical scientific confidence levels to declare, unequivocally, that climate change was already impacting America across food production, forests, coastlines and floodplains, water and energy supplies, transportation and human health. The principal editor of the report, Dr. Thomas Karl, emphasised the imperative for Americans to act quickly to reduce emissions or face severe damages and adaption costs: “Our destiny is really in our hands …. The size of those impacts is significantly smaller with appropriate controls.”

Waxman-Markey Bill

On 26 June 2009, the U.S. House of Representatives narrowly passed the Waxman-Markey[xxiv] Bill, called the “American Clean Energy and Security Act, H.R. 2454” by 219 votes to 212, with 44 Democrats voting against it and 8 Republicans voting in favour. Democrats control 59% of the House but the Democrat vote for the Bill was only 51%. If all Democrats had voted for the Bill, it would have achieved 61% in favour.

The Waxman-Markey Bill includes a cap and trade system to reduce emissions 17% by 2020 (compared to the 2005 level) 42% by 2030 and 83% by 2050. It also has the aim of ending foreign oil, increasing the use of renewable energy, generating new clean-energy jobs and technology and setting efficiency standards for buildings, lighting and industrial facilities.

The proposed reduction of 17% by 2020 (compared to 2005) is equivalent to only 4% by 2020 (compared to 1990). Although permits will be auctioned, it is proposed that about 85% of permits would initially be given away free to industry. Companies that need additional emissions permits can meet their obligation by purchasing additional permits on an emissions exchange. As discussed above, the European Union's similar differential approach of giving away permits is now seen as a major error.

The Bill also proposes a requirement that 20% of electricity be generated from wind, solar and other renewable sources by 2020, including 5% from better energy efficiency.

Although many manufacturers and generators supported the Bill, Republican critics claimed the Bill was “the biggest energy tax in history” and that it would lead to major increases in energy prices and the loss of millions of jobs (Broder 2009a). Democrats were quite nervous about this Bill because in 1993 President Clinton's proposed tax on all forms of energy was defeated and widely seen as a factor in the Democrats subsequently losing government.

Environmental groups Greenpeace, Friends of the Earth and Public Citizen are critical of the Bill because it allows too many free emissions permits for polluting industries. They also claim it is risky because it relies on hypothetical and perhaps unlikely reductions in emissions by developing countries.

An alternative Bill sponsored by Republicans, in the tradition of the former Bush Administration's “drill here, drill now” approach, proposes coastal drilling on all America's coastline, including the Arctic Coastal Plain. There is neither a cap on carbon, nor a mandate for electricity from renewable sources. The only concession to the environment was to add “insult to injury”: that investment in renewable energy research would be funded from future Arctic Coastal Plain oil and gas royalties.

Senate amendments to the Waxman-Markey Bill

Following its acceptance in the House of Representatives, the Waxman-Markey Bill needs to be passed in the Senate. On 1 October 2009 Senators Barbara Boxer and John Kerry introduced an amended Bill for the Clean Jobs and American Power Act.

In matters of international treaties, the United States Constitution requires two-thirds in favour (Article II, Section II): “[The President] shall have Power, by and with the Advice and Consent of the Senate, to make Treaties, provided two thirds of the Senators present concur...” In October 2009, Democrats controlled 59 of the 60 votes required for the Bill to pass.

The Boxer-Kerry Senate Bill differs from the Waxman-Markey Bill in three ways. Firstly, it requires a 20% cut in emissions by 2020 (compared to 2005). The Waxman-Markey Bill requires a cut of only 17% by 2020. This compares to the cut of 14% originally proposed by President Obama. However, emissions are already 8.8% lower than in 2005 due to the American recession. An 83% cut by 2050 is the same in each case.

Secondly, while both Bills include an economy-wide emissions cap and trade system, there is a major difference in the contentious issue of how emission allowances will be distributed. The Waxman-Markey Bill provides for 85% of emissions permits to be issued free of charge. However, the Senate bill does not address the matter and leaves negotiations for later.

Lastly, the Waxman-Markey Bill restraints the Environmental Protection Agency (EPA) from regulating greenhouse gases under the existing Clean Air Act. In contrast, the Senate Bill does not restrict the EPA.

America's engagement at the UNFCC Bonn meeting

Publicly, America and China had hidden behind the other's intransigence on climate change. Neither ratified the Kyoto Protocol. However, in July 2007, Chinese and Bush Administration officials began secret negotiations for a common approach.[xxv] Since that time, each nation has encountered domestic economic and employment issues that have led to pressures to not deal with greenhouse gas pollution.

In June 2009, the UNFCCC's meeting in Bonn of 182 countries with 4,300 participants debated for the first time a draft Copenhagen Protocol to succeed the Kyoto Protocol. The November 2009 meeting in Copenhagen (CoP15) is the culmination of the 2006 Bali Road Map.

This Bonn meeting was the first such conference in which America had fully engaged. Although a 200-page document was compiled, the countries were unable to reach agreement on world action to ameliorate climate change. At the end of the meeting, the exasperated UNFCCC Executive Secretary Yvo de Boer concluded that a worldwide anti-climate change pact was "physically impossible." However, there was a substantial step forward in the grim acknowledgement by all parties that an effective policy was urgently needed.

The United Nations presented three draft protocols. The draft promoted by France and Germany set minimum reductions necessary to cope with climate change as between 25% and 40% by 2020 (compared to 1990 levels) and between 50% and 85% by 2050 (compared to 1990 levels). It was proposed that countries such as America that may be unable to react sufficiently quickly to meet their domestic targets by 2020 would be able to satisfy their obligations by CDMs through financing sustainable activities in developing nations. In addition, the draft provided for levies of approximately US$100 billion per annum for structural adjustment and protection of vulnerable communities, and additional compensation for historical emissions.

Other draft objectives included peaking emissions by 2015 and then reducing emissions by 50% by 2050 (compared to 1990 current levels) in order to limit temperature rise to 2°C and reducing emissions to 2 tonnes per capita. This compares with 2006 per capita emissions of 19.78 tonnes in America, 7.99 tonnes in Europe and 4.58 tons in China 2006.[xxvi] Another objective sought a reduction in atmospheric CO_2 from the current level of 385 ppm to 350 ppm.

At the start of the Bonn meeting, the Inter-Academy Panel, representing the science academies of seventy countries including those of Australia, Britain, France, Japan and America, implored world governments to take action avoid an underwater catastrophe from ocean acidification: “To avoid substantial damage to ocean ecosystems, deep and rapid reductions of carbon dioxide emissions of at least 50% (below 1990 levels) by 2050, and much more thereafter, are needed.” [xxvii] However, all major countries including Japan and Russia persistently resisted any commitment while they awaited a resolution between America and China.

During the conference the world's 6th biggest emitter, Japan, announced an 8% domestic reduction by 2020 (compared to 1990 levels)[xxviii], which is 1% deeper than its Kyoto Protocol undertaking.[xxix] Previously Japan had signalled a wide range from a 4% increase (compared to 1990 levels) to a 25% decrease. However, the UNFCCC and environmentalists were aghast at Japan's meagre new 8% target, with UNFCCC Executive Secretary Yvo de Boer venting his frustration at the lacklustre support from developed countries: “For the first time in my two and a half years in this job, I don't know what to say. We're still a long way from the ambitious emission reduction scenarios that are a beacon for the world”.[xxx]

In his contemporaneous visit to Dresden, President Obama had described the climate change situation as a “potentially cataclysmic disaster”:

> I'm actually more optimistic than I was about America being able to take leadership on this issue, joining Europe, which over the last several years has been ahead of us on this issue …. Ultimately the world is going to need targets that it can meet. It can't be general, vague approaches …. We're going to have to make some tough decisions and take concrete actions if we are going to deal with a potentially cataclysmic disaster …. Unless the United States and Europe, with our large carbon footprints, per capita carbon footprints, are willing to take some decisive steps, it's going to be very difficult for us to persuade countries that on a per capita basis at least are still much less wealthy, like China or India, to take the steps that they're going to need to take …. So we are very committed to working together and hopeful that we can arrive in Copenhagen having displayed that commitment in concrete ways.

However, American support for a new Copenhagen Protocol remains somewhat illusory because of the hurdle that Senate ratification of an international treaty requires a two-thirds vote in support of the treaty. President Bill Clinton had been unable to secure this level of support for the Kyoto Protocol.

Furthermore, the risks of failure are as considerable as President Obama's objectives are courageous; America had not yet done anything at all to reduce emissions (and therefore, by definition, far less than China's energy efficiency initiatives); the Republican Party, conservative Democrats and influential climate change sceptics remained implacably opposed to any actions on emissions; the cost of any climate change policy appears too enormous for America; this comes at a time when America has huge deficits due to poor economic management, the 2008-9 Global Financial Crisis, bank and industry bailouts and employment and health exigencies; and lastly, most Americans remain highly sceptical that they could reduce emissions by even the United Nations minimum goal of 25% by 2020 (compared to 1990 levels).

Nevertheless, American and China, who between them created 47% of world greenhouse gas emissions in 2009, recognised they are the most important participants in the approaching UNFCCC meeting in Copenhagen. In Bonn, they engaged in complex negotiations across the canvas of their financial, economic and climate change relationships. However, each country remained highly suspicious of the others *bona fide* intentions, with both seeking an approach analogous to mutually assured nuclear disarmament. For example, based on measurable, verifiable and reportable reductions and tit-for-tat retaliation to non-agreement or non-compliance (Broder & Ansfield 2009).

The Bonn meeting was also notable for its focus on historical accountability for emissions, which gave rise to the dual concepts of current and historical accountability for climate change debt. The first concept is well understood: it is the liability of industrialised nations to redress the harm to developing countries from changing climate patterns due to both the historical levels of emissions and continuing emissions from industrialised countries. Everyone expects that developing countries will incur significant expenses in adapting to the physical effects of climate change.

However, the second notion of industrialised nation debt has only recently become clear with the increased negotiating power of China and India. It is reasoned that industrialised nations got to the “cookie jar” first and plundered it, leaving developing nations with only crumbs.

The illustration below shows the historical accountability for emissions of 48 countries comparing 95% of accumulated emissions (EarthTrends 2007). Of the total 1066 Gt CO_2, America accounts for 29.5%, Russia and Germany each 8.4%, and the United Kingdom 5.2%.

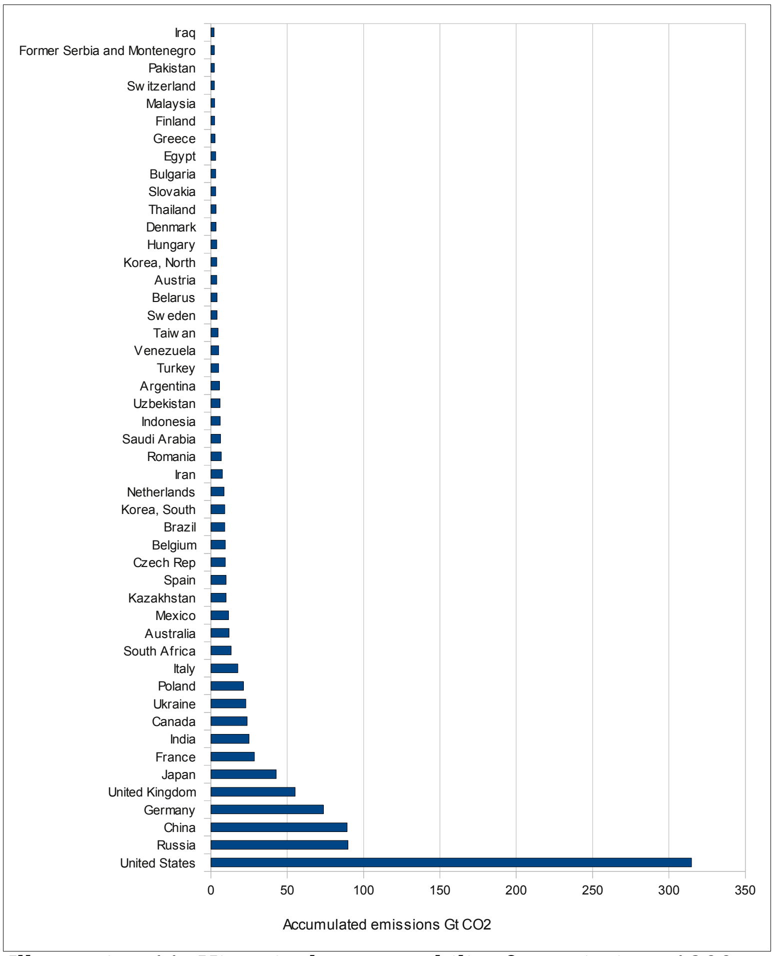


Illustration 11: Historical accountability for emissions 1900-2004 (Source: World Resources Institute EarthTrends 2007)

Now that industrialised nations are desperate for cooperation from developing countries, it no longer a situation of “let's forgive, forget, move on and start anew”. Developing nations are seeking a kind of intergenerational and cross geopolitical equity justice in demanding that withdrawals from the world's fixed pool of emissions capacity be repaid in order that future generations in developing countries are on an equal footing with citizens of developed countries. Reduced to simple terms, China and India's position is that industrialised countries would need to fix the whole global warming situation before developing countries would join to go forward on an equal basis.

China re-emphasised the policy remains "common but differentiated responsibility" following definitions developed by the UNFCCC's 1995 Berlin meeting. The Berlin Mandate placed industrialised and developing countries into different international regimes with differentiated accountability for accumulated emissions and responsibility for the costs of mitigation over forthcoming decades. Indeed, the Berlin Mandate exempted and prohibited developing countries from entering into binding targets. With the benefit of perfect hindsight, it may have been preferable for the Berlin Mandate to have included transition provisions for countries, such as China and India, that had the potential to emerge as major industrial powers and polluters.

As at the 2007 APEC meeting in Sydney, industrialised countries once again reneged on the principle of "common but differentiated responsibility". They endeavoured to lay-off responsibility on developing countries by setting developing country emission quotas and not responding to suggestions of providing funds and environmental technology transfer.

In the event, this strategy didn't work. Both China and India responded by calling America's bluff. Firstly, they accused America and other developed countries of not engaging with the long-established philosophy of "common but differentiated responsibility". Secondly, China demanded performance from America and other industrialised countries as a precondition of its own action. For example, China declined to commit to target levels, while demanding that developed nations including America reduce emissions by at least 40% by 2020 (compared to 1990 levels) and contribute at least 0.5% to 1% of their GDP to help developing countries upgrade technology.[xxxi] These claims were in stark contrast to the Waxman-Markey target of just 4% reduction by 2020 (compared to 1990 levels) and America's foreign aid budget of 0.17% of GDP.

Thirdly, India demanded that developed nations must reduce emissions by 79.2% by 2020 (compared to 1990 levels), by accepting responsibility for both their current emissions and accumulated emissions in the atmosphere since the Industrial Revolution c1750. Any compensation pursuant to this accountability would need to be mandatory in nature and not part of voluntary transfers usual in foreign aid and development cooperation. Industrialised countries responded by arguing against any new institution for mandatory payments and that climate settlements should remain part of development cooperation.

Fourthly, China declined to further engage with America as a kind of leading nations “G-2” to agree emissions quotas. China said that it would only engage with the wider United Nations process (Schwägerl 2009b).

Fifthly, China claimed that green technologies were far too expensive for it to contemplate any emissions target. Developing countries are still smarting from two decades of abrasive dealings with developed countries over the intellectual property rights for new AIDS pharmaceuticals. In emulation or secondary pricing for AIDS pharmaceuticals, developing countries have called on industrialised countries to require private technology developers to license their intellectual property rights.

Even more disturbing for international amity, China demanded that America provide the cheap carbon capture and storage (CCS) technologies that industrialised countries such as America, Australia and the United Kingdom have long touted as the “magic bullet” solution to reduce emissions. Unfortunately, if the IPCC, Al Gore, James Hansen and many environmentalists prove to be correct, Anglo-American nations may be “hoisted on their own petard” by this challenge. Environmentalists refer to CCS as a “dirty lie” because it has been used by the fossil fuel industry as a “red herring” to absorb renewable energy research funding and deceptively mislead voters about climate change. In late 2009, despite fledgling pilot projects, CCS still appears to be merely hypothetical technology. Current indications are that CO_2 collection would reduce boiler burning efficiency by 25% and correspondingly increase the fuel required by 25% to 30%. Perhaps an even greater hurdle is the well known issue of CO_2 egress from storage. The risks of CCS remain exceedingly high, it is unlikely to be commercial before 2025 and, at the current point in time, CCS has a very small probability of ever being available.

Overall, the outcome of the Bonn meeting appeared to be quite counter productive. America failed to shake off industrialised country liabilities for climate change. America's efforts to avoid accountability meant that America and China did not reach any form of mutual empathy. In the end, America was forced to acknowledge that China (and India) would not agree to legally binding targets. America therefore proposed a face-saving solution that would see developing countries legally bound to take measurable action on a basis comparable with other countries but that this would not be enforceable. However, neither China nor India responded to the suggested arrangement (although, as discussed below, China subsequently softened its attitude).

Following the Bonn meeting, IPCC Chairman Rajendra Pachauri reflected on the futility of America's demand for China to cap its emissions (Whiteman 2009):

> I don't think you'd expect any of the emerging markets to take an actual cut or even a commitment to reduce the rate of growth …. It doesn't make sense to be tough because, let's face it, the developed world really has not lived up to what was expected of them. I think there's a far more productive strategy, a constructive approach would be to first make a commitment to reduce emissions in the developed world, get the emerging markets to take some fairly ambitious action within their own territories, and then we move from there onwards …. If you just keep pushing the Chinese that they've got to make some kind of a commitment for cuts or reductions in emissions intensity, you're not going to get anywhere.

These thoughts had already been foreshadowed by William J. Antholis, Managing Director of The Brookings Institution, a key American adviser whose words commenced this Chapter. He adds (Antholis 2009):

> We must understand that the developing world is a diverse place, with a wide range of challenges and opportunities, and hence equities. The simple model of "north" and "south", "industrial" and "developing" no longer applies. Emerging markets blend first world economic cores with still crude industrial development, with rudimentary legal and regulatory frameworks, and with the most of extremes of poverty. Even if there are still hundreds of millions of very poor living in these nations, their central governments do have some resources for addressing their plight …. So our effort to engage with them should begin with the premise that each should be taken at their own level of development, and their own level of capacity for addressing the issues at hand. That means also acknowledging and giving credit for actions that they already may

> be taking to address climate change. In the case of China, these are already considerable, and are growing by the day .... Moreover, working with China and India in particular (as well as Russia) is critically important for how this issue connects to three other global governance challenges: nuclear energy and non-proliferation, re-energizing the global trade regime, and redrawing the scrambled global financial architecture .... The other great challenge lies beyond them, where the poorest are likely to suffer the most from climate change, and also still lack capacity to adapt and respond. Perhaps the most effective way to reach out to developing countries and to the poorest nations is by focusing on real areas of opportunity, where mitigation and adaptation can be addressed simultaneously. This certainly applies in areas such as deforestation and coastal preservation. But it also extends to infrastructure development, especially power generation, transportation, construction.

Pre-G8 Mexico City meeting

In late June 2009, nineteen countries and the European Union met in Mexico City to repair the fragmentation of the Bonn meeting. Together these countries accounted for over 80% of global greenhouse gas emissions.

Unfortunately, once more the meeting was to finish without consensus. American climate envoy Todd Stern dismissed calls for higher reduction commitments and appeared to be delaying negotiations. This lead to perceptions that President Barack Obama was resiling from the strength of commitments in his recent speeches. The Minutes suggest that America, Japan, Canada and Russia were leaning towards targets for 2050 rather than 2020.

As discussed in *Chapter 2 Political economy of the Anglo-American economic world view*, President Obama needs majority support in the Senate for any international treaty. The Senate sees itself as the defender of American unilateralism. It has a history of not supporting any international treaty that constrains America.

America is truly facing the major challenge identified at the end of Chapter 2 of whether Americans will accept a paradigm of constrained growth.

Major Economies Forum on Energy and Climate

On 9 July 2009, seventeen developed and developing economies met in L'Aquila, Italy, to form a new global institution called the Major Economies Forum on Energy and Climate (MEF). The MEF comprises Australia, Brazil, China, India, Indonesia, Korea, Mexico, South Africa and the G-8 group of nations (America, Canada, the European Union, France, Germany, Italy, Japan, Russia and the United Kingdom).

The MEF's inaugural meeting declared that the increase in global average temperatures above pre-industrial levels should not exceed 2°C and that both developed and developing countries need to work towards this goal.

The Kyoto Protocol requires only developed countries to reduce emissions. The MEF declaration restated the responsibility of industrialised countries to do this and "Take the lead by promptly undertaking robust aggregate and individual reductions …. [with] sustainable development, supported by financing, technology and capacity building."

An important new aspect of the MEF declaration was that developing countries "agreed to agree." The *communiqué* stated that developing countries would "[Commit to] promptly undertake actions whose projected effects on emissions represent a meaningful deviation from business as usual in the mid-term." Although it is well understood that any agreement to agree is unenforceable, developed countries see this outcome as providing a faint glimmer of hope that China and India may engage with the Copenhagen process.

However, any meaningful statement would have linked the responsibilities of each group of countries. The declaration fell short of this so it is likely that China and India see the *communiqué* as a mere place-filling political nicety that has little more importance or moral underpinning than the thousands of unenforceable Memorandums of Understanding they sign each year.

With the G20 assuming the mantle of the world's premier policy body in September 2009, the MEF may become a redundant body.

Pre- UNFCCC Copenhagen meeting in Bangkok

On 16 October 2009, nation members of the UNFCCC concluded talks without finding common ground for a draft Copenhagen Protocol. Whilst facing the prospect of a U.S. Senate rejection of the Boxer-Kerry Bill "Clean Jobs and American Power Act," the Obama Administration supported Australia's weak climate change policy proposal. The proposal deprecates the Kyoto Protocol and only requires that every country would agree to set a best endeavours target for emissions reduction, called Nationally Appropriate Mitigation Actions (NAMAs), and report performance (Klein 2009).

Industrialised countries rallied to this new proposal and some began to resile from existing commitments to date. For example, the European Union withdrew its pledge to contribute up to US$22 billion per annum in assistance for developing country adaptation.[xxxii] This unusual and uncharacteristic step by the European Union was later reversed in part (Kanter & Castle 2009).

China and its G-77 coalition of developing countries expressed outrage at the abrogation of responsibility by Kyoto Annex 1 industrialised nations and introducing deal breakers such as cancelling developing country adaptation funds (Pasternack 2009). It seems that this shocked indignation may have been the very response sought by industrialised countries as they endeavour to chasten China and India through playing-out a dire scenario in which no country engages in effective emissions reductions. One may also speculate about the UNFCCC's participation in the negotiations because at the end of the talks Executive Secretary Yvo de Boer, arguably uncharacteristically and prematurely, commented that the UNFCCC would now not ask for a new treaty to replace the Kyoto Protocol (Ramanayake 2009).

Shortly after the Bangkok meeting, India's Environment Minister Jairam Ramesh responded to American and the European Union hard-line demands that India and China should accept internationally-binding caps on emissions, saying “The voluntary actions of developing countries could not be equated with the commitments of developed countries” (RTTNews 2009). Perhaps even more fractious to multilateral co-operation, India and China signed a pact to develop technology and reduce greenhouse gas emissions (BBC News 2009). Their official statement noted "Internationally legally binding [greenhouse gas] reduction targets are for developed countries and developed countries alone, as globally agreed under the [2007] Bali action plan."

The penultimate drafting meeting before the December 2009 Copenhagen will be held in Barcelona in early November 2009. Little is expected to occur at this meeting as various countries have expressed the view that final negotiating positions will be reserved until the Copenhagen meeting.

NGO draft Copenhagen protocol

In October 2009, with UNFCCC member nations unable to agree on a draft protocol for the Copenhagen meeting in November 2009, Greenpeace, the World Wildlife Fund, German Watch and the David Suzuki Foundation issued a draft international treaty (Gupta 2009). As might be expected from such an *avant-garde* policy group, their approach provided a clear and equitable path forward without fear or favour and is reminiscent of the clarity in a High Court judgement. Their “level playing field” carefully closes cherished loopholes and places obligations on newly industrialised countries such as Saudi Arabia, South Korea and Singapore. For this reason it may prove to be unpopular with countries that expect to hold out for concessions and exemptions.

The key features of the draft protocol were equal per capita emissions allowances for each country and a 95% reduction in emissions by 2050 (compared to 1990). Countries would secure their emissions reductions with financial bonds, which would be forfeit should they fail to achieve their target.

Other important aspects of the proposal were enhanced reporting requirements and transparency; cooperative sharing of green technology intellectual property; contributions by industrial countries of US$160 billion per annum to assist poor countries adapt; limiting the potential rort of Clean Development Mechanisms (CDMs) by restricting CDMs to the least developed countries and small islands; and asymmetrically paying countries to reduce deforestation and forest degradation while not paying countries to increase their forest cover.

3.5 Models to manage the commons

In the *tétonnement* of a microeconomic model of supply and demand, supplier's welfare and consumer's welfare are mutually and simultaneously maximised by the equilibrium process.

In the case where the representative agent is the supplier, the model is one of competitive markets. Where the representative agent is the consumer, the model is that of a social planner. *Appendix 2 CGE modelling* provides Uhlig's poof that *a priori* there is no economic difference between competitive market optimisation and a social planners optimisation. Uhlig summarises his findings as: “Whether one studies a competitive equilibrium or the social planners problem, one ends up with the same allocation of resources” (Uhlig 1999).

The economic equivalence of competitive markets and social planning models has wide application in political economy, for example in concepts of private property and strategies to manage common resources. According to ten Raa (2005, p.139), pollution and over-exploitation of natural resources mainly occur when resources don't belong to anyone. He reasons that where ownership rights can be defined, resources will be properly managed because the owner has an incentive to do so and violation can be sanctioned by fines.

Three basic policy frameworks emerge from the concepts of competitive markets, social planing and ownership rights. These have been used to protect natural commons such as air, water, forests and fishing stocks as follows (ten Raa 2005, pp.139-41; Sachs 2008, p.37-41):

- quantitative limits through regulation, such as quotas and standards or limit on the production of a “bad”
- taxing the “bad” to provide a price disincentive
- creating a property right for a “good”, such as clean air, and selling or giving it to someone who will then price the “bad”

Often a policy response requires a complex blending of two or all three of these instruments. In recent times, quantitative limits have been successfully implemented by world governments to ameliorate damage to the ozone layer.

Quantitative limits

In 1995 atmospheric scientists Paul Crutzen, Frank Sherwood Rowling and Mario Molina shared the Nobel Prize in Chemistry "for their work in atmospheric chemistry, particularly the formation and decomposition of ozone." In the 1970s, these distinguished scientists discovered, almost by accident, that man-made nitrous oxides and chlorinated fluorocarbons (CFCs) were severely damaging the ozone layer and leading to acute health risks for humans, livestock, crops and marine phytoplankton (Crutzen 1970; Crutzen 1973; Rowland & Molina 1975).

In order to address ozone depletion, the United Nations sponsored the 1985 Vienna Convention on the Protection of the Ozone Layer. Within two years, governments began to actively phase out CFC usage pursuant to the United Nations' Montreal Protocol of 16 September 1987.[xxxiii] In fact, the ozone layer issue was ameliorated at an actual cost of one percent of the US$135bn originally suggested by critics.

However, more extensive experience has shown that generic quantitative limits are a form of social or central planning that lacks flexibility. Whilst absolute prohibition is useful in an emergency, as was the case with ozone depletion, this policy instrument is very blunt. The main issue with planned quantitative limit policies that try to be more sensitive is that this policy approach has all the deficiencies of an economic system where a government tries to pick winning strategies, industries and firms. As governments of all persuasions have discovered to their dismay, picking winners is fraught with danger.

The performance of production and consumption under any new constraint is not a static balance. It immediately becomes dynamic due to a multiplicity of feedback loops, many of which are beyond the vision of any planner. A new regulated regime rapidly becomes difficult to manage in any flexible way. For example, after the system has commenced, it is almost impossible to alter allocative decisions that have been made about which firms will receive quotas and what amount each will receive.

In his influential 1940s books *The Road to Serfdom (2001)* and *The Use of Knowledge in Society (2005)*, Friedrich Hayek argues that central planners can never have sufficient information to make quantitative decisions such as the optimal level of regulation. Hayek champions market price mechanisms for self-organising societies, which he sees as even more essential to the human condition than democracy (Hayek 1988). In 1974, Friedrich Hayek and Gunnar Myrdal shared the Nobel Prize in Economics “for their pioneering work in the theory of money and economic fluctuations and for their penetrating analysis of the interdependence of economic, social and institutional phenomena.”

In America, the prospect of Environmental Protection Agency (EPA) regulation of emissions has been bitterly opposed within industry. Notwithstanding these fears and divisions, and the issues of political economy in regard to quantitative regulation, President Obama steeled Senators and industry for renewed action by the Environmental Protection Agency (EPA) in the event Senators failed to pass the Boxer-Kerry Bill "Clean Jobs and American Power Act" (Broder 2009b). On the same day as the Boxer-Kerry Bill was introduced into the Senate, 1 October 2009, President Obama authorised a controversial but long anticipated EPA rule requiring the EPA to control the emissions of plants that emit more than 25,000 tonnes of CO_2 per annum. This covers 14,000 coal-fired electricity generators and big industrial plants that collectively are responsible for nearly 70% of American emissions.

Taxation

From 2010, France will become the first country to tax carbon emitters (Butler 2009).[xxxiv] However, the initial tax rate of Euro 17 (US$25) per tonne of CO_2 is less than an estimated Euro 40 per tonne necessary to change consumer behaviour. The tax is expected to rise to Euro 100-200 per tonne by 2020. Currently France's electricity is excluded because 90% of France's generation is from carbon-free nuclear and hydroelectric sources.[xxxv] France has the lowest cost electricity in the European Union. Its competitiveness makes it a large net exporter of electricity and nuclear technology. France stands to become highly resource expansive as other nations increase prices on dirty power.

Taxes on “bads” require the polluter to pay for the damage caused. Economists favour a system of taxes on “bads” and negative taxes (i.e. subsidies) on “goods”. These are called Pigouvian taxes because they are the marginal productivities, marginal rate of substitution and shadow prices of the disutilities (Pigou 1920). Pigou, a pioneer of welfare economics, stressed that market transactions produced externalities, which are indirect social costs and benefits.

Policy makers also favour Pigouvian taxes for simplicity and flexibility. Such taxes are administratively straight-forward, avoid allocative decisions, provide price certainty, capture activities that cannot be controlled in other ways (such as by higher level regulations), can be collected at low cost and do not require expensive overheads (such as an expensive superstructure for a market in tradeable permits). The tax rate can be raised or lowered to directly influence prices across wide sectors, expanded or contracted in coverage, and balanced with other taxes to achieve welfare objectives. They also reinforce other policies and integrate agendas such as long term environmental objectives into mainstream economic policy. The European experience with revenue neutral taxes and double dividends has been discussed above.

Many prominent American economists such as William Nordhaus, argue that taxation is the best approach for addressing global warming. James Hansen succinctly puts the case for a pure revenue neutral environmental tax (Hansen 2009):

> A carbon tax on coal, oil and gas is simple, applied at the first point of sale or port of entry. The entire tax must be returned to the public, an equal amount to each adult, a half-share for children. This dividend can be deposited monthly in an individual's bank account. A carbon tax with a 100 percent dividend is non-regressive. On the contrary, you can bet that low and middle income people will find ways to limit their carbon tax and come out ahead. Profligate energy users will have to pay for their excesses …. Demand for low-carbon high-efficiency products will spur innovation, making our products more competitive on international markets. Carbon emissions will plummet as energy efficiency and renewable energies grow rapidly …. Will the public accept a rising carbon fee? Surely – if the revenue is distributed 100% to the public, and if the rationale has been well-explained to the public. The revenue should not go to the government to send to favored industries. Will the public just turn

around and spend the dividend on the same inefficient vehicle, etc.? Probably not for long, if there are better alternatives and if the public knows the carbon price will continue to rise. And there will be plenty of innovators developing alternatives.

Property rights

In his book, *The Fatal Conceit:The Errors of Socialism* (1988), Hayek argues that the establishment of property rights was the seminal factor instrumental in the rise civilisation. Creating a property right for a resource places its economic exploitation into the hands of a profit maximising decision maker. This may be a person or company, a community management organisation, state authority or international authority, such as the United Nations. Prima facie, the decision maker is expected to act rationally by moderating the harvest of the resource to an economically sustainable level, thereby continuously maximising profit.

In the same way as a Pigouvian tax is equal to the marginal productivity, marginal rate of substitution or shadow price of the disutility, so the price of a property right is an alternative measurement of the same disutility (ten Raa 2005, p.144; Baumol & Wolff 1981).

While in theory the two approaches of tax or property rights are equivalent, there are at least six problems with creating property rights to address global warming. The first is due to the uncertainties that society faces about the marginal benefits and marginal costs of averting climate change. In this respect, a tax on emissions has the economic advantage of certainty (United States Congressional Budget Office 2009, p.4).

A second issue is social equity. Creating property rights has proven subject to corruption and there is an ever present risk that scarce, public resources might end up in the hands of powerful vested interests, who may exercise monopoly power or disenfranchise the population. James Hansen is highly critical of this risk (Hansen 2009):

> Cap-and-trade is fraught with opportunities for special interests, political trading, obfuscation from public scrutiny, accounting errors, and outright fraud …. As with any law, caps can and will be changed, many times, before 2050. The fact is that national caps have been set and are widely rejected. When caps are accepted, they are often set too high – as happened with Russia. If a complete set of tight caps were achieved, global permit trading would likely result in a Gresham’s Law effect – “bad money drives out good.” Some countries will issue too many permits or fail to enforce requirements. These permits, being cheapest, will find their way into the world market and undermine the world cap. Caps are also extremely hard to enforce, as demonstrated by the Kyoto Protocol.

As mentioned in *Chapter 1 Introduction*, Gruber (2007, p.253) agrees:

> The government is assumed to be a benign actor that serves only to implement the optimal policies to address externalities, to provide public goods and social insurance, and to develop equitable and efficient taxation. In reality, however, the government is a collection of individuals who have the difficult task of aggregating the preferences of a large set of citizens …. The core model of representative democracy suggests that governments are likely to pursue the policies of the median voter, which in most cases should fairly represent the demands of the society on average. Yet, while that model has strong evidence to support it, there is offsetting evidence that politicians have other things on their mind. In particular, there are clear examples of government's failure to maximise the well-being of its citizens, with potentially disastrous implications for economic outcomes.

A third issue in creating property rights is the issue of externalities, for example, the destruction of biodiversity of flora and fauna, clean water and clean air. For example, enclosing land that is a migratory path damages fauna. An owner looking only to profit will be unwilling to consider externalities. Only in recent years has the price charged to an owner begun to reflect the social value of species and a clean environment.

The fourth issue is that the private sector has a short term focus on profit and this is reflected in high discount rates on future profits. It will harvest the “low hanging fruit” while leaving higher cost resources to future owners. For example, enjoying open cut above ground mines now, leaving troublesome and expensive underground mines for the future; and avoiding slower growing plants and animals because they are “poor investments” (Sachs 2008, p.40). This means future consumers face a higher cost then current consumers and, all things being equal, intergenerational welfare will be distorted with current consumers enjoy a greater welfare than future consumers who are not represented in the market today.

Fifthly, as Jeffrey Sachs points out, there is a “tyranny of the present over the future” in consumption. Our societies are impatient to consume. The free market is seen as a right to consume as much as is wanted, with no regard for the future.

Lastly, the participation of non-industry sectors such as speculators, brings advantages such as liquidity, but also weaknesses such as volatility and herd behaviour driven by greed and fear.

A number of the above problems with property rights are analogous to criticisms of the unregulated markets, which became an article of reformist belief throughout the 1980s and 1990s. Professor John Freeburn says of managing Australian water rights and other national resources through this period (Slattery 2008):

> Most of the economic successes of the '90s were owed to reforms during the '80s, which were heavily run by economists working in academe, business and government ... What economists have worked out is that if you let the market go, properly define water property rights, then the consumptive uses will get it moved around between different types of uses ... At the same time we've recognised that markets don't work for the environment so we do have to have government intervention.

Lowe (2009, p.1) is far more trenchantly critical of free market dogma:

> In 2005, an almost childlike belief in the magic of the market was widespread. Otherwise intelligent observers and pragmatic politicians abandoned their understanding of the complexity of human society and the need for regulation, in favour of a touching faith that the pursuit of self-interest and the application of market forces would produce a better world. The weight of scientific evidence was showing that both Australia and the world faced very serious environmental problems that threatened our future. Despite that, concerted responses were prevented by the prevailing ideology, the extreme form of market economics.

Notwithstanding these potent criticisms of quantitative limits and property rights, such policy instruments have been successfully applied, as explained above, in ameliorating ozone depletion. Perhaps the greatest success in using property rights to protect the commons has been in abating acid rain.

America's cap & trade system for sulphur dioxide (SO_2)

In order to overcome some of the risks inherent in creating property rights, it is possible for a government to combine property rights with quantitative limits and market trading of the scarce permits. This is called a Coasian market after Coase (1960) who formulated the theory that specifying and allocating property rights for natural resources and other ecotypes leads to a price mechanism and thence to the efficient and unique allocation of resources. The second part of Coase's theorem states that the particular details of the allocation of the property right are unimportant. However, the generality of this second part remains controversial (Hurwicz 1995).

A Coasian market was used in America in 1990 to successfully abate SO_2 pollution from coal-fired generation, which had been causing acid rain for a decade (Broder 2009c).[xxxvi]

Originally, environmentalists saw cap and trade for acid rain abatement as merely a license to pollute because it freely gave valuable pollution permits to powerful vested interests. However, arguably President George H. W. Bush's Clean Air Act amendments have become the most successful domestic environmental legislation ever enacted. According to the Environmental Protection Agency (2004), there was close to complete compliance in achieving a 50% reduction in pollution over the ensuing decade. In addition, the cost of $1-$2 billion pa was significantly less than the EPA's original estimate of $2.7-4.0 billion pa (Weiss 2008; Bohi & Burtraw 1997).

The proposed American cap and trade system for climate change amelioration and abatement is similar to the current European differential model, which runs to 2012. The American government will give all the emissions permits in its treaty limit to large emitters. If emitters manage to increase efficiency and thereby save permits then they may sell their unused permits on the market to other emitters that need additional permits because they have over polluted. Emitters know that the government supply of permits will be progressively reduced and so they must move ahead of this market scarcity or face potentially high market prices for permits.

As a result of its success in abating SO_2 pollution from coal-fired generation, the use of cap and trade in reducing CO_2 pollution is seen as an easier political alternative than top-down regulation with quantity limits or a tax on fossil fuels. However, many economists argue that cap and trade is merely a carbon tax with an expensive superstructure.

Emissions trading between entities with comparative advantage

Microeconomics of Ricardian trading

David Ricardo (1817) developed his inspired theory that international trade should be based on the relative or comparative advantage of each country's commodity production rather than on the absolute advantage. His theory remains the fundamental principle of modern trade and a major argument against protectionism.

From Ricardo's theory, the advantage of an emissions trading market mechanism derives from combining the supply curves of the organisations that trade to form an aggregate supply curve. Trading allows this combination to be achieved through horizontal aggregation.

The illustration below provides an example that demonstrates how a market mechanism operates to reduce the cost for participants. It is based on the American proposals for emissions trading between nations as a condition precedent for America joining the Kyoto Protocol in 1997.[xxxvii]

The illustration shows that hypothetical CO_2 mitigation curves for America and Russia. The slope of the curve for America reflects the high cost of reducing emissions due to America's coal fired generators. The curve for America shows a cost $500 per tonne to reduce 400 tonnes of CO_2.

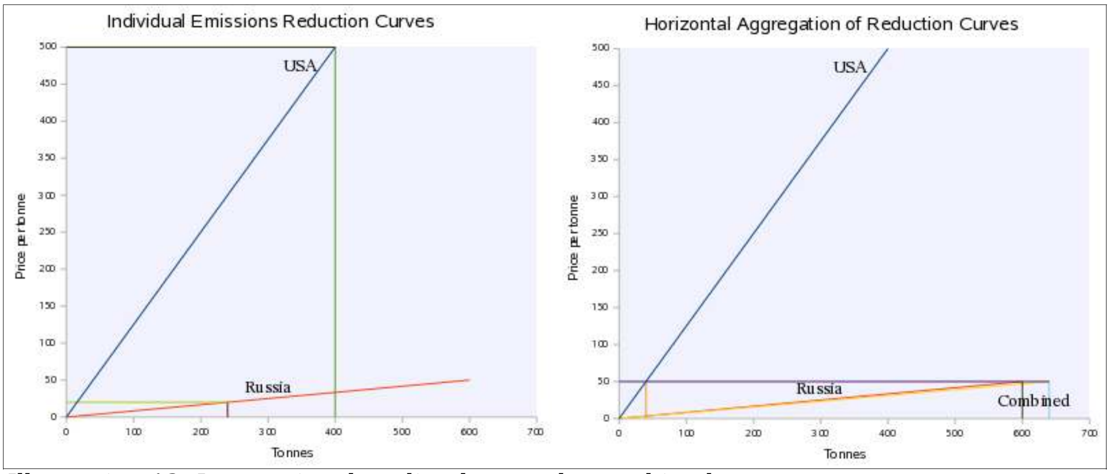


Illustration 12: International trading lowers the combined cost curve

As a predominantly nuclear nation, Russia's supply curve would have a lower cost of, say, $20 per tonne to reduce its 240 tonnes of carbon emissions. Permitting America to buy carbon emission permits from Russia can be modelled by horizontally summing the supply curves, as shown in the right hand illustration. This leads to a Combined supply curve of 640 tonnes (i.e. 400 for America plus 240 for Russia) at a price of $50 per tonne.

In this circumstance, America would reduce its carbon emissions by only 40 tonnes, which would be used for low value opportunities at a cost of $50 per tonne. Russia would reduce emissions by 600 tonnes at the same cost of $50 per tonne. America would pay Russia $50 per tonne for its increased emissions reductions of 360 tonnes.

Problems with naked market mechanisms and where parties have unequal power

Six major inherent difficulties in the market mechanism for emissions trading have been identified. The first is that the price of emissions permits rises under trading due to the price premium. This premium arises because the price of emissions permits includes commodity risk. An attendant volatility is brought into existence. The size of a financial market for a commodity is often an order of magnitude greater than the physical market. The usual volatility of the physical market due to factors such as seasonality and weather is therefore exacerbated and completely overshadowed by the risk introduced through the speculation and gearing strategies of the traders who bear the price volatility.

Secondly, there is a large amount of equity invested in the market and it is looking for a significant return. Recent problems in deregulated commodity markets were discussed in *Chapter 2 Political economy of the Anglo-American economic world view*. Trading in emissions permits will be subject to the same pressures and inefficiencies, particularly as the scarcity of permits increases.

Krugman (2009) has addressed this market deficiency in writing of Goldman Sachs' meteoric success in the immediate aftermath of the global financial crisis “The American economy remains in dire straits, with one worker in six unemployed or underemployed. Yet Goldman Sachs just reported record quarterly profits — and it’s preparing to hand out huge bonuses, comparable to what it was paying before the crisis. What does this contrast tell us? …. First, it tells us that Goldman is very good at what it does. Unfortunately, what it does is bad for America …. Other banks invested heavily in the same toxic waste they were selling to the public at large. Goldman, famously, made a lot of money selling securities backed by subprime mortgages — then made a lot more money by selling mortgage-backed securities short, just before their value crashed. All of this was perfectly legal, but the net effect was that Goldman made profits by playing the rest of us for suckers.”

Thirdly, a market has a large overhead cost for the public. This is in addition to the exacerbated commodity risks that have been so damaging in food and oil in recent years, the professional suckering that withdraws profits from commodity markets, and the public's underwriting of the sector's losses through "bail outs" that have received so much prominence in the 2008-9 Global Financial Crisis. There is a large overhead associated with any market caused by its significant deadweight cost of participants including exchange operators, compliance regulators, policy makers and lawmakers.

Fourthly is the wealthy country effect. There is little incentive for a wealthy country such as America or Australia to turn its attention to *bona fide* reductions in CO_2 emissions; remove obsolete processes or address the linked interdependencies in its economy; develop new core competences in CO_2 emissions reduction and equip local firms with these new technologies so they can have higher productivity and lower emissions; develop new agility that leads to new economies of scope and scale, and new synergies for reduction in emissions; or develop new intellectual property in unexpected ways.

The noble objective of reducing emissions is vulnerable to subversion by the amorality of powerful business coalitions and wealthy nations. Reducing everything to money has the potential to destroy a symbiosis for CO_2 reduction by materially damaging the reputation of the institutions established by the United Nations to avert the "Tragedy of the Commons." For example, Monetarists argue that the only responsibility is to "make a profit" and it is not incumbent upon Western governments and companies to apply the same ethical standards as would in their own country.[xxxviii]

Wealthy countries may well be condescending in their approach to purchasing emissions permits, arguing that whatever a smaller nation receives is better than what it received previously, which was nothing.[xxxix] Already developing countries have been exposed in using their financial position to avert *bona fide* action or even to cheat on their obligations through actions such as buying CO_2 emissions permits from third world nations in lieu of foreign aid.[xl]

Lastly, a series of payments to a small nation through the emissions market is questionable because of the inequality of power between wealthy and poor third world nations. As has been repeatedly shown in South America and Africa, exploitation, corruption and covert actions make it almost impossible for these countries to receive a fair price for their commodities.[xli]

3.6 Conclusion

This Chapter reviewed the history of climate science and policy over the last 50 years with a detailed focus on measures to replace the UNFCCC Kyoto Protocol, which is due to expire in 2012.

An analysis of “Climate change science development” examined the contributions of the pioneers Roger Revelle and Charles Keeling, the Jason Group of scientists and activists James Hansen and former American Vice President Al Gore who brought the issue of global warming to public attention. In 2007, the Intergovernmental Panel on Climate Change Assessment Report AR4 concluded that limiting global atmospheric temperature rise to 2°C (3.6°F) above the pre-industrial level was necessary to avoid severe climate change damage. Since this time many scientific groups have highlighted that emissions are tracking the IPCC worst estimates.

It was found that in mid-2009, scientists recognised that the nations of the world had only about 750 Gt CO_2 emissions capacity remaining if atmospheric global temperature rise was to be kept within 2°C with a two-thirds probability. As the world emitted approximately 45% of this amount between 2000 and 2008, the critical nature of the issue was accepted by all United Nations governments, including those of Anglo-American nations.

An analysis of “Climate change policy development” reviews the Kyoto Protocol and ensuing actions by various countries including the United Kingdom's 2001 climate levies and 2008 Climate Act, which legislated up to 42% reduction in emissions by 2020 and 80% by 2050. The European Union's approach to carbon levies was found to be heavily influenced by its difficult experiences with environmental taxes through the 1990, including the Constitutional Court of France declaring the French Government's Ecological/ Environmental Tax Reform (ETR) project unconstitutional in 2000. In addition, European countries were concerned about “carbon leakage,” which is the migration of heavy industry to countries with cheaper electricity due to a lack of carbon impost. The Asturias region of Spain was reviewed in detail. It was concluded that while the risks were real, other factors such as labour and transport costs were at least as influential as carbon costs.

In 2002, the European Union adopted a “20/20/20” target for a 20% reduction in emissions by 2020, an increase to 20% in the proportion of energy from renewable sources, and reducing energy consumption by 20%. It was found that the European Union emissions trading scheme designed to place a market price on emissions failed due to profiteering by electricity producers and financial institutions. Nevertheless, in late 2008, with the new approach of auctioning permits, the European Union reconfirmed its 20/20/20 targets for the post-Kyoto period commencing in 2013.

An examination of the “APEC Sydney Conference” of September 2007, showed that Anglo-American nations would not engage with climate change mitigation unless China and India agreed to participate. It was found that this commenced a period of testy relationships that were to continue with frustratingly little variation throughout the next two years, notwithstanding the election of Democrat President Obama. For example, the Group of 8 Hokkaido meeting in July 2008, the UNFCCC Poznan meeting in November 2008, the Washington Climate Summit in April 2009, the UNFCCC Bonn meeting and pre-G8 Mexico City talks in June 2009, the Major Economies Forum in July 2009, the G20 Summit meeting in Pittsburgh in September 2009 and the UNFCCC Bangkok talks in October 2009.

An investigation of “American climate policy development” has identified the U.S. Senate's 1997 Byrd-Hagel resolution opposing any climate treaty that would either harm the American economy or omit matching commitments from developing countries as a constant theme of America's climate change negotiations. A senior policy adviser to the American Government, William Nordhaus, brought measure to the climate change debate through climate-economic modelling. He proposed a carbon tax.

In early 2008, the U.S. Congress House Energy and Air Quality Subcommittee began to develop emissions legislation based around carbon capture and storage technology. At the same time, American industry called for tariffs on goods and services from countries with no carbon cap.

However, the climate debate only began to move forward following President Barack Obama's election in November 2008. He addressed America's renewable energy sector as part of stimulating the American economy through the Recovery Act and amended the American Clean Energy and Security Act to include small reductions in emissions of between 6% and 7% by 2020. President Obama also released the EPA to regulate greenhouse gases, as the U.S. Supreme Court had ruled it should do in 2007. The EPA also released California and other States to regulate overall State emissions and new vehicle emissions.

It was found that these measures were consolidated as America began to engage with the UNFCCC process for a new treaty to replace the Kyoto Protocol when it expires in 2012. The White House Office of Science and Technology Policy and the United States Global Change Research Program reported on the impact of global warming on America and for the first time declared climate change to be beyond scientific probability and unequivocal. This was followed with the Waxman Markey Bill and subsequently the Boxer Kerry Senate Bill to reduce emissions 20% by 2020 (compared to 2005 levels).

America's first bona fide engagement with the international community on climate change occurred at the UNFCCC Bonn meeting in June 2009. It was shown that American negotiators continued the Byrd-Hagel demand for China and India to commit to emissions targets, which they needed to convince the U.S. Senate to pass the Waxman Markey Bill. The meeting collapsed with China declining to form a kind of G-2 with America and demanding that America should agree to provide it with unfettered access to green intellectual property. America sought a face-saving solution where China would agree to unenforceable targets, which China ignored.

It was shown that America again pressed for Byrd Hagel conditions without success at UNFCCC Bangkok talks in October 2009. In what had become a somewhat desperate American negotiating strategy, the European Union joined with America to show China a scenario where no nations agreed to reduce emissions. These cliff-edge negotiations are expected to continue through to the UNFCCC Copenhagen meeting in December 2009 as the Obama Administration seeks Byrd Hagel concessions from China to fortify the passage of its Kerry-Brown Senate Bill through the U.S. Senate, which remains hostile to limiting U.S. unilateralism in any way.

There has been considerable debate about models to manage the commons. This Chapter investigated competitive market optimisation, social planners optimisation and three policy instruments for managing "bads." These policy instruments were quantitative limits, taxation and property rights. It was found that all lead to similar outcomes and a mix is often the best policy solution. A number of issues with naked market mechanisms were identified.

Chapter 2 Political economy of the Anglo-American economic world view showed that America is on the cusp of accepting its new reality of resource constrained growth. While America's past behaviour was almost universally unpopular, most world leaders see the future engagement of America across multilateral issue integration and technological entrepreneurship as far preferable to a "fortress America" situation. Nuclear non-proliferation has been the first big issue, although this has not yet reached the stage of a U.S. Senate vote. This Chapter has shown that the next big issue, protecting the global commons from climate change, has reached the stage of a vote and the Obama Administration faces a hostile Senate with little to show for twelve years of negotiation to achieve the Byrd Hagel objectives.

Chapter 2 Political economy of the Anglo-American economic world view also investigated neoclassical economics as a paradigm for Anglo-American policy. It found many strengths and weaknesses in neoclassical economics, particularly that from time to time human behaviour led to spectacular market failures requiring Keynesian lifelines. While recognising that policy formation will always be a messy process, it found continuing relevance in the neoclassical perspective. Drawing on the discussion of policy research in Chapter 1, neoclassical policy research tools remain vitally important in validating policy options.

This Chapter has further established the policy dimensions on which this doctoral research in CGE policy research will be framed. It has established a policy Base Case of 2°C rise, consistent with geophysical modelling of a 750 Gt CO_2 carbon tranche. It has established the framework and risks for carbon commodity markets (in both carbon permits and physical amelioration and abatement). It has also established that a number of scenarios are important to understanding the sensitivity of the Base Case. These scenarios include the various points of view of the dominant groups in climate change debate, the impact from increasingly severe of climate change reduction targets, the strong faith in future technological solutions and the importance of technology cost and availability, and the sensitivity of economic performance to international carbon commodity trading.

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i At Harvard, Al Gore became Revelle's student and research assistant

ii David Keeling, Charles' son, continued this work when his father died in 2005

iii Tripati's CO_2 data is provided at aradhna.tripati.googlepages.com/CO2recon.txt

iv Informally it was known as the *Jason Model of the World*

v The mean temperatures in the USA in the 1930s were very warm and similar to the 1990s while globally the 1940s were warmer. However, the year 2006 was the hottest on record and temperatures generally through 2000-2007 were higher than any other recorded year by 0.4°C to 0.48°C. UAH report the 30 year global trend as +0.13°C per decade, in line with IPCC projections. While it cannot be argued that Hansen was unambiguously correct, it is incorrect to extend this point to a conclusion that there has been zero net warming since 1988. The real problem in these "data arguments" is that there was no reliable data until the 1980s. This is complicated by the fact that terrestrial monitors produce different measurements to satellite monitors. Both climate change advocates and climate change sceptics can choose periods and monitoring technologies that make their case

vi Hansen does not favour a “cap and trade” emissions trading system. Furthermore, a bill to implement a “cap and trade” emissions trading system had recently failed to achieve US Senate support in June 2008

vii With similar letters to Australia's State Premiers

viii The IPCC's dire outlook is highlighted by Pascal's Wager. In finding the existence of God to be beyond reason, the French philosopher Blaise Pascal suggested that it would be wise to behave as if God existed because In doing so one has everything to gain, and nothing to lose (Pascal 1662, Note 233). If Pascal's logic is extended to climate change, then countries would best address the issue of CO_2 emissions because they have everything to gain and nothing to lose. There are three obvious gains. The first gain is to avoid the extraordinarily high risk of a catastrophic situation where the hypothesised outcomes from global warming and sea acidification indeed take place. The second gain is that addressing emissions will greatly reduce pollution. Experience has shown that this is generally a good thing to do. The third gain is that accelerating total factor productivity through rapid technological advances will bring much better standards of living to a much broader base of the world's population. As regards having nothing to lose, there is no cost on consumers of addressing emissions if revenue neutral environmental taxes are used as the policy instrument

ix An increase of 38% since pre-1850 levels of 280 ppm

x “Agree and ignore” where governments are assumed to not act for many reasons ranging from continuing scepticism, a desire to protect their industries, to more complex geopolitical and "game theory" reasons such as free-riding. There is also natural concern about the effects of massive change from voluntary proactive action that has material adverse effects (particularly on powerful groups such as energy companies, generators, automotive producers and petrol consumers) when reasons have an ideological component (because in science there is no absolute certainty), and the new costs and new problems in society that will be exposed such as carbon-profiteering or one nation being advantaged over another (as can occur in free-trade agreements)

xi "Step change" in which all governments respond to major climate change disasters in 2009 and 2010 with strong policy measures. This scenario mirrors acid rain, which is the only time that world governments have acted in concert. The governments agreed to cooperate only when the devastating evidence of pollution was obvious and compelling. In the "step change" scenario, an international treaty would require all carbon producing companies (coal mines and oil and gas wells) in all countries to bid for a limited and decreasing number of carbon permits in a world carbon permit market. The UN would set the "upstream cap". The price of permits would presumably soar because of their scarcity and demand for emissions-intensive products would fall commensurately. The trillions of dollars raised in auctioning permits would be spent on offsetting these impacts on humanity and as part of the the transition to the new low-carbon economy. For example the relocation of the nations like Bangladesh, Kiribati and the Maldives; amelioration of drought in West Africa, Somalia and Ethiopia; cushioning the effect of price rises on poor nations

xii In 2007, Australia's CO_2 equivalent emissions declared under the Kyoto Protocol were 825.9 million tonnes or 39.3 tonnes per capita. Schellnhuber's table draws on these Kyoto Protocol declarations. Some countries benefit from “Land Use, Land Use Change and Forestry” sinks. For example, America's CO_2 net emissions offset a sink benefit of 15% of the industrial total. Australia experiences a “Land Use” source due to bushfires and land clearing. Excluding “Land Use”, Australian emissions were 541.2 million tonnes or 25.8 tonnes per capita, which is the figure publicised by the Australian Government. The attractive concession granted uniquely to Australia so it would sign the Kyoto Protocol, that “Land Use” from bushfires and clearing is offset by new growth, has been actively debated with regard to many countries which would like the same concession. The apparent symmetry in the assumption continues to be seen as an error of logic and a glaring loophole. The current approach in the lead-up to the Copenhagen meeting in December 2009 is that countries would account for their “Land Use” but not be rewarded for new growth

xiii The “About This Report” preamble to the *Global Climate Change Impacts in the United States* report notes: The USGCRP called for this report. An expert team of scientists operating under the authority of the Federal Advisory Committee Act, assisted by communication specialists, wrote the document. The report was extensively reviewed and revised based on comments from experts and the public. The report was approved by its lead USGCRP Agency, the National Oceanic and Atmospheric Administration, the other USGCRP agencies, and the Committee on the Environment and Natural Resources on behalf of the National Science and Technology Council …. The report draws from a large body of scientific information. The foundation of this report is a set of 21 Synthesis and Assessment Products (SAPs), which were designed to address key policy-relevant issues in climate science; several of these were also summarised in the Scientific Assessment of the Effects of Climate Change on the United States published in 2008. In addition, other peer-reviewed scientific assessments were used, including those of the Intergovernmental Panel on Climate Change, the U.S. National Assessment of the Consequences of Climate Variability and Change, the Arctic Climate Impact Assessment, the National Research Council’s Transportation Research Board's report on the Potential Impacts of Climate Change on U.S. Transportation, and a variety of regional climate impact assessments. These assessments were augmented with government statistics as necessary (such as population census and energy usage) as well as publicly available observations and peer-reviewed research published through the end of 2008

xiv Note President Obama's speech to the United Nations General Assembly on 23 September 2009 (refer to discussion in Chapter 2, United Nations Security Council Resolution 1887)

xv Confirmed in 2008 by Dr. George M. Woodwell, one of the few members of that committee still alive: “Yes, I remember well that committee and how it was controlled and deflected by new economic influences as the environmental issues appeared to become acute. The study was under the auspices of the National Research Council of the National Academy of Sciences, not the National Science Foundation. We resorted to individual papers because we could not agree, or see any way to agree, on a single report. Even within my own paper there was systematic pressure to dilute the statements and the conclusions. I had previously written and signed along with Roger Revelle, David Keeling, and Gordon MacDonald a stronger statement for the CEQ at the end of the Carter administration. That statement was widely publicised by Gus Speth, then Chairman of CEQ, and ultimately used in testimony in the Congress and as background for the Global 2000 Report published by CEQ in 1980. As far as the summary statement of the Report was concerned, as the Preface states: there were "no major dissents". That means no one chose to fight with the chairman. It was poor, sickly job, deliberately made so for political reasons characteristic of the corruption of governmental purpose in the Reagan regime. Naomi Oreskes has it right.” Private correspondence disclosed with permission by John Mashey in a comment submitted on Wed, 2008-09-10 17:26 (Littlemore 2008)

xvi The present world consumption of oil is 300 billion barrels per decade. It is estimated that there is only 1.2 trillion barrels remaining. The IEA has forecast that the world needs to increase energy production by 50% from 14 Terra Watt in 2008 to 21 Terra Watt in 2030. The present mix is oil 5, coal 4, gas 3 and other (nuclear and renewable energy) 1.5-2.0. With peak-oil threatening to reduce the availability and percentage contribution of oil, there is an acute need for both substitute energy sources and alternative liquid fuels from coal-to-oil plants and shale oils. While wind, solar, tidal, geothermal, hydrogen and algae are worthwhile technologies and need to be pursued to the utmost, only nuclear fission (and ultimately fusion) has the ability to satisfy increasing demand for electricity while reducing emissions. At present France generates 70% of its power from nuclear. Japan also has a high nuclear component. The nuclear threats are reactor meltdown (as with Chernobyl's graphite cooled reactor) and weapons proliferation. The meltdown issue has been solved with new pebble-bed reactors that do not have the negative coefficients of reactivity in water cooled graphite reactors where a meltdown occurs if the cooling fails. When pebble-bed reactors are turned-off, they simply cool down

xviiSimilar to the Scopes trial in the 1920s, which was a clash of creationists and evolutionists

xviiiDonald Aitkin was formerly the vice-chancellor of the University of Canberra, foundation chairman of the Australian Research Council and a researcher at the Australian National University and Macquarie University

xixDeforestation of an acre of rainforest trees releases about 200 tonnes of carbon

xx Levied on the supply of fuels and electricity to industry, commerce, agriculture and public administration

xxiBy 30% if other developed countries commit themselves to comparable reductions

xxiiAn interregnum in Washington existed when this message was delivered by Barack Obama's informal emissary, John Kerry. President-elect Barack Obama's 20 January 2009 inauguration was still 6 weeks away

xxiiiWilliam Nordhaus uses a 4% discount rate, which is the same conservative rate that economists often use for long term projects. At 4%, a $1,000 benefit at the hundredth year would be discounted to just $29. The same $1,000 at the two-hundredth year would be worth just 39c. However, global warming and long term mitigation over 200 years is not a normal project. The term is considerably longer than the projects to which 4% is usually applied. Sir Nicholas Stern maintains that no discounting should be applied because discriminating between current and future generations is unethical.

xxivRepresentatives Henry A. Waxman of California and Edward J. Markey of Massachusetts (Democrats)

xxvThe meeting was at the Commune Hotel, located at the Great Wall

xxviUS Department of Energy statistics

xxviiOcean acidification would prevent crustaceans forming their shells, dissolve coral reefs, threaten food security, reduce coastal protection and damage local economies. Acidification would be irreversible for thousands of years

xxviiiEquivalent to a 14% reduction by 2020 (compared to 2005 levels)

xxixIn an attempt to placate anger against Japan's 8% target, America's deputy climate change envoy, Jonathan Pershing, noted Japan's new target was for domestic reductions and compared favourably to the European Union's target of 20%, which allows for half of the reductions to be achieved through projects in developing nations. However, the American support is misleading because the important price effects of the two policies are not comparable

xxxDuring the G20's September 2009 Pittsburgh meeting, Japan's recently elected Prime Minister Yukio Hatoyama expressed optimism that Japan would achieve a full 25% reduction in emissions

xxxiChina National Development and Planning Commission Climate Policy Paper, 21 May 2009

xxxiiThe European Union's September 2009 commitment to the United Nations Adaption Fund is part of a total package from industrialised nations of US$33 billion to US$74 billion per annum

xxxiii16 September is now designated World Ozone Day

xxxivPresident Sarkozy has also noted that France and Germany may introduce a “border adjustment tax” on the assessed CO_2 pollution content of goods imported from countries with inferior climate control measures. India noted that it could respond with a 99% tax on goods imported from countries that have created the CO_2 pollution problem

xxxv In 2008, France generated 80% of its electricity from nuclear, compared to 23% from nuclear in Germany. The French say of nuclear electricity generation: “No oil, no gas, no coal, no choice.” As well as being one of the largest net exporters of electricity, France is a major exporter of nuclear technology

xxxvi Scrubbers mix lime with the flue gasses from coal-fired power stations to form calcium sulphate

xxxvii Notwithstanding the adoption of the America's proposal for emissions trading between nations, America did not ratify the Kyoto Protocol

xxxviii There is a common attitude that it is up to the governments of the third world countries to protect their citizens from practices such as sweatshops and child labour. However, often these governments deliberately turn a blind eye to these practices, or merely pay lip-service, in order to earn foreign currency or because they receive incentive payments or even bribes

xxxix Analogous to wealthy nations buying products from nations with sweatshops, child labour, slavery, abuse of human rights and abuse of the environment. Commodities often associated with these types of practices are chocolate, coffee, gold, diamonds, sports products, durable goods etc.

xl As Japan does to secure the votes of small nations in retaining loop-holes in the moratorium on whaling. Another example is that in the period from 2001 to 2007, Australia began a deliberate policy of using foreign aid as a tool of political intervention in surrounding countries

xli For example, a situation analogous to the stealthy take-over of a company on the stock market without making a proper takeover offer including adequate premium for control. Another example in the “property market” is where Israelis acquired the homes of Palestinian families in Jerusalem for modest prices, which was however part of an overall covert plan to remove Palestinian families from areas of Jerusalem. The Government of Israel intervened and declared this process to be unethical in disenfranchising a class of people of their rights without adequate compensation

Chapter 4 Economic Models for Climate Change Policy Analysis

Chapter 1 Introduction identified the role of computable general equilibrium modelling in policy research. *Chapter 2 Political economy of the Anglo-American economic world view* determined that neoclassical economics and modelling had strengths and weaknesses but remained a primary tool for evaluating policies in Anglo-American economies. *Chapter 3 Political economy of the Anglo-American world view of climate change* identified the key elements to be considered in climate policy, including changing stakeholder attitudes and technology concerns, the various ways targets might be framed and policy instruments for achieving these targets. The objective of this Chapter is to build on this fabric of change by identifying a suitable computable general equilibrium modelling approach, mathematical platform and data source to achieve the research aim.

4.1 Survey of Computable General Equilibrium modelling literature

A computable general equilibrium (CGE) model is a system of equations that describe the economy, international trade, technology and, nowadays, climate science. Economists, technologists and ecologists use these models to simulate policy options by solving the complex interactions between different technological processes and labour markets across wealthy, rapidly developing and poor regions. For example, the position taken by America, the United Kingdom and Australia at Kyoto and in Australia's recent Carbon Pollution Reduction Scheme (CPRS) were formulated on the basis of CGE modelling.

Chapter 1 Introduction noted that CGE dependence on simplified assumptions in the internally consistent neoclassical paradigm is both a strength and weakness. In *Chapter 2 Political economy of the Anglo-American economic world view* it was noted that neither individual nor collective behaviour can be fully predicted by sets of equations.

Science seeks to explain natural laws and the working of the universe through testing theories in controlled experiments *ceteris paribus*.[i] In contrast, economic and socio-technical engineering problems are huge, holistic and often pressing issues with many feedback loops and dependencies. These problems are at the core of the fabric of society. They require practical solutions with mathematical precision, while at the same time guarding against misplaced confidence in apparently precise numbers and recognising that the results are merely indicators of possible trends. Examples are Australia's planned Carbon Pollution Reduction Scheme (CPRS), the re-engineering of banking systems and major infrastructure development.

This Chapter briefly addresses the heritage of CGE economic climate models that form the jewel of many public policy centres.[ii]

General equilibrium theory

The discipline of economics arose from attempts to understand changes to the structure of society arising from the Industrial Revolution c1750. The seminal work is Adam Smith's *The Wealth of Nations* (1776), which celebrates the invisible hand of capitalism and in so doing gave birth to “classical economics”.[iii]

Of course, there were many earlier kinds of invisible hands. One of the first was Bernard Mandeville's *The Fable of the Bees, Private Vices, Public Virtues* (1723), in which he marvelled that private vices, which are publicly deplored, such as greed, vanity and ambition, indeed lead to the public virtue of prosperity.

Another invisible hand was the Physiocrats' *le droit naturel*, or natural order of things, which governed economic and social equilibriums. A prominent member of the Physiocrats, François Quesnay is remembered for developing France's *Le Tableau économique* (1758). This was the world's first economic input-output table.[iv] Today a form of Quesnay's table can be found at the core of all systems of national accounts.

In the 1930s, Wassily Leontief developed Quesnay's *Tableau* into a systematic approach to economic analysis. This lay the foundation for modern computable general equilibrium modes of economics and climate change (Wassily W. Leontief 1955; ten Raa 2005). Leontief received the 1973 Nobel Prize “for the development of the input-output method and for its application to important economic problems.” His major contribution in this area is *Input-Output Economics* (1966). Nowadays, the classical textbook on this topic is Miller & Blair's *Input output analysis: foundations and extensions* (1985).

Perhaps the earliest recognition of economics as a formal discipline and the role of “minimax” in social policy optimisation was by Claude-Henri de Rouvroy, Comte de Saint-Simon after the 1794 Terror in France. Erratic but inspired Saint-Simon was the first to maintain that mathematics would determine economics and economics would determine the future history of the world (Strathern 2002, pp.142-3).[v]

It was noted in *Chapter 2 Political Economy of the Anglo-American economic world view*, that the Rev. Thomas Robert Malthus was instrumental in preparing the first mathematical-economic model and refuting Jean-Baptiste Say's assertion that market failure could not occur in capitalism (Malthus 1798; 1820).

Chapter 2 also discussed John Stuart Mill's philosophy that production was not the sole purpose of human existence. His book *Principles of Political Economy* (1848) became the primary nineteenth textbook on classical economics. It provided the unique new insight that production and consumption (or what he called distribution) were decoupled. However, it was not until Alfred Marshall drew his masterful graph of microeconomic supply and demand scissor curves that the ramifications of this were fully appreciated. Nevertheless, Mill did appreciate that there was something akin to producers and consumers surplus and that various moral policies (such as utilitarianism) could be applied to consumption while not affecting production.

In *Elements of Pure Economics* (1877), Léon Walras developed the understanding of what constitutes a general equilibrium, or simultaneous equilibrium and clearing of all market partial equilibriums in an economy. Walras called his version of the hidden hand *tétonnement*, which is the term still employed in all macroeconomic IS-LM models (where the price is interest rate and the quantity is national income or money). Walras' understanding of the interrelatedness of markets is crucial to the solution of major economic climate models where many equilibriums occur within industries in national economies and commodity substitutions occur between industries in different countries.

Walras reduced the general equilibrium to five equations that could not be solved because the number of variables exceeded the equations. In formulating his problem, Walras was perhaps one of the first people to understand how a small number of economic equations can rapidly develop into a complex model requiring the most capable methods of operations research for solution.

Alfred Marshall (1890) is credited with creating neoclassical economics, the mathematical cousin of classical economics. He believed his new discipline would help in social reform. However, the new neoclassical economics could not be raised to the status of a Science. It was unable to be tested for falsification using controlled experiments in human behaviour (Blaug 1992).

Marshall's key innovation in classical economics was to extend Walras' general equilibrium by introducing his famous supply and demand curves for clearing of markets at prices established through partial equilibria based on marginal utility. Marginal utility was a psychological concept developed by William Jevons (1871). Marshall's second innovation was to introduce the concept of time where equilibria evolve with changes in technologies and consumer preferences.

The paradigm of economic actors trading to maximise their utilities formulated by Marshall is comprehensive and internally consistent. However, its simplifying assumptions lead to a number of weaknesses (Self 2000, p.6). These include the assumption that all commodity prices are set by the microeconomic forces of supply and demand; the assumption of perfect competition means that the presence of oligopolies, monopolies and price cartels is ignored; all actors are assumed to be rational and will continue to trade up to the point where their marginal gain is exhausted; that individual preferences, social and other preferences are exogenous to the model; and the distributions of wealth to different classes of individuals (entrepreneurs, landowners and labour) can be ignored.

Although Marshall had brought Walras' general equilibrium to maturity, there was one last step. General equilibrium was thought to be merely a theoretical construct. John von Neumann criticised its two weaknesses: that prices would sometimes need to be negative[vi] and that the model was completely abstracted from sociology, mechanical rather than human and social. In order to address the first point, Von Neumann developed his own approach to general equilibrium modelling (Von Neumann 1938; Champernowne 1945). Later he developed “game theory” to address the behavioural weakness in general equilibrium, which greatly enhanced Saint-Simon's tentative minimax social optimisation (Von Neumann 1928; von Neumann & Morgenstern 1953).

Nowadays, we employ a number of von Neumann's modelling assumptions, for example, that capital investment can be accounted for by the accumulation of commodities. Although Wassily Leontief had received a Nobel Prize for thoroughly developing François Quesnay's ideas, John von Neumann was not rewarded with the honour of a Nobel Prize for developing game theory from the early thoughts of Saint-Simon, perhaps because von Neumann was such a controversial person in other ways (Strathern 2002, pp.xiii-xxii & 275-89).

The real power of general equilibrium modelling arrived when Kenneth Arrow, Gerard Debreu and Lionel McKenzie proved that a general equilibrium could really exist in an economy (Arrow & Debreu 1954; Debreu 1959). The Arrow-Debreu theory of general equilibrium showed that markets discount future events including inventions that have not yet occurred. This led to the widespread use of computable general equilibrium (CGE) models in policy analysis. Arrow shared the 1972 Nobel Prize with John Hicks “for their pioneering contributions to general economic equilibrium theory and welfare theory.” In 1982, Gerard Debreu was also awarded the Nobel Prize “for having incorporated new analytical methods into economic theory and for his rigorous reformulation of the theory of general equilibrium.”

Computable General Equilibrium (CGE) modelling

The development of computing power since the 1970s has allowed policy makers to test the feasibility of economic paradigms and potential interventions in order to reduce the risk of policy failure. The abstract Walrasian general-equilibrium structure has been enhanced to a degree where models for policy analysis have become quite realistic models of regional, national and global economies. *Appendix 2 CGE modelling* describes at length the techniques used in elementary CGE modelling.

Partial equilibrium models are suitable for most regional analysis. In partial equilibrium analysis, major economic parameters such as economic growth are provided exogenously and changes in resources are seen as perturbations to the initial equilibrium. For example, changes to the demand curve do not affect the supply curve.

Partial equilibrium models have the same consumer utility and production functions, market clearance and resource constraints as generic general equilibrium models. The one additional feature of general equilibrium model is an income balance where the prices of commodities multiplied by the commodity volumes is equal to (or less than) the prices of the resources multiplied by the volumes of resources. In the field of linear programming, discussed later in this Chapter, this relationship is called the “Main Theorem of Linear Programming.”

The analysis of national and global affairs has increasingly required general equilibrium models where growth is calculated endogenously, changes to the demand curves of commodities have a major effect on the supply curves, and the imports and exports of countries have a major effect on growth rates.

Most major countries in the world have developed models for World Trade Organisation, GATT and Free Trade Agreements, economic integration, taxation policies, public finance, development strategies, energy security and greenhouse gas pollution policies.

Nevertheless, models are never complete and only ever a snapshot in the journey of emulating the complex and changing marketplace of the globe. There are many specialist mathematical algorithms and optimisation limitations involved. Unless policy makers remain highly specialised they can rarely retain mastery of computable general equilibrium models as a practical policy making tool. This means that the communication of results is always a challenge from specialist researchers in policy at academic institutions to policy makers in government and strategists in corporations.

Traditional computable general equilibrium (CGE) models are a set of simultaneous equations that can be solved to calculate the equilibrium balance of an economy or set of economies. There are four main groups of equations: prices and price elasticities, production and trade, economic actors (households, enterprises, government, and a “rest of the world” institution) and constraints for factors of production and commodities that have to be satisfied for the system as a whole.

The economic equations and behaviour of actors are usually solved analytically before being entered into the system of equations. These equations are then solved simultaneously. Therefore, a traditional CGE model does not seek to optimise any objective function. In practice the equations are nonlinear so cannot be solved by algebraic or linear techniques. Instead, an iterative solution seeking algorithm changes prices until a solution to the model is found.

Before test policies are introduced, the equations are calibrated to explain the payments recorded in national accounts, which are usually provided as an Input-Output table or system of double entries within a Social Accounting Matrix (SAM).

Computable General Equilibrium modelling strengths and weaknesses

The key strengths of CGE modelling are its robust consistency and use of real world data. Neoclassical microeconomic and macroeconomic theory is well developed and integrated into CGE models. The ability to endogenously model consumer and producer behaviour endows CGE with the capacity to model many different policies in the presence of inter-sectoral and intertemporal effects, tax effects and changes to trade flows. It is possible to discriminate between efficiency and distributional effects. In practice, CGE has proven to be a reliable, flexible and readily extensible policy research tool.

Weaknesses in standard CGE formulations either relate to assumptions or computational complexity. Even small CGE models with nonlinear formulations rapidly become computationally complex and demanding (see *Appendix 2 CGE modelling*).

Perhaps the major weakness in generic CGE models is the copious set of assumptions involved. Firstly, markets are assumed to be in perfect competition. It is assumed that both consumers and producers are respectively rational utility and profit maximisers with the only determinant of their behaviour being price. It is assumed that consumers are all price takers.

Secondly, equations are highly sensitive to many exogenous parameter assumptions, such as substitution, income and output elasticities. These are often not well determined. For example, the consumer elasticity of substitution assumes that everyone has the same rational behaviour and set of tradeoffs.

Functional forms developed through detailed engineering, industrial ecology and physical science provide major enhancement to model realism. However, flexible functional forms such as Constant Elasticity of Substitution (CES) and Transcendental Logarithmic (Translog) can be fitted to almost any situation. As we have already observed, correlation doesn't mean causation. The ability to force a fit by increasing the number of parameters isn't necessarily an advantage. In fact, a surprising issue to many new researchers is how quickly model complexity compounds when the researcher strives for realism by this means. The more that a CGE model becomes complex and assumption infused, the more it becomes a black box and loses meaning to everyone else. It is often better to avoid increasing assumptions unnecessarily, and to actively reduce assumptions, as will be discussed in regard to *Occam's Razor* in the next Chapter.

Thirdly, models need to be calibrated. This requires more assumptions using a selected base year for data and analogues for extended data. In addition, exogenous “macro closure” assumptions for government net surplus, aggregate savings and investment, net exports and exchange rate are required to fully determine the model. A key issue with CGE is that the “macro closure” assumptions may come to dominate the performance of the model.

Fourthly, standard Cobb-Douglas and CES functional forms embody an assumption of constant returns to scale. Therefore, standard formulations do not provide for increasing or decreasing returns to scale.

Fifthly, international capital flows are not accommodated because there are no international asset markets.

Sixthly, even though CGE equations are nonlinear, they are still linear in the sense of a single non-discontinuous paradigm or frame of reference. CGE models experience difficulty in migrating from one state to another, for example, from an initial equilibrium to a new equilibrium in a dramatically different paradigm.

One further weakness is common to all outputs from large, complex and processing intensive models. Modellers need to be so diligent with assumptions that they can fall into the trap of believing that the accuracy of outputs, which is only an artefact of the technique, is or indeed should be reality. However, the old maxim of "garbage in, garbage out" remains as valid as ever and outputs are merely a function of the assumptions, equations and numerical methodologies.

Of course, much work continues to improve CGE models. For example, the complexity of CGE models has been solved in three ways. The first is specialist modelling platforms such as GAMS and AMPL, which are discussed later in this Chapter. Presolver eliminations and linearisation algorithms have contributed greatly to computational feasibility. Lastly, new formats of equations have been developed to simplify equation schemas, for example the Negishi (welfare optimum) format and mixed complementarity open economy (MCP) format that is well suited for econometric estimation (Ginsburgh & Keyzer 1994, pp.93-7, 101-7 & 112-5). Stochastic programming has been introduced to improve the understanding of risk.

Functional forms also have been extended for scale effects, monopolistic competition, non-substitutable commodities and expanded product variety. Different types of institutional behaviour have been modelled, for example, changing consumer preferences and intertemporal tradeoffs through different discounting techniques.

Exogenous assumptions have been progressively reduced by endogenously determining investment and capital accumulation, technology innovation and diffusion, changing labour force skill levels and population growth.

World class integrated assessment models

The first CGE model has been variously attributed to Ramsay/Cass/Koopmans (Ramsey 1928; Cass 1965; Koopmans 1965); Leontief's work for the American Government (1937; 1951; 1955), Johansen's important multi-sectoral study of economic growth (MSG) using input output analysis to dispute the Arrow-Debreu model (Johansen 1960), Leontief's student Hollis Chenery, who first computed the Arrow-Debreu model (Chenery & Uzawa 1958; Chenery & Raduchel 1969), Scarf's general equilibrium following Walras (Harberger 1962; Scarf 1967; Shoven & Whalley 1984) and Adelman and Robinson's work for the Korean Government (Adelman & Robinson 1978).[vii]

CGE energy models became popular following the 1973 and 1979 oil price crises. For example, the Ford Foundation's model (Hudson & Jorgenson 1974; Ford Foundation 1974) and Manne's ETA-MACRO model (Manne 1977). Mäler (1974) is credited with the first CGE model encompassing public goods such as environmental resources. However, it was not until the 1990s that energy CGE models evolved into climate policy models, such as the OECD's global energy and environment model GREEN (Burniaux et al. 1992).[viii]

World class American and European neoclassical optimal growth integrated assessment models now include the Leontief's well known environmental extension to Input Output analysis (Wassily Leontief 1970), Dixon's ORANI (Dixon 1975; Dixon et al. 1982), which became Hertel's GTAP model (1999), and the European Union's JOULE Project model GEM-E3 (Capros et al. 1995).

It would be appropriate to include numerical assessment models such as William Nordhaus' global DICE model (Nordhaus 1979; Nordhaus & Yohe 1983; Nordhaus & Radetzki 1994; Nordhaus 2008) and Nordhaus' regional RICE model (Nordhaus & Yang 1996; Nordhaus 2009). However, in a comprehensive classification of CGE models, Bergman (2005) argues that Nordhaus' models should not be classified as CGE because they have no industries to settle in equilibrium.[ix]

In addition, there are numerous other models such as MERGE (Manne et al. 1995; Kypreos 2005; 2006; 2007), DIAM3 (Ha-Duong & Grubb 1997), DIMITRI (Annemarth M. Idenburg & Harry C. Wilting 2000; A. Faber et al. 2007; Harry C. Wilting et al. 2004; 2008), Duchin's world trade model (Duchin et al. 2002; Duchin & Steenge 2007), RESPONSE (Ambrosi et al. 2003), G-Cubed (McKibbin & Wilcoxen 1999; 2004), ENTICE (Popp 2004; 2006; 2006), MIND (Edenhofer et al. 2005), WIAGEM (Kemfert 2005), Lenzen's generalised Input-Output (Gallego & Lenzen 2005), WITCH (Bosetti et al. 2006), a Japanese information technology infused model DEARS (Homma et al. 2006), E3MG (Köhler et al. 2006), GINFORS (the Global INterindustry FORecasting System) (Meyer et al. 2007), IAM (Muller-Furstenberger & G. Stephan 2007), the World Bank's ENVISAGE model (Bussolo et al. 2008) and the PAGE2002 model used by the United Kingdom Stern Review (Hope 2006).

One of the remaining goals of CGE development is to endogenise the long term propagation of technological change through industries. This is a somewhat elusive aim because technological change tends to come in disruptive waves. Stone's RAS bi-proportional matrix balancing and scaling approach has been used for many years to introduce technological change into input output analysis (Kruithof 1937; Deming & F. F. Stephan 1940; W. W. Leontief 1941; Stone et al. 1942; Stone 1961; 1962; Stone & Brown 1962).[x] *Appendix 3 Input output tables* provides the modern approach of Wilting et al (Harry C. Wilting et al. 2004; 2008). Haoran Pan, ten Raa's former student and now research collaborator introduced S-shaped logistic, Gompertz and Bass model propagation curves (Pan 2006; Pan & Kohler 2007). As an alternative to these methods, Goulder proposes that R&D be modelled as a traded commodity (Goulder & Schneider 1999; Goulder & Mathai 2000).

World Bank & Global Trade Analysis Project (GTAP)

While many organisations such as the International Monetary Fund and Australian Treasury are keen CGE modellers, two dominant CGE groups have emerged in the world over the last decade. The first is the World Bank with the

International Food Policy Research Institute (IFPRI).[xi] The second is Purdue University's Global Trade and Analysis Project (GTAP) with Monash University's Centre of Policy Studies (CoPS). Within each group, the institutions regularly cross publish and swap staff and management.

Australia researchers have been most interested in the latter group. In 1993, the Australian Productivity Commission and Monash University assisted Thomas Hertel establish the Global Trade Analysis Project (GTAP) at Purdue University. Purdue accepted the Australian Productivity Commission's project database and CGE model of the world economy, called the Sectoral Analysis of Liberalising Trade in the East Asian Region (SALTER) (Jornini et al. 1994).[xii]

The Australian Bureau of Agricultural and Resource Economics (ABARE) became a founding member of GTAP and the Monash Centre for Policy Studies (CoPS) contributed its CGE models ORANI[xiii] and IMPACT[xiv], its Australian CGE databases and models. At GTAP, Monash's ORANI has been actively developed as GTAP's CGE model. Although it is a static single period model, GTAP's CGE model is widely used around the world, for example by Fondatzione Enri Enrico Metti (Eboli et al. 2008) and the Kiel Institute of the World Economy (Deke et al. 2001). Monash CoPS continued to develop ORANI as a dynamic model, which is now called MONASH.

In return for these Australian models, Purdue's GTAP undertook to invest in consistent Input Output tables with reconciled bilateral trade data. It now provides this data to all world modellers for a modest fee. The underlying strengths of GTAP's business model is its open source databases derived from many international and national agencies, an emphasis on quality of data through full reconciliation, an active CGE development community and a strong commitment to conferences and training.

Australian economic-climate modelling

When Australia came to investigate the impact of climate change, it already had a vigorous thirty year tradition of economic modelling at Melbourne, La Trobe, Monash and Sydney Universities and in government departments such as the Australian Bureau of Agricultural and Resource Economics and the Australian Productivity Commission.

In its literature study for the Garnaut Climate Change Review, Frontier Economics (2008, pp.2-3) listed the requirements for a CGE model that could estimate the benefits as well as the costs of greenhouse emissions:

- capable of modelling economic shocks from climate damage feedback over long time periods, not just a snapshot for a particular time, because the benefits of preventing climate change will occur in the future while the costs of the policy to prevent climate change will occur at the beginning
- the focus needs to be global, not just national, because all countries are affected by aggregate emissions and the indirect effects on a country's economy might be more important than the direct effects, for example, trade flows and exchange rate
- sufficiently flexible to take into account the numerous uncertainties in the science and economics of climate change through sensitivity analysis and eventually probabilistic inputs.

Following a review of Australian and international models, Frontier Economics concluded (pp 1 & 4) “There are numerous published CGE-based Australian studies of the costs of policies aimed at restricting Australia's greenhouse emissions but only the ABARE GIAM project has modelled the economic impact of climate change occurring …. we spent some time on GAIM because …. it allowed us to explain the underlying structure of integrated assessment models in general.”

The Global Integrated Assessment Model (GIAM) is a joint venture between ABARE and Australia's Government research organisation CSIRO (ABARE 2008) CSIRO's physical climate modelling of CO_2 induced global warming is called Mk_3L. Increases in atmospheric temperature are interpreted within GIAM as a damage function, which is used to apply negative shocks to total factor productivity. In this approach GAIM is similar to Nordhaus' DICE model. Frontier Economics notes of the GIAM project (p8) “The GIAM Project is innovative in the Australian context, is well documented (at least as far as its GTEM[xv] sub-model is concerned) and certainly represents the type of structure that is appropriate for the modelling analysis that the [Garnaut] Review requires.”

While the combination of GTEM and CSIRO's Mk_3L facilitates a climate change feedback loop and spatial economic disaggregation, a major disadvantage is that GIAM remains two distinct sub models. The coupling between climate and sectoral industry performance is therefore indirect and together with the production function, in and between industries and countries, significantly impact GIAM's dynamic performance.

On 3 October 2008, Professor Ross Garnaut discussed the *Garnaut Climate Change Review Final Report* at the Committee for Economic Development of Australia (CEDA), in a talk titled *Australia as a low-emissions economy (Garnaut 2008).* His description of the modelling process ably demonstrates the complexity and cross-disciplinary economic, technological and scientific nature of such modelling:

> The story of the transition of the Australian economy to a low emissions economy is anchored in this modelling exercise …. [which] involved some of the most complex modelling ever undertaken in Australia …. we mapped structural change in the economy out to 2100 …. Venturing into timeframes and levels of mitigation not previously explored has had its challenges. You have to make assumptions about the level of innovation you can expect to see and in a standard technology case, which is the first step in the modelling, I think we've got a set of reasonably cautious assumptions, where improvements of technology at a steady rate from bases that are known, has been assumed. But we modelled two variations on that technology theme, apart from the standard technology, which assumes best estimate improvements to known technologies based on experience. The second case we modelled was an enhanced technology scenario, which assumed improvements on the standard scenario through greater energy efficiency gains, faster learning by doing for electricity and transport and the backstop technology in agriculture. And the third variation, which we put in as an alternative to the second, was that

> at some time a backstop technology would emerge, which would at some high cost, absorb emissions from the atmosphere and offset emissions elsewhere and we assume that backstop technology would come in at US$200; that's about AU$250 today. At that point, on this third assumption we assume that there would be a technological breakthrough, that is, substantial costs would remove carbon dioxide from the air for sequestration.

Shortly after this conference, the Australian Treasury published its modelling report *Australia's Low Pollution Future* (Australian Treasury 2008). Appendix 1 of the report briefly outlines the models used (pp 203 & 218): "Treasury's climate change mitigation policy modelling includes three top-down, computable general equilibrium (CGE) models developed in Australia: Global Trade and Environment Model (GTEM)[xvi]; G-Cubed model[xvii]; and the Monash Multi-regional Forecasting (MMRF) model[xviii]."

At a Senate Estimates Enquiry, an Australian Treasury representative responded to a question from the Greens Party Senator for Tasmania, Christine Milne, describing the difficulty being experienced in modelling Australia's place in the world climate framework "These are complex models with complex exercises and take many days to solve. They are computationally very difficult for all scenarios, whether they are deep cuts or not …. We are doing simulations out over 100 years and these models are based on historical relationships and views around the near term …. We have found it computationally difficult. We have several different models that we are putting together, and the complexity of the exercise is quite significant" (Australian Standing Committee on Economics 2008)

The Australian Treasury further commented on their approach to assembling partial equilibrium models (Australian Treasury 2008, p.221):

> Most Australian results are, in the first instance, from MMRF …. Since MMRF is a multi-sectoral general equilibrium model of Australia, it takes world market conditions as given. This means that it does not determine endogenously the prices Australia faces in the world market, nor does it project the changes that may occur in demand for Australian exports. GTEM determines such prices and

> quantities, which are aggregated over all other regions using 'free on board' and 'cost insurance freight' value shares as weights. This required careful linking to ensure that the world demand curve determined within GTEM was inputted into MMRF in an appropriate way …. A partial-equilibrium representation of the export demand function faced by Australia for each GTEM commodity was derived. Responsiveness of the export demand to world price changes were estimated using GTEM parameters assuming that the rest of the world does not respond to supply-side changes that occurred in Australia. As the world economy responds to a given shock, such as the imposition of an emission price, the export demand faced by Australia shifts. A consistent measure of the shift in the export demand functions was derived and used as input into the MMRF model …. GTEM also determines the global emission price that clears the global permit market. The equilibrium permit price trajectory was used as input into the MMRF model.

Nordhaus DICE model

William Nordhaus, Sterling Professor of Economics at Yale University, has been instrumental in advising the American Government on climate policy. His Dynamic Integrated model of Climate and the Economy (DICE) discrete mathematical model has been continuously developed since 1974 to provide analysis of climate policy (Nordhaus 2008, pp.6&9):

> The [DICE] model links the factors of economic growth, CO_2 emissions, the carbon cycle, climate change, climatic changes and climate-change policies. The equations for the model are taken from different disciplines – economics, ecology, and the earth sciences. They are then run using mathematical optimization software so that the economic and environmental outcomes can be projected …. The relationships that link economic growth, GHG emissions, the carbon cycle, the climate system, impacts and damages, and possible policies are exceedingly complex. It is extremely difficult to consider how changes in one part of the system will affect other parts of the system. For example, what will be the effect of higher economic

> growth on emissions and temperature trajectories? What will be the effect of higher fossil-fuel prices on climate change? How will the Kyoto Protocol or carbon taxes affect emissions, climate and the economy? The purpose of integrated models like the DICE model is not to provide definitive answers to these questions, for no definitive answers are possible, given the inherent uncertainties about many relationships. Rather, these models strive to make sure that the answers at least are internally consistent and at best provide a state-of-the-art description of the impact of different forces and policies.

At the CEDA Conference on 3 October 2008, Professor Garnaut spoke about the William Nordhaus DICE model in response to my question about its similarity to Garnaut and Treasury modelling. Professor Garnaut commented:

> Bill Nordhaus at Yale did some very important pioneering work that I've certainly learnt from as I was gearing up to this effort. I think that our modelling is much more sophisticated on the structural side than Nordhaus'. It takes the detail of changing technologies much further than Nordhaus' work, but his was very important pioneering work. We come up with higher costs of mitigation and higher costs of climate change than Nordhaus. Now, the biggest reasons for that are not technological. The biggest reason for that is that having reworked all the numbers on business as usual growth in emissions, we've formed the confident view that business as usual growth in emissions is far faster than Nordhaus assumed and the IPCC assumed and Stern assumed, and that changes the outcome quite a lot. Nordhaus took the view that we've got longer to deal with this than our work shows that you have.

Nordhaus seeks to constantly update his model with the latest knowledge in these areas and openly invites criticism of all his assumptions and methodologies. To facilitate this he provides all his materials on his web site, including laboratory notes of sub-models (Nordhaus 2007). An outline of the DICE model is provided in *Appendix 4 Nordhaus DICE model*.

Nordhaus also details various shortcomings in his model as follows (Nordhaus 2008, pp.28, 34-5, 45, 53, 64-5, 193-4): whilst 600 years are projected, results beyond 2050 become highly speculative because of expanding variances in economic, scientific and technological factors; damage functions are a major source of modelling uncertainty; the DICE model is global and aggregates regional data sub models, which makes the model less useful for calculating the costs and benefits of impacts and mitigation on specific regions and countries (although a parallel effort called RICE is devoted to a multiregional model); total factor productivity and carbon specific technological change are exogenous rather than an endogenous variables because the robust modelling of induced technological change has proven extremely difficult; the model has no provision for ocean carbonate chemistry, which scientific models have shown leads to reduced CO_2 absorption over time; projecting in decades is computationally efficient but leads to a loss of annual detail; and the CONOPT optimisation solver is fast but at the expense of linearising DICE's nonlinear climate equations (it also doesn't guarantee a global solution but this has not been an issue).

Without detracting from William Nordhaus' exceptional accomplishment in building DICE, we may highlight four further limitations. The first is that DICE's inability to address regions means the model does not allow for the expansion of national and international trading, such as emissions permits trading, and spatially disaggregated substitution between these activities.

Nordhaus (2009) recently addressed this issue with a model called RICE. This model has 12 regions, including America, China, the European Union and Latin America. However, each region is assumed to produce only a single commodity and Bergman's criticism of the model not being a true CGE settlement of industries, discussed above, continues to apply. Also, RICE remains in an experimental form as Microsoft Excel spreadsheets.

The following illustrations show that geophysical outputs from RICE are quite similar to those of DICE, while a higher carbon trading price (or tax) is required due to changes in assumptions and higher growth in global output.

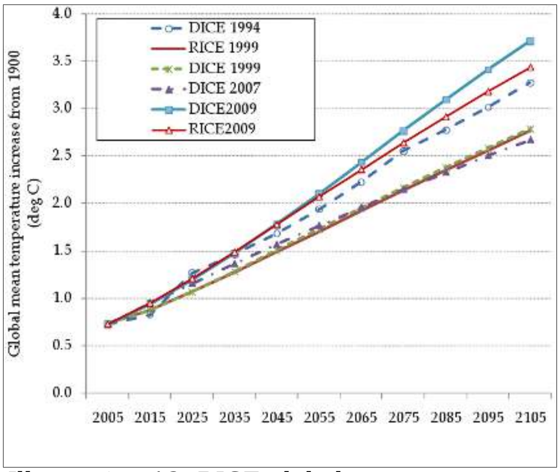

Illustration 13: RICE global temperature increase compared to previous models (Source: Nordhaus 2009 Figure 9)

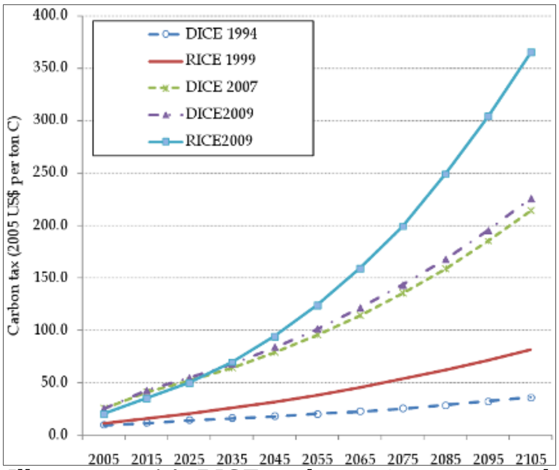

Illustration 14: RICE carbon price compared to previous models (Source: Nordhaus 2009 Figure 10)

A second limitation in DICE is the Cobb-Douglas production function used to calculate economic output. Cobb-Douglas functions are widely considered to be somewhat simplistic in comparison to Constant Elasticity of Substitution.

A third limitation, or at least a potential deficiency highlighted by Garnaut, is that climate impacts are too low because DICE uses a relatively low estimate of population growth. Population is the main driver for consumption, economic activity and emissions. Nordhaus models population saturating at 8.6 billion people in 2050 (W. Lutz et al. 2008). This compares to the United Nations median estimate of 9.15 billion, rising to a long term saturation level of 11.03 billion (United Nations 2009).

Lastly, DICE is a consumption-preferred model. Investment is the residual of production and consumption. In reality, the level of investment and accumulated capital is an important factor in economic performance. *Appendix 4 Nordhaus DICE model* shows that for any period, the increments of production, capital and consumption are all constant and predetermined by the values of various factors and starting capital. As regions, industries and commodity trade flows are not settled in equilibrium, DICE is essentially a black box function where emissions or temperature rise constraints are met by changing the emissions control rate.

Recent innovations in integrated assessment models

The integrated assessment models above indicate that the main distinction between modelling approaches has been whether the models are global, multiregional or single region models.

The second dimension of classification is whether models are fully computable general equilibrium (CGE) optimisations (either static or intertemporal) or more straightforward Leontief-type investigations into the input output table technology matrix. Elementary Input Output analysis is suitable for investigating economic interdependencies but is less so for research into sustainable policies. This is because the basic limitation of Input Output analysis is that a model is for a single country or region, a single period and “open” with respect to international trade. There is no treatment of commodity stocks and no way to ensure that prices are consistent with markets of resources because consumption, investment and exports are specified outside the model rather than endogenously determined within the model as virtual marketplaces. For example, there is no way to ensure that provision of labour and capital is consistent with returns on labour and capital, or that net exports are consistent with the comparative advantage and competitiveness of technology functions of the country or region.

Nevertheless, Input Output analysis remains popular because, in its own way, the Leontief inverse is a straight forward form of optimisation. It is equivalent to solving a system of linear equations for commodity flows. The analysis can be enhanced by introducing production functions that closely match the technology of the industry through engineering life cycle analysis. Alternatively, a generic Transcendental Logarithmic (Translog) function can be fitted to time series data using econometrics.

While the Leontief inverse remains at the centre of all CGE economic analysis, to evolve toward full CGE status it needs a superstructure of objective function, constraints and optimisation techniques.

CGE modellers generally use Input Output tables only for the data. Their systems of equations then determine economic output using a range of elasticities and production functions. Production functions can range from a relatively simple Cobb-Douglas multiplication and Constant Elasticity of Substitution (CES) to quite complex Translog functions.

Professor of Structural Economics at Tilburg University, Thijs ten Raa, has developed linear programming benchmarking into a comprehensive CGE approach for the Leontief modeller. This has built a much needed bridge between traditional CGE optimisation and relatively static Leontief investigations.

The advent of ten Raa's technique closes the Input Output model and thereby obviates the hoary old chestnut of friction between CGE modellers and Leontief modellers. It means that it is no longer necessary to classify models as CGE or Leontief, as top down or bottom up, and to join one or other of the camps. In any case, nobody could really decide whether Leontief input output analysis was indeed top down or bottom up.

4.2 Survey of Input Output modelling

As briefly mentioned above, input output analysis in economics draws its inspiration from François Quesnay's *Tableau économique* (1758). Wassily Leontief won a Nobel Prize in Economics in 1973 for his models of the US economy and trade flows using U.S. Bureau of Labor Statistics across 500 sectors, published as *Input output Analysis and Economic Structure: Studies in the Structure of the American Economy: Theoretical and Empirical Explorations in Input output Analysis* (Wassily W. Leontief 1955). Leontief also developed the linear activity model of general equilibrium or studies at a macro level. His major contribution in this area is *Input Output Economics* (1966).

Input Output tables are now widely used to predict flows between sectors of the economy. There has been considerable work on disaggregating high level inter-industry flows, for example in transportation, and investigating the effect of industry investments on profits and trade flows.

Interregional and multiregional Input Output models capture complex bilateral trade flows between trading partners and provide reliable models of global interactions. *Appendix 3 Input output tables* provides background to the

However, after frantic development through the post-war period and a quieter time in the 1990s, Augusztinovics (1995, p.275) announced the demise of Input Output analysis: “Game theory and chaos [theory] have already established themselves in economic model building. Young people, particularly, want challenging problems and are eager to respond to the new type of demand, coming mainly from the excessive financial superstructure. This is not to say that there are no valuable new results in the input-output field. Interesting and innovative papers are continuously being published that report on expansions and new applications, address novel problems, extend the subject-matter and polish the method. The heyday of Input-Output as a simple, transparent, deterministic, static linear model are, however, certainly over.”

As Mark Twain was to wryly remark in New York Journal on 2 June 1897 “The report of my death is an exaggeration”. A decade after Augusztinovics' courageous pronouncement, Input Output analysis saw a renaissance as an important analytical approach as a means of understanding globalisation. Faye Duchin, President of the Input Output Association from 2004 to 2006, noted of its renaissance: “After a lapse of a quarter of a century, models of the world economy are once again in demand in connection with prospects for improving the international distribution of income and for reducing global pressures on the environment. While virtually all empirical models of the world economy make use of input-output matrices to achieve consistent sector-level disaggregation, only input-output models make full use of sectoral interdependence to determine production levels” (Duchin 2005, p.144).

The unique feature of Input Output analysis is that rather than a single data processing technique or a mathematical formula, it provides a platform for evolving and customising new solutions to new global problems such as those involving CO_2 emissions.

The OECD has recently provided harmonised Input Output tables and bilateral trade data to support the growing interest in world models. Wixted et al. (2006) have summarised the types of policy questions that can be addressed with this data, including world value chains, R&D and embodied technology, productivity, growth, industrial ecology and sustainable development. Ahmad & Wyckoff (2003) have already demonstrated the use of bilateral trade patterns in analysing CO_2 emissions embedded in trade.

However, many economists continue to criticise input output models because the inter industry, trade and final consumption flows are purely in money values and important factor inputs such as energy and water are reduced to the "value added" sum of wages, rent, interest and profit.

Nowadays, scientists, engineers, industrial ecologists, economists and policy makers need greater flexibility in their models to incorporate physical material flows of commodities, constraints on variables such as SO_2 and CO_2 emissions and assumptions such as peak oil.

Investigating equilibria with Input Output analysis

The relationship between the additional demand and the total effects generated across the economy is called the "multiplier effect of the industry." The study of multipliers is called "impact analysis."

Multiplying the row of technical coefficients and the column of interdependence coefficients provides partial multipliers, for example to show how the balance of trade is affected by changes in import requirements in the commodities for final consumption. Partial multipliers can also be used to evaluate changes in indirect taxes, employment, capital, depreciation and subsidies.

Partial multipliers are always less than one because household income is exogenous to the input-output table. Complete Keynesian multipliers can be determined by bringing household income into the intermediate matrix. This is called "closing the matrix".

As Input Output tables are static, it is only possible to solve for the endogenous variables in one equilibrium at a time. Investigation of the shift between equilibria with different sets of values of parameters and exogenous variables is known as "comparative statics".

Comparative static analysis may be extended to dynamic analysis by taking into account the process in moving from one equilibrium state to another and investigating stability. This can be extended to dynamic optimisation where a maxima or minima is sought by setting the first differential to zero.

World multiregional input output modelling

A major reason for the renaissance in Input Output modelling over the last decade has been its ability to address spatial general equilibrium. For example, the IPCC's Special Report on Emissions Scenarios (SRES) is based on distinguishing policy in two dimensions: from efficiency to equity and from regional to global (IPCC 1995; IPCC 2001; IPCC 2007).

Wilting et al. (2004; 2008) classify the SRES scenarios as follows:

A1	Efficiency & globalisation, market economy solutions for a convergent, globalised, interactive world
A2	Efficiency & regionalisation, market economy solutions but in heterogeneous local areas for self-reliance
B1	Equity & globalisation, where local identity is important and the government generally takes a larger role to focus on resilience, robustness and ecology within a convergent, globalised, interactive world
B2	Equity & regionalisation, where local identity is important and the government generally takes a larger role to focus on resilience, robustness and ecology in heterogeneous local solutions and self-reliance

Using their DIMITRI demand driven Input Output model, Wilting et al. investigate these IPCC policy scenarios in the Netherlands for the period 2000-2030. including the effect of technological change. The authors found that current environmental pollution is in many cases due to non-sustainable production and consumption (A. Faber et al. 2007). They also concluded that technology changes this pattern but leads to unanticipated side effects.

Spatial Input Output analysis can be based on either a full specification of interregional trade flows or multi-regional flows. Leontief's Interregional (IRIO) Input Output model and the Harvard Economic Research Project's

Multiregional (MRIO) Input Output model (Polenske 1980) are each described in detail in *Appendix 3 Input output tables*.

Miller & Blair (1985, pp.69-73) differentiate between IRIO and MRIO. Theoretically, IRIO is superior to MRIO because it incorporates all inter-industry flows whereas MRIO uses some averages. However, IRIO requires significantly more data. MRIO only needs the standard format of bilateral trade input data, where the declaring importer country identifies its own importing industry and the partner exporting country. MRIO models are nevertheless quite difficult to prepare. Miller & Blair outline the issues in data handling, correcting conflicting and missing data.

In contrast, IRIO is even more fine grain. It requires the additional identification of a partner country's export industry. Unfortunately, the latter is not collected by declaring countries customs agencies and it cannot be reconciled with declaring countries records of exports.

Linear programming in input output analysis

Duchin's World Trade Model is an input output model employing linear programming to minimise the use of factor inputs like water and land, replacing international trade coefficients with the cost structure of countries and "closing" or endogenising international trade: "The values of endogenous variables – output, exports, imports, factor scarcity rents for each region, and world prices for traded goods – are determined through production assignments for all goods that are made according to comparative advantage" (Duchin 2005, p.142).

Duchin's World Trade Model identifies optimal resources uses for a given (exogenous) final demand under radical policy scenarios of sustainability rather than the incremental scenarios usual in traditional CGE models.

The key features of Duchin's model are combining both price and quantity input-output models (the price model has both resource prices and product prices with flows in the quantity Input Output model stated in physical units); mapping "value-added" from a monetary concept to payments for the factors of production; and in addition to flows, including factor stocks and extending the usual linear framework with nonlinear production functions that allow substitution of factors.

Duchin's claim of minimising factor use for a given consumption, rather than maximising consumption for a given factor use, needs some explanation. While this is an advantage over traditional CGE models, the primal and dual models inherent in all constrained Negishi-format welfare optimising models contemporaneously solves both the output maximising and input minimising formulations.

Benchmarking

Standard Costing

Managers have long endeavoured to drill into organisational performance using variance analysis. This has usually been the comparison of actual against budget performance.

Following World War II, simple variance analysis evolved into a large schema of standard costing with detailed drill-downs of production performance. The factory was seen as a “cost centre” that needed to be micromanaged across overheads, labour and materials. Each of these was finely divided into spending, efficiency and volume variances.

Unfortunately, this perfect mathematical approach to micro managing the factory led to unexpected behavioural modifications in managers and employees.[xix] The first issue was “Who set the standards?” In the zeal to bear down on costs, standards were usually tightened each year to create stretch budgets. The result was that managers and employees had a high probability of delivering negative variances, which was found to be very stressful and demotivating. Managers responded with strategies such as buying cheaper materials to maximise their divisional gross profit, which led to quality problems occurring in downstream manufacturing or service divisions.

In the 1980s, standard costing was heavily criticised for its distortions that led managers to make decisions that did not reduce costs or maximise profits.

Standard costing became regarded as mostly suitable for mass-production industries with large variable costs (such as labour) compared to fixed costs.

Standard costing was seen as inappropriate for technologically advanced or service companies with low direct labour content and multiple products sharing expensive machinery. As a result, standard costing was seen to have less relevance for the emerging service economy and custom manufacturers.

Activity Based Costing

In response to the criticism of standard costing, the management accounting profession developed new approaches that it hoped would be more logical for management behaviour. One of the most important of these was Activity Based Costing (ABC). ABC identifies “activity centres” and assigns the costs in these centres to products on the basis of cost drivers. ABC has the great advantage that products are not loaded with overheads they don't use. It appears to be beyond the controversial question of “Who sets the standards?” Unfortunately, human behaviour being what it is, managers squabbled just as much over the cost drivers in order to minimise their own cost allocations. Experience using ABC then showed that maintaining the system required extensive accounting capabilities like Enterprise Resource Planning (ERP). After all this was implemented the only benefit of ABC was the self-evident outcome that low volume products are more costly to produce than high volume products. It was possible to obtain the same results from simpler costing approaches.

Strategic Management Accounting

Management accountants then turned to strategic management accounting.[xx] By this time, Master of Business Administration students had been learning about financial, performance and strategic analysis for many decades, mainly using ratios such as sales and profit growth, market share and expenses per employee. In order to help managers focus on late twentieth century concerns, such as attracting customers, retaining customers and repelling competitors, management accountants introduced key performance indicators (KPIs). These included non-financial ratios such as customer satisfaction, quality and personnel commitment.

However the use of KPIs did not solve the basic problems in measuring performance. It was still not possible to provide unbiased answers to important performance questions (ten Raa 2008). For example, “What should be done if different companies, divisions, industries or even countries scored differently on the various ratios? What does one do with a business that scores well on one dimension and poorly in another? Which division should get the capital or the new business?”

There are various strategies in dealing with a business that has mixed performance ratios. The management of the business can be directed to excel on all ratios. Another is to bring in expertise to assist the managers do better where they are weak. A third strategy is to permit the business to continue specialising in its strengths and remove the causes of weak performance.

However, any change brings major issues with it. Doing anything always affects something else because of dependencies. One of Donald Rumsfeld's more memorable quotes was: “There are the known knowns, the known unknowns and the unknown unknowns.” Changes always lead to expected as well as unexpected tradeoffs in price and quality, and things like lower profits from the reallocation of overheads and higher wages for more specialised staff.

With KPIs not providing sufficient guidance, management turned to various other techniques, such as quality management (ISO 9000/ BS 5750 and TQM), Kaplan & Norton's Balanced Scorecard, Value-based Management and the Business Excellence Model. While all of these techniques have proven valuable in their own way, the above questions still cannot be answered definitively.

Principal Components Analysis

Organisations increasingly realised that they need to reframe the questions in new ways that captured the concept of efficiently using resources. This is very important because it changes the focus from output alone to maximising the value of assets, people and other organisational resources. The substituted questions became: “What divisions should receive the allocation of resources because the managers have done well with what they have? What level of outputs have been achieved for the input level and is this the most efficient?”

Statistical analysis contributed the technique of Principal Components Analysis (PCA), which regresses performance against input parameters to determine a production function. Residual errors from the regression line are analysed as inefficiency. It is assumed that these inefficiencies are observed in the presence of statistical noise having a normal distribution. Inefficiency is therefore the non-noise component of the error. It is expected that inefficiency will have a one-sided normal, exponential or gamma distribution.

Data Envelopment Analysis

In order to answer these same questions, Joseph Farrell developed a markedly different approach to rank production units in an unbiased way. Farrell outlines his new method of data envelopment analysis (DEA) in *The Measurement of Productive Efficiency* (1957). *Appendix 6 Benchmarking with linear programming* provides an outline of using DEA with both constant and variable returns to scale.

DEA is now widely used in management and operations research to identify inefficiency and to suggest strategies for maximising output while minimising input. It is sometimes called “frontier analysis.” A guide to DEA practice is provided by the Australian Steering Committee for the Review of Government Service Provision (1997).

DEA uses linear programming to locate piecewise linear planes or facets of the production function that sit at the outer of the observations where the greatest efficiency occurs. This technique assumes that at least some of the production units are successfully maximising efficiency, while others may not be doing so. Implicitly, the method creates a best virtual proxy on the efficient frontier for each producer. By computing the distance of these latter units from their best virtual proxy frontier and partitioning inefficiency among the inputs, strategies are suggested to make the sub-optimally performing production units more efficient.

DEA production function, marginal productivity & marginal prices

In contrast to standard costing where the budget prices are set by assumptions and managerial agendas, DEA relies on Marshall's basic tenet of classical economics that scarce resources are priced according to their marginal productivities. Organisations bid for labour and commodities until supply and demand is satisfied, which is the equilibrium where a price is set for the resource.

The prices of resources, whether value-added or not, are determined by their underlying resource content. As is shown in the discussion of CGE modelling, this is in turn determined by the technology used to manufacture the resources.

For example, air is free because there is no constraint on its availability. To date the right to pollute air with CO_2 has been free as well. This is because no-one owns the air and so there is no property right that requires payment of a rent to pollute the air. If the world's nations reach an international agreement binding countries to reduce atmospheric emissions then the right to pollute suddenly becomes scarce and binding on production. This results in the emergence of a price for the right to pollute. The price depends upon the degree of scarcity. The price also depends upon the ability of industry and consumers to reorganise themselves away from this new cost (i.e. amelioration) and the price of backstop technology services to remove emissions from industrial processes so emissions permits are not required (i.e. abatement).

How are these underlying prices set? The major feature in solving a problem of constrained resources is that shadow or accounting prices are automatically calculated by the dual solution to the linear programming primal problem (Hotelling 1932; Samuelson 1953; Houthakker 1960). These shadow prices are the Lagrange multipliers, denoted by the Greek letter *lambda* λ in honour of Joseph Louis Lagrange (1736-1813).[xxi] These prices are also the same as the marginal productivities of the resources. Free market prices of resources usually directly reflect these marginal productivities. Indeed, the difference between market prices and shadow prices provides a penetrating analytical technique to investigate the inefficiency of monopolies and oligopolies.

ten Raa (2008) shows that shadow prices can be derived from the Lagrange multipliers. For example, in the illustrations below, the performance of production unit B can increase its output by adopting best practice from A and C. Unit A might be a firm using labour to best advantage, while C might be using capital to best advantage.

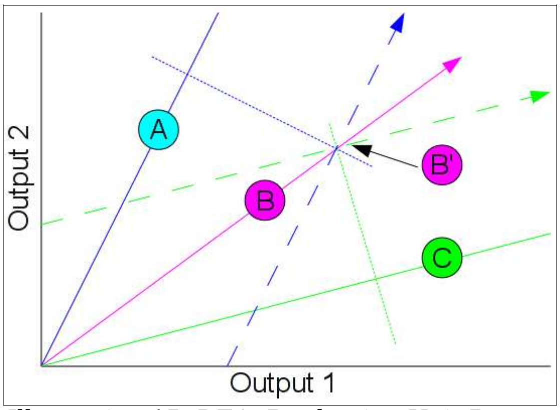

Illustration 15: DEA: Production Unit B can expand to B' using the best practices of A & C

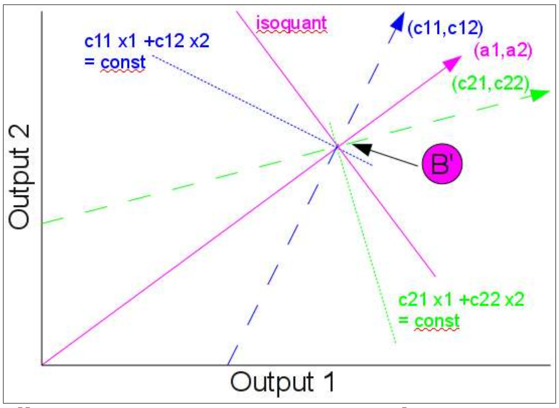

Illustration 16: DEA: Corresponding vectors and normals

Building on this example, we can see that the isoquant is the weighted average of constraints from A and B, and the vectors likewise:

$(a_{1,} a_2) \ = \ \lambda_1 (c_{11,} c_{12}) + \lambda_2 (c_{21,} c_{22})$

Where λ_1 and λ_2 are accounting prices set by the market

and λ_1 and $\lambda_2 \ \geq \ 0$

If constraint A is labour, then λ_1 is the wage rate

If constraint B is capital, then λ_2 is the interest rate to rent capital

The primal linear programming and Lagrangian dual formulations of this DEA problem are:

Maximise the isoquant: $a_1 x_1 + a_2 x_2$

Subject to:

$c_{11} x_1 + c_{12} x_2 \leq b_1$

$c_{21} x_1 + c_{22} x_2 \leq b_2$

The equivalent Lagrange formulation:

$a_1 = \lambda_1 c_{11} + \lambda_2 c_{21}$

$a_2 = \lambda_1 c_{12} + \lambda_2 c_{22}$

$\lambda_{1,} \lambda_2 \geq 0$

The "Theorem of Complementary Slackness" provides that if a constraint is non binding and slack exists, then the Lagrange multiplier is zero for that constraint i.e. $\lambda = 0$; and if a constraint is "binding" then the Lagrange multiplier is non-zero i.e. $\lambda \neq 0$.

Therefore, the following Lagrangian equations can be prepared for each constraints where either $\lambda = 0$ or $[b_1-(c_{11}x_1+c_{12}x_2)] = 0$ but both cannot be zero simultaneously:

$$\lambda_1*[b_1-(c_{11}x_1+c_{12}x_2)] = 0$$
$$\lambda_2*[b_2-(c_{21}x_1+c_{22}x_2)] = 0$$

From the “Theorem of Complementary Slackness”:

$$\lambda_1[b_1-(c_{11}x_1+c_{12}x_2)] = 0$$
$$\lambda_2[b_2-(c_{21}x_1+c_{22})x_2] = 0$$

So we can directly sum these equations, which gives:

$$\lambda_1[b_1-(c_{11}x_1+c_{12}x_2)] + \lambda_2[b_2-(c_{21}x_1+c_{22})x_2] = 0$$

Upon expanding and rearranging:

$$\lambda_1 b_1-\lambda_1 c_{11}x_1-\lambda_1 c_{12}x_2+\lambda_2 b_2-\lambda_2 c_{21}x_1-\lambda_2 c_{22}x_2 = 0$$
$$\lambda_1 b_1+\lambda_2 b_2 \quad = \lambda_1 c_{11}x_1+\lambda_2 c_{21}x_1+\lambda_1 c_{12}x_2+\lambda_2 c_{22}x_2$$
$$\lambda_1 b_1+\lambda_2 b_2 \quad = (\lambda_1 c_{11}+\lambda_2 c_{21})x_1 + (\lambda_1 c_{12}+\lambda_2 c_{22})x_2$$
$$\lambda_1 b_1+\lambda_2 b_2 \quad = a_1 x_1+a2\,x_2$$

This provides the “Main Theorem of Linear Programming” that the prices λ_1 and λ_2 measure the marginal productivity of the constrained resources b_1 and b_2 and the prices multiplied by the quantity of the input resources is equal to the output.

$$\lambda_1 b_1 + \lambda_2 b_2 = a_1 x_1 + a_2 x_2$$

Shadow prices exist even when market prices may not exist. It is this unique feature of DEA that allows organisations to be readily studied using DEA even when there are no market prices for an organisation's inputs and outputs, for example government departments and non-profit organisations.

In the above example on clean air, the second point was the ability of industry and consumers to reorganise themselves to minimise the new cost of emissions permits. This focus on reorganisation and reallocation underlies the continued evolution of CGE benchmarking out of the DEA benchmarking paradigm.[xxii]

CGE Benchmarking

From a Service Sciences perspective, the idea of CGE benchmarking is that a decision making unit is efficient if it cannot expand its output by changing its practices. In other words, the decision making unit is operating at a Nash Equilibrium.

In CGE benchmarking there is simply one number, usually denoted by the Greek letter *gamma*, that is the expansion factor achievable by using all means possible to reach maximum output, while complying with all constraints.

In the economic context, benchmarking is the process of maximising the Negishi welfare of a multi-economy system using the utilitarian assumption that the maximum welfare is the sum of the national expansions in per capita consumption. This is discussed at length in the next Chapter.[xxiii]

In 1932, von Neumann wrote “We are interested in those states where the whole economy expands without change of structure, i.e. where the ratios of the intensities $x_1 : \ldots : x_m$ remain unchanged, although $x_{1,} \ldots, x_m$ themselves may change. In such a case they are multiplied by a common factor α per unit of time. This factor is the coefficient of expansion of the whole economy” (Von Neumann 1938, p.3).

In an intertemporal context, this becomes the discounted value of the sum to infinity of the national expansions. Here we are using expansion in consumption as a proxy for the real problem of contemporaneously using all resources in the most efficient way. In an optimisation production function, the two objectives are the same, respectively the primal and dual formulations of the problem.

The mathematical calculation of the objective function with its utilitarian assumption is only of limited usefulness in comparing strategies and policies. Of much greater importance is the behaviour of shadow prices, the local and international substitution of labour and commodities and, in the case of climate models, the rate of switching from financial payment for emissions permits to paying for backstop abatement technology services to remove emissions. For example, after industry and consumers have reorganised themselves nationally and internationally as much as possible in response to price signals, it is the absolute reduction in emissions that is the important factor in ameliorating climate change.

As a result, most of the interest in benchmarking is in the constraints rather than in the objective function. Unfortunately, constraints are the most computationally expensive area. It is also where the complexity of the economic model shows itself. While the objective function may be relatively simple, each constraint in each time period is an exceedingly long symbolic equation containing the whole of the accumulated model of the economy and the climate change science equations.

Benchmarking an intertemporal multiregional input output model adds a significant layer of complexity. Firstly, consumption demand and labour supply in each country is a function of population growth. Secondly, there is a substitution of labour between industries of a country as well as the mutual substitution of commodity production with other countries, which all use different technologies. Thirdly, investment becomes an endogenous variable. Finally, accumulating climate factors become a major feedback issue.

To add even more complexity to the task, the climate equations are non-linear. This means that heavy duty non-linear optimisation techniques, such as modern interior point optimisation, need to be called upon instead of the usual fast linear programming algorithms, such as Simplex.

ten Raa input out models

In the 1970s, Thijs ten Raa was one of Wassily Leontief's research assistants. ten Raa recognised that the potential to use primary national accounts Make and Use tables for economic analysis instead of Leontief's input output tables.[xxiv] Leontief encouraged ten Raa in this alternative perspective. In 1993 it become possible for ten Raa to apply his new methodology when nations began to implement the United Nations' revised System of National Accounts, *SNA93* (United Nations 1993). A decade on, ten Raa's methodology has begun to emerge as the bridge between Leontief analysis and CGE models as mentioned above.

In addition to his reformulation of Leontief's work in terms of Make and Use tables, ten Raa's second main innovation has been the application of benchmarking in national and multiregional efficiency analysis. These innovations have been communicated through his seminal papers, which have been integrated into textbooks, such as *The Economics of Input Output Analysis* (2005) and *The Economics of Benchmarking:Measuring Performance for Competitive Advantage (2008).* A practical example of these new techniques being used that shows the extraordinary scope and impact of such studies is *Competitive pressures on China: Income inequality and migration* (ten Raa & Pan 2005).

However, it is not so much ten Raa's substituting of Make and Use tables for the Leontief A matrix in economic flows where Make and Use tables have their key advantage. It is in intertemporal models where investment and capital are endogenously calculated.[xxv]

4.3 Survey of mathematical modelling platforms

The main programs used today for solving linear and nonlinear equation systems in engineering and economics are the World Bank's General Algebraic Mathematical Solver (GAMS) and Bell Laboratories' A Mathematical Programming Language (AMPL).

The author is also aware of the requirement in economic modelling for acyclic network solvers, having previously implemented such solvers in projects involving production scheduling for ambulance and special vehicle manufacture, an accounting system and in the creation of a modelling language similar to Decision Support System (DSS).

For the purpose of building a new type of CGE model, the author conducted a survey of algebraic modelling packages using as evaluation criteria the functionality of the development packages in acyclic solvers, operations research and data visualisation.

Issues with GAMS and AMPL

Aside from the usual matters of proprietary software being expensive to licence and subject to restrictions, there are a number of issues with GAMS and AMPL programs arising from their development heritage, which stretches back to the 1970s. Firstly, the use of these packages demands a significant amount of file handling. Data is returned in files that then need to be re-read for further in packages such as R or Mathematica for further processing (e.g. data envelopment analysis, input-output analysis or graphing).

Secondly, development times can be enormously extended due to the extra time spent in pre-processing and post-processing for what is essentially a one-off research implementation. Furthermore, the locked-down environment can lead to additional features being difficult or costly to implement.

Lastly, linking the packages to various commercial and open source solvers requires understanding of the various platform specifications.

Proprietary closed-source solvers

Large scale modelling programs such as GAMS and AMPL depend upon separate solvers for which extra license fees need to be paid. These proprietary solvers include CONOPT, KNITRO, MINOS and SNOPT.[xxvi]

The key issue with these older solvers is that they do not assume convexity and seek only a local minima. However, a non-convex objective function can have several local minima, or a unique minimum given a set of constraints. For example, the energy reference system optimisation model Markal uses the MINOS solver.[xxvii] MINOS in turn uses a quasi-Newton approximation to the first gradient derivative (Hessian) method. This has no reference to convexity so if it finds a minimum and this is global minimum then this outcome is pure chance.

An issue with both a nonlinear objective and nonlinear constraints is that the problem becomes more complex in terms of convexity. CONOPT and SNOPT are usually used in this circumstance. For example, Nordhaus uses CONOPT with GAMS.

BARON, an award winning “solver-of-solvers”, uses other solvers for individual problems in global minima.[xxviii]

Programming environments

The author investigated and experimented with a number of programming environments as shown in the following table:

Environment	Description
Algencan	Stand-alone non-linear solver with integration to various languages[xxix]
AMPL	Student version of commercial package with limited number of variables & constraints. Designed for large economic models but no graphics.[xxx]
Ascend	Open source computer algebra environment, with the extraordinary advantage of generously granted access to the CONOPT solver[xxxi]
Axiom (also FriCAS, OpenAxiom)	Open source equivalent of Mathematica
Dr AMPL	Open source AMPL model checking in preparation for submission to NEOS server[xxxii]
Galahad	Stand-alone non-linear solver used by NEOS and Dr AMPL. Includes the general nonlinear solver Lancelot. Requires programs to be prepared in AMPL or Standard Input Format (SIF)
GAMS	New student version of commercial package with limited number of variables and constraints. Designed for large economic models but no graphics[xxxiii]
IPOPT	Stand-alone non-linear solver with integration in GAMS, Neos and ascend
Maple	Mathematica equivalent - literature research only
Mathematica	UTS Enterprise Licence. Exceptional symbolic and functional processing, LISP list management, Prolog pattern management, graph processing, graphics and exception optimisation functions including an implementation of the most advanced interior point solver (IPOPT) and augmented

Environment	Description
	Langrangian techniques. Unique advantage is ability for “whole of model” symbolic constraints in optimisation. Graphics output is an important feature with major advantages for communication with policy makers. While Lagrange multipliers are provided by the DualLinearProgramming function, unfortunately access is not provided for the KKT multipliers in nonlinear analysis.[xxxiv] Also tested Culoili KKT and Loehle solvers.
Matlab	UTS Enterprise License. Procedural processing primarily for matrix manipulation and inferior graphics to Mathematica
Maxima (Macsyma)	Open source equivalent of Mathematica
MuPAD	Literature research only
NEOS Server	Comprehensive solver service for no charge to run GAMS and AMPL models.[xxxv] Requires either GAMS of AMPL to design programs. Batch processing rather than interactive and no graphics.
Ocaml	Open source symbolic processor similar to Mathematica, significantly faster due to compilation but limited functionality and lacking ease of use
Octave	Open source equivalent of Matlab
OpenOpt	Open source Python framework for accessing solvers[xxxvi]
Pyneos	Open source python connector to NEOS[xxxvii]
R	Open source statistical package based on S.[xxxviii] This includes network (Carter Butts' R package for graph theory), mathgraph and genopt (Patrick Burns' R packages for graph theory and genetic non-linear solver from S Poetry[xxxix]), solver packages BB and Rdonlp2
Reduce	Literature research only
Sage	Open source equivalent of Mathematica - literature research only
Scilab	Open source equivalent of Matlab
yacas	Open source equivalent of Mathematica[xl]

Toolboxes investigated in survey:

Toolboxes	Description
Nordhaus	Equations for climate change policy modelling in GAMS[xli]
perturbationAIM	Eric Swanson's Mathematica toolbox for stochastic perturbation modelling[xlii]
Stochastic 4	Uhlig's Matlab/Octave toolbox and associated equation

Toolboxes	Description
	generator for stochastic modelling
CUTEr	Fortran procedures providing the low level functionality required by industrial solvers. Requires programming in Standard Input Format (SIF)

This hands-on survey concluded that Mathematica has many significant advantages as a development environment for complex models. Firstly, it is an “all-in” environment where all functionality is available. Secondly, it has extensive database capabilities and includes Mathematica's Country Databases with extensive economic data sets.

Thirdly, Mathematica is an algebraic symbolic processor rather a than a numeric processor like Matlab. This high productivity agile environment allows development in Mathematica's functional forms, similar to LISP list structures and Prolog pattern handling. In contrast to procedural programming in C++, Fortran, Basic or Matlab, development in Mathematica development is quick and iterative, at a very high level of abstraction. The ability to hold constraints in symbolic form is a very important advantage in complex optimisation models.

Lastly, key advantage for rapid development is Mathematica's exceptionally robust operations research functions, particularly the function FindMinimum, which incorporates the COIN Project's highly regarded interior point optimiser IPOPT. Finally, Mathematica's data visualisation functions far exceed the capability of other applications.

Acyclic processing

Many people involved with the development of solvers see an equation to be optimised as something like the polynomial $f(x) = a.x + b.x^2$ or a set of simultaneous equations like:

$$f(x) = b.x_1 + b.x_2^2$$
$$g(x) = c.x_1 + d.x_2^2$$

Solver developers rarely envisage the more complex case of recursion, for example $f(t) = a.f(t-1) + b.g(t)$. Recursive equations require a higher level of analysis using graph theory to topologically sort equations and constraints into a solvable stream.

It may be helpful to describe the problem with the analogy of a spreadsheet for those not familiar with recursive computer algebra. Spreadsheet cell connections create a geographical connection between cells. If there is a time dimension in the columns, for example 2009 to 2012, then the intersection of the column 2010 with a row, say $Revenue$, may have a formula that calculates $Revenue(2010)$ as say $Revenue(2010) = Revenue(2009) * (1 + inflation)$.

Thus recursion exists and is mapped to the geography (or topology) of the spreadsheet. From this geography, the spreadsheet algorithm calculates a network which, continuing with our example, identifies that $Revenue(2009)$ must be calculated before $Revenue(2010)$ can be calculated.

This is called an acyclic network. Sometimes the spreadsheet algorithm will not be able to calculate an acyclic network because a circular reference exists. Using our example, a circular reference would be generated if for some reason in our mass of equations that $Revenue(2009)$ depended for some reason on $Revenue(2010)$. Circular references are often found in calculating loans and interest.

Algebraic equations with time recursion like $f(t) = a.f(t-1) + b.g(t)$ therefore lead to a whole spreadsheet of variables over the domain of time. Each variable is analogous to a cell in a spreadsheet. Say there are 100 periods and 20 equations, then 2,000 variables exist. These need to be processed through a transformation stage to compute the acyclic network for the topology of the problem. Thus there are additional matrices of pointers to the next variable to be solved.

Therefore, using a non-linear solver (or optimiser) is quite difficult when a small number of equations generates a very large “spreadsheet” with a complex structure. This is where major algebraic environments like GAMS and AMPL first found their market niche.

Notwithstanding that acyclic graphs are at the heart of Mathematica's own structure and optimisation functions such as “Solve”, the survey was unable to locate a compatible acyclic solvers or solver with intermediate acyclic layer for use in Mathematica. While, many of Mathematica's functions include acyclic solvers internally within the function, this does not facilitate large scale external networks. Perhaps it is an oversight that the required functionality had not yet been developed in either the R or the Mathematica environment, particularly given that many people could find this functionality useful and Fortran network algorithms have been around for forty years.

The stochastic toolbox “perturbationAIM” by Swanson, Anderson & Levin (2005) provides a starting point to build a Mathematica acyclic processor. Using techniques drawn from this package together with Mathematica's graph processing package “Combinatorica,” the author prepared an acyclic solver for Mathematica. This allows objective functions to be stated as an acyclic network and facilitates the use of Brent's powerful non-derivative method for evaluation of unconstrained problems such as the basic Nordhaus model. *Appendix 5 Acyclic solver for unconstrained optimisation* provides the derivation of this acyclic processor.

At present, large scale acyclic processing is unsuitable for constrained problems. This is because modern constrained solvers use first and second derivatives. The development of an acyclic solver for constraints within Mathematica's “FindMinimum” solver would provide an increase in flexibility.

For example, the economic-climate model developed in this dissertation has the whole of the intertemporal economic model embedded via the constraints rather than in the objective function. The Net Present Value objective function is comparatively simple. If the value of acyclic processing in unconstrained optimisation is a good guide, the development of an acyclic solver for constraints having significant complexity would greatly enhance Mathematica's optimisation effectiveness. It is recognised that embedding an acyclic processor for constraints could be a very large and challenging task because the development of modern Interior Point techniques (for example, IPOPT) has taken three decades to reach standard solvers.

4.4 Survey of data sources

In addition to reviewing potential CGE modelling approaches and algebraic development platforms, development of a CGE policy tool requires an understanding of the structure and extent of available data through investigation and hands-on experimentation where feasible. The four sources of data investigated were National Accounting Matrices including Environmental Accounts (NAMEAs), the OECD Input Output tables and bilateral trade data, Global Trade Analysis Data Project (GTAP) and EXIPOL.

NAMEA

National Account Matrices including Environmental Accounts (NAMEAs) are national accounts of environmental emissions of 10 to 15 gases. De Haan & Keuning (1996) describe how NAMEAs provide the direct contributions of individual industries to environmental pressures, in both absolute and relative terms. For example, ores, biomass, CO_2, CO, N_2O, NH_3, NOx, SO_2, CH_4, NMVOC, Pb, PM10, nutrient pollutants, value added and full-time-equivalent jobs produced per tonne of mineral consumed. Input Output analysis of NAMEA data reconstructs the production chain, notwithstanding it may not be homogeneous.

The submission of NAMEAs by European Union member countries is voluntary, which contrasts to the requirements of ESA95 to submit an input output table every five years and annual Source and Use tables.

NAMEA matrices are used in Input Output analysis for evaluating efficiencies and targeting environmental policies. However, according to Tukker (2008), the information within NAMEAs is merely sufficient to analyse global warming impact and perhaps acidification but not the range of analysis required for external costs, total material requirements and ecological footprints.

OECD

The OECD Input Output and bilateral trade databases have been mentioned above in regard to input output models. In November 2007, the OECD released its 2006 edition of harmonised Input Output tables and bilateral trade data (OECD 2007a; 2007b).[xliii] These Input Output tables cover 28 OECD countries (all members except Iceland and Mexico) and 10 non-member countries (Argentina, Brazil, China, Chinese Taipei, India, Indonesia, Israel, Russia and South Africa. This has increased from 18 OECD countries and 2 non-OECD countries (Brazil and China) in the previous edition.

The OECD's data is insufficient for comprehensive global models. However, it has become an important foundation of all world economic databases, such as the Global Trade Analysis Project (GTAP).

GTAP

The Global Trade Analysis Project (GTAP) Version 7 database of national input output models, trade data and energy data has 2004 data for 57 sectors and 113 regions. It relies heavily on OECD's harmonised input output and STAN bilateral trade data and on IEA's energy data.

GTAP's focus on the factors of production and a world economy MRIO table are exceedingly useful in analysis. Hertel and Walmsley (2008, Chapter 1, 1.1.2) note that:

> Due to its economy-wide coverage, GTAP is particularly useful for analyzing issues that cut across many diverse sectors. This data base is particularly popular with researchers analyzing the potential impact of: (a) global trade liberalization under a future WTO round, (b) regional trade agreements, (c) economic consequences of attempts to reduce carbon dioxide (CO_2) emissions via carbon taxes, and (d) domestic impacts of economic shocks in other regions (e.g., the Asian financial crisis, or rapid growth in China). Sector-by-sector analyses of these questions can provide a valuable input into studies of these issues. However, by their very nature, these shocks affect all sectors and many regions of the world, so there is no way to

avoid employing a data base which is exhaustive in its coverage of commodities and countries. The Global Trade Analysis Project is designed to facilitate such multi-country, economy-wide analyses.

EXIOPOL

Tukker (2008) describes “A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis” (EXIOPOL). This is a Euro 5 million collaborative project of 37 institutes funded by the European Union with the 2010 objective of building a world multiregional Input Output model (MRIO) from officially reported data as well as OECD and GTAP data.

Environmental themes will be linked to the MRIO model, including the interactions and spill overs between countries of global warming, acidification, eutrophication and photochemical oxidants. The results will be used to estimate the external costs of environmental impacts and applying these results to major policy questions.

The EXIOPOL project expects to unify current work in IO analysis (IOA), material flow analysis (MFA) and life cycle assessment of products (LCA) at the company (or micro) level.

It also hopes to contribute new insights on cost-effectiveness and cost-benefit analysis to many EU Policy fields including *inter alia* a policy for integrated products, strategy for natural resources, action plans for environmental technologies, sustainable consumption and production. This will involve scenario-analysis at regional (or meso-) level and national or world (macro) level using input output analysis (given exogenous technology, emission and demand scenarios), CGE models and macro econometric models.

Data Survey Results

NAMEAs and OECD data are excellent advances but lack integration and have limited scope. The compelling advantage of GTAP data is its availability, consistency, geographic coverage and linkage with World Bank, OECD and IEA data. While commodity classification has some inconsistencies with the OECD, GTAP is progressively resolving these issues. In the future EXIOPOL may provide valuable enhancements to the GTAP database.

4.5 Conclusion

This Chapter investigates computable general equilibrium (CGE) theory and models, mathematical platforms and data sources in order to establish how the quality of climate-economic policy research might be improved by bringing together recent developments in CGE policy research techniques and assets. The Chapter extends the policy framework of *Chapter 1 Introduction* and the analysis of political economy set out Chapters 2 and 3.

A consistent thread of classical market economics and neoclassical modelling is found. This extends from Bernard Mandeville's *The Fable of the Bees, Private Vices, Public Virtues* (1723), to Léon Walras identification of mathematical equilibrium (1877), the commencement of neoclassical economics with Alfred Marshall's microeconomic supply and demand curves for partial equilibrium (1890) and to modern CGE techniques authenticated by the work of Kenneth Arrow, Gerard Debreu and Lionel McKenzie (1954).

A requirement for general equilibrium policy modelling in national and global affairs is identified with bilateral trade allowing countries to change their competitive positions. The general limitations of CGE tools were discussed from a policy perspective in *Chapter 1 Introduction*. This Chapter elaborates on the strengths and weaknesses of CGE modelling from a technical perspective.

World class integrated assessment models are reviewed. Recent best practice climate-economic modelling by the Australian Garnaut Review and Australian Treasury is closely examined. A major issue in calculating and communicating regional and commodity spatial results was identified.

Chapter 3 Political economy of the Anglo-American world view of climate change identified the policy research of the American Government's adviser William Nordhaus. This Chapter evaluates Nordhaus' Dynamic Integrated model of Climate and the Economy (DICE) model and recent regional RICE model. These models are found to have great value in understanding climate change policy, even though their equilibriums are mostly a function of the emissions control rate and do not settle across both regions and commodities.

This Chapter focuses on the renaissance of Input Output analysis in multiregional economic and technology modelling. It finds that a new form of Input Output modelling by Thijs ten Raa brings together relatively static Leontief Input Output analysis with traditional CGE optimisation.

The evolution of benchmarking from "standard costing" through to Data Envelopment Analysis is reviewed. The use of benchmarking techniques that use linear programming as a CGE market pricing technique is found to provide a new and compelling theoretical approach for intertemporal CGE modelling.

Mathematical platforms are reviewed for their ability to support benchmarking of intertemporal multiregional Input Output models and to facilitate agility and communication of spatial results through advanced data visualisation. Mathematica is found to be the most appropriate programming environment. This was verified by solving William Nordhaus' DICE model with an acyclic processor using the theory of graphs.

Data sources suitable for a benchmarking multiregional Input Output model were reviewed. The Global Trade Analysis Data Project (GTAP) database was found to be the most consistent and comprehensive data platform.

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i *ceteris paribus*: all other factors being equal
ii For example, Monash University Faculty of Business & Economics, Centre for Policy Studies Massachusetts Institute of Technology Joint Program on the Science and Policy of Global Change, Purdue University Agriculture Centre for Policy Studies
iii Although much of Smith's insights were presented in his first work *The Theory of Moral Sentiments* (1759)
iv Of course Francois Quesnay was not the first to create national accounts, which is attributed to William Petty in 1664
v Saint-Simon was also to become the father of *positivism*, which is a philosophy that accepts the existence of only positive facts
vi In fact prices can sometimes be negative, as in the case of a negative real interest rate
vii Specifying who developed the first computable general equilibrium (CGE) model is not straightforward because CGE is not a closed class of model. Traditionally, CGEs have been static single period models, run for one period or concatenated into a few periods. Since the 1990s, CGE models have become intertemporal, which is fully dynamic over multiple periods. The common characteristics of CGE models are: multiple economies with multiple sectors; the technology in each industry exhibits constant returns to scale; all markets are perfectly competitive; preferences for production and consumption are based on the single criterion of price (i.e. homothetic with no econometric estimation of supply and demand elasticities); firms seek to maximise profit and consumers seek to maximise utility; prices clear product and factor markets; there is no storage of product or factors (except capital); and there is no long term borrowing. The latter characteristic is because CGE models deal with the real economy in contrast to microeconomic models that encompass financial assets. CGE models may have technology coefficients that are determined by relative prices compared to Leontief input output models, which have fixed technology coefficients.
viii GREEN became the MIT-EPPA model

ix Nordhaus responded to this criticism by settling DICE (2007) as an equilibrium.
x Stone's acronym *RAS* for the biproportional adjustment technique is seeming his two initials *R* & *S*, with *A* inserted for the Leontief *A* direct requirements matrix. *R* & *S* were Stone's pre- and post- multiplying matrices for the *A* matrix
xi The World Bank's model is called ENVISAGE. It is based on its global trade model called LINKAGE and run in conjunction with the Bank's GIDD simulation model for personal income distribution
xii The Australian Productivity Commission developed SALTER to support APEC trade negotiations. ABARE also joined GTAP as a founding consortium member.
xiii The ORANI model is based on Lief Johansen's multisectorial study of economic growth (MSG) model. Monash CoPS has since transformed the static ORANI into a dynamic intertemporal model called MONASH. ORANI-G remains a template for single country models
xiv IMPACT is the CGE model of the Australian Industry Commission's IMPACT Project. Monash CoPS currently hosts the IMPACT Project. The IMPACT Project has assisted Monash develop ORANI, MONASH and the GEMPACK modelling environment, which is used around the world
xv GTEM is in turn a variant of the GTAP model
xvi Australian Treasury 2008 (p203): GTEM is a recursively dynamic general equilibrium model developed by ABARE to address policy issues with long-term global dimensions, such as climate change mitigation costs. It is derived from

the MEGABARE model and the static GTAP model. The dimension of GTEM used in this report represents the global economy through 13 regions (including Australia, the United States, China and India) each with 19 industry sectors and a representative household (for society). The regions are linked by trade and investment. Government policies are represented by a range of taxes and subsidies. The model also disaggregates three energy-intensive sectors into specific technologies: electricity generation, transport, and iron and steel. Some modifications have been made as part of the Treasury modelling program.

xviiAustralian Treasury 2008 (p209) G-Cubed models the global economy and is designed for climate change mitigation policy analysis. An important characteristic of G-Cubed is that economic agents are partly forward-looking: they make decisions based not only on the present day economic situation, but also based on expectations of the future. G-Cubed has limited detail on technologies. Modelling using the G-Cubed model was conducted in conjunction with the Centre for Applied economics Analysis (CAMA) and the Treasury. A report from CAMA covering the joint modelling work is available on the Treasury website.

xviiiAustralian Treasury 2008 (p211): The Monash Multi-Regional Forecasting (MMRF) model is a detailed model of the Australian economy developed by the Centre of Policy Studies (CoPS) at Monash University. MMRF has rich industry detail (with 58 industrial sectors) and provides results for all eight states and territories. It is also dynamic, employing recursive mechanisms to explain investment and sluggish adjustment in factor markets.

xixFrederick Winslow Taylor, *Father of Scientific Management*, identified this around 1900

xx Along with strategic management accounting came life cycle analysis, competitor accounting (i.e. hypothesising the performance and costs of competitors), marginal costing and target costing. In target costing, the future selling price in the market was estimated and the designers and engineers were instructed to reduce costs to the market price less the profit margin.

xxiLagrange multipliers occur in linear programming. In non-linear programming, the correct terminology is Karush Kuhn Tucker (KKT) multipliers.

xxiiRather than comparing an individual industry to its peers, generic benchmarking for CGE switches some or all of production to the most efficient industry.

xxiiiThis embodies the assumption that national expansions can only be greater than or equal to 1

xxivThe United Nations *System of National Accounts* (SNA93) requires data to be measured in make (also called “source”) tables and use tables. A Leontief input-output table can be calculated from the make-use format. The equations that connect the two formulations are: $A = U\ .\ Transpose[V]$ and $x = Transpose[V]\ .\ s$, where V and U are the make and use tables, respectively, A is the Leontief technology matrix, x is the commodity volume and s is the activity of the production sector that produces the commodity. In the Commodity-technology model using make use tables, consumption Y is determined by the equation $Y = (Transpose[V] – U)\ .\ s$ This is similar to the Leontief material balance where $x = a\ .\ x + y$

xxvPersonal communications with Thijs ten Raa in January 2009 and with ten Raa's former PhD student and now research collaborator, Haoran Pan*, suggest that ten Raa's work will address this further*

xxviCONOPT solver by ARKI Consulting & Development A/S, Bagsvaerd, Denmark (www.conopt.com). KNITRO solver by Zenia Optimization Inc. (www.ziena.com). MINO solver by Stanford Business Software, Inc (sbsi-sol-optimiSze.com/asp/sol_product_minos.htm). SNOPT solver by Philip Gill, Walter Murray and Michael Saunders, available through Stanford Business Software, Inc. (sbsi-sol-optimize.com/asp/sol_product_snopt.htm) xxviiMARKAL by the International Energy Agency (IEA) Energy Technology Systems Analysis Programme (ETSAP) (www.etsap.org/markal/main.html)

xxviiiThe Branch And Reduce Optimization Navigator (BARON) by The Sahinidis Optimization Group of Carnegie Mellon University Department of Chemical Engineering (www.andrew.cmu.edu/user/ns1b/baron/baron.html)

xxixSee www.ime.usp.br/~egbirgin/tango/index.php

xxxAMPL and GAMS employ pre-solvers to detect redundancy, determining the values of some variables before applying the algorithm and so eliminate variables and constraints. The pre-solve phase also determines if the problem is feasible. Corresponding to the pre-solve phase, a post-solver is required to restitute the original problem and variables

xxxiSee ascendwiki.cheme.cmu.edu

xxxiiSee www.gerad.ca/~orban/drampl/

xxxiiiSee AMPL and GAMS footnote above

xxxivPrivate communication with Mathematica suggests that following major enhancements in the optimisation functions, further functionality will not be possible until new developers are appointed

xxxvSee neos.mcs.anl.gov/neos/

xxxviSee scipy.org/scipy/scikits/wiki/OpenOptInstall

xxxviiSee www.gerad.ca/~orban/pyneos/pyneos.py

xxxviiiSee cran.r-project.org

xxxixSee www.burns-stat.com

xl See code.google.com/p/ryacas

xli See www.econ.yale.edu/~nordhaus/homepage/DICE2007.htm

xliiSee www.ericswanson.us/perturbation.html

xliii“Harmonised” means that the OECD input output tables use common industry definitions with the OECD's *STAN Industry Database* (STAN), Business R&D Expenditures by Industry (ANBERD) and Bilateral Trade Database (BTD). All industry classification is based on ISIC Revision 3 (OECD Input-Output Database edition 2006 - STI Working Paper 2006/8). The OECD estimates that between 85% and 95% of world trade is covered in its Bilateral Trade Database

Chapter 5 A new spatial, intertemporal CGE policy research tool

Chapter 4 Economic models for climate change policy analysis identified a suitable computable general equilibrium modelling approach, mathematical platform and data source to achieve the research aim. The objective of this Chapter is to describe and validate a benchmarking model that achieves the research aim. The new model is called Sceptre, which is an acronym for Spatial Climate Economic Policy Tool for Regional Equilibria.

5.1 Sceptre model flowchart

The flowchart in the illustration below is an abridged version of that provided along with the Mathematica code in *Appendix 8 The Sceptre model*:

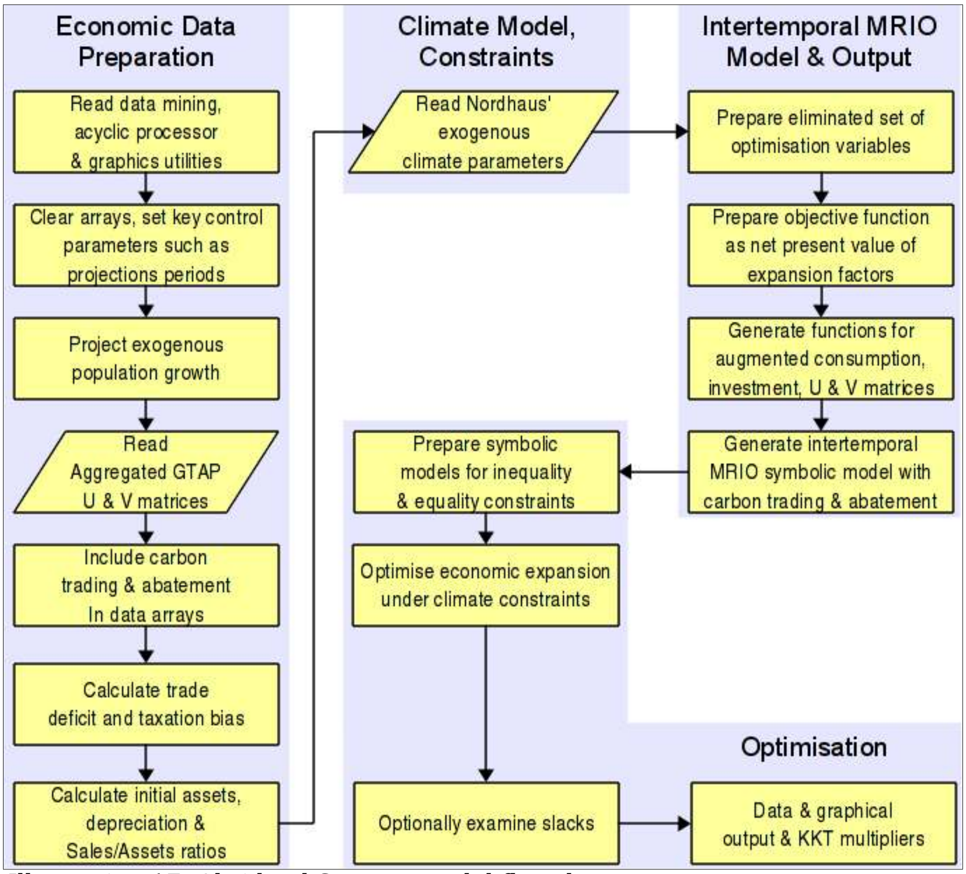


Illustration 17: Abridged Sceptre model flowchart

It may be noted that the above flowchart has three vertical swim-lanes and an optimisation pool. The first swim-lane contains those activities concerned with mining GTAP's economic and emissions data. The second swim-lane calculates exogenous climate equations and builds an endogenous symbolic model for Nordhaus' DICE model economic-climate equations. These scientific equations become a climate feedback loop within the constraints. The third swim-lane builds a multiregional input output model in symbolic form, which becomes the economic model embedded within the constraints. The optimisation pool draws upon these models to interpret the optimisation constraints in terms of the most fundamental or “minimum set” of input variables of the underlying models.

The schematic structure of the model is generally as follows:

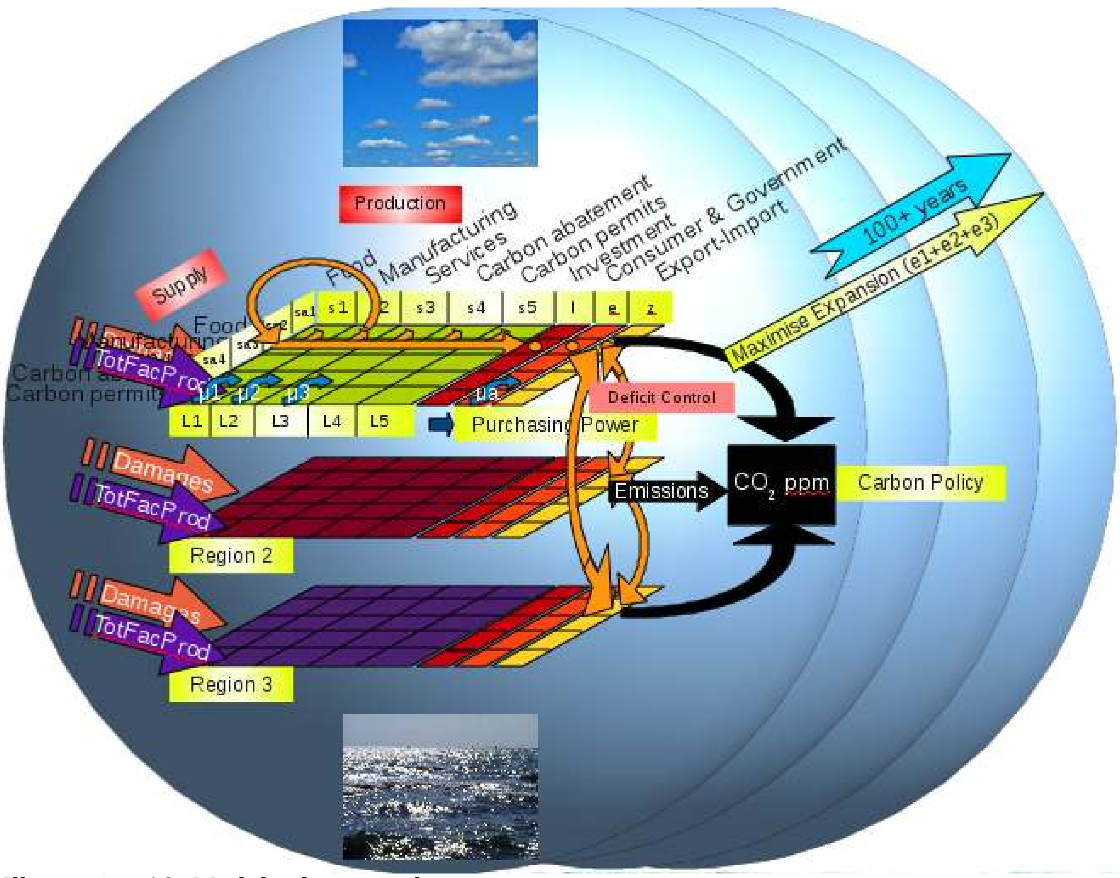


Illustration 18: Model schematic diagram

In this schematic diagram, multiple globes represent the intertemporal nature of the model. The atmosphere and oceans are geophysical carbon sinks.

Three regions are shown, which are bilaterally interconnected through trade. Trade deficits of each are controlled such that unrealistic global imbalances do not occur.

In addition, the regions are subject to an economic damage function from the common effect of carbon emissions induced global warming. A Total Factor Productivity function offsets the damage function in each region.

In each region the economy comprises aggregated food, manufacturing and services sectors together with carbon abatement and permit markets. Small blue arrows represent permit markets evolving to abatement markets as the price of carbon rises. The endogenous rate that each commodity market evolves is indicated as μ_1 to μ_3 .

The regional matrices represent tabular production functions for each commodity with s_1 to s_5 being the activity levels of the respective commodity productions sector. L_1 to L_5 represent labour constraints in each commodity sector. Sa_1 to sa_5 represent sales-to-asset ratios that mediate the relationship between the stocks and flows of each commodity.

The overall use of commodity production comprises Investment, Consumer and Government consumption and Net Exports, together with industrial uses of commodities (represented by the orange arrows). The Purchasing Power links between labour and the Consumer and Government consumption vector indicates the closure of the model for households.

The complete mathematical model is shown in the following problem specification:

Maximise $NPV(\sum \frac{\gamma}{pop})$: *where NPV is the discounted net present value of the simple sum of regional indexes of consumption per capita, calculated as the index of expansion of consumption in each regional economy* (γ), *compared to the initial period, divided by the index of population growth in each region* (pop)

$$s,\ z,\ i,\ \gamma,\ inv,\ \mu$$

Subject to:

Commodity flows balance	$(V^T - U)s * TFP * dam - \gamma\, y_0 - inv * i - exim * z = 0$	*where* V^T *is the Make matrix,* U *is the Use`matrix,* s *is industry activity, TFP is Total Factor Productivity, dam is the fractional economic damage feedback multilpier due to global temperature rise,* y_0 *is initial consumption vector, inv is investment vector with activity i & exim is net exports with activity z*
Sales $(V^T * s)$ *being limited by assets*	$V^T * s \leq s2a \cdot closewdv_{t-1}$	*where s2a is sales to asset ratio &* $closewdv_{t-1}$ *is the previous period closing written down value of assets*
Maintenance Consumption per capita	$ypc_{t-1} \leq ypc_t$	*where* ypc_t *is per capita consumption at time t*
Final Period Investment	$inv_{n-1} \leq inv_n$	*where* inv_n *is Investment in the final period*
Closing model for Trade	$Deficit_t \leq Deficit_0$	*where* $Deficit_0$ *is the initial Balance of Payments trade deficit*
Labour Endowment	$\sum L_{sector} * s \leq N$	*a region s aggregate utilisation of labour is constrained by the total labour endowment of the region*
Closing for Households	$\sum L_{sector} * s \geq$ *initial labour employed* $* \gamma$	*aggregate region workforce wages need to increase at the same rate as the consumption vector* (γ)

(continued next page)

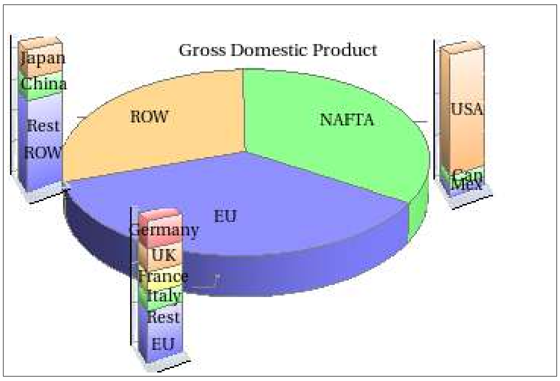
Industrial Emissions Amelioration & Abatement	*physical emissions* = $s*(1-\mu)*emissions_0$	*where* $emissions_0$ *is the initial level of industrial emissions and* μ *is the engineering control rate of emissions, which incurs a regional backstop technology cost dependent upon both* μ *& time*
Emission Permits Market	*emission permits* = $s*\mu*emissions_0$	*Emissions permits is a commodity required for carbon emitting production*
Economic Damage Function	*dam = nonlinear DICE function of cumulative emissions*	*In the DICE geophysical model, solar radiation absorbed by carbon in the atmosphere heats the atmosphere and ocean reservoirs*
Constraint on Atmospheric Temperature	*temp rise* ≤ 2 *degC (temp rise = nonlinear DICE function of cumulative emissions)*	*Example of consensus international constraint to limit prospective atmospheric temperature rise, economic damages & adverse social impacts*

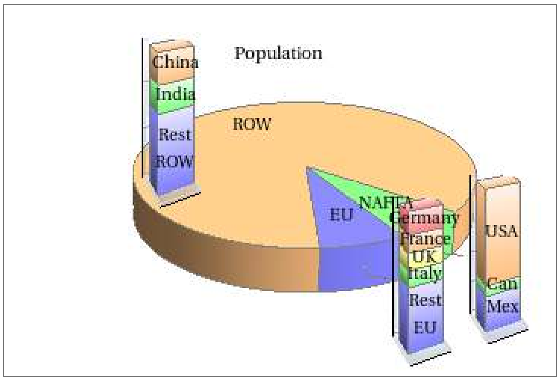
The assumptions used in developing these relationships and components are now discussed.

5.2 Model assumptions

Data

The GTAP economic and greenhouse gas emissions databases and acyclic processing are discussed in *Chapter 4 Economic models for climate change analysis*. A detailed procedure for aggregating GTAP data and preparing the data for generic economic modelling is provided in *Appendix 7 Mining the GTAP database*. The Appendix also shows how the data is cross-checked by rationalising it to GTAP's Social Accounting Matrix.





The above illustrations show how the aggregated regions of the European Union, NAFTA and Rest of World (ROW) compare in terms of Gross Domestic Product and population. It may be noted that the three aggregated regions have approximately the same share of Gross Domestic Product.

Key parameters

Four important control parameters in Sceptre are the number of periods in the projection, social discount rate, depreciation rate and labour endowment unemployment rate.

Projection periods

Mention is made a number of times above of symbolic models in the flowchart. As constraints are expressed symbolically in terms of underlying models and these models are cumulative, each additional period doubles the computing time required to prepare and optimise the policy scenario. The number of periods in a projection is therefore a balance between demonstrating long term economic and climate effects, the mathematical complexity of optimising the system, processing power and system memory.

Two issues exacerbate the problem of large models. The first is nonlinearity because it obviates the use of fast linear programming solvers. The introduction of a nonlinear economic-climate feedback loop means all linear constraints are interpreted through a nonlinear framework. This makes it much harder to satisfy constraints and leads to performance issues. For example, the linear programming optimisation of a 90 period Multi-regional Input Output (MRIO) model might take only three hours to process on a high power research computer node. Introduction of a nonlinear economic-climate equation means it becomes increasingly difficult to satisfy all constraints and necessary to find the best solution by scrubbing away at the constraints over 2,000 iterations. The capacity of the MRIO model drops to 13 periods and even this takes 15 hours to compute.[i]

As mentioned in the discussion of acyclic solvers in Chapter 4, at this point of time a sequential topological processor for constraints is not available. Therefore, extended symbolic complexity in constraints is dealt with by modelling decades rather than single years. This is consistent with Nordhaus' DICE model, which projects in decades, and facilitates the use of his calibrated economic-climate equations without modification.

Discount rate

Long term discount rates have received considerable attention amongst economists. In *A Mathematical Theory of Saving (1928, p.553)*, Ramsey assumed that:

> The rate of discounting future *utilities* must, of course, be distinguished from the rate of discounting future sums of money. If I can borrow or lend at a rate r I must necessarily be equally pleased with an extra £1 now and an extra £(1+r) in a year's time, since I could always exchange the one for the other. My marginal rate of discount for money is, therefore, necessarily r, but my rate of discount for utility may be quite different, since the marginal utility of money to me may be varying by my increasing or decreasing my expenditure as time goes on.

Ramsey derived the relationship that the rate at which consumption is discounted is equal to the sum of the rate of interest on savings and the percentage change in marginal utility times the growth of consumption. This equation, sometimes called the “Ramsey equation” provides the real rate of return on capital r, which is also called the social discount rate:

$$r = \rho + \alpha g$$
$$\text{where:}$$
$$\rho \text{ is the pure time rate of preference}$$
$$\alpha \text{ is the marginal elasticity of utility}$$
$$g \text{ is the rate of growth of consumption per generation}$$

Ramsay argued that ρ should be zero because:

> Discounting of future utilities is ethically indefensible and arises purely from a weakness of the imagination.

Sir Nicholas Stern (2007), Nordhaus (2008, pp.10 & 61; 2009) and The Garnaut Climate Change Review (2008, p28) all use the Ramsey equation, albeit with quite different parameters:

Parameter	**Stern**	**Nordhaus DICE & RICE**	**Garnaut**
Exogenous pure rate of time preference ρ	0.1%	1.5%	0.5%
Exogenous marginal elasticity of utility α	1	2	1 & 2
Endogenously calculated growth g	1.3%	Average of 2% for first 50 years and 1.25% over 100 years	Average of 1.3% for period 2003-2100
Social discount rate for savings and investment r	1.4% (Nordhaus notes that this doesn't match historical performance of 2.7%)	Average of 5.5% first 50 years and 4% over 100 years	Average of 1.35% & 2.65%, corresponding to the two values for α

Nordhaus suggests that high social discount rates reflect the real situation. This is because entrepreneurs need to create new technology having returns commensurate with other high technology investments. For example, the returns from genetically modified crops.

However, the situation is more complex than Ramsey's equation (above) suggests. For example, traditional intertemporal CGE models employ a consumption welfare function embodying Arrow-Pratt's constant relative risk aversion (CRRA) criterion. This provides a constant elasticity of intertemporal substitution of ε :

$$\varepsilon = 1/\alpha$$

$$u(c) = \frac{-c^{1-\alpha}}{(1-\alpha)}$$

where:

ε is the constant elasticity of intertemporal substitution

α is the marginal elasticity of utility

ρ is the pure time rate of preference

u is welfare utility

c is per capita consumption

This welfare function is often modified by subtracting one from the numerator in order to simplify the welfare function to the log utility $\ln(c)$ for the special case of $\alpha = 1$. By applying L'Hopital's Rule (Rudin 1976, p.109):

$$u(c) = \left[\frac{-(c^{1-\alpha}-1)}{(1-\alpha)}\right]_{\alpha\to 1} = \lim_{(1-\alpha)\to 0}\frac{-(c^{1-\alpha}-1)}{1-\alpha} = -\ln(c)$$

The effective discount rate, analogous to r in Ramsey's equation, can be calculated for the unmodified welfare function by determining the net present value and comparing to the net present value of an equivalent standard function for growth to perpetuity:

$$NPV\left[\sum_{t=1}^{\infty} u(c)\right] = \sum_{t=1}^{\infty}\frac{-[c(1+g)^{(t-1)}]^{1-\alpha}}{(1-\alpha)(1+\rho)^{t-1}} = \sum_{t=1}^{\infty}\frac{[c(1+g)^{(t-1)}]}{(1+r)^{t-1}} = c\,\frac{(1+r)}{(r-g)}$$

The result of this comparison is that the effective discount rate r is:[ii]

$$r = \frac{(1+g)^{\alpha}[c^{\alpha}(\alpha-1)+g](1+\rho) - c^{\alpha}(1+g)(\alpha-1)}{c^{\alpha}(\alpha-1)[(1+g)^{\alpha}(1+\rho)-(1+g)] - (1+g)^{\alpha}(1+\rho)}$$

In the case of $\alpha = 1$, this equation simplifies to the well-known relationship that the discount rate is equal to the growth rate of the economy $r = g$. However, in other cases the effective discount rate r is a function both of the level of consumption c and the Ramsey parameters $\{\rho, \alpha, g\}$. As a consequence, the respective equivalent discount rates for the Stern, Nordhaus and Garnaut studies vary widely with the consumption per capita c (except in the special case marked with an asterisk where $\alpha = 1$):

Social Discount Rate	**Stern**	**Nordhaus**	**Garnaut**
Ramsey (as above)	1.3%*	5.5% & 4%	1.3%* & 2.65%
With $c = 0.5$	1.3%*	2.9% & 1.9%	1.3%* & 1.8%
With $c = 1$	1.3%*	5.6% & 4%	1.3%* & 3.1%
With $c = 2$	1.3%*	1.8% & 13.4%	1.3%* & 9.0%
With $c = 3$	1.3%*	47.1% & 33.7%	1.3%* & 20.6%

While the Stern, Nordhaus and Garnaut CGE models endogenously calculate real discount rate, this is based on four independent assumptions with non-diversified cumulative errors. Two assumptions, $\{c, g\}$ vary within and across cases and the other two $\{\rho, \alpha\}$ are not well understood at all. For example, Heal (2005) notes that the utility discount rate reflects ethical judgements and its relationship to the social discount rate requires a wide understanding of political economy issues such as preferences, complementarities and substitutabilities.

For example, Weitzman (2001) reminds us that this is particularly poignant in the case of the marginal elasticity of future utilities α, which is an assumption that cannot be fully validated:

> Economic opinion is divided on a number of fundamental aspects, including what is the appropriate value of an uncertain future “marginal product of capital” …. which depends, after all, on the ultimately unpredictable rate of technological progress.

Occam's Razor, or law of parsimony, suggests *Entia non sunt multiplicanda praeter necessitatem*, which approximately translates to *Entities should not be* *multiplied more than necessary.*[iii] As one of the major weaknesses in traditional CGE modelling is the copious number of assumptions, restricting the number of assumptions in the Sceptre model has been one of the guiding principles in its design. In regard to consumption and production functions, this means a simpler explanation is better than a complex one.

As the benchmarking of economic expansion does not require a welfare utility function with constant elasticity of utility, there is no need be other than parsimonious with this assumption. The rationale for this decision is that a benchmarking model seeks to reorganise the factors of production to expand an economy by more efficiently using all available resources but at the same keeping the basket of consumed commodities in constant proportions. This contrasts to a welfare model that seeks to maximise aggregate consumption. The difference in these methods is analogous to the complementary techniques of benchmarking using Data Envelopment Analysis (DEA) and, say, using Principal Components with the Translog production function.

In an earlier survey of empirical practice, Weitzman (1998) found that the future real discount rates being used by practitioners had a mode of 2% pa, median of 3% pa and mean of 4% pa. In 2001, Weitzman suggested that economists “should” be using a schedule for real discount rates of 4% for 1 to 5 years, 3% for 6-25 years, 2% for 26-75 years and 1% for 75-300 years.

Discounting long term financial returns is relatively uncontroversial amongst equities analysts and project finance credit analysts. These finance sector analysts consider that the perpetuity growth rate of company earnings trends to the historical long term sustainable growth in Gross Domestic Product. Avoiding the recent decade of extraordinary economic stimulus and leverage, the historical median growth rates in Retained Earnings for the S&P was about 4% pa from 1960 to 1995 (Penman 2001, p.188).

A discount rate of 4%pa appears justified from the review of Anglo-American political economy in Chapters 2 & 3. A rate of 4%pa is consistent with Nordhaus' application of the Ramsey discount rate. Furthermore, in response to Weitzman's warning above, it is apparent that Anglo-Americans hold a shared and pervasive belief in the virtue of markets and technology. It is regarded as a truism of markets that future problems will elicit entrepreneurial technological innovation to solve those problems. This belief is also expressed as a strong preference for current consumption over future consumption, given that the welfare of people in the future can be "dismissed" because they will be better off due to technological progress.

A constant real discount rate of 4% pa is utilised in this research in recognition of Anglo-American confidence in economic growth through technological innovation; preference for current consumption over future; a desire for consistency with Nordhaus' economic-climate model; consistency with other researchers and the financial industry; and a desire to avoid introducing unnecessarily variables.

Depreciation rate

In accounting, depreciation is usually treated as either straight line or declining balance. The latter, declining balance, calculates depreciation in a year as the opening net balance multiplied by a depreciation rate. The base depreciation rate is assumed to be 4% pa, which is the same as GTAP's default rate. This default rate is modified to the lower of the default rate and investment as detailed below.

Unemployment rate

The labour employed in each industry may be aggregated to a labour resource. However, if the labour endowment is set to the aggregated labour resource then the constraint will be immediately binding. In an analysis of the Dutch economy, ten Raa (2005, pp.121-2) shows that the labour constraint needs to be released or freed-up by setting the labour endowment to a higher figure by compensating the resource for the unemployment rate.

In developed countries, the unemployment rate can be a slippery figure because of factors such as differences in employment participation, substitution of part-time for full-time jobs, government work programs and differential unemployment in socio-economic or demographic groups, for example, youth unemployment. The situation in developing economies is even more fluid and a term like "unemployment rate" has no meaning.

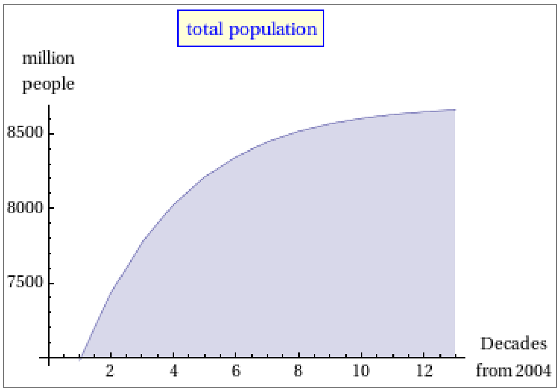
Therefore, the labour constraint is de-bound by allowing for a notional unemployment rate of 6.5% in the calculation of labour endowment. This is not a critical assumption because the labour constraint is rarely binding for two reasons. The first reason is that labour is assumed to grow with regional population. The second reason is that the climate and asset constraints bind before the labour constraint, except in extreme policy scenarios that force the economies to contract. If policy scenarios binding labour are to be investigated then the nature of the labour endowment in each region may need to be researched in more detail.

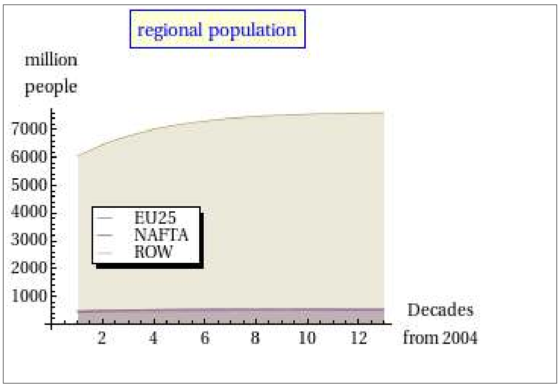
Exogenous population growth

As discussed in *Chapter 4 Economic models for climate change policy analysis*, the United Nations median estimate of population is 9.15 billion by 2050, rising to a long term saturation level of 11.03 billion (United Nations 2009). In contrast, Nordhaus assumes population saturating at 8.6 billion people in 2100, based on the forecasts by the International Institute of Applied Systems Analysts (Lutz et al. 2008).

For consistency with Nordhaus' model, the assumption for the time being within Sceptre is that population saturates at 8.6 billion in 2100. Following the effluxion of 10 decades, the actual year of population saturation would be 2104.

The population profile in each region is calculated from GTAP's data of regional population in 2004. This is increased by a regional population growth rate, commencing at an aggregated rate derived from Mathematica's Country Database, which is for the 2006 year. The common uniform exponential deceleration factor in the population growth rate is manually balanced to saturate global population after 10 decades. The population profiles are shown in the following illustrations:





It may be seen that the population saturates with EU25 nations growing from 458 million people to 489 million, NAFTA growing from 433 million people to 559 million and the Rest of the World (ROW) growing from 5.5 billion to 7.6 billion. The absolute increases over the 130 year projection period are EU25 6.7%, NAFTA 29.1% and ROW 38.1%.

Aggregation of GTAP U and V matrices

Mining the GTAP database for U and V matrices has been discussed at the beginning of this Chapter. It only remains to note that various commodities are treated in different ways. For example, GTAP's services commodity, which includes electricity generation and distribution and water reticulation, is identified as a commodity that is not traded between regions. It is recognised that a small proportion of services are internationally traded. However any error effect from this assumption will be small. Dealing with it this way is preferable to allowing services to trade and introducing an additional set of constraints to restrict the traded proportion.

International trading of the emission permits commodity and the amelioration or abatement commodity could be restricted in this way if desired. However, the only one policy scenario modelled in Sceptre assumes that these CO_2 pollution commodities are not internationally traded.

Inclusion of carbon trading & abatement

If the only carbon pollution policy option was to place a quantity limit on CO_2 emissions, then emission permits would be subject to a simple resource constraint in the same way as labour has a labour endowment.

However, the introduction of a new commodity of CO_2 *amelioration or abatement* means that both emissions permits and amelioration or abatement need to be modelled as substitutable commodities. The new amelioration or abatement commodity includes higher cost energy source like solar or nuclear power, consumer ameliorations such as house insulation and electric cars, and abatement services such as CO_2 collection and sequestration (CCS).

Another of the significant advantages of the Use-Make $U-V^T$ format is that additional commodities and industries can be directly augmented to the matrices. To the Use matrix, two rows are appended with GTAP's reformatted IEA industrial emissions data. The only difference between the two rows is that the first additional row (for abatement) is multiplied by μ while the second additional row (for emissions permits) is multiplied by $(1-\mu)$. The parameter μ is exceedingly important. It is the proportion of carbon emissions actually eliminated by carbon pollution policies. Optimisation determines the optimal rate of switching from the financial solution of emissions permits to the hard task of becoming a low carbon emissions economy. The consumption and investment vectors are similarly augmented. Of course, each of the ameliorations or abatements has a cost and this is included in the ameliorations and abatement column as a projected backstop technology cost. This backstop technology cost is a function of μ because the first units of ameliorations and abatements will be relatively inexpensive and the last units will have a very high price.

If the Use matrix is augmented then the Make matrix needs to be likewise augmented. There is an industry producing amelioration and abatement services and another producing emissions permits, albeit the latter is most likely run by the government. The diagonal elements of the Make matrix are set to the sum of the corresponding uses plus net exports, thereby facilitating international trade.

Trade deficit and taxation bias

Trade deficits

ten Raa's approach of limiting national trade deficits to a maximum of the current deficit is outlined in *Appendix 6 Benchmarking with linear programming*. For a single period multi-regional input output (MRIO) model, ten Raa ensures that countries do not increase their trade deficits by a secondary optimisation that scans the primary solutions of a linear programming maximisation of economic expansion.

Sceptre adopts ten Raa's approach. However, external optimisation of a linear programming formulation and nonlinear optimisation of a combined model were tested. Given the need for additional nonlinear climate constraints, the latter was found to be more convenient.

Valuation and supranational freight

Leontief's multiregional input output (MRIO) model is provided as *Appendix 3 Input output tables*. The Leontief model ignores the source of the imported inputs and assumes a constant product-mix in order to manageably manipulate the Leontief A matrix of technical coefficients. In this product mix approach, inputs per unit of output are assumed to be constant across regions and the input coefficient matrix of regions is assumed to be the average of the detailed coefficients of the supra-entity (in our case the world) weighted by the proportions of sub-sector outputs to total sector output in each region.

ten Raa's MRIO method utilises net exports (exports less imports) and so ignores the source of imported inputs in the same way as Leontief. However, the use of U and V matrices means that the somewhat unrealistic product-mix assumptions can be relaxed.   This method is described in *Appendix 6 Benchmarking with linear programming*.

Traditional CGE modelling of international trade flows can be quite complex. Friot (2007, pp.14-6) discusses the need to address valuation effects of import and export taxes and freight in the supranational trade sector freight in CGE models using GTAP data.

When compared to traditional CGE modelling, ten Raa's MRIO method introduces a significant advantage and some disadvantages. The significant advantage is that internal exports and imports within aggregated GTAP regions are inherently eliminated by the use of net exports. This removes the need to distribute exports and imports within the domestic intermediary and final demand and supply matrices on some arbitrary basis, such as proportional allocation.

However, valuation issues are not as straightforward. If the U and V matrices are considered to be commodity volumes, when divided by common commodity prices, then taxation and freight issues in international trade introduce distortions into the export-import (exim) data.

The approach taken in Sceptre is to value exports and imports at world prices and treat the difference of freight and taxes as a constant bias. This approach is detailed in *Appendix 7 Mining the GTAP database*. The calculated bias becomes less appropriate if the trade in particular commodities significantly rises or falls, or reverses. However, the alternative is to introduce trade multipliers on net exports. This also has problems. For example, as the mix of imports and exports changes then the multiplier becomes inappropriate. It may even be the case that import taxes become applied to exports. In addition, such multipliers cannot be easily implemented in a linear programming schema, which is the overall controlling paradigm for both linear and nonlinear formulations.

Initial assets, depreciation & Sales/Assets ratios

Accounting stocks and flows model

The economy's commodity accounts can be modelled using normal accounting techniques. $(U-V^T).s$ is the productive gross margin and this is spent on investment and consumption. Consumption is analogous to the payment of a dividend.

Profit & Loss

Gross Profit	$(V^T - U)\cdot s_t$
Depreciation	$-\delta\, ninvt_{t-1}$
Dividend	$-\gamma\, a_t$
Increase of Retained Earnings	ΔRE_t

where:

s_t *is the activity vector*

$ninvt_{t-1}$ *is the net investment at the end of period* $t-1$

$invt_t$ *is the investment for period* t

δ *is the depreciation rate*

γ *is the economic expansion factor*

a_t *is the consumption vector*

For simplicity in explanation, it is assumed here that the trade vector for net exports is part of the consumption vector. The accompanying Cash Flow is:

Cash Flow

Gross Profit	$(V^T - U)\cdot s_t$
Investment	$-invest_t$
Dividend	$-\gamma\, a_t$
Increase of Cash	$\Delta Cash_t$

Since all value added is used for investment or consumption (here the Dividend), then $\Delta Cash_t = 0$. This provides commodity "flows model" analogous to standard accounting principles where the Cash Flow is the cash flows model:

$$(V^T - U)\cdot s_t - invest_t - \gamma\, a_t = 0$$

The commodity "stocks model" requires additional discussion. If the profit of the economy is analogous to Gross National Income (GNI) less depreciation of capital, and consumption and net exports are together analogous to a dividend, then investment is analogous to retained earnings.[iv]

Again by period, country and commodity, the stocks equation is:

$$closing\ capital = opening\ capital - depreciation + investment$$

The net investment in a production unit comprises both inventory and fixed capital investment. It is quite clear that inventory of a commodity is the accumulation of the commodity. In addition, the fixed capital investment and depreciation of this investment can be modelled as accumulations of the commodity. In 1932, Von Neumann observed the remarkable duality between monetary variables and technical variables such as commodity production intensity. He concluded that money could be eliminated leaving only commodities in economic models (Von Neumann 1938, p.1; Champernowne 1945, p.13).

Von Neumann also noted that household consumption and investment are each parcels of commodities and that wear and tear (i.e. depreciation of the net investment in the production process) could also be treated as a commodity. Ultimately all net investment in a production process is absorbed into the commodities produced by the production process itself. Depreciation is the annual quantum of this depreciation. Therefore, von Neumann's assumptions implicitly assume that commodities are equivalently bartered at fair value to achieve the mix of commodities required for fixed capital equipment.

Applying von Neumann's assumptions, the “stocks model” for the production unit is:

$$
\begin{aligned}
& ninvt_t = ninvt_{t-1} + invest_t - \delta\, ninvt_{t-1} \\
& where: \\
& ninvt_t \text{ is the net investment at the end of the current period} \\
& ninvt_{t-1} \text{ is the net investment at the end of the previous period} \\
& invest_t \text{ is the new investment for the current period} \\
& \delta \text{ is the depreciation rate}
\end{aligned}
$$

Apart from net investment in a production unit, surplus commodities do not exist in the commodity model of an economy. Therefore the economy's Balance Sheet has $Cash$ of zero at each of time $t-1$ and time t and the Balance Sheet at each time period is given by:

Balance Sheet at time:	$\boldsymbol{t-1}$	$\boldsymbol{t}$
Cash	0	0
Net Investment	$ninvt_{t-1}$	$ninvt_{t-1}+invest_t-\delta\, ninvt_{t-1}$
Total Assets	$\overline{ninvt_{t-1}}$	$\overline{(1-\delta)\, ninvt_{t-1}+invest_t}$
Retained Earnings	RE_{t-1}	$RE_{t-1}+\Delta RE_t$

Total Assets and *Retained Earnings* are balanced at time t because:

$$
\begin{aligned}
RE_t &= RE_{t-1}+\Delta RE_t \\
&= ninvt_{t-1} + (invest_t - \delta\, ninvt_{t-1}) \\
&= (1-\delta)\, ninvt_{t-1} + invest_t
\end{aligned}
$$

So the Balance Sheet indeed balances:

Balance Sheet at time:	$\boldsymbol{t-1}$	$\boldsymbol{t}$
Cash	0	0
Net Investment	$ninvt_{t-1}$	$ninvt_{t-1}+invest_t-\delta\, ninvt_{t-1}$
Total Assets	$\overline{ninvt_{t-1}}$	$\overline{(1-\delta)\, ninvt_{t-1}+invest_t}$
Retained Earnings	RE_{t-1}	$(1-\delta)\, ninvt_{t-1}+invest_t$

ten Raa has developed an alternative approach to stocks and flows based on convolution dispersions. This is described in *Appendix 6 Benchmarking with linear programming*. However, after modelling both accounting and dispersion models, the accounting model was found to be simpler to implement.

If we were only to model stocks and flows to this stage then the model would be unstable. This is because the drive to maximise consumption will cannibalise capital by sending investment negative. Whilst a constraint can be set to ensure investment is not less than zero, this is not sufficient because maximising total consumption will still set investment to zero and depreciation will relentlessly cannibalise accumulated capital to zero.

It is necessary to ensure investment remains sufficient for the needs of each economy. In finance, DuPont analysis has been used for many years to investigate trends in return on capital.[v] The Sales/Assets ratio is one of the key indicators in this analysis. Sales/Assets ratios have the advantage of remaining stable for long periods, so much so that rules of thumb are often used. For example, the Sales/Asset ratio is typically 1 for manufacturers and close to 2 for retailers.

For the Sceptre model, a Sales/Assets constraint can be readily calculated using the Make matrix as a proxy for Sales, analogous to Bródy's approach (1974; 2004). Corresponding Assets are available from an economic database. The equation for each commodity in each country in each period is:

$$V^T \cdot s_t \leq ninvt_{t-1} * \frac{Sales}{Assets}$$

For intertemporal models, this dynamic constraint takes the place of a static material balance.

Depreciation rate

A single year depreciation rate for GTAP 2004 data is calculated for each commodity in each country. The maximum depreciation rate of 4%pa was discussed above. However, in the industries of some countries the annual investment can be less than the net accumulated investment multiplied by the default depreciation rate. In this case, the single year depreciation rate is set to equal the annual investment divided by the net accumulated investment.

As the Sceptre model is expressed in decades, the depreciation rate for a single year is compounded for ten years to provide the depreciation rate appropriate for a decade. It is recognised that aggregating measured annual depreciation across a decade would be a better approach. However, the latter approach is not feasible on a consistent basis given available data.

Sales to Asset Ratio

An analogous approach is taken to depreciation rate. A single year of Sales to Assets is readily calculated for GTAP's 2004 year. Sales for 2004 is then multiplied by a decade compounding factor where the proxy for annual growth is the rate of population growth for each particular country. The rate of population growth is derived from Mathematica's Country database as described in Project exogenous population growth (above).

Sales to Assets ratios tend to remain stable over long periods. A comparison over a period of 7 years may be calculated using GTAP data sets for the base years of 1997 and 2004.[vi] The Sales to Assets ratios for each commodity and region are shown in the following illustration.

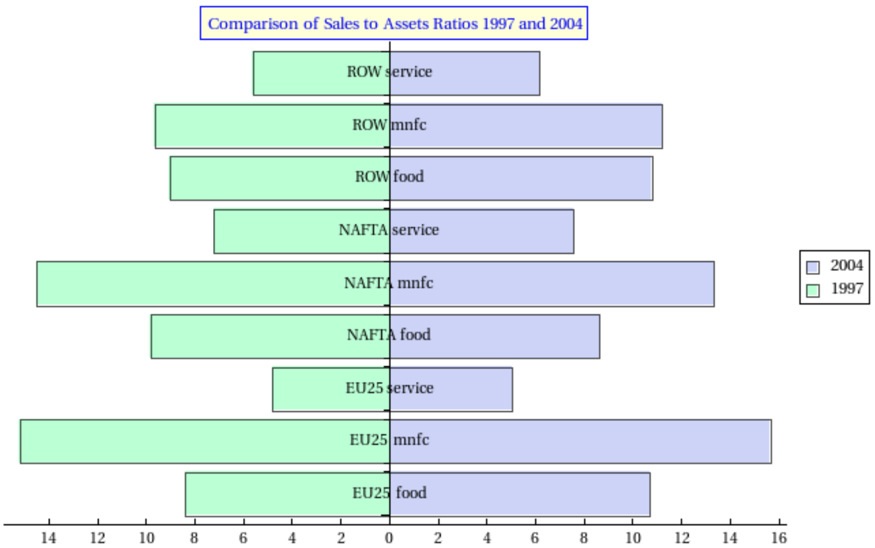


Illustration 19: Comparison of Sales to Assets Ratios 1997 (GTAP5) and 2004 (GTAP7)

Performance of the elementary economic model

The utilisation of DuPont sales-to-assets ratios as resource limit inequalities mediates flows by stocks, thereby bringing realism to the performance of the economic model while retaining the elegance of tableau productions functions. The model's useful and lively economic environment is demonstrated in this section.

The following specification of a simple optimisation problem has two constraints, one for the commodity balance and the other to mediate stocks and flows by sales to assets ratios. The objective function maximises welfare defined as the Net Present Value of Consumption per capita.

$$\text{Maximise } NPV(ypc): \text{ where } ypc \text{ is consumption per capita}$$
$$s, y, inv$$

Subject to:

Commodity flows balance	$(V^T - U) * s - y - inv = 0$ ($*$ signifies convolution product)	where V^T is Make matrix, U is Use matrix, s is the industry activity, y is the consumption vector & inv is the investment vector
Sales $(V^T * s)$ *being limited by assets*	$s2a \cdot closewdv \geq V^T * s$	where $s2a$ is sales to asset ratio & $closewdv$ is closing asset written down value

In the above specification, the closing written down value of assets $closewdv$ is calculated as the convolution over time of investment with the per unit depreciation profile used to write down the value of accumulated investment. For example, with say 10% depreciation on a declining balance basis, the profile for wring down assets would be $\{1, 0.9, 0.81, \ldots etc\}$. Accumulated depreciation is the difference between accumulated investment to the end of a period and the closing written down value of assets at the end of that period. Annual depreciation may then be calculated from this series as required.

It may be noted that the above sales to assets constraint uses the $closewdv$ of the current period rather than the prior period (as in the specification of Sceptre). The current period is demonstrated here as the most computationally difficult situation because of the circular dependence of sales on assets, assets on investment, and investment (and consumption) on sales.

However, the problem specification above has an infinite number of solutions since industrial production activity is variable. Traditionally the main constraint on industry activity has been labour resource. With service economies this has become less compelling albeit the constraint still applies in many circumstances. For example, my own country Australia traditionally solves its labour constraints by expanding immigration to rapidly increase the labour resource. During a recent national manpower shortage arising out of a mining boom, migration was increased to the highest level ever experienced.[vii]

It is useful to consider the economic model's performance in a Negishi welfare maximising mode. More simply, to see how much growth can be driven through the model when it is restrained merely by sales-to-asset infrastructure limits.

However before this can be implemented, Game Theory compensation needs to be introduced. The first Game Theory effect relates to investment and accumulated assets. The essence of free markets is that demand evokes production. As a result, present consumers have no concern to ensure future production, which is assumed to arise through the invisible hand of enterprise. As a result, consumers that are not wealth limited will maximise their utility by consuming all production and even cannibalising assets. The reason that this is referred to here as a Game Theory effect is that it is analogous to finite game behaviour in elementary Game Theory. In a game with a defined end, the most profitable strategy on the last iteration of the game is to consume the most without compunction (i.e. “cheat” if desired). Furthermore, if that strategy is pursued, then the next most profitable strategy is to cheat on the penultimate iteration. Then on the iteration before that … and so on. In other words, a consumer who has no imperative to care for the future will take the maximum possible at every iteration.

A second Game Theory issue is that the model requires a system of inter-period equity or else the model will simply place consumption where it is maximised and not where it is needed for the real welfare needs of society.

Traditionally CGE models have applied a saturating demand characteristic to control consumers' avariciousness within the model. However, in the current specification having constant returns to scale production, consumption and investment are expected to grow monotonically over time. Therefore, it is possible to minimally regulate the elementary model by constraining both consumption and investment to be the same as the previous period or grow.

This constraint on investment removes the “finite game” limitation, which mirrors the real world situation where businesses will use their ability to generate high returns on investment to ensure their need for resources is met. Furthermore, Government policies actively support the flow of financial and commodity resources to firms in order to ensure social stability through continuity of the virtuous cycle that converts labour to consumption.

The following model specification includes the new monotonic constraints on consumption and investment, while the objective function continues to maximise the Net Present Value of Consumption per capita.

$$\underset{s,\,y,\,inv}{Maximise\ NPV\,(ypc)}: where\ \ ypc\ is\ consumption\ per\ capita$$

Subject to:

Commodity flows balance	$(V^T - U) * s - y - inv = 0$ ($*$ signifies convolution product)	*where* V^T *is Make matrix, U is Use matrix, s is the industry activity, y is the consumption vector & inv is the investment vector*
Sales $(V^T * s)$ *being limited by assets*	$s2a \cdot closewdv \geq V^T * s$	*where s2a is sales to asset ratio & closewdv is closing asset written down value*
Maintenance Consumption per capita	$ypc_t \geq ypc_{t-1}$	*where* ypc_t *is consumption per capita at time t*
Maintenance of Investment	$inv_t \geq inv_{t-1}$	*where* inv_t *is Investment at time t*

The model problem remains linear and may be quickly solves using a Simplex or Revised Simplex method. In the illustration below, computed results are shown for simplified example inputs. These inputs are a commodity V matrix with a single element having value 100, the corresponding single element in the U matrix having a value of 80, initial consumption 11, sales-to-asset ratio of 1.0, written down value of assets brought forward of 100, depreciation rate of 4% (declining balance basis), population growth rate of 2% and discount rate 4%.

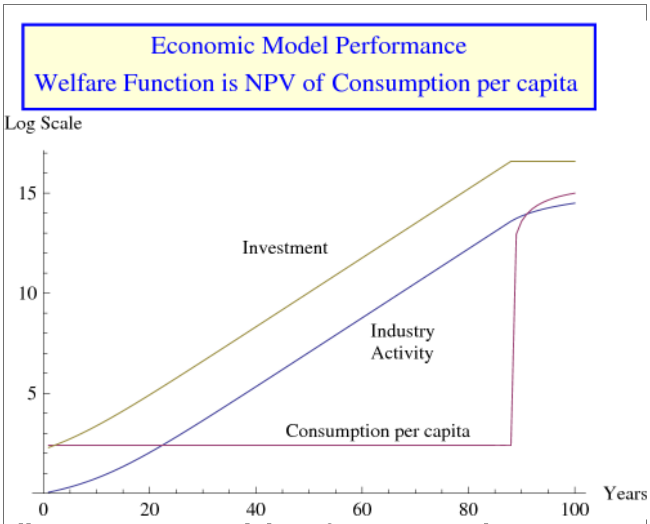


Illustration 20: Model Performance with an objective function to maximise the Net Present Value of Consumption per capita

Notwithstanding the discounting of future consumption, the model minimises (i.e. maintains constant) consumption for around 90% of the projection period in favour of accumulating assets, which builds a prodigious industrial asset base. In the final years this production base is applied to a monumental consumption “binge” as shown above.

Of course, this “consumption party” could not occur in a model closed for households for two reasons. The first is that the very large increase in industry activity would increase the quantum of wages, with both the workforce and the level of wages increasing. Both would lead to increased consumption. Secondly, the massive consumption vector in the final years could not be afforded by consumers in those years. Closing for households will stabilise the model and is used within the final Sceptre model.

Before turning to labour and other exogenous constraints to stabilise the model, it is insightful to investigate how the model might be endogenously controlled. It has just been demonstrated that discounting future consumption in the objective function is insufficient to stabilise the model's dysfunctional preference for asset creation over consumption. Previously it was mentioned that demand elasticity has often been used to force demand saturation in each period. However, the basis of collective demand saturation has always remained somewhat questionable and risks expanding the number of assumptions for the sake of it.

Another form of endogenous stabilisation is possible. Businesses and governments look for monotonic growth over quite long periods. While payback periods as short as one to three years are applied to incremental investment, the business plans that underpin infrastructure investment decisions usually range across the period of debt repayment. This is three to five years as a minimum and might be as long as ten to fifteen years. Some infrastructure facilities in the resource industry would be evaluated over production lifetimes of twenty to fifty years. Long term business plans seek to maximise growth in every year. Expressed as a single number objective, such business plans seek to achieve the maximum throughput in the present as well as in the future by maximising the minimum annual growth, which is a Minimax function.

Here a Minimax objective function, similar to the functions proposed by von Neumann and Rawls, may be used in the model specification to maximise the minimum annual growth of Consumption per capita. This also requires the constraint for Growth of Consumptions per Capita to be suitably modified. One feature of this formulation is that the minimum annual growth rate may indeed be negative. This implicitly relaxes the requirement that consumption per capita be maintained or monotonically increase.

The following model specification introduces the Minimax objective function to maximise the minimum Growth of Consumption per capita:

Maximise ygr : s, y, inv, ygr	*where* ygr *is the minimum growth of consumption per capita in any period*	
Subject to:		
Commodity flows balance	$(V^T - U) * s - y - inv = 0$ ($*$ *signifies convolution product*)	*where* V^T *is Make matrix*, U *is Use matrix*, s *is the industry activity*, y *is the consumption vector* & inv *is the investment vector*
Sales $(V^T * s)$ *being limited by assets*	$s2a \cdot closewdv \geq V^T * s$	*where* $s2a$ *is sales to asset ratio* & $closewdv$ *is closing asset written down value*
Growth of Consumption per capita	$ypc_t \geq (1 + ygr)\, ypc_{t-1}$	*where* ypc_t *is consumption per capita at time* t
Maintenance of Investment	$inv_t \geq inv_{t-1}$	*where* inv_t *is Investment at time* t

This Minimax formulation is still a linear model that can be solved by Simplex methods but it takes quite a long time to find the Minimax solution. It may be noted that consumption per capita at 100 years is approximately 6 on the log scale, compared to 14 in the consumption party example above.

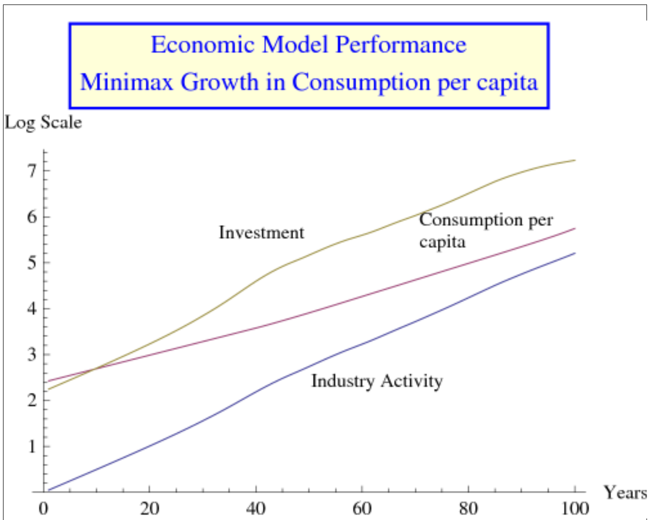


Illustration 21: Model specification with Minimax objective function

In this example the Minimax solution is a minimum annual growth rate of 3%. As the “wavy” lines in the figure above show, growth in other years is variable but all rates of growth are higher than in the minimum year. Overall, the compound constant growth rate corresponds to a fairly robust 3.4% pa. This equivalent constant growth rate is not itself a feasible solution because the dynamics of the model require negative investment (i.e. cannibalised assets) in many years. Indeed, the growth rate is constrained to be constant, the maximum growth rate is a much more moderate 1.2% pa. This leads to a significant reduction in economic performance, as shown in the following figure.

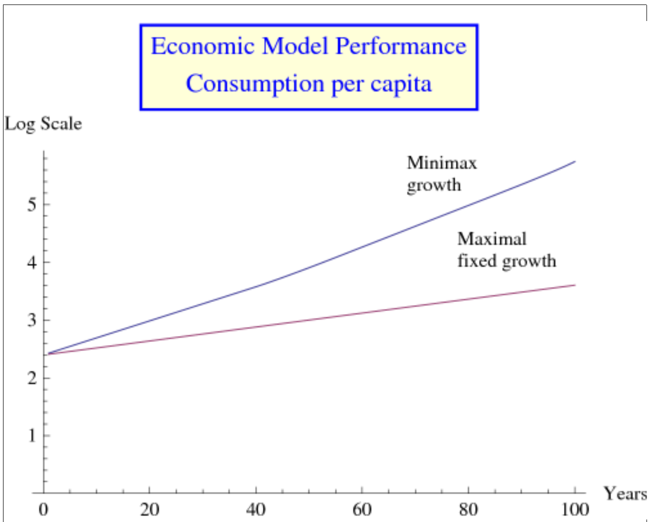


Illustration 22: Minimax growth compared to Maximised fixed growth

To conclude this discussion of the characteristics of the elementary intertemporal economic model it is noted that the behaviour of the model is highly realistic given appropriate stabilisation.

Climate feedback loop and damage function

Nordhaus' DICE model and equations are provided as *Appendix 4 Nordhaus DICE model*. Industrial emissions lead to rises in atmospheric and ocean temperatures and ultimately to an economic damage function. This damage feedback increases the inputs required for production. However, technological change acts in the opposite direction, reducing production inputs through growth in Total Factor Productivity. These effects are used to modify the Use matrix.

Nordhaus' basic scientific model is detailed in Appendix 4 and included here as an illustration for reference:

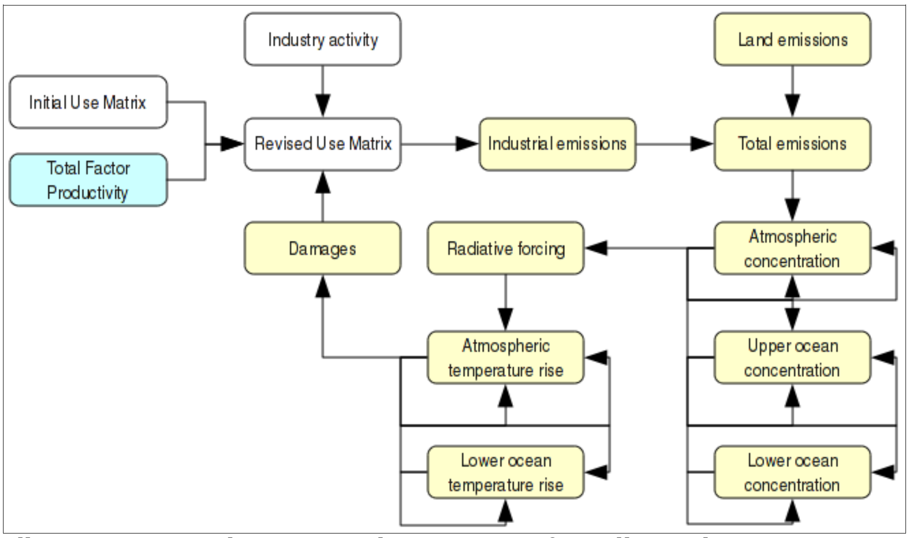


Illustration 23: Schematic implementation of Nordhaus climate equations

The main economic-climate equations from Nordhaus' DICE model used in this research are shown below. The definitions of parameters can also be found in Appendix 4. However, the reader is referred to the specific implementation within Sceptre. This is provided in *Appendix 8 The Sceptre model* and further referred to in the discussion of assumptions below.

A.04	Q_t	$= \Omega_t \, [1 - \Lambda_t] \, A_t \, K_t^{\gamma} \, L_t^{1-\gamma}$	*industrial output*
A.05	Ω_t	$= \dfrac{1}{[1 + \psi_1 \, T_{AT,t} + \psi_2 \, T_{AT,t}^2]}$	*economic damage function*
A.06	Λ_t	$= \pi_t \, \theta_t \, \mu_t^{\theta_2}$	*abatement cost function*
A.12	E_t	$= E_{ind,t} + E_{land,t}$	*total emissions*
A.13	$M_{AT,t}$	$= E_t + \phi_{11} \, M_{AT,t-1} + \phi_{21} \, M_{UP,t-1}$	*atmospheric carbon conc.*
A.14	$M_{UP,t}$	$= \left\{ \begin{array}{c} \phi_{12} \, M_{AT,t-1} + \phi_{22} \, M_{UP,t-1} \\ + \phi_{32} \, M_{LO,t-1} \end{array} \right\}$	*upper oceans carbon conc.*
A.15	$M_{LO,t}$	$= \phi_{23} \, M_{UP,t-1} + \phi_{33} \, M_{LO,t-1}$	*lower oceans carbon conc.*
A.16	F_t	$= \eta \log_2 [\dfrac{M_{AT,t}}{M_{AT,1750}}] + F_{EX,t}$	*radiative forcing function*
A.17	$T_{AT,t}$	$= \left\{ \begin{array}{c} T_{AT,t-1} + \xi_1 \, F_t + \xi_1 \, \xi_2 \, T_{AT,t-1} \\ - \xi_1 \, \xi_3 [T_{AT,t-1} - T_{LO,t-1}] \end{array} \right\}$	*atmospheric temperature rise*
A.18	$T_{LO,t}$	$= T_{LO,t-1} + \xi_4 [T_{AT,t-1} - T_{LO,t-1}]$	*lower oceans temperature rise*
A.19	π_t	$= \varphi_t^{1-\theta_2}$	*participation cost markup*

Method of including CO_2 and non-CO_2 emissions

Nordhaus (2008, pp. 35 & 43) describes how CO_2 and non-CO_2 greenhouse gas emissions are included in the DICE model:

> In the DICE-2007 model, the only GHG that is subject to controls is industrial CO_2. This reflects the view that CO_2 is the major contributor to global warming and that other GHGs are likely to be controlled in different ways (chlorofluorocarbons are a useful example). Other GHGs are included as exogenous trends in radiative forcing: these include primarily CO2 emissions from land use changes, other well mixed GHGs, and aerosols …. Equation (A.12) provides the relationship between economic activity and greenhouse-gas emissions. In the DICE-2007 model, only industrial CO_2 emissions are endogenous. The other GHGs (including CO_2 arising from land use changes) are exogenous and are projected on the basis of studies by other modelling groups.

While Nordhaus demonstrates that DICE outputs are consistent with other physical modelling, there is a significant difference between industrial CO_2 emissions and the equivalent global warming potential from all six greenhouse gases (CO_2, CH_4, N_20, PFC, HFC, SF_6) as shown in the table below (Baumert et al. 2009).

2005 $MtCO_2e$	CO_2 emissions	Five Other GHG	Total
Energy	26,372	2,036	28,407
Industrial	1,154	712	1,866
Agriculture		6,075	6,075
Other	959	1,419	2,378
LUCF2000	7,619		7,619
Total	36,103	10,241	46,345

Global CO_2 and other Greenhouse Gas Emissions. Year 2000 Land Use Change & Forestry (LUCF2000) has been used as this is the latest figure in the database (Source: Baumert et al. 2009)

In the above table, the global warming potential of CO_2 gas emissions represents only 78% of all six greenhouse gases combined. In other words, total global warming potential is 28% greater than that from CO_2 gas emissions alone. A large part of this increase comes non-CO_2 emissions in Agriculture.

Prima facie agricultural CH_4 and N_2O emissions might be expected to rise proportionately with food production. This suggests that the DICE approach of treating CO_2 as the sole element could be improved in a spatial model. Notwithstanding the potential issues arising from the balance of fixed and variable emissions, this dissertation adopts the same approach as Nordhaus DICE in order to remain consistent with the geophysical model.

Data consistency is one of the key features of the GTAP database. Utilising this advantage, energy related CO_2 emissions have been matched to the economic structure of the database (Lee 2008).

CO2 gas $MtCO_2e$	Declared 2004	GTAP 2004 Energy Related	GTAP 2004 Adjusted Total	DICE 2005 viii
EU-25	4,264	3,840	3,840	
NAFTA	6,720	7,050	7,050	
ROW	24,209	15,140	15,140	
Subtotal	35,192	26,030	26,030	27,276
DICE Eland		4,037		4,037
Industrial	(incl. above)		1,092	
Bunkering	(incl. above)		910	
Land Use Chg & F	(incl. above)		7,619	
World	35,192	30,067	35,651	31,313

Comparison of 2004 Declared CO_2 Gas Emissions with GTAP energy-related and adjusted CO_2 gas emissions (Sources: Baumert et al. 2009, Lee 2008 & DICE 2008 model equations)

The table above compares the regional aggregations of GTAP energy related CO_2 emissions used in this dissertation with declared CO_2 gas emissions from energy, industrial, international bunkering and Land Use Changes and Forestry (LUCF) that have been similarly aggregated.

This dissertation uses GTAP 2004 Energy Related emissions, with the DICE “eland” adjustment. The reasons for this are:

- total DICE 2005 CO_2 gas emissions of 31,313 Mt is significantly less than declared emissions of 35,192 Mt (2004) and 36,103 Mt (2005)
- total energy-related GTAP 2004 CO_2 gas emissions of 30,067 Mt (adjusted with DICE eland) is 4% different to 31,313 Mt for DICE 2005, which is not significant. Taking into account the 911 Mt difference between declared emissions in 2004 and 2005, this difference is 1%
- the Land Use Change & Forestry (LUCF) component varies considerably as a global aggregate and is highly volatile at the regional level
- there is no consistent basis for selecting all or part of industrial, bunkering and LUCF emissions, for classifying any arbitrary trimming amount into regional and commodity aggregates, or for choosing which components are fixed and variable with commodity activity
- the variance in CO_2 gas emissions is small when compared to the variance in the global warming impact of the other five non-CO_2 greenhouse gases, which is dealt with through exogenous trends in radiative forcing (as described above)
- the DICE model is calibrated in decades. It is difficult to represent any level of emissions as unambiguously accurate with intra-decade emissions increasing considerably
- in a policy context, the main purpose of modelling is to determine policy feasibility and analyse the differences between sensitivity cases. In achieving this purpose it is essential to maintain a strong methodology and recognise that all assumptions have variability. This is far preferable to meeting particular numbers by modifying equations with extra trim factor assumptions (Occam's Law was discussed earlier).

It may be concluded from the analysis in this section that there is an element of “modeller's art” in incorporating the global warming potential of CO_2 and non-CO_2 gas emissions into geophysical models. The means that element-by-element comparisons are not always straightforward and validity needs to be established with outputs rather than inputs. For many decades William Nordhaus has demonstrated that the results from DICE are consistent with those from researchers with other approaches and with the linear development of his model over time.

Given the importance of precedence in evidence based policy research, the approach adopted in this dissertation is to retain consistency with DICE's geophysical model while developing a new benchmarking approach to the economic model. This retains comparability with DICE. An overall check on model “output” emissions is undertaken in Section 5.3 of this Chapter, *Comparison of Sceptre with physical modelling*. Following GTAP's release of non-CO_2 data rationalised to the GTAP7 database it may be possible to move forward to refine the whole of the geophysical model while keeping the new economic framework constant.

Optimisation variables

The minimum set of optimisation variables comprises the input variables for the acyclic topological structure of the economic model. This can be investigated in two ways. The first is by using the topological processor developed in this research for serial processing of the objective function in the Nordhaus DICE model. The second method is to manually use Mathematica's Solve function to determine the input variables. The difference is that topological processor uses the initial processing order of the equation set to make choices of input variables. Mathematica's Solve can be iteratively customised to take advantage of consistent patterns in the MRIO model.

Objective function

The traditional CGE welfare function has been discussed in relation to discount rate (above). The consumer welfare function was:

$$u(c) = \frac{-c^{1-\alpha}}{(1-\alpha)}$$

where:
u is welfare utility
c is per capita consumption
α is the marginal elasticity of consumption utility

While it is possible to implement this utility function as Sceptre's objective function, this has not been done for two reasons. The first reason is identified in the previous discussion of discount rate. The second reason is that people in various regions of the world have very different marginal elasticities of utility for their next dollar of consumption.

Nor does Sceptre use consumption as in the traditional CGE welfare function. For example, the utility function is suitable for a partial equilibrium study of a single region. However, in a general equilibrium the function is weighted toward large economies. For example, a 1% expansion of the American economy would be valued at many thousands of times a 1% expansion of an African economy.

In Sceptre, the objective function is simply net present value of the sum of the annual per capita economic expansion of each country. The economic expansion factor for a country is the multiplier of the GTAP 2004 data consumption vector for the country divided by the index of population for that year. Discounting expansion per capita means that all regions in the model are evaluated in an unbiased way. For example, a 1% increase in the per capita welfare of an American or an Australian has the same merit as a 1% increase in the welfare of, say, a Chinese, Indian or African person.

The economic expansion factor for an economy applies to the whole consumption vector and therefore implies a constant mix or bundle of commodities is consumed over time. In other words, the amount of manufacturing, food, services and emissions (or substituted emissions abatement) remains in a constant proportion. While this is patently unrealistic over long periods such as 100 years, the assumption serves well in evaluating policies *ceteris paribus.*[ix]

In the conclusion to his analysis of intertemporal modelling, ten Raa writes (2005, Chapter 13: Dynamic Modelling, pp.174-5):

> Prescribing desired proportions on the household stock we could maximize its level, subject to material balances and a labor constraint. The imposition of desired proportions is troublesome in a dynamic context. Food may not be a substitute for a car, but a car now is certainly a substitute for a car tomorrow. The fixed proportions are therefore dropped in intertemporal settings. In fact, it is standard to go to the other extreme, to model current and future consumption as perfect substitutes by entering them into a linear function, where the coefficients are the discount factors.
>
> To avoid specialization in resource-extensive commodities, a non-linear contemporaneous utility function is used. Commodities will not be wasted when reasonable utility functions are maximized. Consequently, the material balances will be binding and activity levels will depend on the final demand path of the economy …. Capacities are fully utilized …. [which is] an easy way to raise the standard of living.

In designing Sceptre, this research investigated various nonlinear contemporaneous utility functions. For example of the forms:

$$a\,e^{-k\gamma},\quad a-\frac{b}{\gamma}\ \text{ and }\ a\frac{(1-b)}{\gamma}$$

where:

γ *is the economic expansion factor*

These alternative functions were found to extend the time in locating an equilibrium solution and not to provide any noticeable improvement in avoiding specialisation. As discussed in regard to discount rate (above), a decision was made to limit the number of additional assumptions and apply simple discounting of the normalised economic expansion factors.

Augmented consumption, investment and U & V matrices

Augmentation for emissions

The ensuing discussion refers to the following illustration of the emissions relationships between the V and U tables:

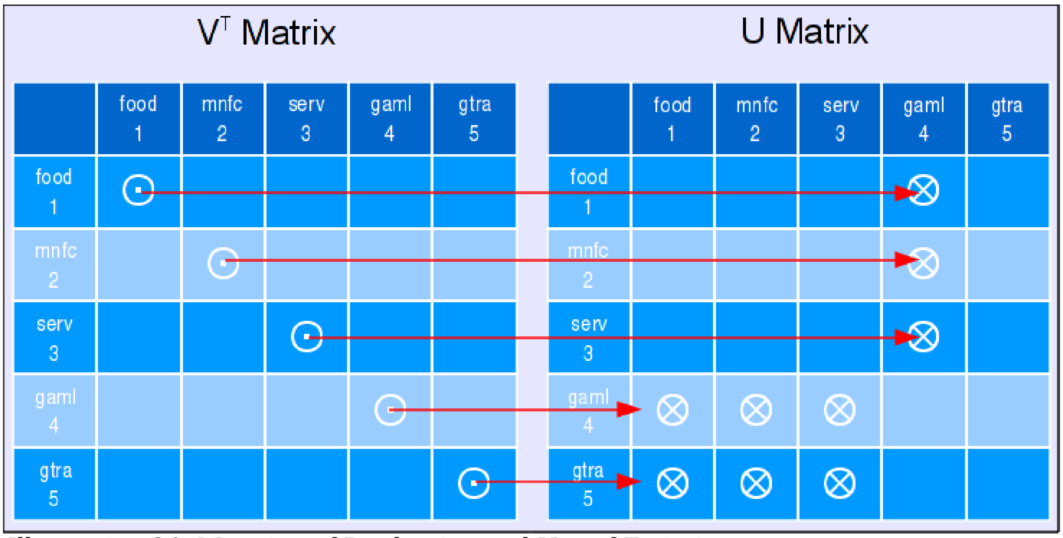


Illustration 24: Mapping of Production and Use of Emissions

Use matrix rows

Each of the matrices U and V, and the vectors for consumption and investment are derived from GTAP data as described in above and in *Appendix 7 Mining the GTAP database*.

The matrices U and V are square matrices with the rows and columns equal to the number of aggregated commodities. In this policy research, there are three commodities $\{food, mnfc, services\}$, which form 3x3 matrices for each of the three regions $\{NAFTA, EU25, ROW\}$. The consumption and investment matrices for each of these regions is a single column vector of the three commodities $\{food, mnfc, services\}$.

As discussed above, the U and V matrices are augmented with two rows and two columns, for amelioration and abatement services and for emission permits trading:

$$\begin{array}{ll} gaml & CO_2 \ amelioration \,/\, abatement \ services \\ gtra & CO_2 \ emission \ permits \end{array}$$

The difference between the terms amelioration and abatement is merely one of form over function. Abatement of emissions in power generation might be a particular service such as carbon sequestration. In contrast, amelioration achieves a similar effect by replacing the facility, for example retrofitting a coal-fired generation plant with a nuclear boiler.

Following the augmentation of U and V by the creation of rows and columns for $\{gaml, gtra\}$, the commodity set becomes $\{food, mnfc, services, gaml, gtra\}$. The last two rows of the U matrix have formulae in the cells, not unique data. Emissions are read from the GTAP industrial emissions database for each production unit in each country. A production unit is a column in the U matrix (and in the transposed V matrix). Emissions are treated as a new industrial input requirement for permits rather than a production output of a "bad" from the process.

Emissions trading row

In each column of the U matrix, the final row for emissions permits $gtra$, has the formula of emissions of the production unit (converted to carbon instead of CO_2 because Nordhaus climate equations are based on carbon emissions) multiplied by $(1-\mu)$, where μ is the emissions control rate, which is the proportion of emissions physically ameliorated or abated.

Amelioration or abatement row

Correspondingly, the penultimate row of the U matrix, representing amelioration and abatement $gaml$ is emissions multiplied by the emissions control rate μ .

Additional rows are added to the consumption vector in the same way. The only difference is that multipliers in the penultimate and final rows are:

$$\{1-\mu a, \mu a\}$$
$$where:$$
$$\mu a \text{ is the proportion ameliorated or abated for the consumption vector } a$$

Use matrix columns

In Sceptre, it is assumed that the production of emissions permits and amelioration or abatement services requires neither material inputs nor labour. However, the production of each of these commodities does consume an equivalent volume of emissions. As national accounts address labour in this sector, this assumption can be reassessed.

Amelioration or abatement column

The penultimate column in the U matrix uses resources to produce the amelioration and abatement commodity $gaml$. There is a tangible cost to producing amelioration or abatement services, which is the backstop technology cost per tonne of carbon multiplied by the number of tonnes of carbon.

The resources to produce amelioration and abatement services need to be purchased from the commodity sectors $\{food, mnfc, services\}$. Of course, the resources could all be purchased from, say, the $services$ sector. This would be an over simplification because there could be considerable manufacturing $mnfc$ and conceivably even $food$. An insight on how to proceed is provided from von Neumann's assumption that investment can be represented by commodities both directly and through barter at fair value. A sound working assumption is to purchase the same proportion of resources from a commodity sector as that sector consumes of the amelioration or abatement service.

In Nordhaus' DICE model (Nordhaus 2008, pp.41-3, 52 & 77-9), the adjusted cost of backstop technology per tonne of carbon Θ is:

$$\Theta = \frac{pback}{\theta} \cdot \frac{backrat - 1 + e^{-gback*(t-1)}}{backrat}$$

where:

Θ	*abatement cost exponent*	2.8
pback	*maximum marginal backstop cost per tonne of carbon*	1.7
backrat	*ratio of backstop technology final cost / initial cost*	2
gback	*rate of decline of backstop technology cost per decade*	0.05

The *pback* value of 1.7 means the last unit of amelioration or abatement in the most value-adding industries, such as jet fuel or plastics has a cost of US$1,700 in 2005 dollars.

The profile of average backstop technology cost with time, assuming full amelioration or abatement of emissions is shown in the following illustration:

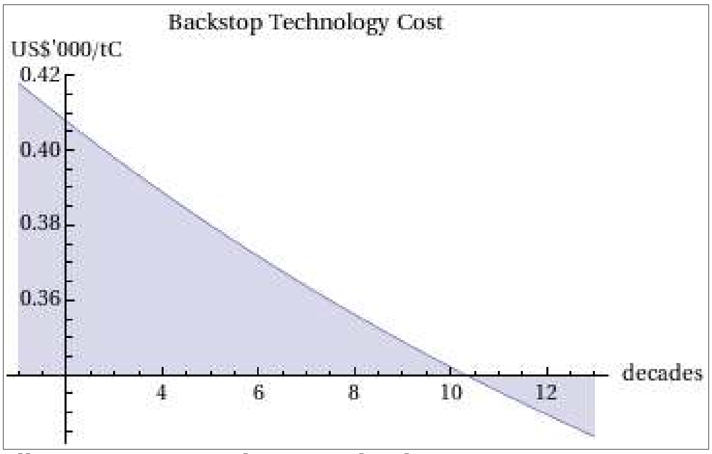


Illustration 25: Backstop Technology Cost

However, the amelioration or abatement cost increases with the proportion of emissions controlled μ :

$$abatement\ cost = \Pi[t]\Theta[t]\mu^{\theta-1}$$

where:

$\Pi[t]$ *is the ratio of abatement cost with* $\mu < 1$ *divided by cost with* $\mu = 1$

The following illustration shows how abatement cost varies with time and the control rate μ :

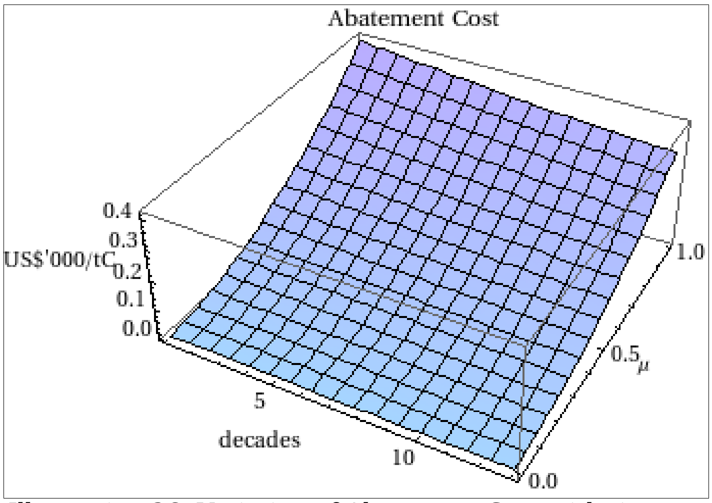


Illustration 26: Variation of Abatement Cost with time and controlled emissions

It may be seen that the average price of abatement can be as low as a few US dollars per tonne of carbon. This low level of cost applies to the “low hanging fruit” of amelioration and abatement opportunities. However, low costs have also been suggested for large-scale geoengineering abatement, which is nowadays known as “climate engineering”. While this geoengineering technology providing such a low cost does not yet exist, it may include, for example, large shades in space to block the sun's radiation, spraying seawater into clouds to make them reflective, seeding clouds with aerosols that reflect shortwave radiation and the air-capture of carbon dioxide. For comparison, Charles (2009) estimates the cost of abating emissions from coal-fired power stations as being about US$60/tonne for carbon capture and storage, albeit still a hypothetical technology.

An emissions control rate μ is calculated for each commodity in each region. This is used for an industry specific abatement cost since each regional commodity will have different sets of amelioration and abatement opportunities. However, there is also an argument to use a regional average μ for pan regional amelioration or abatement.

Emissions trading column

The final column in the U matrix has the resource purchases for the production centre of emissions permits $gtra$. All these cells are zero since the Government has no cost in issuing emissions permits.

End usage vectors

In the same way as the U and V matrices were augmented, additional rows are also appended to the consumption, investment and net exports vector. However, GTAP doesn't provide emissions data for investment and net exports. In the investment vector, the cells are simply zero.

In the net exports vector, synthetic entries are made to facilitate international emissions trading. These synthetic entries need to be small in order to not disturb the material balance and initially sum to zero for the country. Therefore, in examining trade flows in emission permits and amelioration and abatement services, the interpretation of emissions permits traded by each country will need to be divided by the vector of synthetic emissions used to seed the international trading.

Make matrix rows

The illustration of V and U above shows sales from the V^T matrix. The GTAP V^T matrix is diagonal. Augmentation commodities become further diagonal elements for amelioration or abatement $\{gaml\}$ and emission permits sales $\{gtra\}$. Sales of each of these commodities are the sum of the respective commodity demand including industrial uses, investment, consumption and net exports.

The proceeds from sale of emission permits needs to be returned to consumers in one way or another. This may be in the form of reductions in other taxes, as investigated in the discussion of environmental taxes in *Chapter 3 Political Economy of the Anglo-American world view of climate change*.

Sceptre has been structured to evaluate policy responses to various constraints on atmospheric temperature rise. A rising emissions control rate μ catalyses when the atmospheric temperature rise constraint becomes binding. The backstop technology cost then generates a price for amelioration and abatement. It can be expected that emission permits will trade at the marginal cost of amelioration and abatement.

Once the government settles on a policy to limit atmospheric temperature rise, the government may then introduce quantity limits to create a profile of scarcity and stimulate a price on emission permits. Sceptre can also be operated in this mode, where a resource limit is placed on emission permits so a price is generated.

Modification of U matrix for economic damage

Nordhaus' DICE model uses a Cobb-Douglas production function, where the economic output of the world without climate impacts is adjusted by applying multipliers for economic damage and total factor productivity. In this policy research, the required damage can be implemented either in the U matrix or in the MRIO equations. The former is preferred following trials of both methods.

In U,V terms, the impaired output following economic damage is $(V^T - U) * \Omega_0$, where Ω_0 is the damage multiplier. If this economic impairment is represented by adjusting the original U matrix U_0 to a new U matrix $U_{observed}$, then:

$$V^T - U_{observed} = (V^T - U_0) * \Omega_0 \quad \text{or} \quad \frac{(V^T - U_{observed})}{\Omega_0} = V^T - U_0$$

Given a new level of damages dam , the revised U matrix is U' :

$$V^T - U' = (V^T - U_o) * dam$$
$$substituting\ the\ equations\ above:$$
$$U' = V^T - \frac{(V^T - U_{observed})}{\Omega_0} * dam$$
$$So\ the\ revised\ U'\ is\ given\ by:$$
$$U' = V^T - (V^T - U_{observed}) * \frac{dam}{\Omega_0}$$

Modification of U matrix for total factor productivity

Total factor productivity al is exogenously calculated and introduced into the U matrix in the same way as economic damage (above):

$$U' = V^T - (V^T - U_{observed}) * al$$
$$where:$$
$$al \text{ is the index of total factor productivity}$$

Combining the effect of total factor productivity with economic damage, the resulting matrix is:

$$U' = V^T - (V^T - U_{observed}) * \frac{dam}{\Omega_0} * al \quad .$$

Neither economic damages nor total factor productivity benefits are applied to amelioration or abatement services and emissions permits.

Nordhaus' DICE model assumes increasing energy efficiency. In contrast, Sceptre's approach is that energy efficiency is part of amelioration and abatement. This is because an energy efficiency multiplier would double count. For example, one unit of industry activity produces an increased amount of output due to the rise in Total Factor Productivity. For the same level of industry output, a lower level of industry activity is required. Therefore a lower level of energy is required and less emissions are produced. If, in addition, energy efficiency is introduced, the same level of output would require significantly lower energy, reduced by both Total Factor Productivity and energy efficiency.

Labour factor productivity

Total Factor Productivity (or Multi factor Productivity) is the residual growth in gross value added after accounting for changes in factors such as labour and capital.

Labour productivity is the single factor or partial productivity with respect to labour. It is the change in gross value added divided by labour hours

$$(V^T - U) / Labour\, hours \quad .$$

The illustration below shows that labour factor productivity in America and Australia has grown by about 2%-3% pa over the last three decades (RBA

2009). On a per decade basis, this is equivalent to about 32% and 36% per decade respectively.

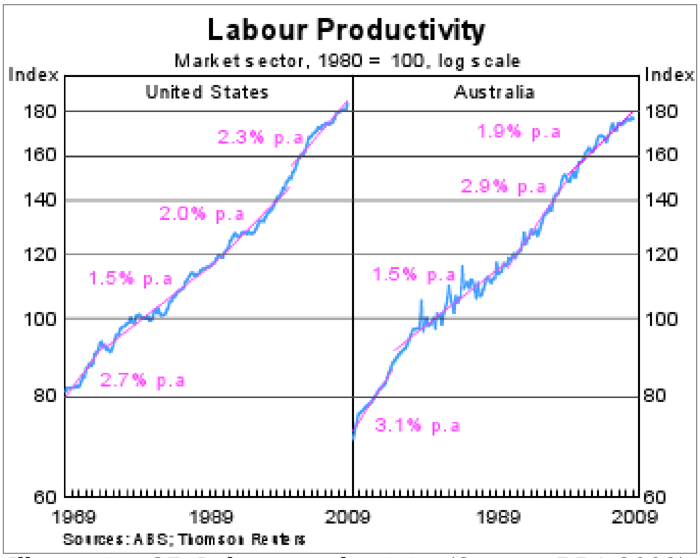


Illustration 27: Labour productivity (Source: RBA 2009)

Spatially disaggregated labour productivity varies considerably by commodity and region. In addition, there will be different relationships between Labour Productivity and Total Factor Productivity across different commodities and regions.

However, Hicks (1932) and subsequently Solow (1957) suggest that production functions be characterised with a constant relationship between the factors and that Total Factor Productivity is independent of the factors. It is assumed that the marginal rates of substitution of the factors remains constant and the proportional balance of labour and other factors in a production function remains unchanged notwithstanding an increase in economic output occasioned by technological progress. This is discussed in Appendix 3 Input Output Tables, in regard to Solow's variable for technological change A .

In addition to Solow's assumption that technological change is exogenous and independent, Solow also assumes that constant returns to scale are inevitable. Sceptre similarly employs a Leontief-type $V^T - U$ tableau with constant returns to scale, a fixed factor relationship to labour and an exogenous and independent Total Factor Productivity A .

As a consequence of these three assumptions, labour per unit of industry activity L/s remains unchanged when total output $A(V^T - U)s$ is increased through an improvement in Total Factor Productivity A. The improvement in Total Factor Productivity leads to an implicit improvement in Labour Factor Productivity that is proportional to the growth in Total Factor Productivity, as shown in the following example.

$$\text{Growth in the Partial Productivity of Labour} = \frac{\dfrac{A_2(V^T-U)s_2}{L_2} - \dfrac{A_1(V^T-U)s_1}{L_1}}{\dfrac{A_1(V^T-U)s_1}{L_1}}$$

$$= \frac{\dfrac{A_2 s_2}{L_2} - \dfrac{A_1 s_1}{L_1}}{\dfrac{A_1 s_1}{L_1}}$$

$$= \frac{[(\dfrac{L_1}{s_1})/(\dfrac{L_2}{s_2})]A_2 - A_1}{A_1}$$

$$\text{With constant returns to scale } (\frac{L_1}{s_1}) = (\frac{L_2}{s_2}),$$

$$\text{Growth in the Partial Productivity of Labour} = \frac{A_2 - A_1}{A_1}$$

$$= \text{Growth in Total Factor Productivity}$$

The increasing dominance of services in developed economies supports the assumption of constant returns to scale and a proportional improvement in Labour Productivity with Total Factor Productivity.

The Economist defines a service as “anything sold in trade that cannot be dropped on your foot.” In making use of this rough but effective definition, references to the services and manufacturing sectors in the following discussion are generic rather than specific to Sceptre's commodities.

Services includes every activity except agriculture, fishing, manufacturing, construction and mining. By this definition, the services sector is by far the largest sector in world economy. As shown in the illustration below, changes in technology have led to the situation of approximately 40% of all jobs globally being in service related areas (Morris 2007). This rises to 80% in advanced Western economies. The service sector is now twice as large as the manufacturing sector.

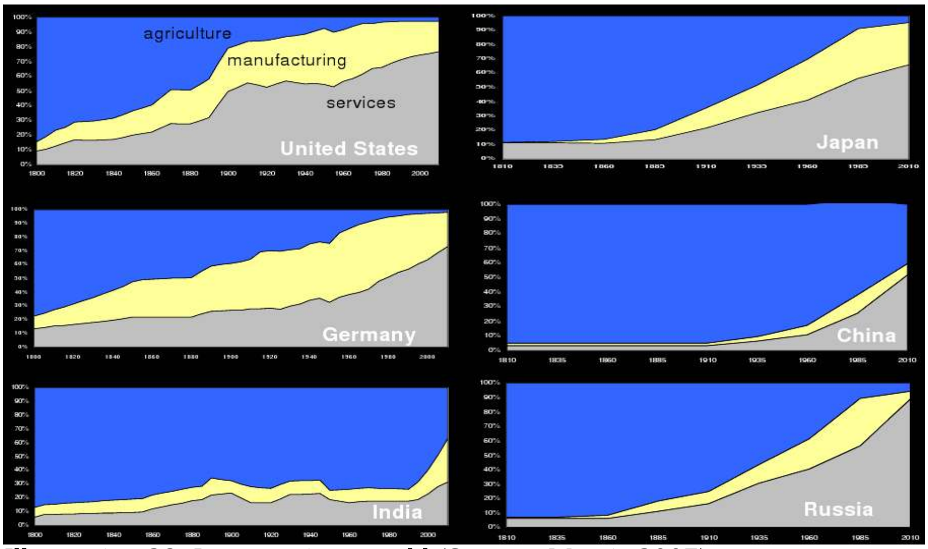


Illustration 28: Its a services world (Source: Morris 2007)

There are three considerations in comparing Labour Productivity to Total Factor Productivity. Firstly, Total Factor Productivity improvement is primarily due to rents on capital, not on labour (ten Raa & Mohnen 2008). Secondly, while manufacturing labour productivity has improved significantly over recent years, services productivity has not (ten Raa & Wolff 2001). A large part of manufacturing labour productivity improvement has been due to outsourcing those tasks where it is difficult to improve labour productivity. For example, outsourcing transport, cleaning, IT and professional services.

Thirdly, improvements in labour productivity have derived from the manufacturing sector while the wages benefits have been enjoyed by both the manufacturing and services sectors (Baumol 1967). Productivity growth in services is very difficult to achieve, for example the same student to lecturer ratios and the same time for a cleaner to vacuum a carpet. A new academic discipline called Service Sciences has arisen to address the intransigence of services productivity by applying new multidisciplinary approaches across IT architectures, engineering systems and behavioural psychology (Spohrer et al. 2007; Chesbrough & Spohrer 2006; Morris 2007).

Notwithstanding the differences in labour productivity between the manufacturing and service sectors, competitive markets for labour are heavily influenced by the sector with the highest capacity to pay. As manufacturing has the highest marginal productivity then it often influences wages. The increase of wages in the services sector without corresponding increase is productivity is known as the Baumol disease (ten Raa & Wolff 2001).

Intertemporal MRIO symbolic model with carbon trading & abatement

Basic economic model

The flow equations for each commodity in each country in each time period are the aggregate of the following items, which sum to zero:

- the consumption vector *a* multiplied by the benchmarking efficiency expansion factor γ. Consumption is the sum of consumer and government consumption
- the net industrial consumption vector (which will be negative numbers) multiplied by the optimal activity vector *s.* This is equal to the Use matrix less the transpose of the Make matrix $(U - V^T)$. It is also equal to the negative of Gross National Income (GNI)
- net exports multiplied by the optimal export vector *z.* As net exports is used, trade between countries of the same aggregated region is inherently eliminated
- investment multiplied by investment activity vector *i*
- a bias created by adjusting net exports to world prices, representing net export and import taxes

The illustration below shows this in a linear programming schema:

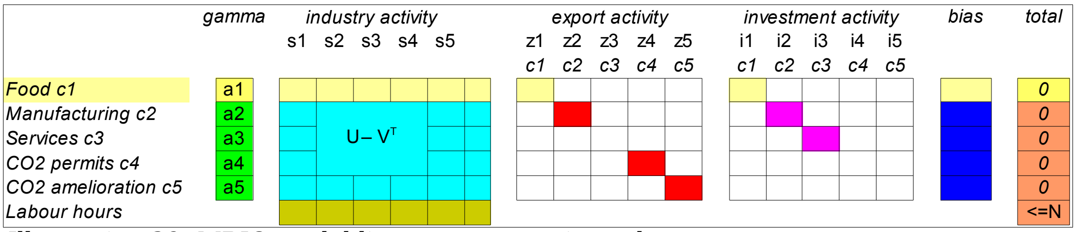


Illustration 29: MRIO model linear programming schema

It may be seen in the above illustration that the labour used by industry is constrained to be less than the labour endowment, *N*. The labour endowment is usually calculated as the sum of the labour hours divided by one minus the unemployment rate. The unemployment rate assumption has been discussed above. When industry activities vary, labour hours are redistributed across the industries.

If the model was static then a capital constraint would be present with a limiting endowment *M*. However, capital is dynamically calculated in an intertemporal model.

Constraints

While the objective function and its relationship to discount factor has been extensively addressed above, the heart of a benchmarking model is in the constraints. The theorem of complementary slackness and the main theory of linear programming were discussed in *Chapter 4 Economic models for climate change policy analysis*. These constraints make the commodity and factor markets through the Dual formulation. The Lagrange multipliers are the prices of the constraint resources.

In Sceptre, a nonlinear constraint schema is constructed by specifying constraints at a high level of abstraction, and then substituting constraint variables with symbolic solutions to the combined MRIO and climate feedback model. This results in the constraints being expressed in equations comprising only the most fundamental input variables to the MRIO model.

For example, *Appendix 6 Benchmarking with linear programming* shows how constraint schemas are designed for multi-regional input output models. In this single period model described there, the linear equations for material balance are relatively simple and can be analytically expressed. When the model becomes multi-period intertemporal, there is a rolling forward of single period models. Each successive phase of the model comprises all the symbolic equations of the antecedent models. The process relies on powerful symbolic processing in Mathematica and results in extremely long, complicated and highly nonlinear equations.

An advantage of this approach is that, at the abstract level of description, an intertemporal MRIO climate model has a relatively small number of inequality and equality constraints.

Inequality Constraints

MRIO inequality constraints

Constraint	**Description**
Sales/Asset ratio: Net investment in the previous period * sales to asset ratio ≥ V . sector activity	As discussed in the accounting stocks and flows model (above), the material balance is brought into the optimisation model through the Sales to Assets assumption. Sales in the current period, represented by the V matrix multiplied by the activity vector, must be less than or equal to the assets in the previous period multiplied by the Sales to Assets ratio. In dynamic input-output modelling this is known as “closing the model for investment”. This constraint also forms part of “closing the model for trade”. This Sales to Asset constraint is very important and a major part of Sceptre's innovation. This is because it substitutes a dynamic material balance for ten Raa's static material balance. Therefore, the Main Theory of Linear Programming is able to form a series of dynamic markets that maximise outputs while minimising inputs. Furthermore, using Sales to Assets ratios is a stable approach because these ratios tend to be stable over medium term time fames. Therefore ratios have not been changed over time.
Final period investment: current period investment ≥ previous	Accumulated investment cannot be cannibalised for consumption (except through depreciation). As production is divided between investment, consumption and net exports, the simplest assumption to achieve the

Constraint	Description
period investment	anti-cannibalism outcome is to require each industry's investment be maintained in the final period
Country deficit limit: exim . export activity ≥ deficit	As discussed above, net exports multiplied by the activity vector, must be less than or equal to the country's actual GTAP 2004 deficit. The deficit is a negative number. This constraint is part of what is known as “closing the model for trade” in input-output modelling.
Labour constraint: labour endowment ≥ vector of labour in sector . vector of activity of sector	Each country's labour endowment is assumed to rise with its population growth. The labour used in a country is the sum of the labour used in each sector multiplied by the activity of the sector. The labour used in a country must be less than the country's labour endowment. All countries are assumed to have 6.5% unemployment in 2004 such that the initial labour endowment of a country is the total labour used in 2004 divided by (1 - unemployment rate).
Purchasing power constraint: vector of labour in sector . vector of activity of sector ≥ labour employed * economic expansion	As the labour force purchases the commodities that constitute final demand, the vector of labour in sector . vector of activity of sector (i.e. the labour used) must be greater than or equal to the initial labour employed in a country multiplied by the country's economic expansion. This constraint is equivalent to “closing the model for households” in input-output analysis, where employment and consumption are linked.
investment ≥ 0 sector activity ≥ 0 economic expansion ≥ 0	Investment, sector activity and economic expansion must all be greater than zero.
$1 \geq \mu \geq 0$ $1 \geq \mu a \geq 0$	The proportion of substitution of amelioration or abatement services for emissions permits must be between 0 and 1, for both industry (μ) and consumers (μa).
Limits on international trading of emissions permits	Limits on international emissions trading may be introduced here but have not been applied in this policy research.
Limits on national emissions	Quantitative limits on national emissions trading may be introduced here but have not been applied in this policy research.

Climate inequality constraints

Climate constraints will reflect the policy feasibility being investigated. For example, in limiting the temperature rise to 2°C in 100 years time:

Constraint	Description
2°C ≥ temperature rise at period 10	The temperature rise in 100 years cannot exceed 2°C
Following period 10: previous period temperature rise ≥ current period temperature rise	Following the maximum temperature rise, the temperature rise must remain stable or decline
Following period 10: previous period emissions ≥ current emissions	If emissions are not controlled in addition to temperature, the end effect of the model will be to accelerate emissions. Therefore, following the maximum temperature rise, industrial emissions must remain stable or decline

Equality constraints

There are two types of equality constraints. The first are called boundary conditions such as $x = 4$, which is a light imposition on optimisation and normally eliminated by the in-built pre-solver. However, a second type of equality constraint heavily encumbers the solution. These are equalities of endogenous variables that lead to internal feedback loops.

Constraint	Description
damage function active in current period = damage function resulting from the period	Economic damage increases resource usage and increases emissions. Increased emissions cause increased temperature rise and increased economic damage. Therefore, a feedback loop exists. The initial economic damage needs to be settled in general equilibrium with the resulting economic damage as they are the same number. This is how the nonlinear climate equations enter into the intertemporal MRIO model.

Optimisation

A number of factors needs to be considered in nonlinear optimisation. Prime amongst these are the trade-offs between global and local minimisation, methods of solution, and accuracy and iterations.

Global and local optimisation

Global optimisers seek to find the best solutions in the presence of saddle-points, where two or more optima may exist. Nordhaus (2008, p.45) notes that the DICE model uses the local optimiser CONOPT. Experience with the DICE model over many decades has not indicated any issue arising from saddle-points.

The Mathematica package has both global and local optimisers. Use of these packages in this current policy research confirms the robust nature of the optimisation and that faster local optimisers can be confidently used.

Methods of solution

As mentioned above, Nordhaus' DICE model employs the CONOPT solver, which linearises equations and solves the approximated model quickly with a linear program.

Mathematica's solver FindMinimum provides many different methods of solution but for nonlinear constraints only interior point is available. In *Chapter 4 Economic models for climate change policy analysis*, the survey of programming environments found that the interior point algorithm is based on the COIN Project's IPOPT solver, which is regarded as a very fast nonlinear solver. Nevertheless, it is significantly slower than CONOPT. The key advantage of IPOPT over CONOPT is that the interior point solution finds a full nonlinear equilibrium rather than an approximated linear solution.

An in-depth discussion of methods of solution, including a detailed outline of global and local optimisation and interior point, is provided as *Appendix 5 Acyclic solver for unconstrained optimisation*.

Accuracy and iterations

The difficulty of finding equilibrium in the presence of nonlinear constraints was discussed above. For example, a base case projection of just 13 periods (130 years) involves 926 nonlinear constraints, 429 independent optimisation variables and 1089 unique variables and parameters in total.

Locating an equilibrium within a reasonable time frame involves many computing issues such as the internal working precision; the desired accuracy in locating variables and satisfying the objective function; and the number of hours or days of computing time involved. In this research it has been found that about 2,000 iterations is a convenient control parameter because the calculation of an equilibrium for 13 periods takes about 15 hours and the outcome has a good degree of accuracy. The number of iterations is increased to 4,000 or 6,000 if additional accuracy is required.

Constraint slacks

In cases where Mathematica's FindMinimum function cannot return an optimisation result accurate to say 6 decimal places, it returns the best solution found together with a message indicating residuals. For example:[x]

```
FindMinimum::eit :
  The algorithm does not converge to the tolerance of 4.806217383937354`*^-6 in 4000 iterations. The
        best estimated solution, with feasibility residual, KKT residual, or complementary
        residual of {5.80212×10^-9, 0.000473744, 7.3061×10^-12}, is returned. >>
```

Illustration 30: FindMinimum return message when constraints not fully satisfied

In this example a Karush, Kuhn, Tucker (KKT) residual of 0.000473744 means that the sum of the errors is $4.7 * 10^{-4}$ and has not converged to the solver's default accuracy of $4.8 * 10^{-6}$. However, it may be noted that the accuracy is still excellent and perhaps would be acceptable in other circumstances. The reason that the criterion for solver completion is manually set with iterations is that with some 1,000 constraints, not all may be decisively satisfied. A model's best fit needs to be discovered by diligent residual minimisation, rather than arbitrarily reducing the requested accuracy to achieve a more timely solution.

The source of the inaccuracy may be inspected by printing out the unsatisfied constraints having non-zero slacks and observing the magnitude of the slacks that are unsatisfied. It is assumed in this model that slacks greater than $1*10^{-4}$ merit investigation. In the Base Case model with 4,000 iterations, there are 13 unsatisfied constraints but none are material as shown by the output slacks:

```
There are 926 constraints. Following optimisation
 13 remain unsatisfied compared to 43 prior to optimisation.

All 13  of the unsatisfied constraints have slacks < 0.0001
```

Illustration 31: Evaluation of unsatisfied constraints

With fewer iterations, there is more change of unsatisfied slacks. For example, a message of the following form is produced with 2,000 iterations:

```
There are 926 constraints. Following optimisation 14 remain unsatisfied compared to 70 prior to optimisation.
The only key unsatisfied constraint with slack > 0.0001 is
```

$\{2.12051\times10^{6}\, s[1, 1, 1] + 8.54037\times10^{6}\, s[1, 1, 2] + 3.50544\times10^{7}\, s[1, 1, 3] - 4.57152\times10^{7}\, \gamma[1, 1] \geq 0, -0.000415802\}$

Illustration 32: Materiality of unsatisfied constraints

It may be noted in the above illustration that the slack is very small, and even more so when considered as a proportion of the magnitude of the variables. In the last line, the slack of $-4.16 * 10^{-4}$ results from the difference of very large numbers having magnitudes of 10^{6} and 10^{7}.

Mathematica's linear optimiser DualLinearProgramming conveniently provides the Lagrange multipliers and slacks. In a nonlinear context, KKT multipliers are equivalent to Lagrange multipliers. Unfortunately, at this stage, Mathematica's nonlinear optimiser FindMinimum does not expose its Karush Kuhn Tucker multipliers even though it uses these multipliers and calculates a KKT residual as shown in the message above.[xi]

Data and graphical output

Along with Mathematica's powerful symbolic processing capability, its other compelling advantage is a rich set of graphical functions that can be used for agile development and instant communication. Overall, Sceptre within Mathematica provides a high productivity development platform model for policy investigation.

5.3 Comparison of Sceptre with physical modelling

Chapter 2 Political Economy of the Anglo-American world view of climate change introduced the concept of a fixed tranche of atmospheric emissions capacity for a 2°C temperature rise.

As shown in the table below, the results of the Sceptre model developed in this research compare favourably with physical climate change modelling by Allen et al. (2009) and Meinshausen, M. et al. (2009) using a linear extrapolation of emissions.

Gigatonnes of CO_2 in period 2000-2050 for 2°C temperature rise		
Allen et al.	**Meinshausen et al.**	**Sceptre Model**
1,550-1,990 from 2000-50 2,055 in total from 2000	1,000 for 25% probability & same as Allen if non-CO_2 gases are included	1,409 from 2004-2054 2,194 from 2004-2134

For a 50% probability of exceeding 2°C, Meinshausen's tranche of CO_2 emissions rises to 1,440 GtC. The authors note that including non-CO_2 gases in their defining tranche of 1,000 Gt CO_2 (for a 25% probability of exceeding 2°C) provides the same result as Allen et al.

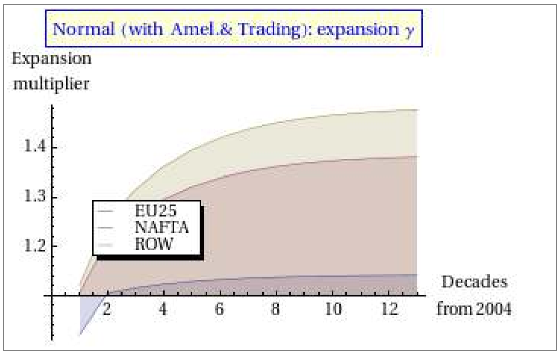
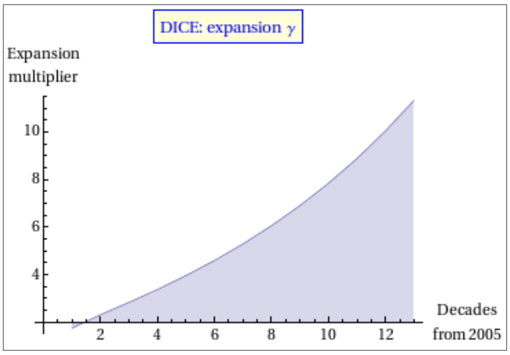
The Sceptre model is consistent with both sets of results. As discussed earlier in this Chapter, minor differences are expected because the geophysical framework deals with non-CO_2 gas emissions through a combination of fixed emissions and trends in radiative forcing.[xii]

5.4 Comparison of Sceptre and DICE

The climate-unconstrained case for both Sceptre[xiii] and Nordhaus' DICE model[xiv] is provided in the following sets of illustrations “Comparison of Sceptre and DICE” (below). Climate-unconstrained “business as normal” means that economic expansion is not constrained by global warming factors, for example limits on emissions or temperature rise. The illustrations for Sceptre and DICE are not symmetric because DICE does not produce the same spatial and industry information as Sceptre.

Economic expansion

It is immediately apparent in comparing the first illustrations for economic expansion that Sceptre and DICE are fundamentally different models.

Sceptre Normal Case economic expansion	**DICE Business as Usual economic expansion**
	

After 6 decades, Sceptre's economic expansion saturates at 1.1x for the European Union 25 country group (EU25), 1.38x for NAFTA trade zone and 1.46x for the Rest of the World (ROW). In contrast, DICE's economic expansion of is 4.6x in the same 6 decade period. It continues to rise strongly to 11.3x by decade 13. These results are presented in terms of expansions from the current situation, which is consistent with the principles of benchmarking discussed in *Chapter 4 Economic Models for Climate Change Policy Analysis*.

Prima facie there is quite a dramatic contrast between Sceptre and DICE. This is especially so considering that these projections are in real dollars rather than nominal dollars taking account of inflation. One would not intuitively expect real income to increase in a J-curve.

One reason for the startling difference between DICE and Sceptre is to be located in the difference between unconstrained and constrained models. In DICE, the economic model underpins the objective function rather than the constraints. In contrast, the economic model and climate damage feedback loop in Sceptre appears within the constraints which is computationally a much more expensive situation.

Most climate-economic modellers such as Garnaut are happy with a 100-year time horizon. Indeed, Nordhaus notes that it would be unwise to rely on more than the first 50 years. However, Nordhaus extends DICE to 60 decades (600 years) to show how the climate-economic ecosystem responds in the long term. Operating experience with Sceptre has shown that a time-frame of at least 13 decades is required so performance up to 10 decades is unaffected by end effects.

Nordhaus implements DICE's “business as usual” model using inequality constraints. However, the use of constraints is not essential because the paradigm is objective function-centric. Projecting 13 decades directly from the equations is straightforward. However, the end effects in DICE are extraordinarily significant, requiring projection over 25 decades for a clear observation of 13 decades. As there is only one regional economy for the whole globe, there are only 25 region-periods to project. In the business as usual case, there is no binding constraint so there are only 25 constraint-region-periods and 50 optimisation variables in total.[xv]

Constraint-centric models like Sceptre are significantly more complex. For example, the spatial and commodity disaggregation in Sceptre means that there are three regions, each with a five-by-five matrix of commodities and industries. Thus, for 13 periods there are 975 region-periods to project. In fact, each matrix of commodities and industries is in reality more complicated because the Use and Make matrices together provide different production technologies for each of the commodities (particularly as some of the Use rows are calculated). This has already been examined (above) so consideration of the additional information in these detailed Leontief production functions will not be pursued in this brief comparison of model complexity in terms of constraints, regions and periods.

Sceptre has 919 symbolic constraints compared to zero in DICE's business as usual case. Each of Sceptre's constraints is embedded with up to the entire 975 region-periods. This provides 68,925 constraint-region-periods. Some of Sceptre's symbolic constraints are very long and use all of the 429 optimisation variables. This is because the constraints progressively compound all the foregoing periods of regional performance.

Although both models share Nordhaus' scientific-economic equations, it may be seen that Sceptre is optimising in a different way to DICE. Sceptre is constrained optimisation compared DICE's unconstrained “business as usual” case. In Sceptre, the consumption expansion in each region is constrained by the natural endowments of labour and capital, although capital is endogenously calculated. In addition, consumption is constrained by three other important factors. These are the purchasing power of labour, a limit on trade deficits and by the preference given to investment.

In DICE, none of these constraints apply. The most important of all is DICE's preference for consumption over investment, which arises because consumption is maximised with respect to capital. This is discussed in *Appendix 4 Nordhaus DICE model* and other aspects of DICE performance are discussed in *Appendix 5 Acyclic solver for unconstrained optimisation*.

Amelioration and abatement

The DICE unconstrained model is geared to high consumption, high emissions and high emissions control. While economic projections are “apples and oranges” for the reasons highlighted above, DICE and Sceptre have similar geophysics outcomes due to DICE's high emissions control. For example, DICE maximises economic expansion with 33% participation in emissions control by decade 6, rising to 63% by decade 13.

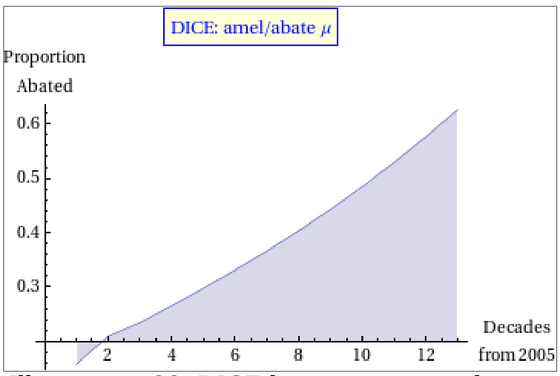
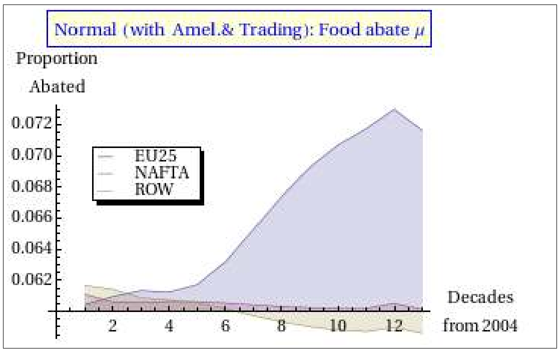
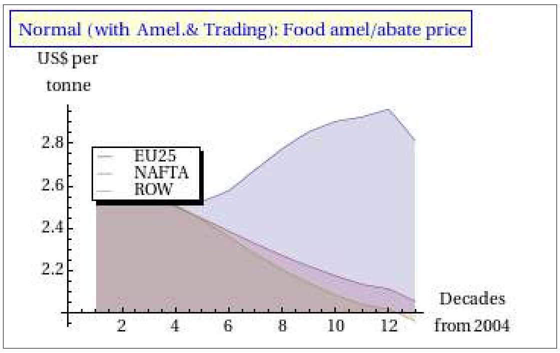


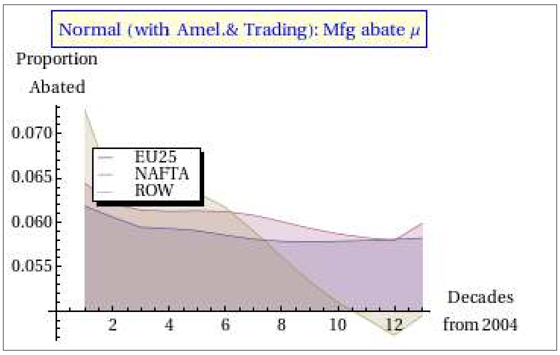
Illustration 33: DICE business as usual emissions control rate

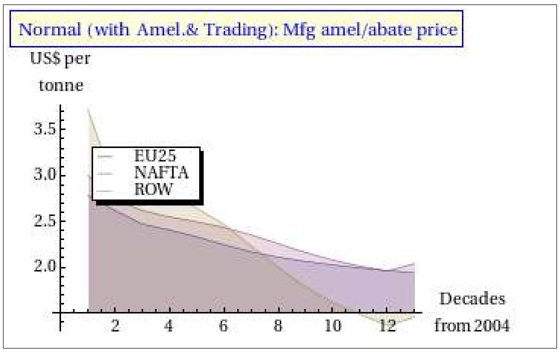
In contrast, Sceptre shows 5.5% amelioration and abatement in food, 4% in manufacturing and 7% in services. Sceptre's emissions control rate and price are shown in the following illustrations:

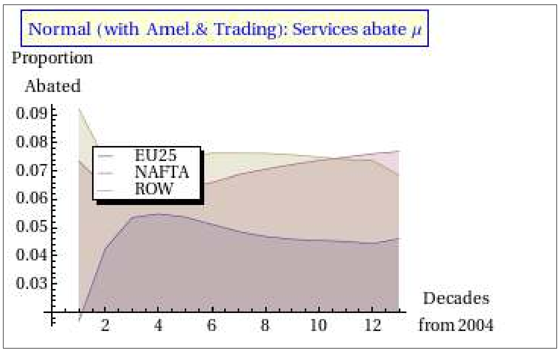
Sceptre Normal Case	**DICE Business as Usual**

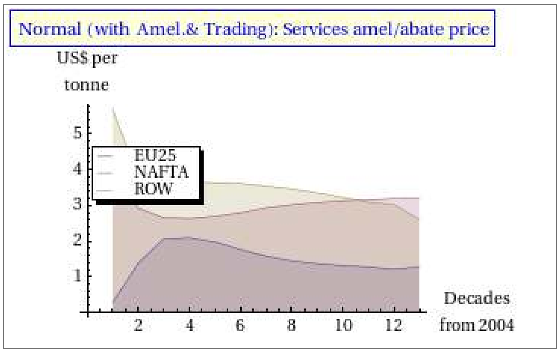




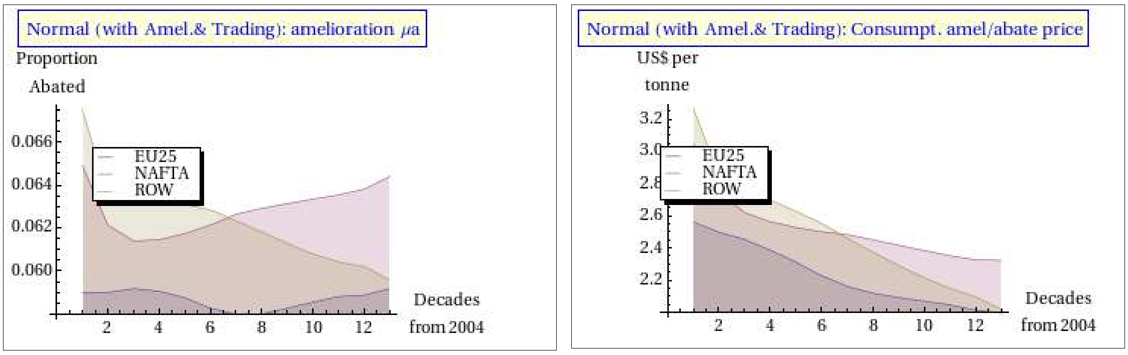








Sceptre Normal Case | DICE Business as Usual

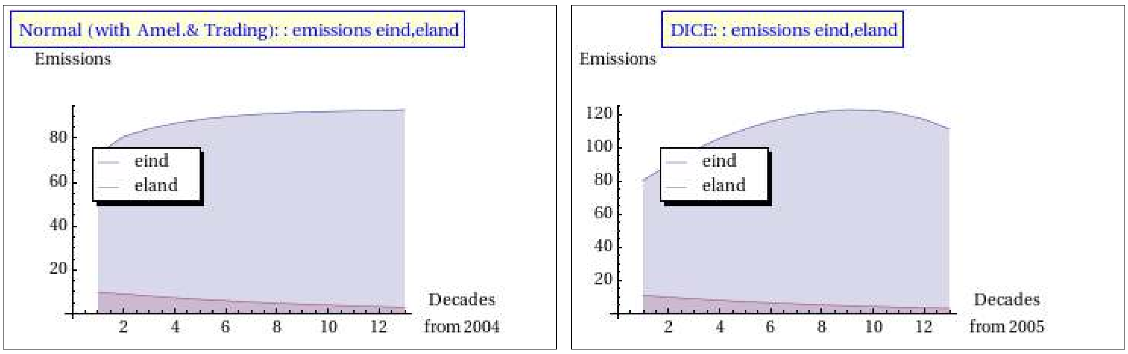


Due to its high participation rate, the price of amelioration and abatement in DICE rises to US$142/tonne at decade 6 and US$390/tonne at decade 13. This is significantly higher than Sceptre's amelioration and abatement cost of a few dollars per tonne.

Industrial Emissions

Sceptre shows industrial emissions rising quickly over 1 decade from about 70 GtC to 80 GtC and then slowly stabilising at about 90 GtC. In contrast, DICE's very high projection of production and consumption cause industrial emissions to rise to 91 GtC after one decade and stabilise 40% higher at 128 GtC in decade 9, before slowly decreasing to 115 GtC at decade 13.

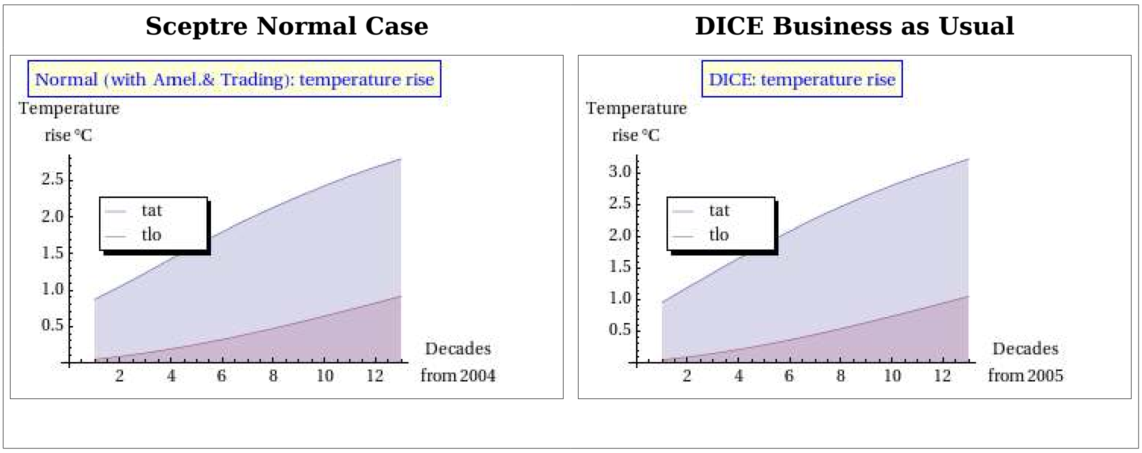
Sceptre Normal Case | DICE Business as Usual



Over the first five decades, total CO_2 emissions are 1515 Gt and 1785 Gt for Sceptre and DICE respectively.

Temperature rise

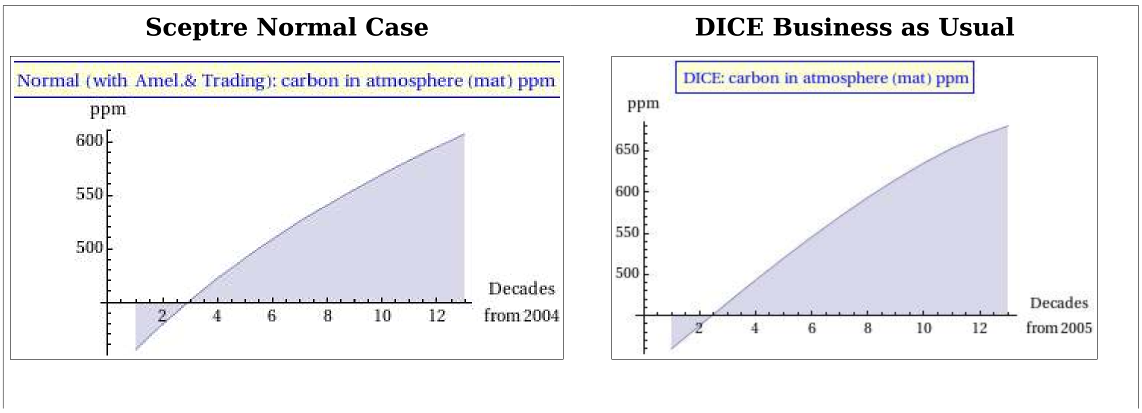
Initially, both models have similar atmospheric and sea temperature rise profiles although DICE is more aggressive.

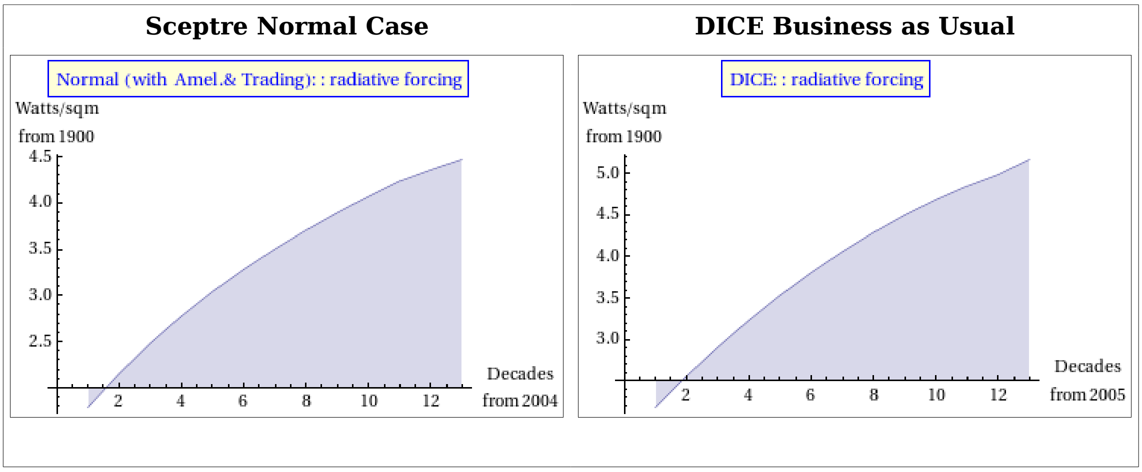


DICE's atmospheric temperature rise doubles increases from the present 0.8°C to 1.0°C over 1 decade and then doubles from the present to 1.65°C over 4 decades. The same doubling in Sceptre occurs after 5 decades. With a similar difference, the atmospheric temperature rise at the end of the projection period of 13 decades is 3.2°C for DICE and 2.8°C for Sceptre. It will be shown in the next section for the Base Case that such a difference in temperature rise has extraordinary consequences for environmental cost.

Atmospheric carbon concentration and radiative forcing

Atmospheric carbon concentration causes temperature rise and therefore shows the same pattern of difference as temperature rise. Over the 13 decade projection period, DICE shows 680 ppm compared to 610 ppm for Sceptre.

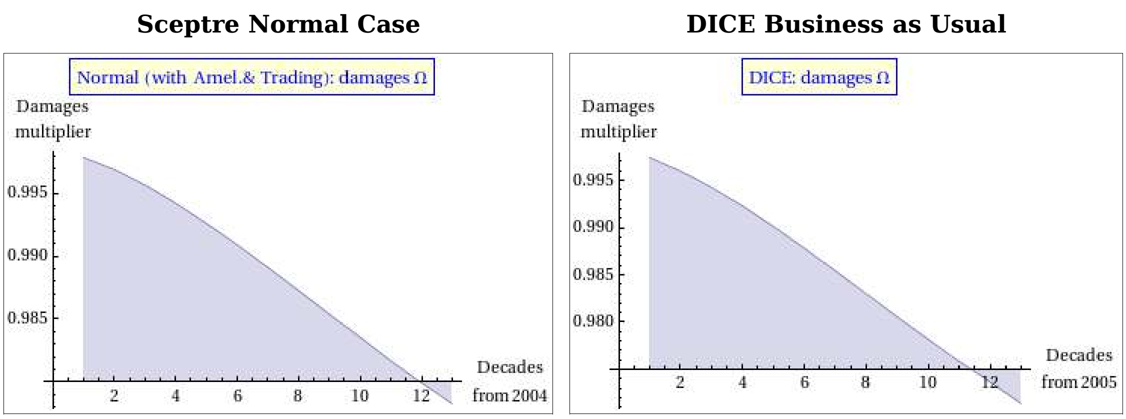




Radiative forcing also mirrors CO_2 concentration. DICE reaches 5.2 Watts/m^2 after 13 periods and continues to accelerate. Sceptre reaches 4.5 Watts/m^2 while flattening.

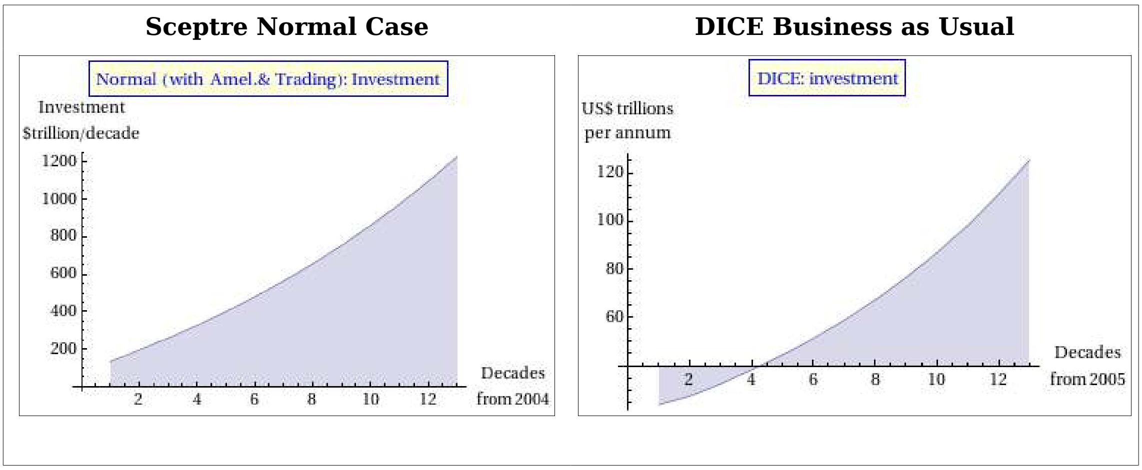
Damage multiplier

As would be expected from similar temperature rises, the damage multipliers of 0.971 and 0.977 after 13 periods for DICE and Sceptre, respectively, are comparable. This is equivalent to economic output declining by 2.3%.

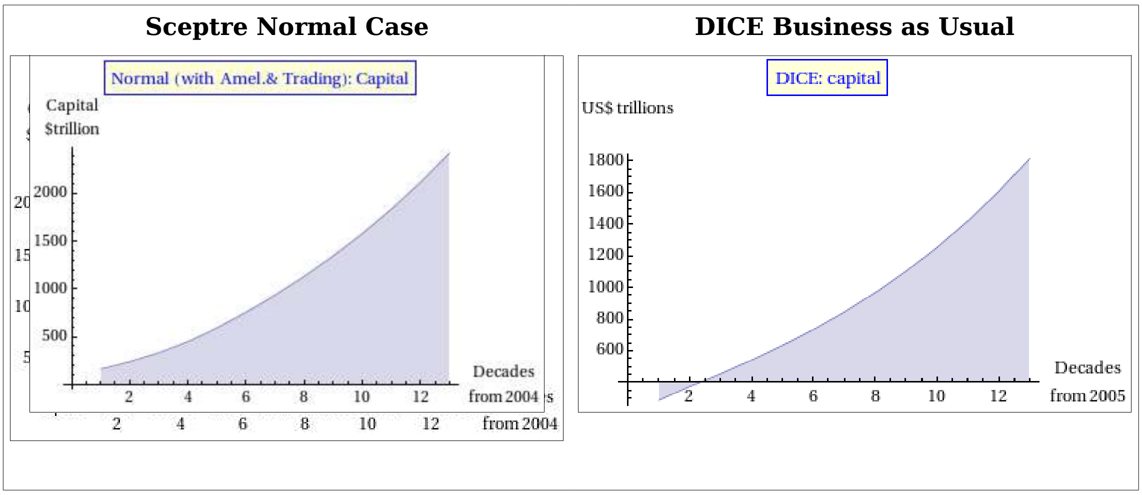


Investment and capital

Sceptre shows investment rising to US$500 trillion per decade after 6 decades and to US$1200 trillion per decade at the end of the projection period. In contrast, DICE investment per decade is similar at US$512 trillion after 6 decades and US$1254 trillion at decade 13.



However, net accumulated investment or capital in Sceptre is considerably higher at US$700 trillion after 6 decades and US$2500 trillion by the end of the projection period. The lower investment in DICE results in the same capital of US$733 trillion after 6 decades but only US$1813 trillion, or about 72% of the capital at the end of the projection period.



5.5 Conclusion

This Chapter presented a new intertemporal computable general equilibrium (CGE) model applying the Service Sciences technique of benchmarking to multiregional Input Output modelling. Major design assumptions have been set out and discussed. Key amongst these were the net present value discount rate, population growth, climate scientific-economic equations, a new method of intertemporal modelling using accounting stocks, flows and Sales/Assets ratios, and the selection of an objective function.

Make and Use table augmenting methods have also been presented in regard to carbon commodities (carbon permits and amelioration and abatement services), impairing economic output for climate damage and enhancing output for total factor productivity.

Technical optimisation issues have been evaluated. Foremost amongst these were methods developed for working with marginally satisfied constraints that occur in real world problems.

The model developed in this Chapter was validated with recent geophysical research and found to be consistent. The model was also compared to the William Nordhaus DICE model using a Normal case where output is maximised without a climate change constraint. This is a “business as usual case” with economic damages occurring as a result of global warming and with carbon markets responding to this damage in order to maximise output.

It was found that the Nordhaus DICE model is a high growth, high emissions control model. This contrasts to the benchmarking model developed in this Chapter that has lower growth and a correspondingly lower the emissions control regime.

In comparison with the Nordhaus DICE model, Sceptre proves to be stablised by the usual neoclassical labour resource constraint, a labour purchasing power constraint to close the model for households, a cap on trade deficits plus a new form of intertemporal capital constraint. This new capital constraint is a substantial stocks and flows model that governs the relationship between stocks and flows through Sales/Assets rules.

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i One model was run continuously for over 5 weeks on a high speed research computing node in an unsuccessful test of ultimate constraint satisfaction

ii Fortunately, calculated very quickly using Mathematica's symbolic processing

iii Attributed to the Franciscan friar William of Ockham (1285-1349)

iv In this example, it may help to think of consumption plus net imports, where net imports is just a negative number for net exports

v It is interesting to note that the use of DuPont analysis completes a full circle in Leontief and CGE modelling. The Physiocrat Pierre Samuel du Pont de Nemours, who became a prominent American industrialist, advocated low tariffs and free trade

vi As there have been changes in the collection and classification of data between GTAP5 and GTAP7, a more reliable analysis would require extended econometric analysis using supplementary data sources

vii For example, Australia's net migration was 285,000 in 2009, compared to a more normal level of 90,000 per annum

viii DICE 2005 emissions is calculated from the equation for industrial emissions:

eind(0) = 10 $\sigma(0)$ (1 – $\mu(0)$) ygr(0) + eland(0)
= 10 x 0.13418 x (1 – 0.005) x 55.667 + 11
. = 85.3205 GtC per decade

Converting this equation into $MtCO_2$ per annum:

eind(0) = 0.13418 x (1 – 0.005) x 55.667 x 3.67 x 1000 + 11/10 x 3.67 x 1000
= 27,276 + 4,037
= 31,313 $MtCO_2$ per annum

ix *ceteris paribus:* other things being held constant

x This example is drawn from the file m12_13p_2C_100.nb

xi Personal communication with Wolfram indicates that this issue will be addressed in a future release of Mathematica

xii GTAP's future release of a mapped non-CO2 gas emissions database will facilitate further improvement in the geophysical model

xiii m12_13p_normal.nb

xiv topo_test12_comp_sceptre.nb

xv DICE "business as usual" has various miscellaneous non-binding constraints

Chapter 6 Assessment of changes in regional and industry performance under resource constrained growth

The foregoing Chapters have established the framework for a new lens through which climate-economic polices may be analysed to address the research question of identifying the regional and industry effects where resources are limited by climate change. *Chapter 5 A new spatial, intertemporal CGE policy research tool* described a new intertemporal, multiregional CGE model called Sceptre, which is an acronym for Spatial Climate Economic Policy Tool for Regional Equilibria. The objective of this Chapter is to use this new lens for policy research to address an example of climate policy.

The Base Case adopted for this policy investigation is that the increase in global average temperatures above pre-industrial levels should not exceed 2°C and that both developed and developing countries need to work towards this goal. This policy was accepted by the Major Economies Forum at its July 2009 inaugural meeting in L'Aquila, Italy (see *Chapter 3 Political Economy of the Anglo-American world view of climate change*). This objective is consistent with the IPCC's recommendations to ameliorate global warming and is supported by the vast majority of scientists. In September 2009, 133 countries and the European Union had accepted the proposed 2°C limit.

The multiplicity of results from spatial models is often celebrated and lamented in rapid succession. Fortunately, Mathematica's rich data visualisation capabilities allow the communication of the results to be relatively enjoyable or, if not, then at least bearable.

Chapter 1 Introduction discussed the value of policy modelling: firstly for the ability of modelling to test feasibility and secondly to provide an appreciation of risks through the differences between scenarios. It was noted that other modelling techniques would supplement CGE and ultimately public pluralist processes, such as forums for stakeholder debate, would determine policy decisions. So the aim in using the Sceptre policy investigation tool is to contribute a reference position to the process of policy formation.

The 2°C Base Case is important in its own right. However, for the reasons of systemic modelling risk discussed in *Chapter 1 Introduction* it is not an immutable outcome of the policy. With this caveat, features of the Base Case are discussed in this part of the Chapter. In the ensuing sensitivity cases, the Base Case is used to contrast sensitivity scenarios for Point of View Analysis, Constraint Severity Analysis, Technology Cost Analysis and Impaired Sales to Asset Ratio Analysis.

The results are presented in terms of expansions from the current situation, which is consistent with both the language and the mathematics of benchmarking discussed in *Chapter 4 Economic Models for Climate Change Policy Analysis*. Aggregate investment, accumulated capital and carbon commodities are presented in absolute terms. These absolute values need to be approached with the usual caveat concerning apparently accurate numbers in projections.

6.1 Policy investigation with the Sceptre tool

6.1.1 Base Case results and analysis

Economic expansion

In 2004, the regions NAFTA (America, Canada and Mexico), the European Union (25 countries) and the Rest of the World (ROW) had Gross Domestic Products as shown in the following table:

Gross Domestic Product 2004 US$ trillion	
EU25	13.3
NAFTA	12.8
ROW	14.8
Total	41

Illustration BC01 (below) shows the regional expansion of consumption. It may be seen that there is a marked difference between regions. The EU25 has subdued performance. Its economic expansion starts with a 2% increase in the first decade and saturates at about 14%. This compares to a 6.7% increase in population as shown in *Chapter 5 Sceptre model development*.

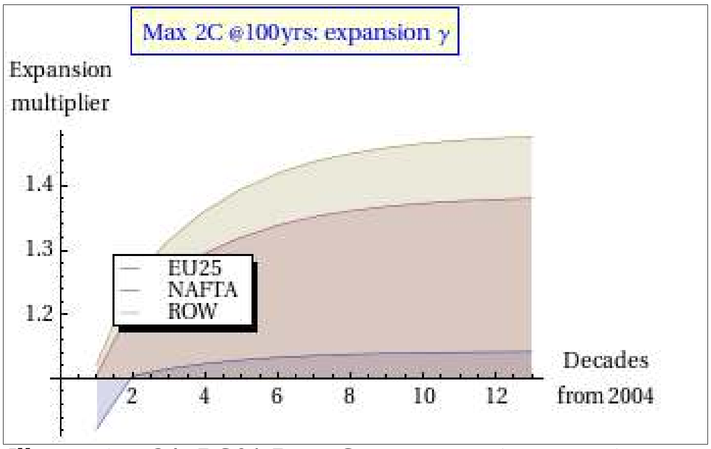


Illustration 34: BC01 Base Case economic expansion factors

NAFTA's economic expansion jumps 10% in the first decade and saturates at about a 38% increase. This compares to a 29.1% increase in population. The Rest of the World (ROW) sector expands 12% in the first decade. This saturates toward a 48% expansion, which compares to an increase in population of 38.1%.

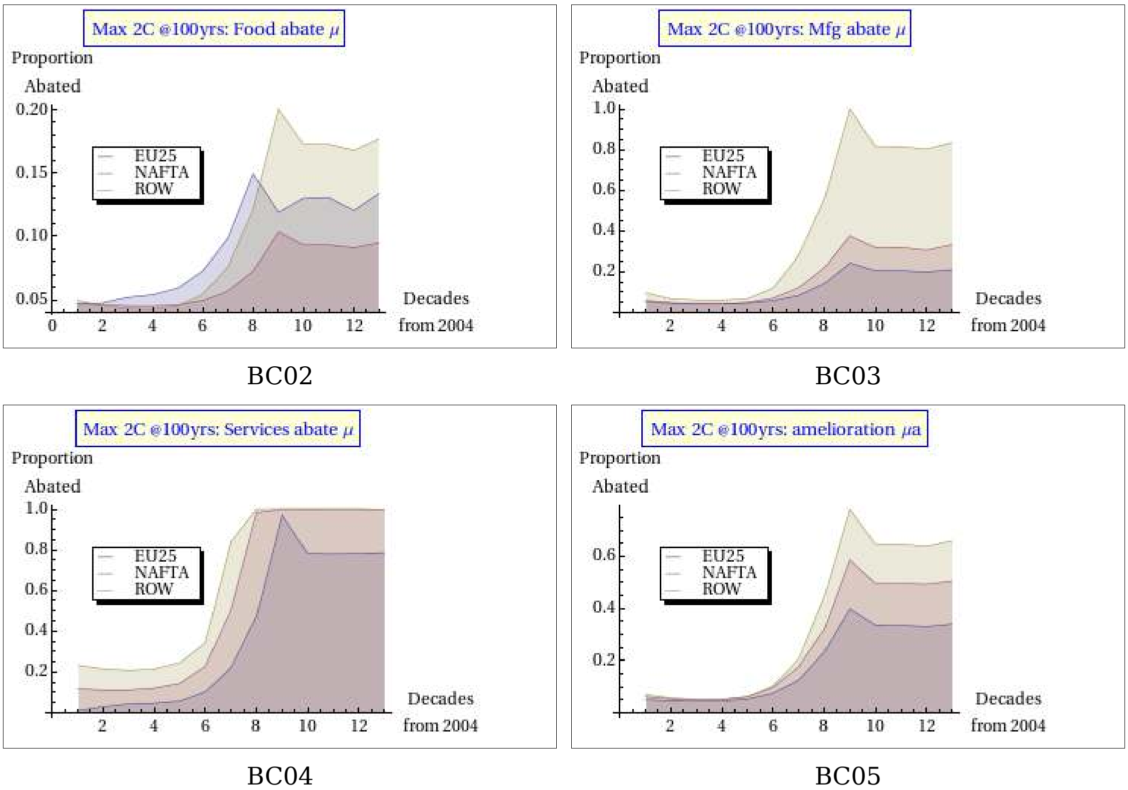
When due only to trade and production efficiency and the growth of labour availability, these increases suggest a significant increase in output in real terms. The average increase in living standard at the end of the projection is the same in each case at about 6.95% in real terms. This reflects the objective function that equally weights per capita increases in welfare in all regions.

Proportion of emissions ameliorated or abated

The control profile is the proportion of emissions actively ameliorated or abated, in comparison to being satisfied by the purchase of emissions permits. It may be noted that after an interregnum of 6 decades, control requirements rapidly increase in order to achieve the 2°C temperature rise constraint.

The illustrations BC02 to BC04 below show the emissions control profile for the production of food, manufactured goods and services respectively. Illustration BC05 shows the control profile for consumer generated emissions.

Base Case emissions control rate by commodity



The following table summarises the saturation emissions control levels in each country and industry.

Base Case saturation emission control rates			
Emissions controlled	**EU25**	**NAFTA**	**ROW**
Food	14%	9%	18%
Manufacturing	21%	33%	83%
Services	79%	100%	99%
End Consumption	34%	50%	66%

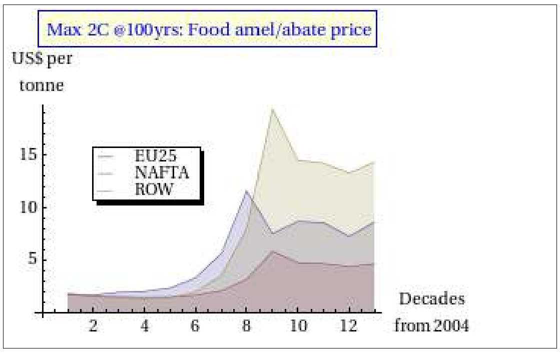
It may be seen in the above table that the control requirements for food are relatively modest. However, the high figure for ROW manufacturing and end consumption shows how energy and emissions intensive these sectors are across the ROW region. It may be noted that for services production, which includes electricity production, very high or complete control is required in all regions. This demonstrates the crucial importance of controlling emissions from electricity generation.

Price of amelioration and abatement

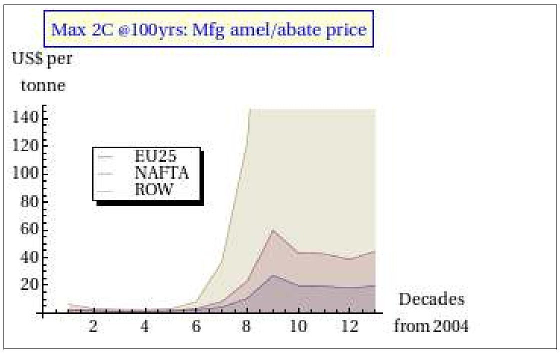
Anuradha's (2009) identification of contract conditions that would enable developing countries to join with industrialised countries is discussed in *Chapter 1 Introduction*. A paramount issue is the cost and availability of green infrastructure and technology. The Sceptre policy tool may be employed in developing a policy response to the technology factor. Sceptre is able to exemplify the potential cost of amelioration or abatement where the emissions control rate varies across regions and industries. This is shown in the following three illustrations for the Base Case of Maximum 2°C rise at 100 years.

The illustrations BC06 to BC09 below show the average price of amelioration and abatement based on the above control rates.

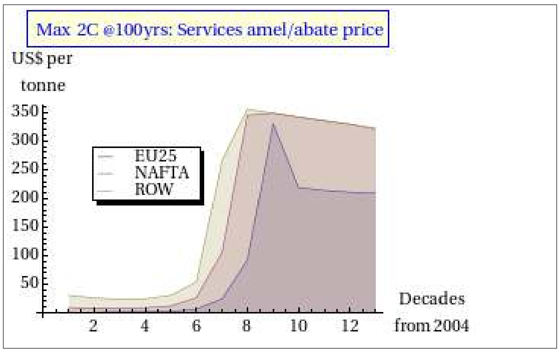
Base Case emissions control prices by commodity



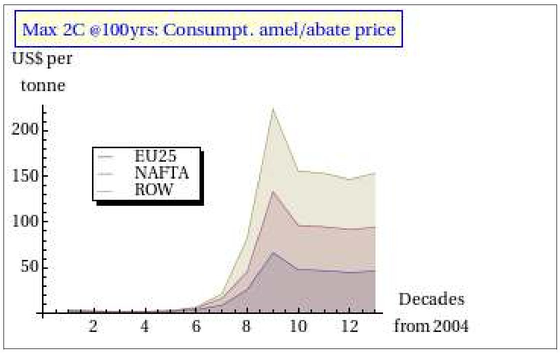
BC06



BC07



BC08



BC09

The saturation prices for each commodity in each region are shown in the following table:

Emissions control technology prices			
US$ per tC	**EU25**	**NAFTA**	**ROW**
Food	9	5	14
Manufacturing	19	44	233
Services	209	322	320
Consumption	46	94	153

In an international market, emission permits could be expected to trade at the marginal cost of the next unit of amelioration and abatement. In the table above, emission permits would trade at US$322.

While costs of amelioration or abatement are relatively low in the food industry, an exceedingly high cost of adjustment may be seen in ROW manufacturing, comprising mainly developing countries. In the services sector, which includes electricity generation, the amelioration/ abatement cost is high for all countries. This demonstrates that developing countries are very exposed to the cost of green technology and infrastructure. However, under this Base Case scenario, these high costs do not become an imperative until mid-century.

Industrial emissions

Illustration BC10 shows land clearing emissions in purple and industrial emissions in blue. Total emissions is the sum of these two components.

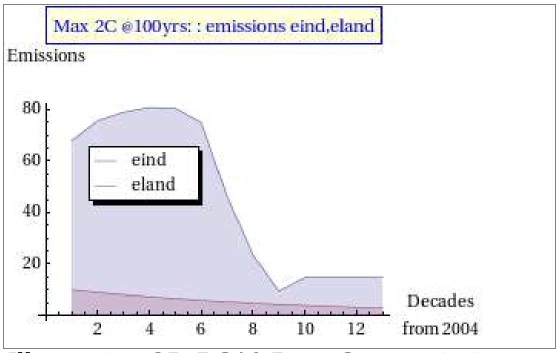


Illustration 35: BC10 Base Case emissions from industrial activities and land clearing

In order to meet the 2°C temperature rise constraint while maximising welfare, industrial emissions show an increasing profile for 5 decades to a maximum of 80 GtC/decade. This is 8 Gt per annum, which is 38% higher than the 1990 level of 5.81 GtC.

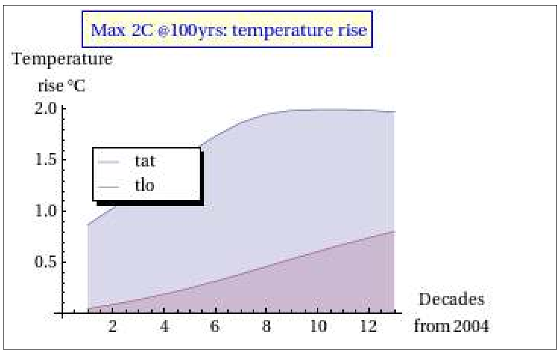
After reaching the 80GtC/decade maximum, emissions must drop by 88% to 9.4 GtC/decade after 9 decades. This level is equivalent to 0.94GtC per annum, which is an 83% reduction compared to the 1990 level.

This shows that various widely discussed objectives for a 20% or 40% reduction by 2020 (compared to 1990 levels) and 50%, 60% or 80% reduction by 2050 may not be fully consistent with maximising economic welfare but do represent a progressive approach to controlling emissions that mitigates the risk of needing to reduce emissions 88% in just one decade.

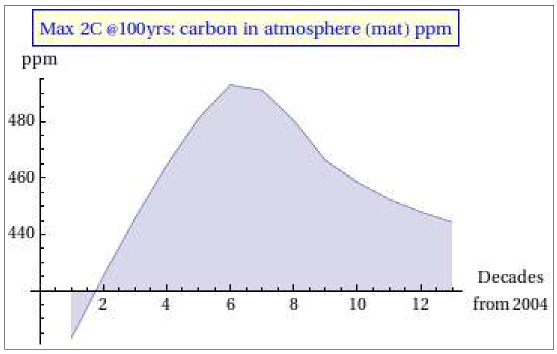
Temperature rise and economic damage function

Illustration BC11 shows how the 2°C limit on atmospheric temperature rise is approached after 8 decades and then stabilises. There is also a strong, albeit delayed rise in ocean temperature, where the effects are yet to be fully appreciated. Illustrations BC12 and BC13 show the associated concentration of carbon and radiative forcing.

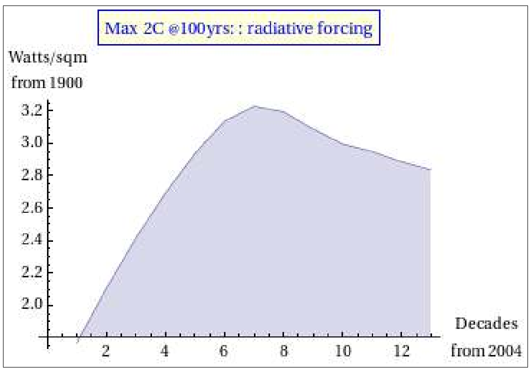
Base Case geophysical parameters



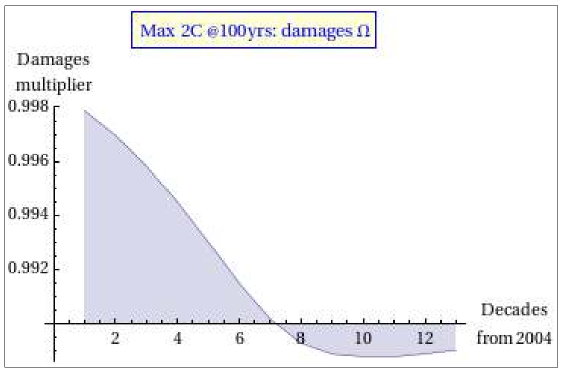
BC11



BC12



BC13



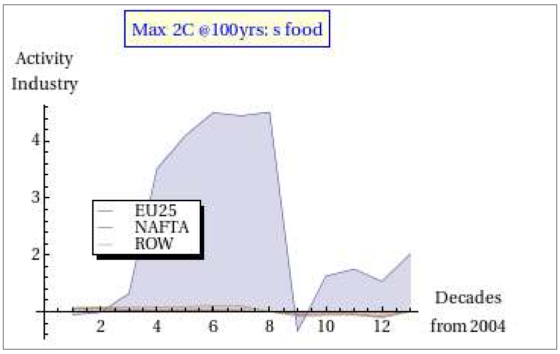
BC14

The second most important illustration is BC14, which is the economic damage feedback multiplier. This is a function of atmospheric temperature rise and asymptotically approaches 0.989, which is a reduction of economic output of about 1.1%.

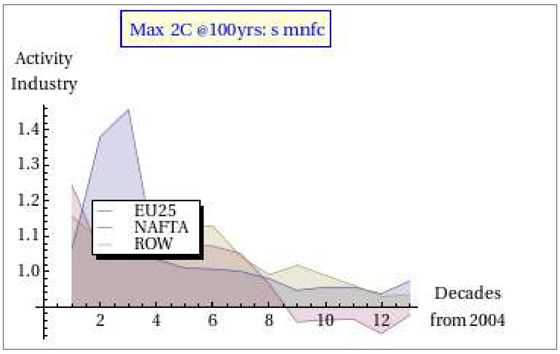
Industry activities

Illustrations BC17 to BC21 show the level of industry activity by commodity by region. These are complemented by Illustrations BC22 to BC24 that cross-tabulate to show industry activity by region by commodity.

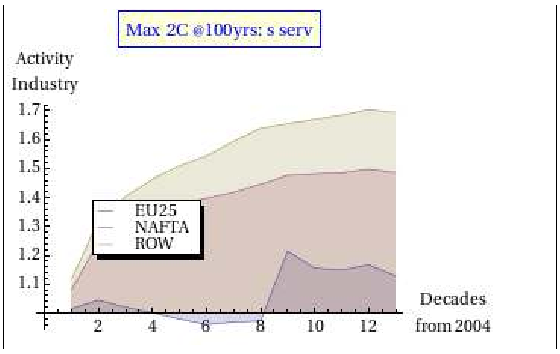
Base Case industry activity expansion by commodity and by region



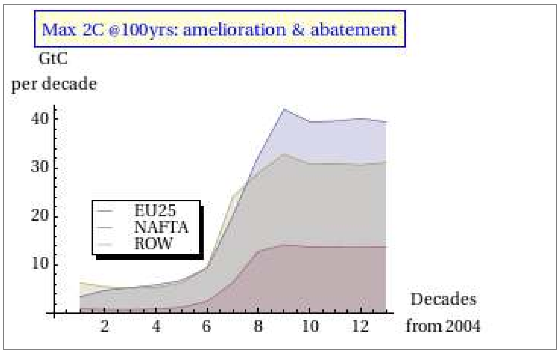
BC17



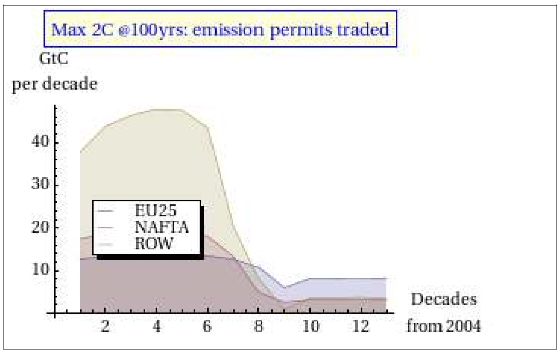
BC18



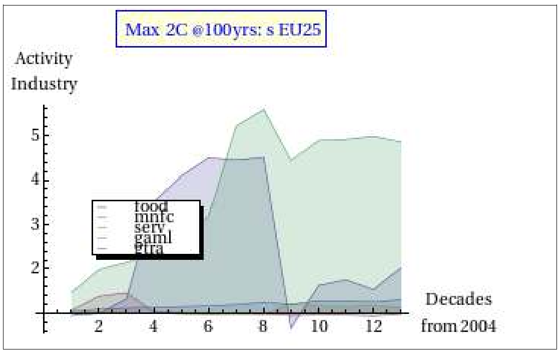
BC19



BC20

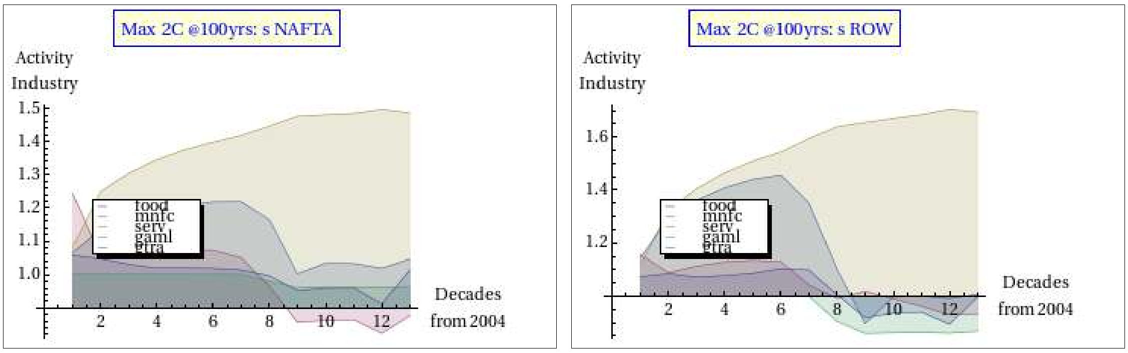


BC21



BC22

Base Case industry activity expansion by commodity and by region



BC23 BC24

Specialisation

A major feature of the industry activity illustrations, for example in BC17 (above), is that for a time the EU25 becomes a food bowl for the Rest of the World (ROW). The activity of the sector is very strong, increasing from 1 to 4.5 times over six decades. It also exhibits a volatile profile by dropping to 0.65 at decade 9 and then returning to 2 times by decade 13.

Specialisation is not the result of a fixed input-output coefficient schema. It occurs because of trade substitution in resource extensive sectors of factor abundance, guided by the general equilibrium that maximises value-added per unit of labour resource (ten Raa 2005, pp.48-9, 110-1,& 127-8). Production is switched to the most viable location until this process becomes limited by a binding constraint. Higher cost sectors are deactivated. This occurs because of the Theorem of Complementary Slackness. Sectors are either active, with zero slack and have positive shadow prices for inputs; or are closed with positive slack and zero price for inputs (see *Chapter 4 Economic Models for Climate Change Policy Analysis* and *Appendix 6 Benchmarking with Linear Programming*).

The presence of specialisation in Sceptre's super-free trade model is not regarded as weakness but as a generic issue inherent in neoclassical modelling and starkly apparent following optimisation. It is not a matter of suppressing specialisation. Indeed, the well-known Ricardian benefits that derive from multiplying the volume of free trade are due to a general equilibrium optimisation of bilateral specialisation with trade partners (Romer 1994). This has been observed in the off-shoring of Anglo-American jobs to Asia and China. The real issue is when and how to control specialisation into a practical range.

The only approach taken in Sceptre is to limit trade deficits. It is acknowledged that this is less than perfect because specialisation may still occur in one commodity if production of another is relinquished.

In cases where policy studies have specific requirements it will be necessary to better control specialisation. Saturating consumer utility before too much specialisation occurs is a synthetic method of achieving this. A carefully constructed nonlinear contemporaneous utility function is required (ten Raa 2005, p.175). Various non-linear objective functions were evaluated in the course of Sceptre's development. However, a simple yet effective general purpose saturating utility function that addressed excessive EU25 food production was not forthcoming. Ultimately, other social welfare considerations led to the selection of Sceptre's objective function, as set out in *Chapter 5 Sceptre model development*.

Two better methods for controlling specialisation are to employ additional engineering or ecological infrastructure constraints and the use of differential technology propagation. Infrastructure constraints are specific to the specialised commodity. For example, food production in the European Union would be limited by the availability of arable land. Such a constraint may be implemented in the same way as a labour constraint with resource data drawn from GTAP's land use database or Mathematica's Country database. In other regions or countries where farming is on marginally viable land such as Australia or China, a better constraint may be water resources.

Differential technology propagation would change value-added functions and the pattern of substitution. *Chapter 3 Political Economy of the Anglo-American world view of climate change* showed that the differential propagation of HIV pharmaceutical technology and future green energy technologies are major concerns of developing countries. In relation to limiting EU food specialisation, it might be that genetically modified crops in NAFTA and the Rest of the World would act to reduce the resource extensibility of EU food production.

Further investigation into Sceptre's objective function, engineering and ecological infrastructure constraints, and technology propagation remain policy research opportunities and are set out in *Chapter 7 Conclusions and Suggestions for Further Research*.

Total Factor Productivity

Illustration BC18 (above) shows manufacturing industry activity in all regions rapidly increasing and then declining. The rapid increase is due to growing output for all regions, while the decline is due to technological progress through increased factor productivity leading to more output for the same amount of input and industry activity.

Illustration BC19 (above) shows the Service Industry greatly prospering in NAFTA and ROW, while initially sluggish in EU25. This sluggishness is due to the EU's specialisation in food production as discussed above.

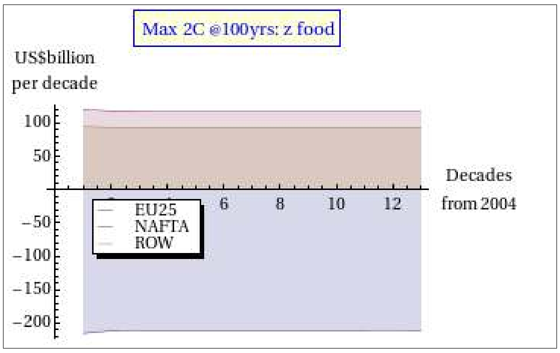
Carbon sector activity

Illustrations BC20 and BC21 (above) show the outputs of the augmented carbon sectors, the amelioration and abatement sector and emission permits trading sector respectively. It may be noted that in decade 6 the trading of emissions permits switches over to physical amelioration and abatement. A feature of the illustration is the strong growth EU25 emissions (for the reasons discussed above) and in the region's equally strong amelioration and abatement. Total emissions dealt with by both processes rises from 78GtC in the first decade to 99 GtC in decade 13.

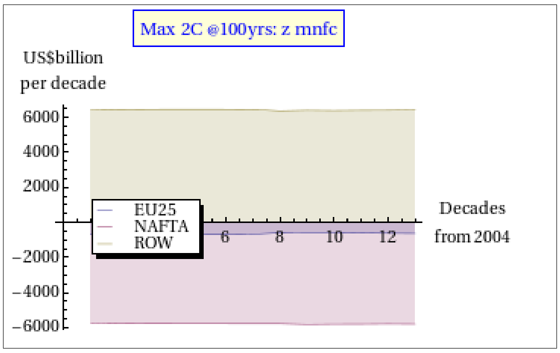
Commodity Export

Illustrations BC25 to BC29 show the export outputs for each commodity. A positive amount is a net import while a negative amount is a net export. Illustration BC27 shows no export activity because Services has been defined as a nil-export commodity.

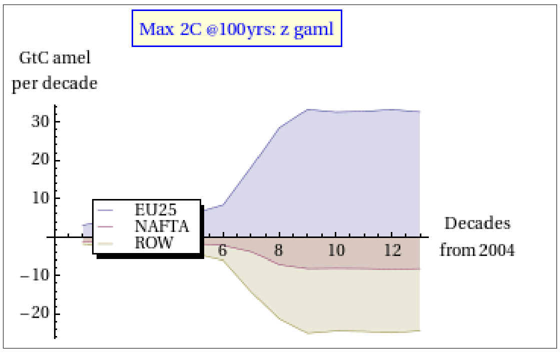
Base Case international trade in food, manufactured and carbon commodities



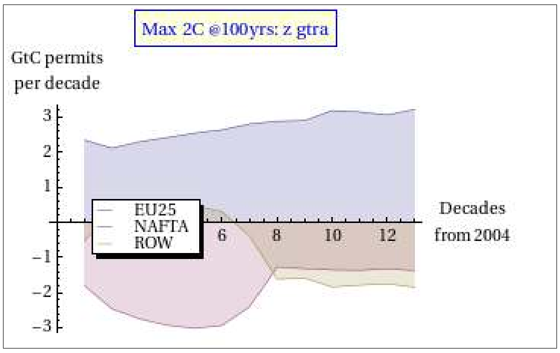
BC25 (food trade)



BC26 (manufactured commodities trade)



BC28 (carbon amelioration services trade)



BC29 (carbon emissions permits trade)

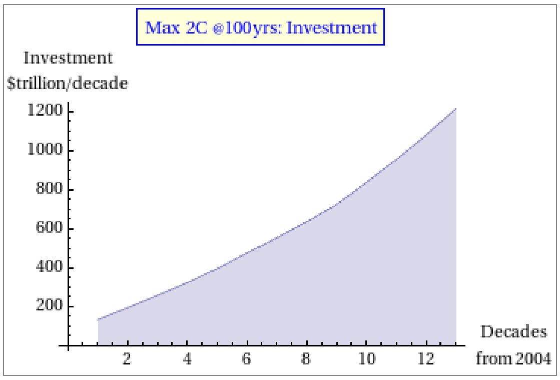
It may be noted in illustration BC25 that EU25 is a net exporter of food to NAFTA and ROW, as has been recognised in its specialisation. The EU25 is quiescent in the export of manufacturing. Illustration BC26 shows NAFTA exporting manufactured products to ROW.

In order to achieve its food expansiveness, illustration BC28 shows that the EU25 imports permits from NAFTA and after decade 6 begins to import significant permits from the ROW. However the dominant feature in illustrations BC28 and BC29 is that after decade 6, EU25 imports large amounts of both amelioration and abatement services and emissions permits.

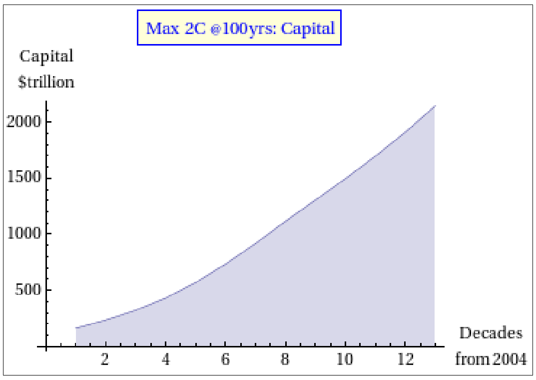
Aggregate investment and capital accumulation

Illustrations BC15 & BC16 show aggregate investment and capital in absolute terms, which are mainly used for comparisons across scenarios.

Base Case aggregate investment and capital accumulation



BC15



BC16

The table below compares the Normal or "business as usual" scenario with no climate constraint (see Chapter 5) to the 2°C Base Case. it may be seen that the 2°C limit reduces accumulated capital in decade 13 by 11% or US$280 trillion.

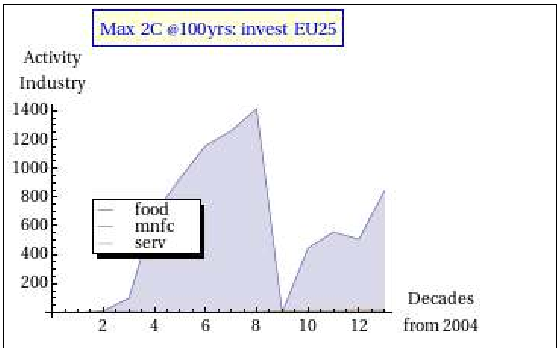
Investment and capital accumulation (in decade 13)		
2004 US$ trillions	**Business as usual**	**Base Case 2°C rise**
Investment per decade	1,229	1,214
Accumulated capital	2,424	2,143

Illustrations BC30 to BC33 (below) show the investment activity for each region by commodity. This is a plot of the multipliers of the existing investment vectors. Cross-tabs of investment activity for each commodity by region are shown in illustrations BC33 to BC35.

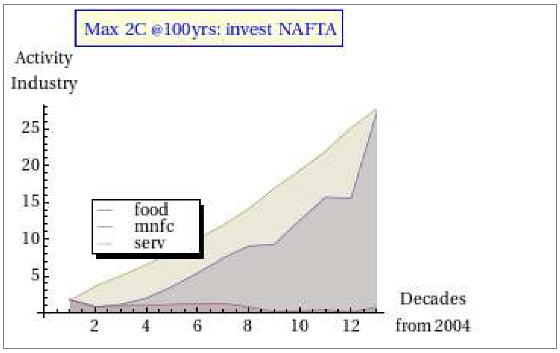
These activities are the multiple of existing investment vectors, which are:

Initial investment (per decade) 2004 US$ trillion			
	Food	**Manufacturing**	**Services**
EU25	0.07	9.3	11.3
NAFTA	0.32	10.3	14.6
ROW	0.24	12.6	23.0

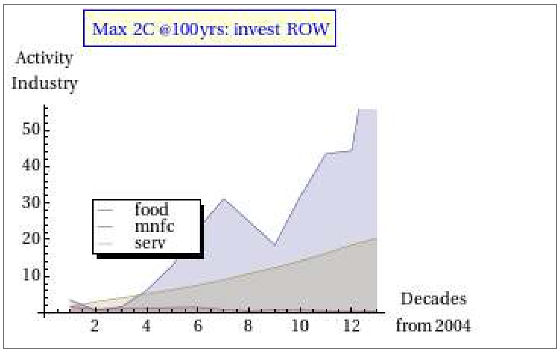
Base Case disaggregated investment by region and by commodity



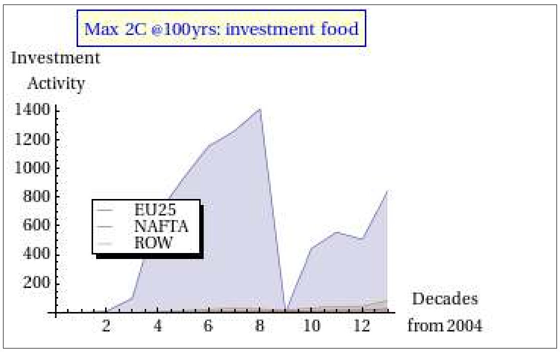
BC30



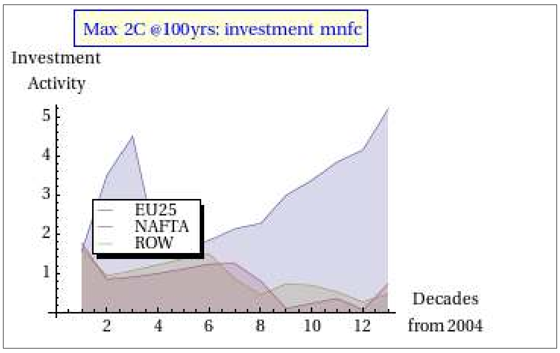
BC31



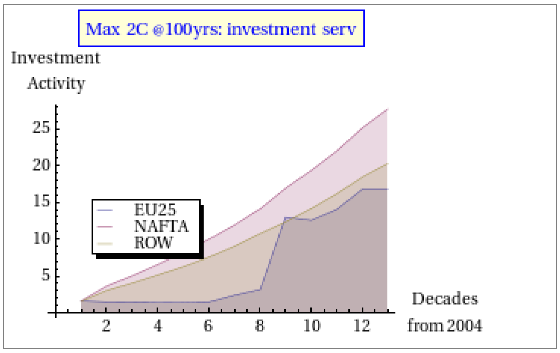
BC32



BC33



BC34



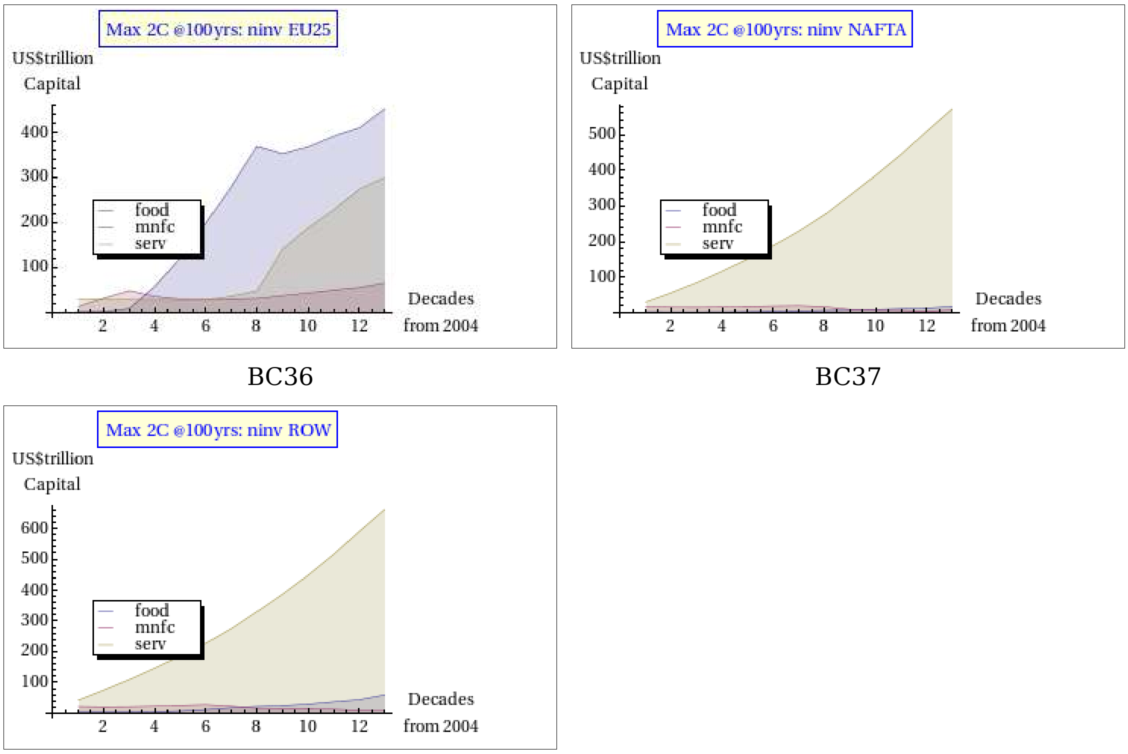
BC35

In illustration BC30, the EU's small investment vector is increased by very large multiples for its specialisation in food. Illustrations BC31 and BC32 show that NAFTA and ROW also grow their food investment by more than 25-fold and 50-fold, respectively.

There is only sustaining investment in manufacturing in all regions. However, investment in services in both NAFTA and ROW grows the same 25-fold as NAFTA's food investment.

Illustrations BC36 to BC38 show the net accumulated investment in each region by commodity. As expected, illustration BC36 shows EU25 accumulated investment in the food industry is high.

Base Case disaggregated accumulated investment by region



BC36

BC37

BC38

Illustrations B36, B37 and B38 exhibit the feature that investment in services rises strongly due to the demands of amelioration and abatement.

Marginal cost of global economic expansion

Pursuant to the Theorem of Complementary Slackness, each binding constraint has a resource productivity and zero slack, while the opposite is true for each non-binding constraint.

The following constraints in the Base Case meet the first definition of the Theorem of Complementary Slackness that the slack is zero when a constraint is binding.[i] From the original 996 constraints, only 20 constraints have slack of zero. These are shown in the following illustration.

Constraints with non-zero KKT multipliers:

$$\left\{\left\{\mathrm{tat}[10]-\mathrm{tat}[11]\geq 0,\ \frac{168}{5},\ 1.22939\times10^{-8}\right\},\ \left\{2.12051\times10^{6}\,\mathrm{s}[1,1,1]+8.54037\times10^{6}\,\mathrm{s}[1,1,2]+3.50544\times10^{7}\,\mathrm{s}[1,1,3]-4.57152\times10^{7}\,\gamma[1,1]\geq 0,\ \frac{102}{5},\ -0.0000578761\right\},\ \left\{1-\mu[8,3,3]\geq 0,\ -\frac{126}{5},\ 1.36596\times10^{-7}\right\},$$

$$\left\{1-\mu[9,2,3]\geq 0,\ \frac{553}{10},\ 2.5812\times10^{-7}\right\},\ \left\{1-\mu[9,3,2]\geq 0,\ -\frac{51}{5},\ 2.38241\times10^{-7}\right\},$$

$$\left\{1-\mu[9,3,3]\geq 0,\ -\frac{933}{10},\ 1.56048\times10^{-8}\right\},\ \left\{-\mathrm{dam}[1]+\Omega[1]=0,\ \frac{111}{2},\ 0.\right\},$$

$$\left\{-\mathrm{dam}[2]+\Omega[2]=0,\ \frac{557}{10},\ 1.11022\times10^{-16}\right\},\ \left\{-\mathrm{dam}[3]+\Omega[3]=0,\ \frac{49}{5},\ 6.66134\times10^{-16}\right\},$$

$$\left\{-\mathrm{dam}[4]+\Omega[4]=0,\ -\frac{89}{2},\ -1.11022\times10^{-16}\right\},\ \left\{-\mathrm{dam}[5]+\Omega[5]=0,\ -\frac{113}{10},\ -5.55112\times10^{-16}\right\},$$

$$\left\{-\mathrm{dam}[6]+\Omega[6]=0,\ \frac{129}{2},\ -2.22045\times10^{-16}\right\},\ \left\{-\mathrm{dam}[7]+\Omega[7]=0,\ -\frac{131}{10},\ 8.88178\times10^{-16}\right\},$$

$$\left\{-\mathrm{dam}[8]+\Omega[8]=0,\ \frac{261}{5},\ 3.10862\times10^{-15}\right\},\ \left\{-\mathrm{dam}[9]+\Omega[9]=0,\ -\frac{414}{5},\ -1.55431\times10^{-15}\right\},$$

$$\left\{-\mathrm{dam}[10]+\Omega[10]=0,\ \frac{256}{5},\ 2.22045\times10^{-15}\right\},\ \left\{-\mathrm{dam}[11]+\Omega[11]=0,\ 40,\ -3.33067\times10^{-16}\right\},$$

$$\left\{-\mathrm{dam}[12]+\Omega[12]=0,\ -\frac{189}{5},\ 7.77156\times10^{-16}\right\},\ \left\{-\mathrm{dam}[13]+\Omega[13]=0,\ \frac{137}{2},\ 5.55112\times10^{-16}\right\}\right\}$$

Illustration 36: Binding Constraints, KKT multipliers and Residual Slacks for Base Case

It may be noted from the table above that excluding the binding constraints for the damage feedback function and emissions control rate, the only two binding constraints remaining are for temperature rise and the EU25 food commodity.

As discussed in *Chapter 4 Economic models for climate change policy analysis*, Mathematica's FindMinimum function (in Version 7.01) does not expose its Karush-Kuhn-Tucker (KKT) multipliers from the underlying C++ code. For Sceptre's large scale optimisations, the current lack of direct access to KKT results means that multipliers need to be calculated from first principles using the results of the optimisation. This task has two disadvantages. Firstly, the solution of the KKT set of simultaneous equations may not be unique. Therefore, it is not certain that the KKT multipliers obtained are identical to those implicit in the results from Mathematica's FindMinimum function. Secondly, the calculation can be quite long in duration.

A guide to the non-uniqueness of KKT multipliers can be gauged from the first binding constraint, which is the main constraint of 2°C rise at 100 years (i.e. the tenth decade):

$$\left\{\mathrm{tat}[10]-\mathrm{tat}[11]\geq 0,\ \frac{168}{5},\ 1.22939\times10^{-8}\right\}$$

This constraint shows a KKT multiplier of $\frac{168}{5}$. However, this is the lowest multiplier of the set of possible solutions as shown in the illustration below:

$$\begin{pmatrix} \frac{168}{5} & \frac{807}{10} & \frac{183}{5} & \frac{433}{10} & \frac{193}{5} & \frac{553}{10} & 99 & 92 & \frac{391}{5} \\ 33.6 & 80.7 & 36.6 & 43.3 & 38.6 & 55.3 & 99. & 92. & 78.2 \end{pmatrix}$$

The KKT multiplier for a constraint represents the productivity of the resource, which is the change in the objective function for a unit change in the resource of the constraint. As Sceptre's objective function is the net present value of the unbiased or unweighted sum of country expansion factors, the KKT multipliers or shadow prices are given in terms of Net Present Value of economic expansion rather than in dollars.

A KKT multiplier of 33.6 for the above constraint implies that a 33.6 increase in the value of the objective function will result if the temperature rise is relaxed by one unit, from 2°C at decade 10 to 3°C at decade 11.

However, the shadow price is strictly applicable as a differential only at the one point of $\{2C, decade\ 10\}$ and will vary through the unit rise of 1°C. So it is usual to express prices in terms of incremental increases. For example, an increase of one-hundredth of a unit of the resource, 0.01°C or 0.5%, leads the objective function to rise by 0.336. This is a 5.11% rise compared to the optimisation value of 6.574. Therefore, the output elasticity is approximately 10x (5.11% / 0.5%).

To convert shadow prices given in terms of population adjusted expansion factors to absolute prices in dollars requires the objective function to be mapped to one where expansion factors are multiplied by the weighted proportions of consumption in each country. This provides the following conversion:

Objective Function (see Chapter 5)	
Raw Expansion Factor Basis	**Dollar Weighted Equivalent**
6.57	US$759 trillion
1 (or per unit)	US$116 trillion

From the table, it may be noted that the dollar value of the objective function is about 100 trillion times the expansion value. Therefore a relaxation of the temperature constraint by 0.01°C and consequent increase of 0.336 in the NPV of the expansion factors is worth about US$38.8 trillion. This is almost equal to the single year GDP US$40.97 trillion (2004).

6.1.2 Point of view analysis

Chapter 1 Introduction highlighted the importance of appreciating diverse points of view of various prominent stakeholder groups when investigating policy. Many dimensions are needed to capture the diversity of views in society. In addition, there is a range of views emanating from other national governments, global corporations and community action groups.

While there may be a preferred point of view, there is no such thing as a “best” one. Usually each point of view has a prominent and unique perspective. Often, these points of view are orthogonal, that is, coming from different philosophical or ideological bases and so are not strictly comparable.

For example, in the climate change debate, national and supra-national polity need to engage with a range of views from sceptics to environmental radicals, which represent two rather public clusters in climate change. As different as the dichotomy of these two views may be, they are united in the uncompromising demand that society adopt fundamental positions and accept large risks. For example, sceptics shrug-off the risk of a climate change induced collapse of civilisation. Radicals equally shrug-off the social risk associated with mass dislocation of employment.

Although uncomfortable for many policy makers, extreme views have a place because they stretch the debate. However, as discussed in *Chapter 2 Political economy of the Anglo-American world view* the plurality of fundamentalist views can be breathtaking. These range through such diverse approaches as free-market, conservative, liberal, evangelical and Marxist-Leninist perspectives. Even in establishment views great rifts exist. Krugman (2009) notes that the global financial crisis has reignited irreconcilable differences between American Keynesian and Monetarist philosophies in establishment macroeconomics.[ii]

These multidimensional perception spaces offer many interesting pathways for additional research to achieve a fine reduction and classification of policy understanding. For reasons of expediency and policy making pragmatism, it is assumed in this research that Pareto's Rule applies so that 80% of the desired analysis in points of view can be understood through examining 20% of views, subject to these being sufficiently diverse.

The points of view selected for analysis include the two extreme positions of sceptic and radical. Somewhere in the multidimensional space in between are points of view for *Laissez-faire* free markets and Government-regulated markets. These latter two points of view roughly correspond to American free-enterprise individualism and European free-market social democracy.

Sceptical point of view

Climate change Sceptics do not subscribe to the assumption that industrial emissions are causing climate change. This group has three sub-clusters: those who deny the existence of global warming; those that claim the effects of global warming will be mainly beneficent and profess to eagerly anticipate the benefits of global warming; and those who believe that global warming is beyond the influence of human activity and are ambivalent or diffident about any scientific evidence.

It needs to be kept in mind in analysing this point of view (as in the ones below) that point of view analysis seeks to model the underlying assumptions in the point of view. For example, a representative person might say “I feel that this will be the outcome”. In the case of a Sceptic, it might be “I don't acknowledge any global warming so I feel that there will be no climate induced effects to look at.”

The point of view analysis does not endeavour to criticise these assumptions. Nor does it seek to demonstrate whether or not the point of view is logically consistent. Furthermore, nor does a point of view sensitivity seek to project a realistic outcome. In other words, point of view projections try to encompass the representative view at face value.

The assumptions used to model the Sceptic point of view are that there will be no constraints on emissions, no carbon trading is required (in Sceptre, all emissions will be ameliorated at no cost) and there will be no climate-economic damage function.

The difference between this scenario and the Normal case (in Chapter 5) is that in the Normal case the climate-economic damages mechanisms are operating and, although there is no climate constraint, the model draws on amelioration and abatement services in order to improve its economic expansion. In this Sceptic point of view, it is never necessary to draw on amelioration and abatement services as emissions have no impact on climate change or economic performance.

Radical point of view

Radicals generally have a narrow focus, for example on the environment or on single issues such as the flora or fauna at a specific location. Their chosen opposition parties are often global companies, big business or developers. For example, in Australia the unlikely hero of planning ethics was Jack Mundey. Now a distinguished Australian, in 1969 he led the Building Labourers' Federation to impose highly controversial Green Bans on the redevelopment of heritage and naturally significant sites.

A representative Radical approach to climate change might be “now that we know about the effect of greenhouse gas pollution, to continue is wanton destruction of the planet and the people doing this are criminals”. James Hansen's testimony to Congress in *Chapter 3 Political Economy of the Anglo-American world view of climate change* is an eloquent example. Radicals believe that there can be only one logical corollary, that all pollution must cease forthwith and sanctions be applied to any business that wilfully continues to pollute.

The assumptions used in Sceptre to model the radical perspective are that all emissions must be immediately ameliorated or abated in full and the climate-economic damage function operates even though the low emissions prevent the damage multiplier from significant activity.

Laissez-faire free market point of view

Market systems form the middle ground. The first point of view investigated in market systems is *Laissez-faire* free market dogma. This is often identified with unfettered Anglo-American capitalism and often called neoliberalism. With regard to climate change, its underlying assumption is that any climate induced economic damage will become priced in the market. The invisible hand of capitalism will silently move to evoke entrepreneurial technologies to solve any problem, if indeed there is money to be made in solving it. This means “business as usual” and managers acting with self-enlightenment if it suits them and is earnings accretive. The subject of market failures is met with complete cognitive dissonance. For example, the Great Depression was merely people choosing to have a holiday rather than being willing to work for lower wages (Krugman 2009).

This point of view can be modelled in two ways. The first is the Normal “business as usual” scenario presented at the beginning of this Chapter as a comparison with Nordhaus' DICE model. It was seen there that Sceptre's projection of temperature rise was increasing strongly through 2.5°C at decade 10.

The *Laissez-faire* free market view would be that if temperature is rising strongly, then this is a situation people are happy with otherwise business would have been paid to arrest the rise. It is phenomenological, positivist and optimistic. While there may be a climate-economic damage function there is no temperature rise until it occurs. Looking on the bright side, temperature rise may never happen if the sceptics are right, so why fix something that *ain't broken*.

Therefore, the representative outlook or point of view is that there are neither constraints on emissions nor any need for emission permits trading or amelioration and abatement services. Optimistically all emissions will be dealt with and a reasonable scenario will unfold. Therefore Sceptre's assumptions are no constraints on emissions, no carbon trading (all emissions ameliorated at no cost) but a climate-economic damage function is operating.

Government-regulated market point of view

The second market related point of view investigated here is one where governments intervene to address potential or actual market failures. Its underlying assumption is that *Laissez-faire* free markets have many advantages over planned economies but that free markets do not work in regard to commons, such as the environment. The planned adjustments are designed to ensure sustainability. *Chapter 2 Political economy of the Anglo-American world view* discussed the European Union's market system with particular reference to Germany. *Chapter 3 Political Economy of the Anglo-American world view of climate change* placed this discussion in the context of climate change.

The United Nations was formed in 1945 to replace the League of Nations, which America had never joined. Both organisations represent the type of supranational symbiotic community that countries need to take ownership of the international commons and protect it. In the climate change policy debate, the UNFCCC and its' IPCC scientific panel represent the supra-national body. The IPCC has recommended a maximum post-industrial temperature rise of 2°C. As there was no discernible temperature rise in the period from 1750 to 1900, the 2°C temperature rise effectively applies post 1900.

Therefore, this Government-regulated market point of view is represented by the Base Case of 2°C limit at 100 years, emission permits trading and amelioration at full cost, with a climate-economic damage function operating.

Results and analysis of alternative points of view

These four points of view were modelled in Sceptre model with the following assumptions. The illustrations of the results are shown overleaf:

Climate Change Sceptic[iii]	Laissez-faire Free Market[iv]	Maximum 2°C rise @ 100 years[v]	Radical Planet Protection[vi]
No constraints on emissions, no carbon trading (all emissions ameliorated at no cost) & no climate-economic damage function	No constraints on emissions, no carbon trading (all emissions ameliorated at no cost) but with a climate-economic damage function	2°C limit at 100 years with carbon trading and amelioration at cost, with a climate-economic damage function	All emissions ameliorated at full cost and with a climate-economic damage function

The Sceptic, *Laissez-faire* and Radical perspectives all lead to similar outcomes because each assumes the outcome will be fine (see results in the next section of this Chapter). However, all three scenarios differ materially from the Base Case. For example, Sceptic, *Laissez-faire* and Radicals all believe that temperature rise will continue to hover at 0.8°C, in comparison to the Base Case where it rises to 2°C.

A comparison of the objective functions of the Radical and the Base Cases shows the extra Net Present Value cost of the Radical case to be US$3.8 trillion (2004 dollars) (*cf.* Previous Base Case analysis for method of estimation). The Sceptic and *Laissez-faire* cases, which are not meaningful comparisons, show savings over the Base Case of US$75 billion and US$14 billion respectively.

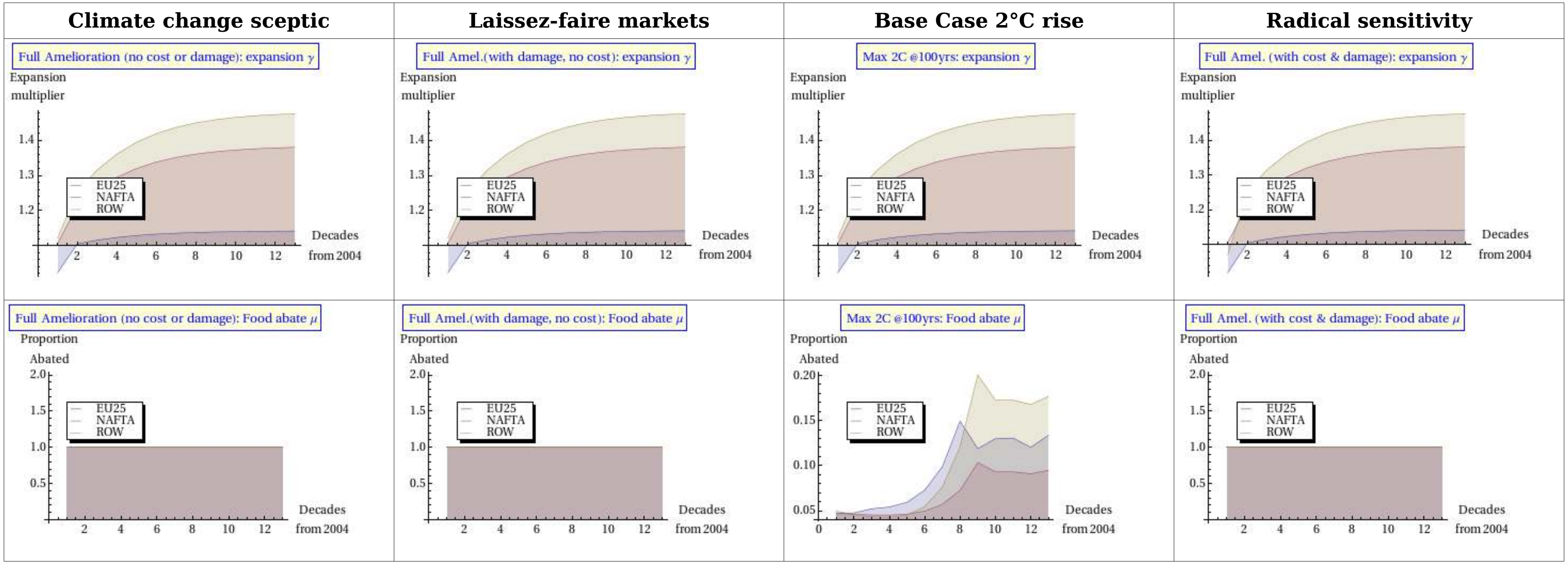
The similarity between these points of view has an interesting precedent. In August 2009, the Australian Parliament provided confirmation of this unlikely congruence. The Liberal Party and Greens joined to vote down Government's Carbon Pollution Reduction Scheme (CPRS) legislation. The reason for the unusual alliance between Greens and Liberals comprising Sceptics and Laissez-faire free marketeers was that each remained intransigent in the belief that their preferred path would be the only means of achieving a benign future. Indeed, perceptions of the benign future were identical but the means of getting there were dramatically different.

i For this purpose, an arbitrary chop of 10^{-6} is applied to slacks. This means that slacks smaller than 10^{-6} are considered to be zero

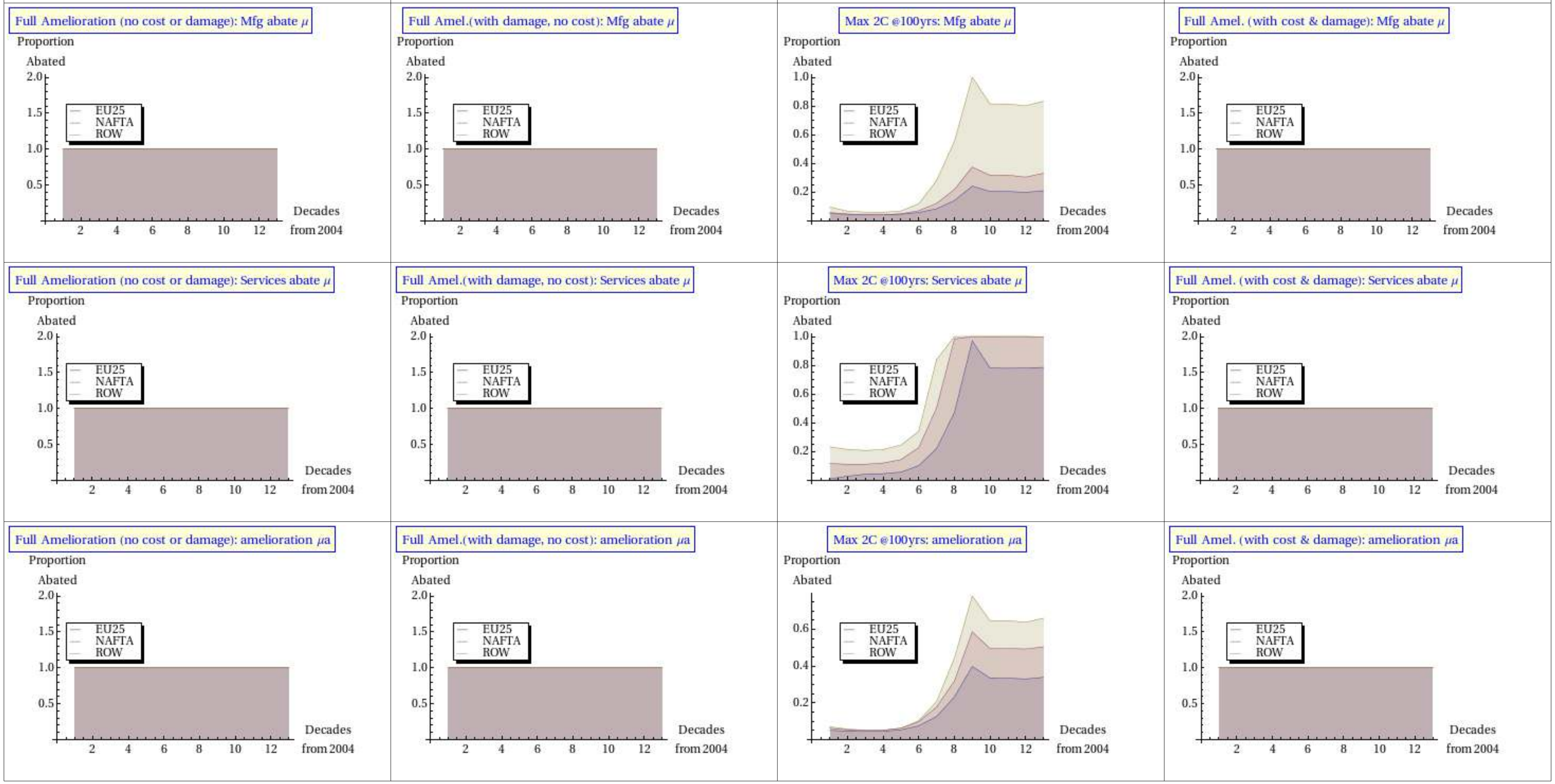
ii Krugman (2009) refers to Keynesians as “saltwater economists” because they tend to live on the East or West coast and Monetarists (or Chicago School) as “freshwater economists” because they tend to live inland

iii m12_13p_full_amel_no_cost_no_dam.nb
iv m12_13p_full_amel_no_cost.nb
v m12_13p_2C_100.nb
vi m12_13p_full_amel.nb

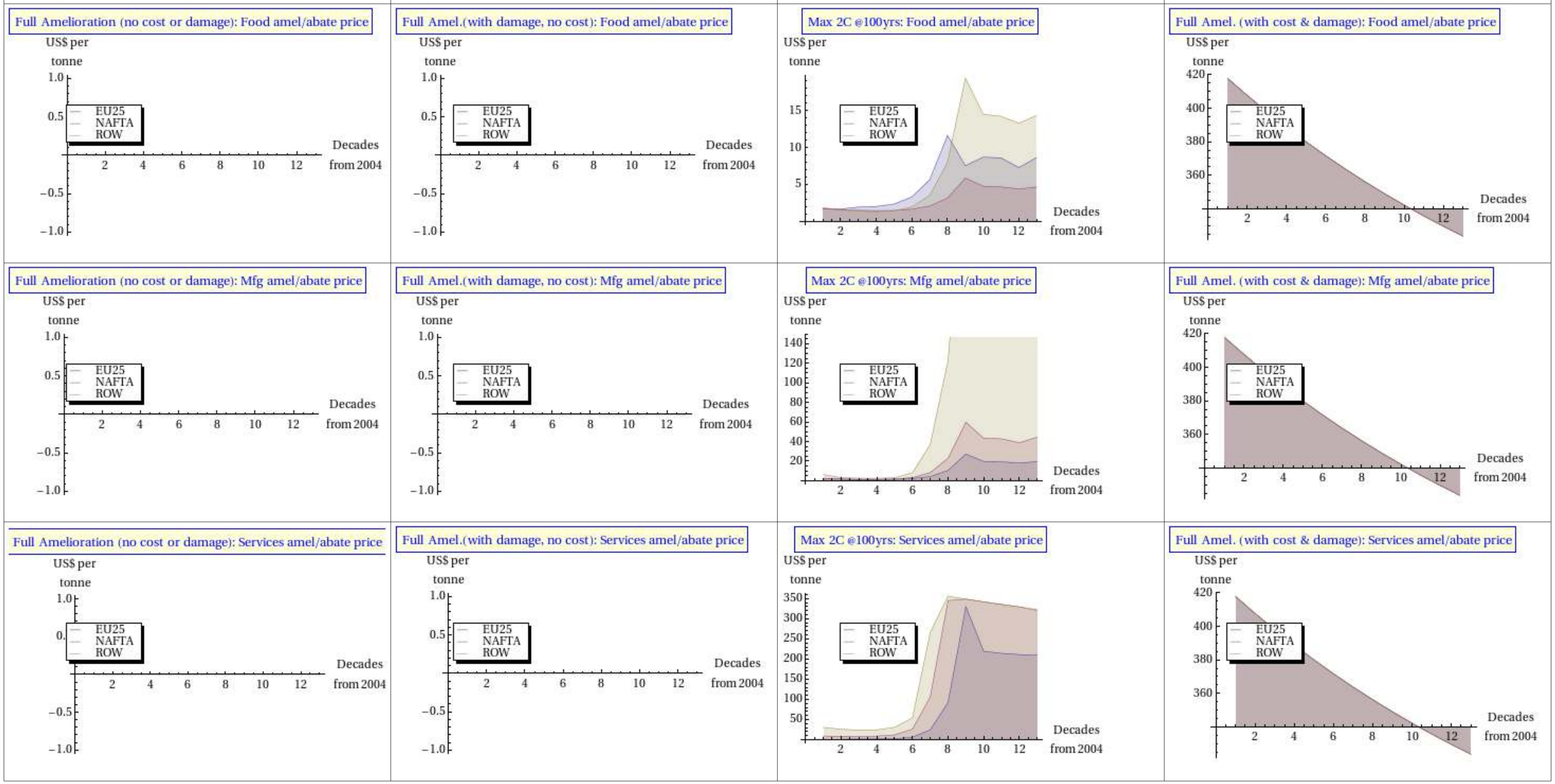
Point of view simulation results

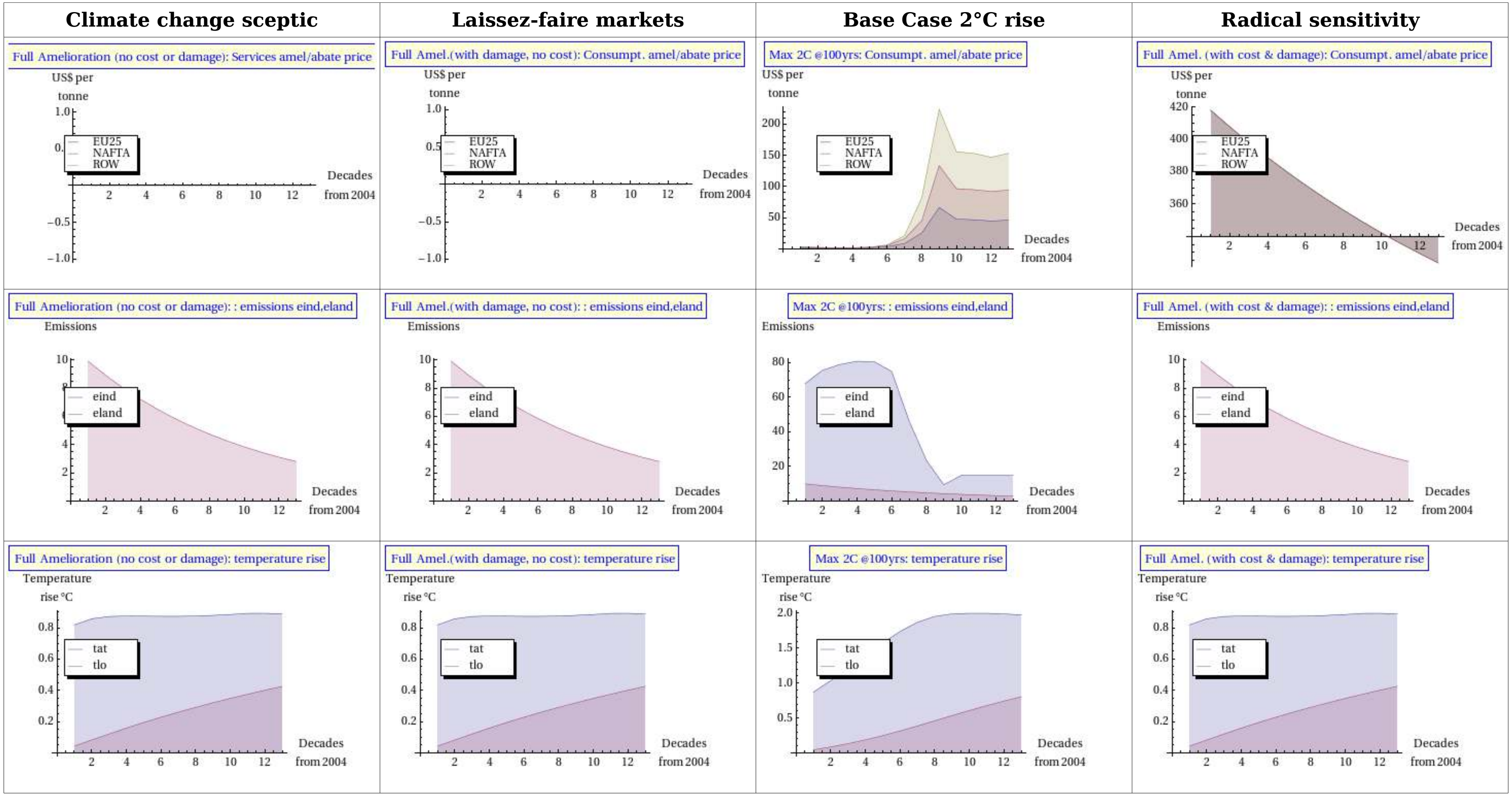


Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity

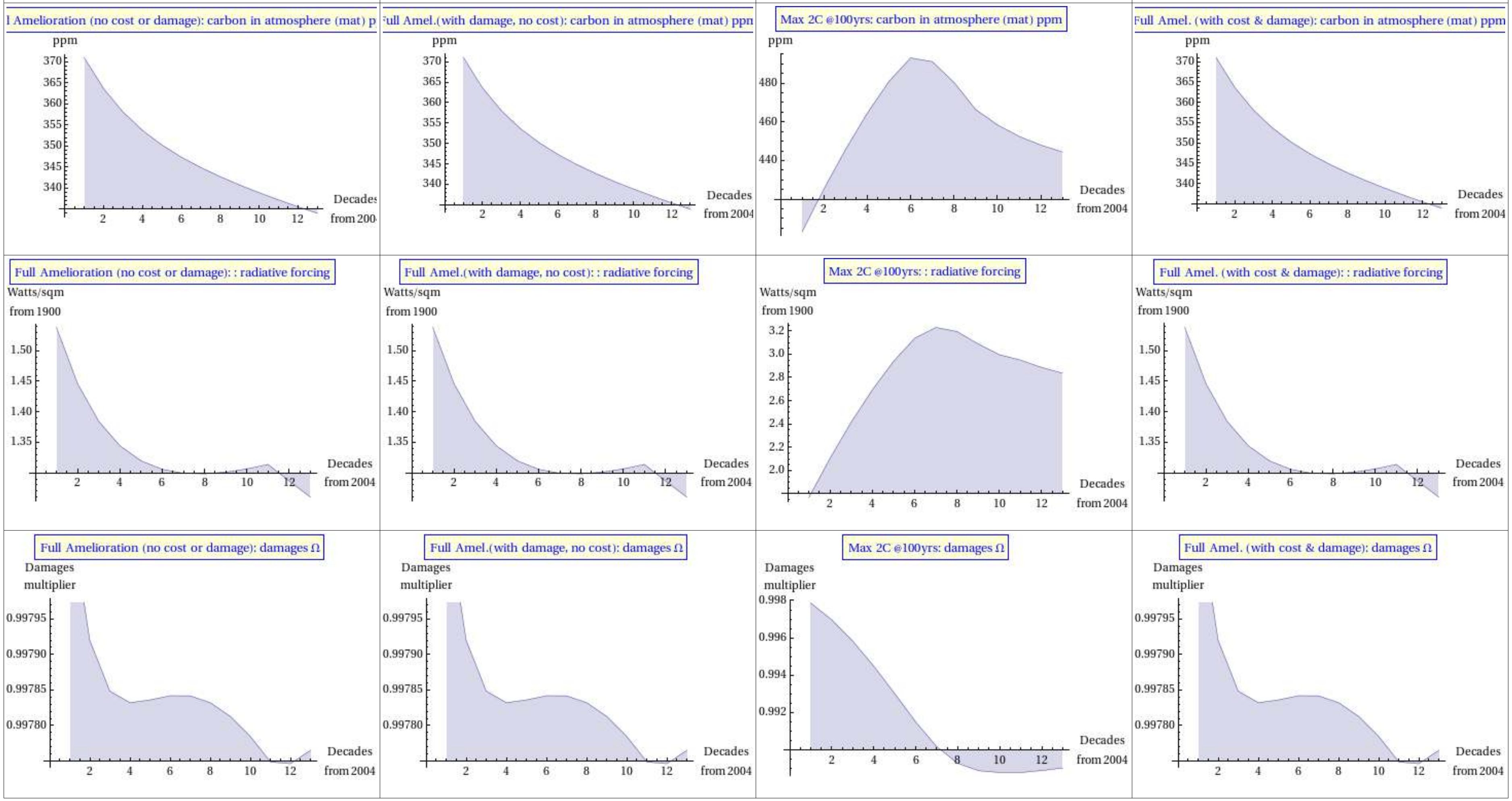


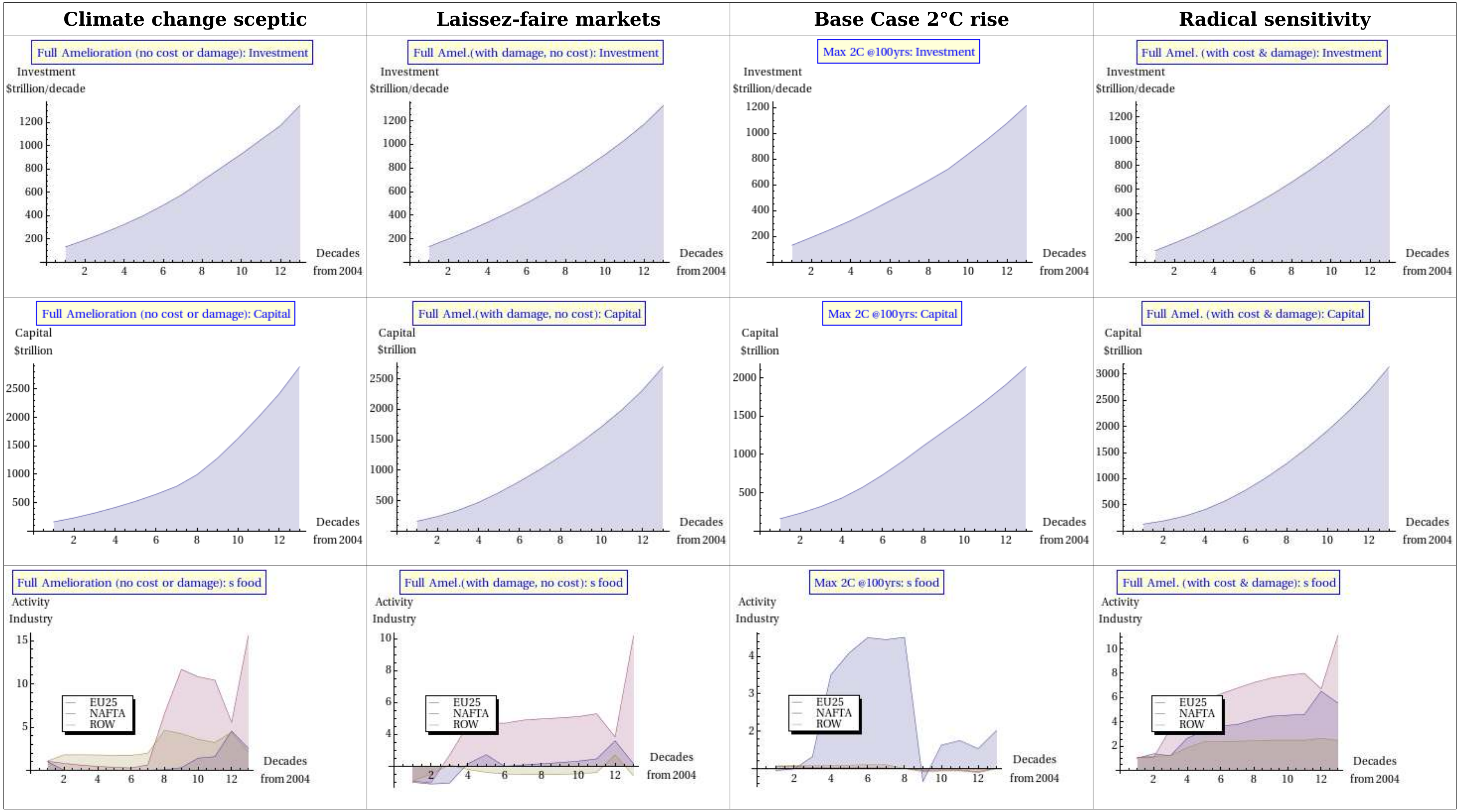
Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity



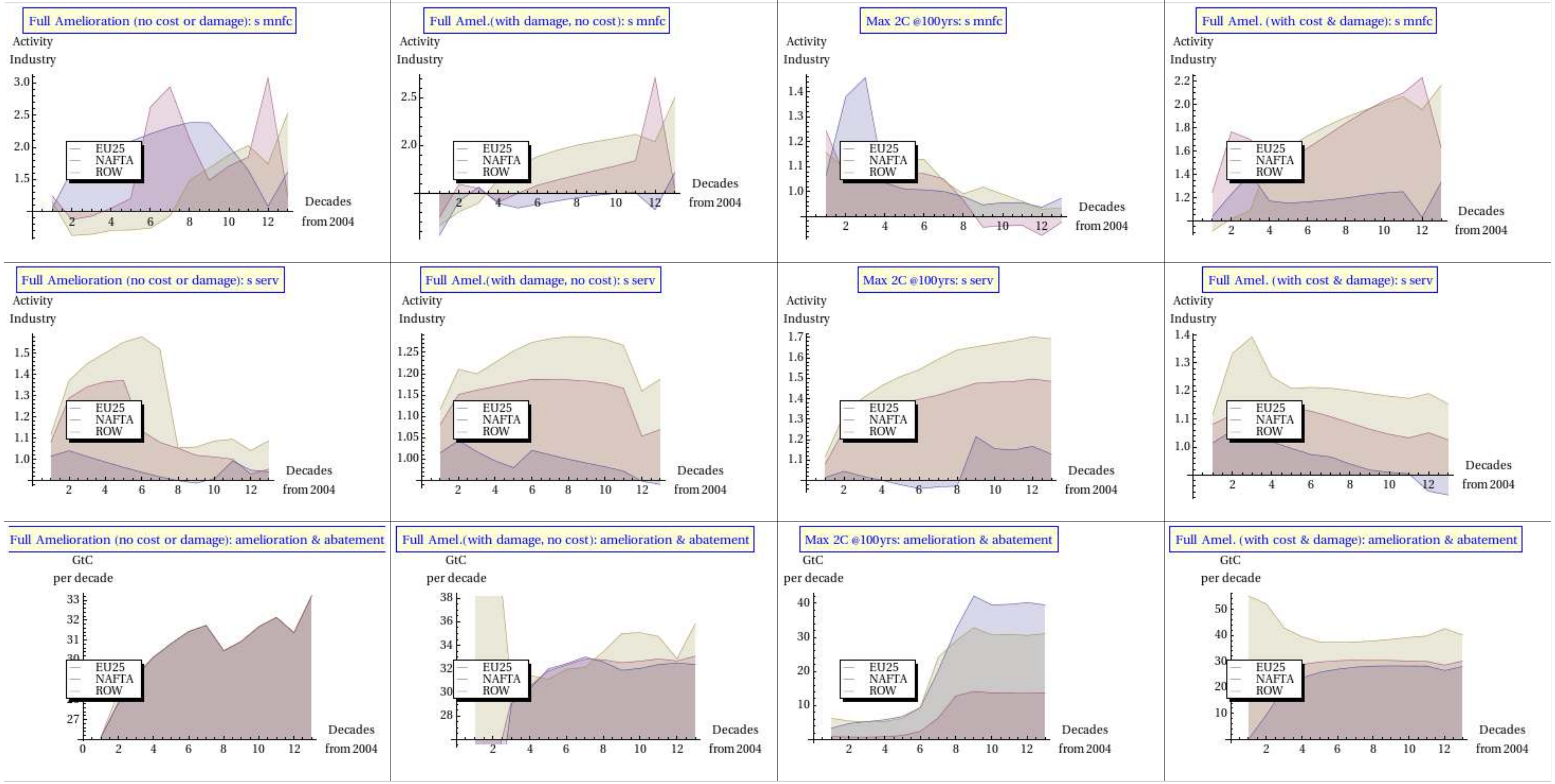

Climate change sceptic
Laissez-faire markets
Base Case 2°C rise
Radical sensitivity
Full Amelioration (no cost or damage): Services amel/abate price
US$ per tonne
EU25
NAFTA
ROW
Decades from 2004
Full Amel.(with damage, no cost): Consumpt. amel/abate price
Max 2C @100yrs: Consumpt. amel/abate price
Full Amel. (with cost & damage): Consumpt. amel/abate price
Full Amelioration (no cost or damage): : emissions eind,eland
Emissions
eind
eland
Full Amel.(with damage, no cost): : emissions eind,eland
Max 2C @100yrs: : emissions eind,eland
Full Amel. (with cost & damage): : emissions eind,eland
Full Amelioration (no cost or damage): temperature rise
Temperature rise °C
tat
tlo
Full Amel.(with damage, no cost): temperature rise
Max 2C @100yrs: temperature rise
Full Amel. (with cost & damage): temperature rise

Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity

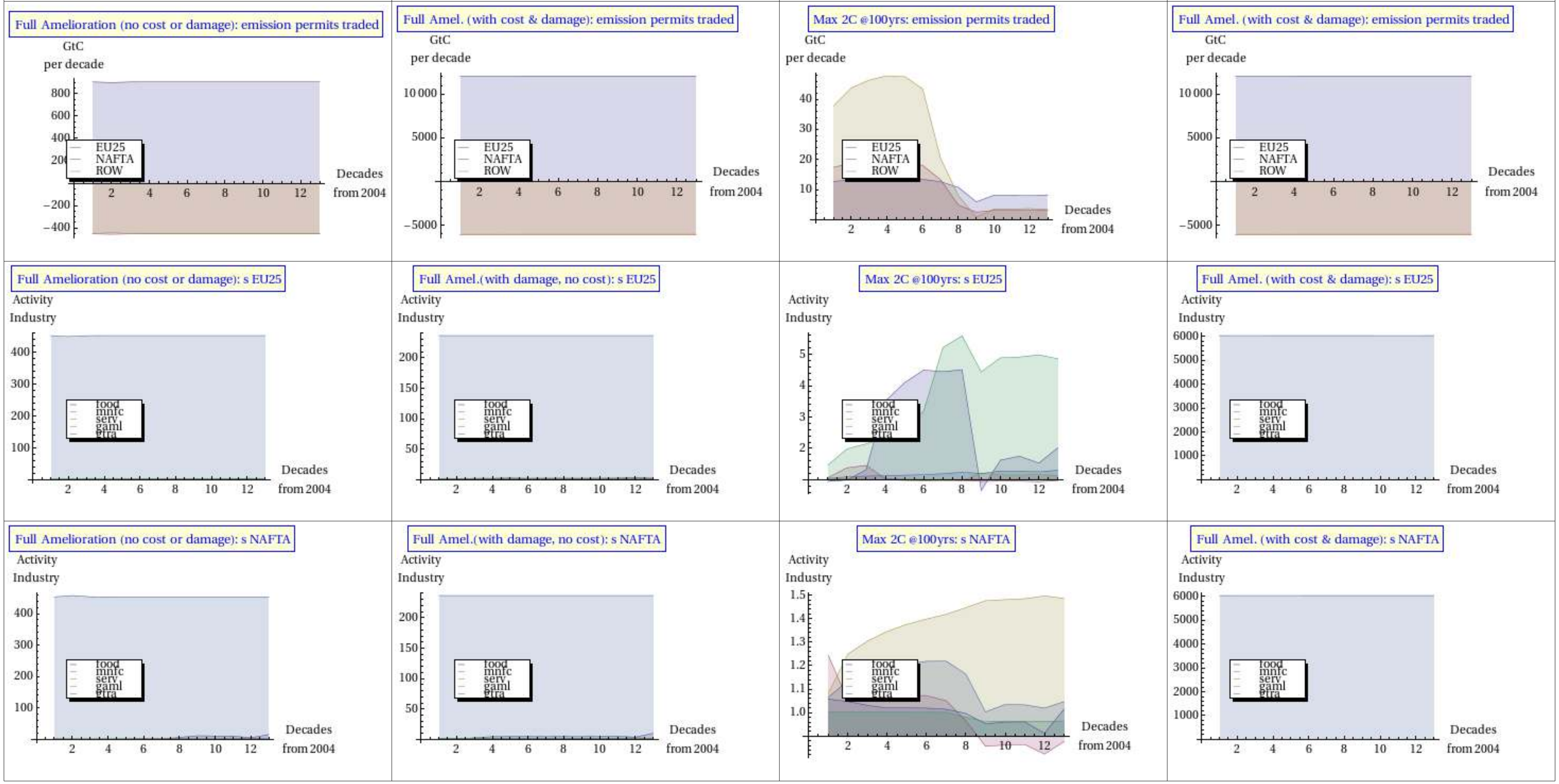



Climate change sceptic
Laissez-faire markets
Base Case 2°C rise
Radical sensitivity
Full Amelioration (no cost or damage): Investment
Full Amel.(with damage, no cost): Investment
Max 2C @100yrs: Investment
Full Amel. (with cost & damage): Investment
Investment
$trillion/decade
Decades
from 2004
Full Amelioration (no cost or damage): Capital
Full Amel.(with damage, no cost): Capital
Max 2C @100yrs: Capital
Full Amel. (with cost & damage): Capital
Capital
$trillion
Full Amelioration (no cost or damage): s food
Full Amel.(with damage, no cost): s food
Max 2C @100yrs: s food
Full Amel. (with cost & damage): s food
Activity
Industry
EU25
NAFTA
ROW

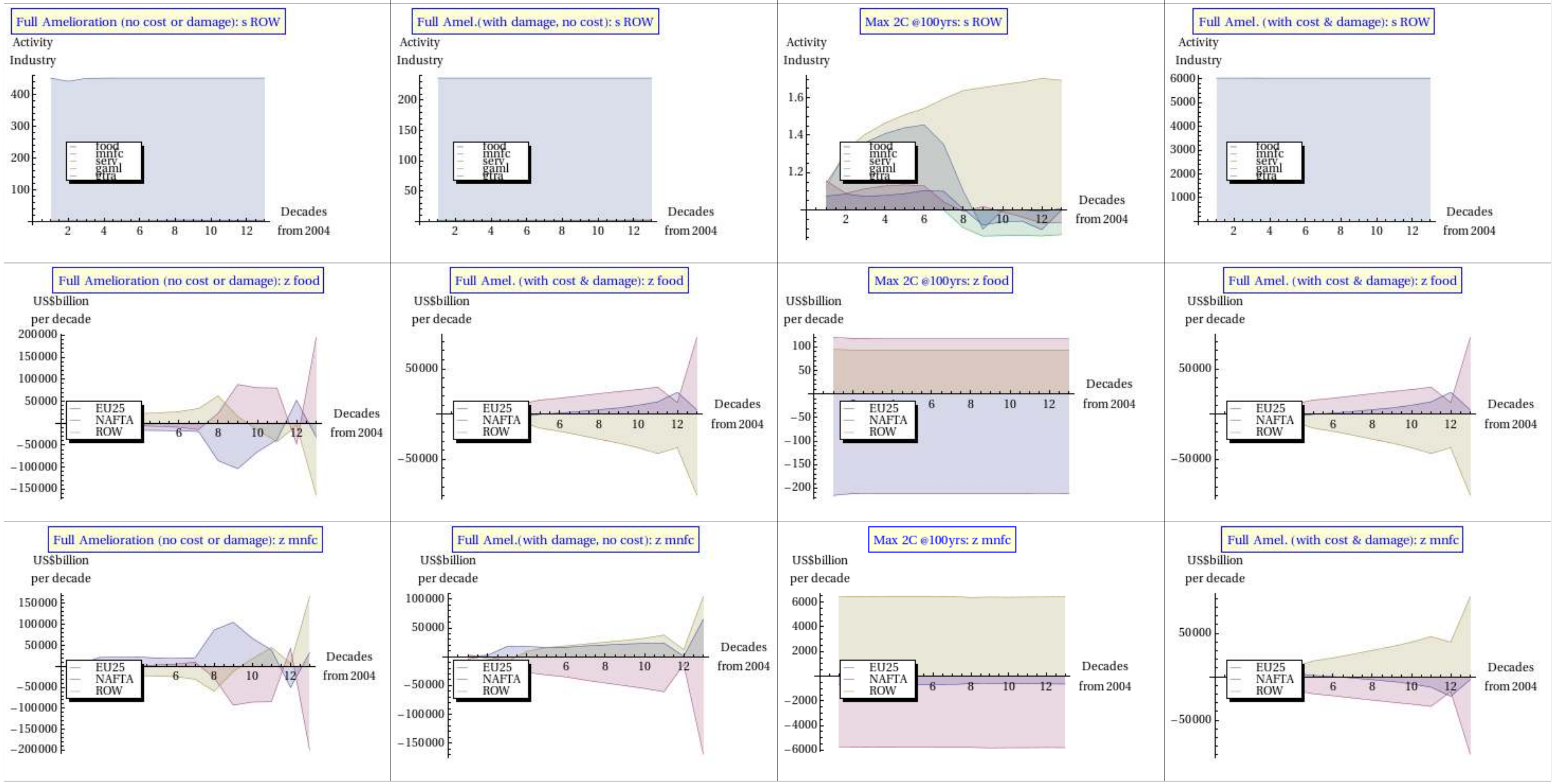
Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity



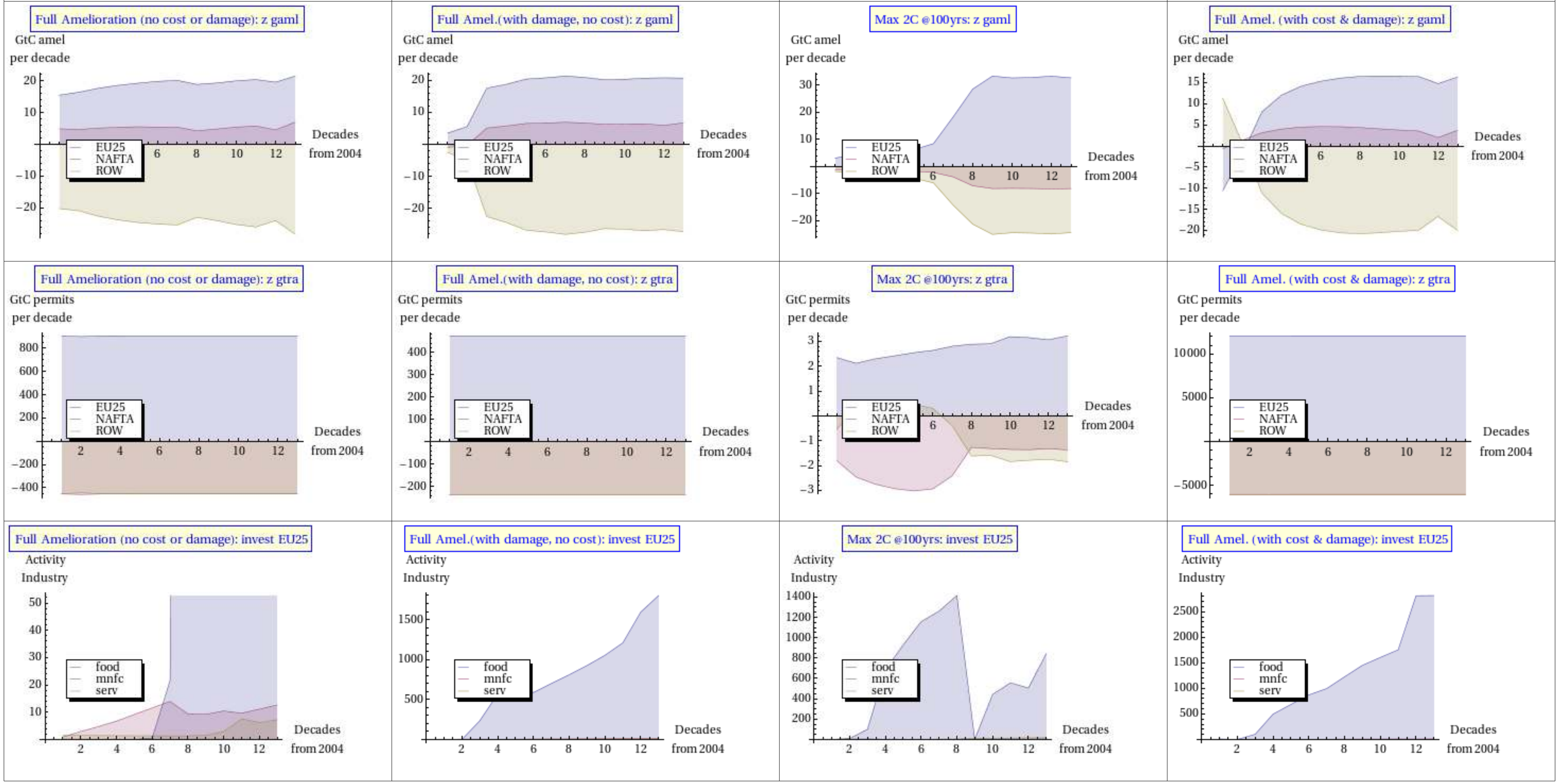
Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity



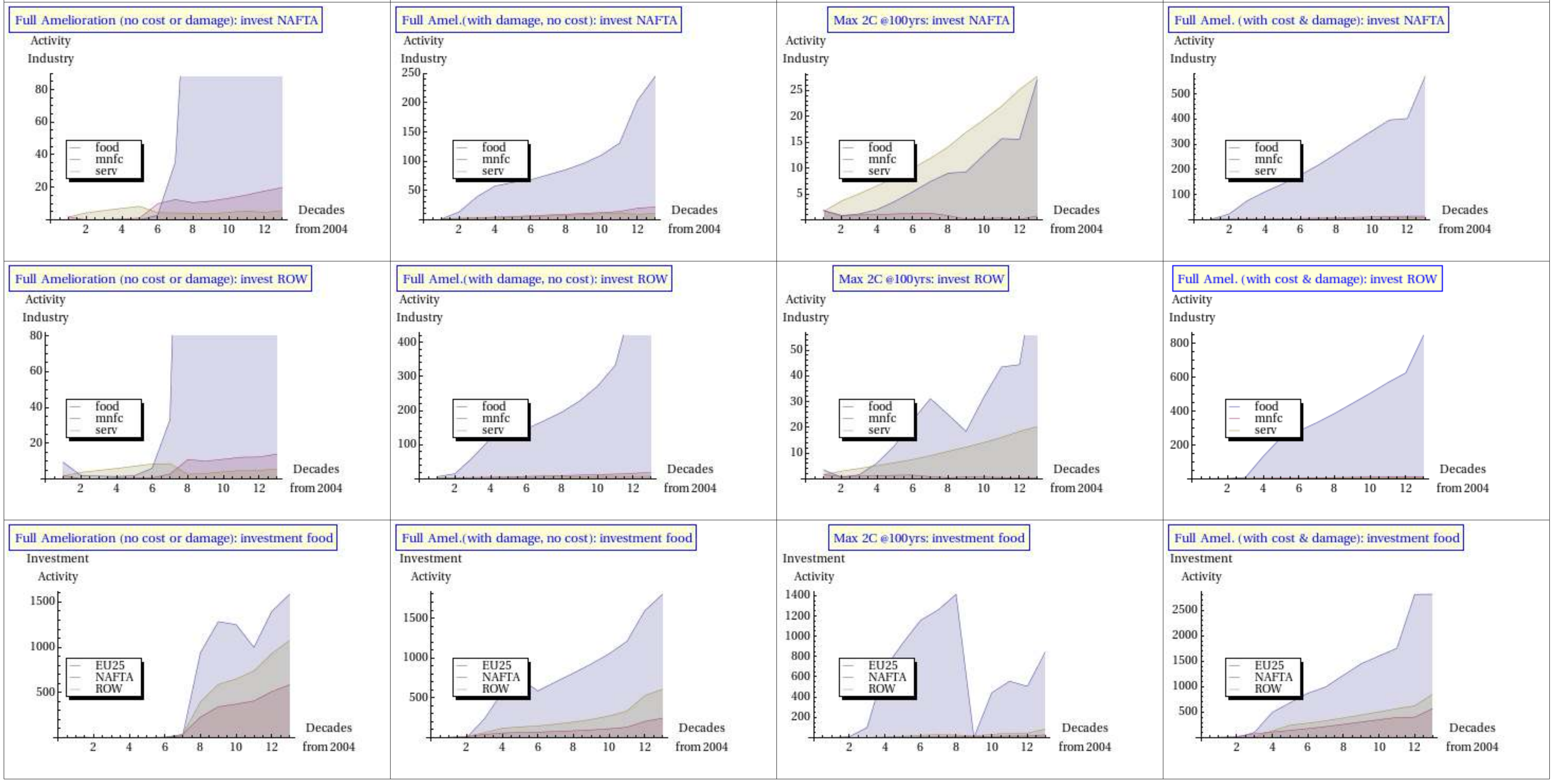
Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity

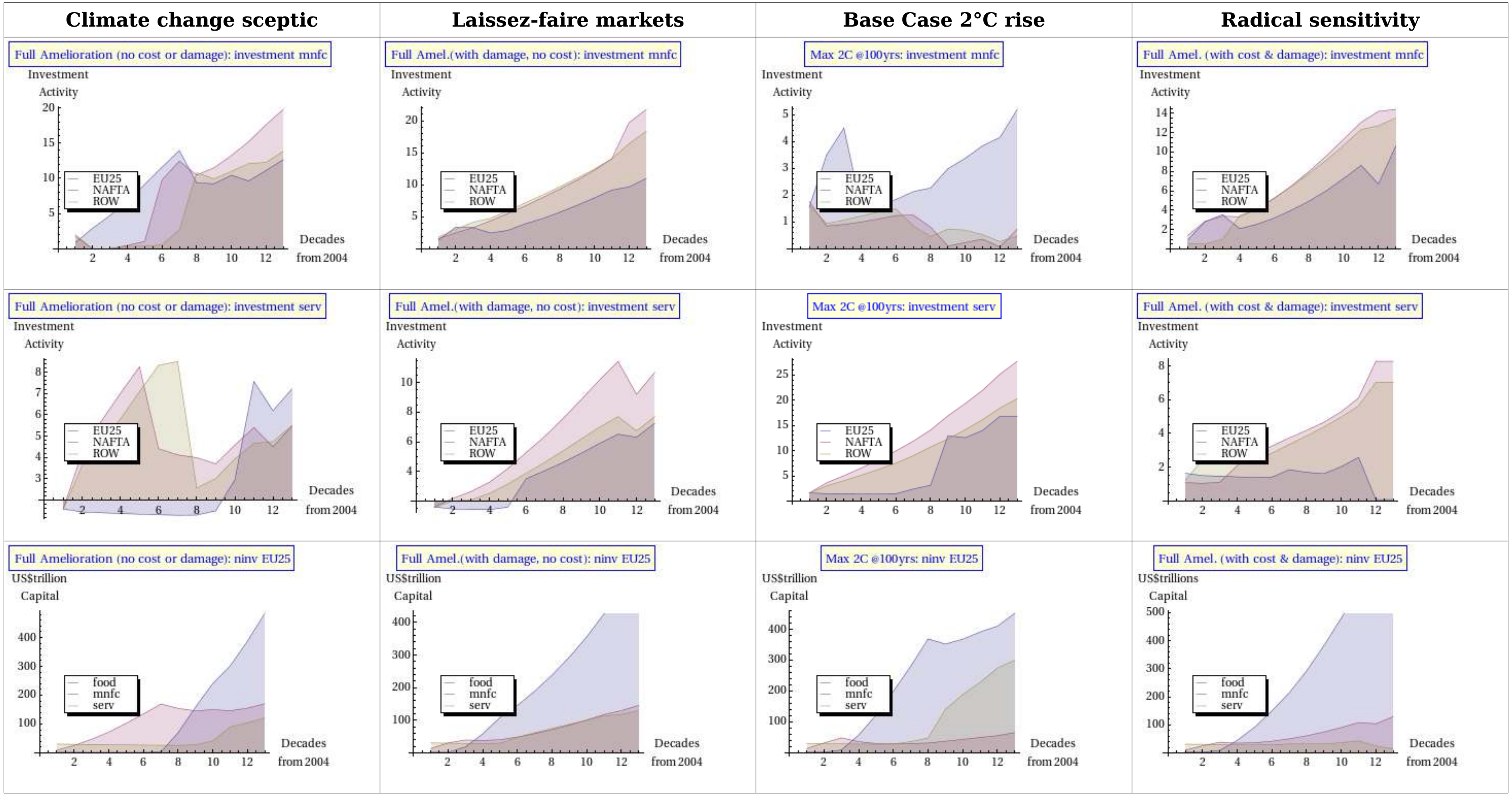


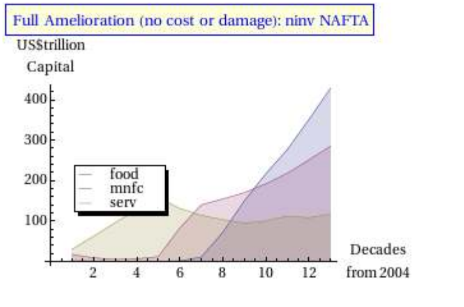
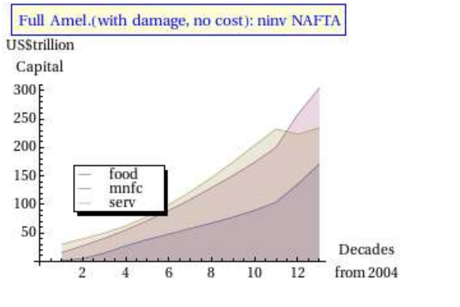
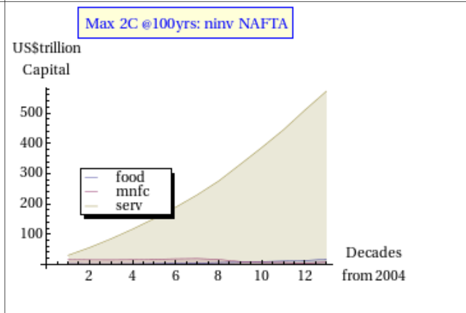
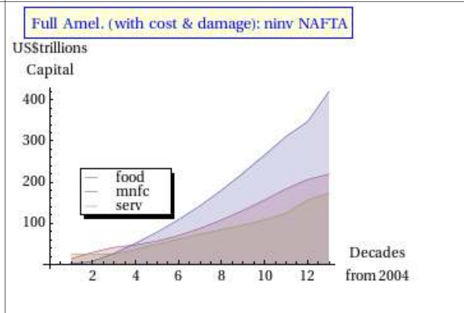
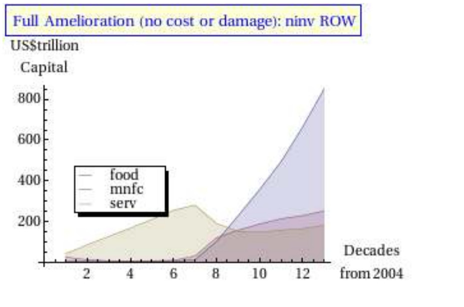
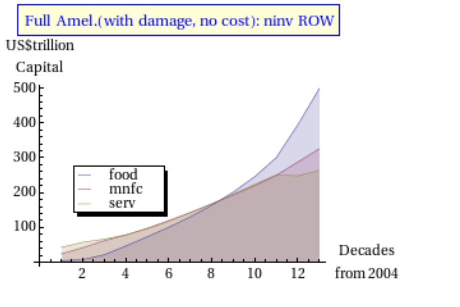
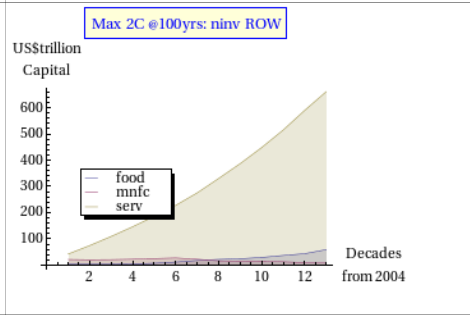
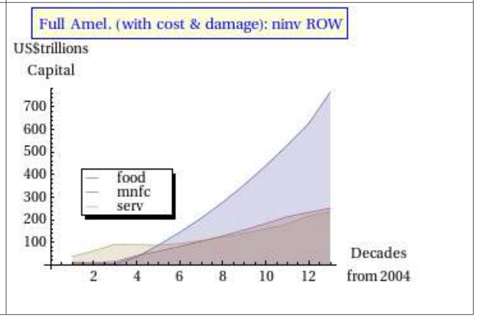
Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity



Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity




Climate change sceptic
Laissez-faire markets
Base Case 2°C rise
Radical sensitivity
Full Amelioration (no cost or damage): investment mnfc
Full Amel.(with damage, no cost): investment mnfc
Max 2C @100yrs: investment mnfc
Full Amel. (with cost & damage): investment mnfc
Full Amelioration (no cost or damage): investment serv
Full Amel.(with damage, no cost): investment serv
Max 2C @100yrs: investment serv
Full Amel. (with cost & damage): investment serv
Full Amelioration (no cost or damage): ninv EU25
Full Amel.(with damage, no cost): ninv EU25
Max 2C @100yrs: ninv EU25
Full Amel. (with cost & damage): ninv EU25
Investment
Activity
US$trillion
US$trillions
Capital
EU25
NAFTA
ROW
food
mnfc
serv
Decades
from 2004

Climate change sceptic	Laissez-faire markets	Base Case 2°C rise	Radical sensitivity
			
			

6.1.3 Atmospheric concentration constraint severity

In *Chapter 3 Political Economy of the Anglo-American world view of climate change* it was noted that the Tällberg Foundation, Al Gore, James Hansen and others emphatically seek an atmospheric concentration of 350 ppm compared to 380 ppm in 2009. Until recently the IPCC and member governments concurred with a 400 ppm or 450 ppm limit. However, with this target becoming frustrated, MEF governments adopted a 2°C rise limit in lieu.

Constraint severity analysis seeks to identify the spatial regional-commodity trends arising from various atmospheric concentrations of carbon. The assumptions used in the sensitivity analysis are set out in the following table:

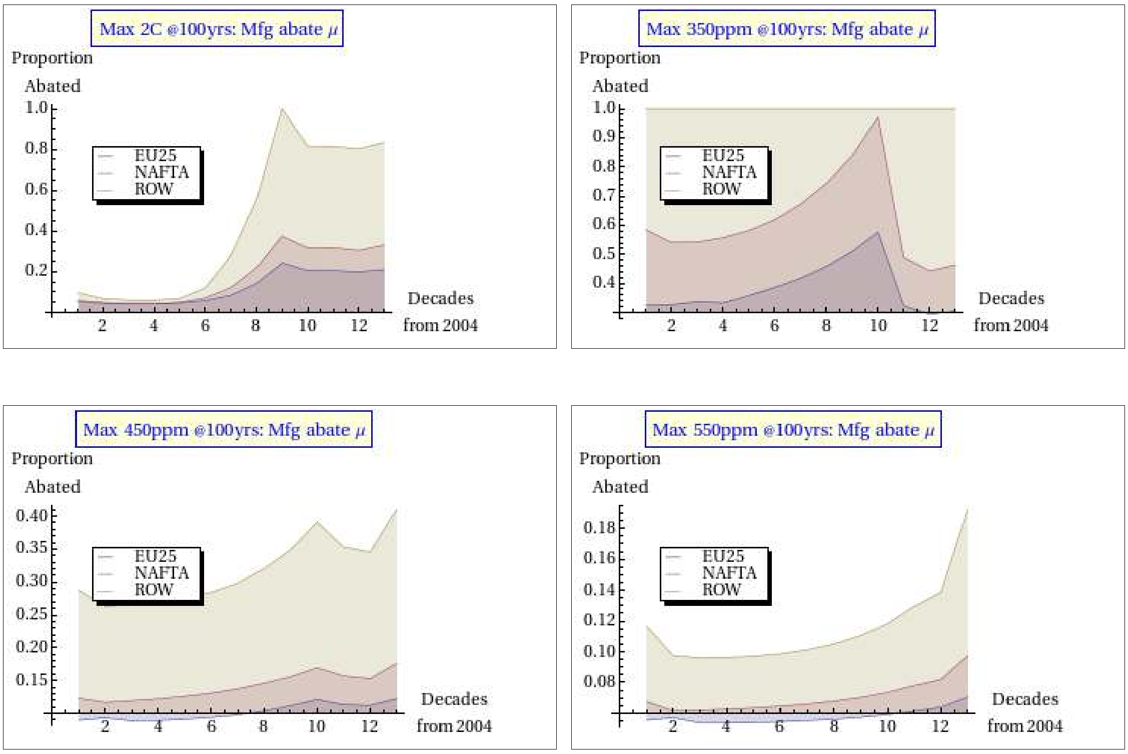
350 ppm[vii]	**450 ppm**[viii]	**550 ppm**[ix]	**Base Case 2°C**[x]
Assumption: Atmospheric concentration of carbon maximum of 350 ppm and emissions declining after 100 years	Assumption: Atmospheric concentration of carbon maximum of 450 ppm and emissions declining after 100 years	Assumption: Atmospheric concentration of carbon maximum of 550 ppm and emissions declining after 100 years	Assumption: 2°C limit at 100 years with carbon trading and amelioration at cost, with a climate-economic damage function

Results and analysis

The values of the objective function for the three sensitivity scenarios of 350, 450 and 550 ppm show that these constraints impose an increased cost on the economy compared to the Base Case of a 2°C temperature rise. However, this increased cost is only in the order of US$15-20 billion, which is far less than US$3.8 trillion for the Radical point of view discussed above.

Trends across the severity scenarios show that the control rate for amelioration and abatement dramatically declines and is strongly delayed as the atmospheric tolerance increases to 500 ppm. The 2°C Base Case has a delayed requirement for emissions control but otherwise is similar to the 450 ppm case. The manufacturing emissions control rates are shown below for each sensitivity:

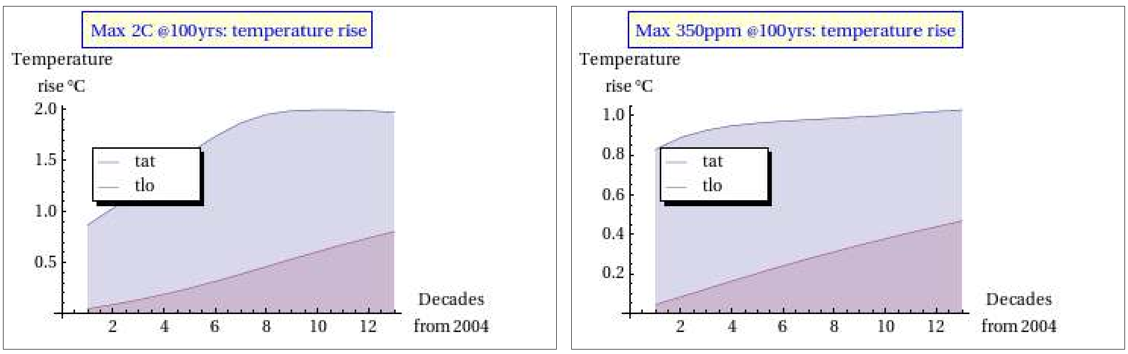
Manufacturing emissions control rate for Base Case 2°C, 350, 450 & 550 ppm



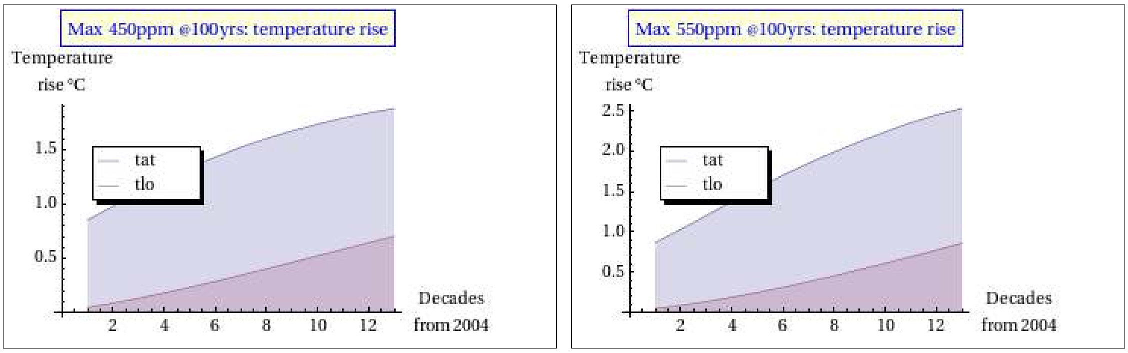
However, because the emissions control begins immediately for 450 ppm mitigation, the emissions profile approaches half that of the Base Case. After 10 decades the profile for 350 ppm begins to decrease for EU and NAFTA, while the emissions control requirements for 450 and 550 ppm mitigation rise.

These trends are reflected in temperature rise illustrations (below), which show 2°C for the Base Case but only 1°C for 350 ppm, 1.7°C (rising) for 450 ppm at decade 10 and 2.2°C (strongly rising) for 550 ppm.

Atmospheric temperature rise for Base Case 2°C, 350, 450 & 550 ppm

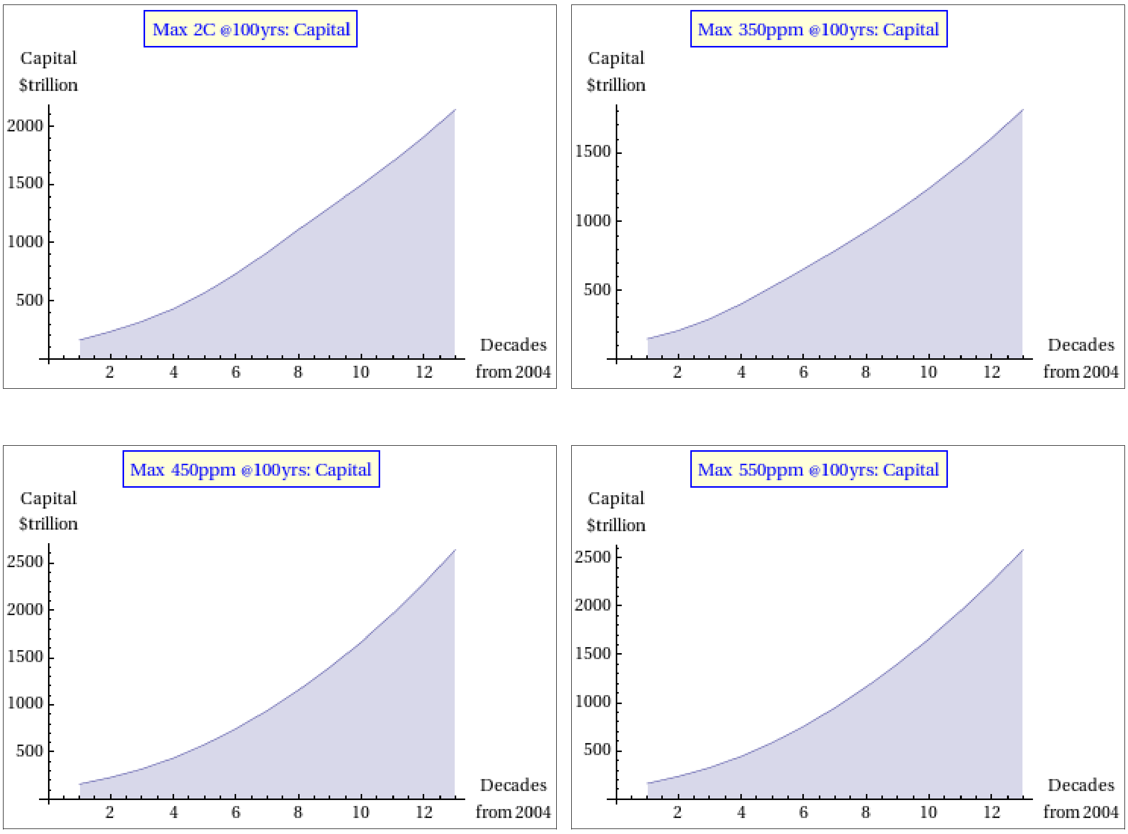


Atmospheric temperature rise for Base Case 2°C, 350, 450 & 550 ppm



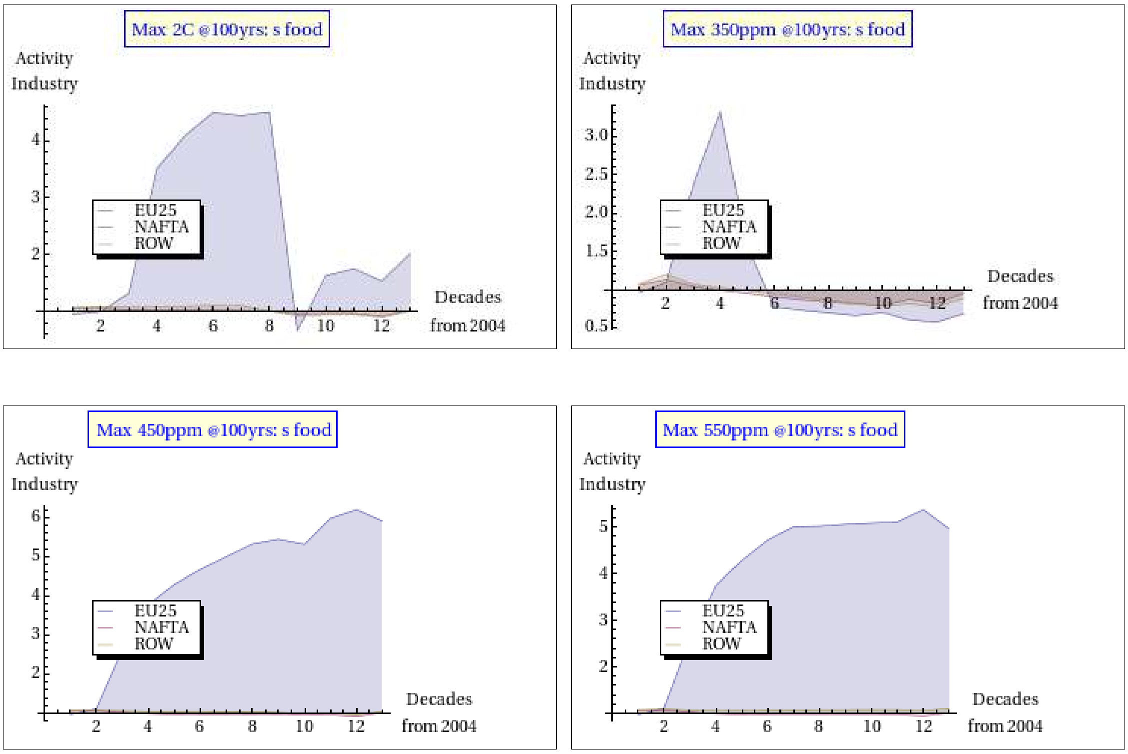
Another notable feature is global accumulated capital. This is only US$1,200 trillion (2004 dollars) at decade 10 for the 350 ppm case compared to US$1,700 trillion for 450 ppm and US$1500 trillion for both 550 ppm and the Base Case.

Accumulated capital for Base Case, 350, 450 & 550 ppm



As shown in the illustrations below, a limit of 350 ppm limits EU25's resource expansive food production. This restriction is removed once the atmospheric concentration is relaxed and EU25 food production increases markedly in the 450 ppm and 550 ppm cases and Base Case.

Food industry activity level for Base Case, 350, 450 & 550 ppm



The disaggregated results in the following section of this Chapter provide many other insights for analysis into regional industry activity, trade and investment.

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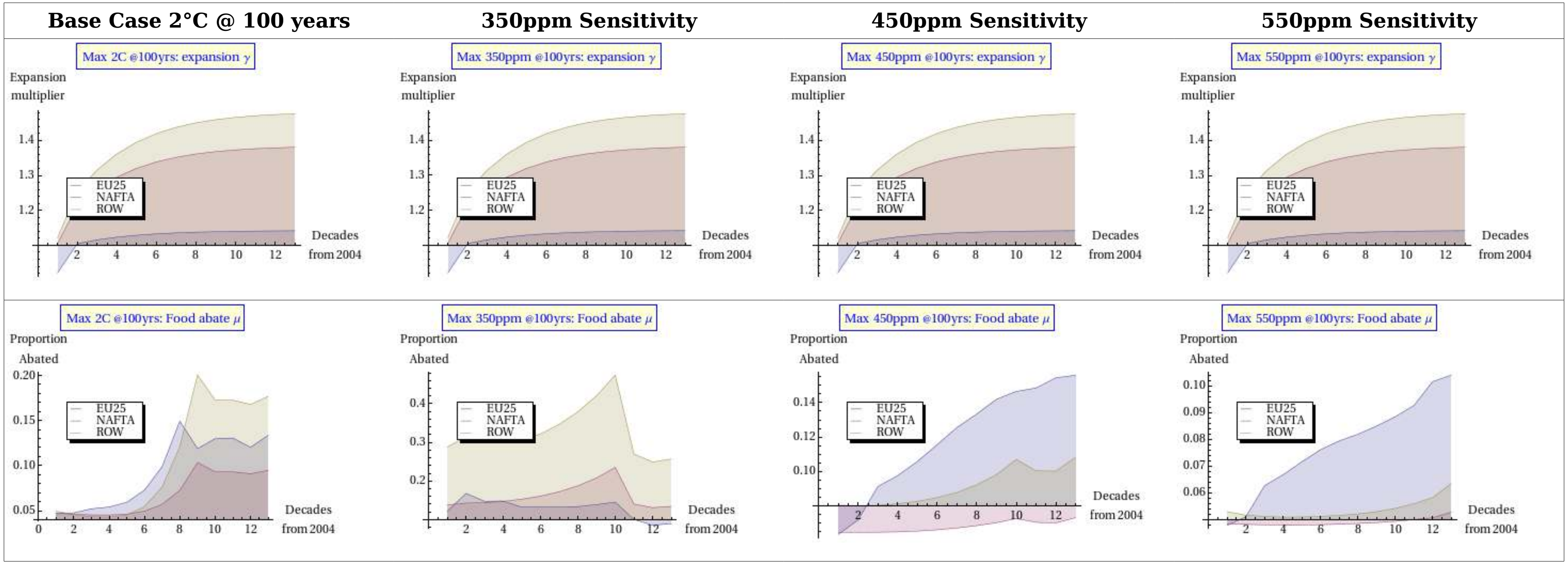
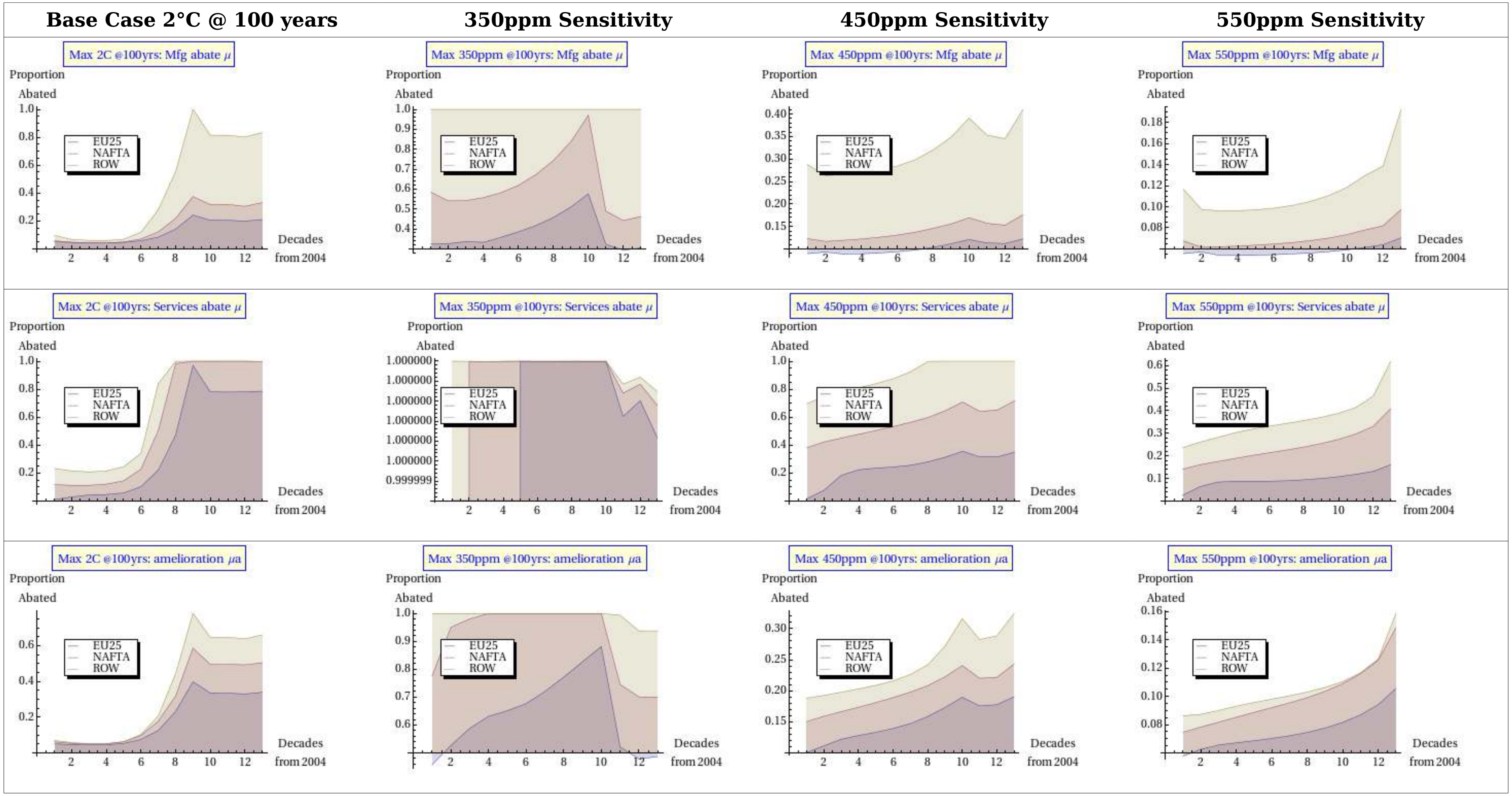
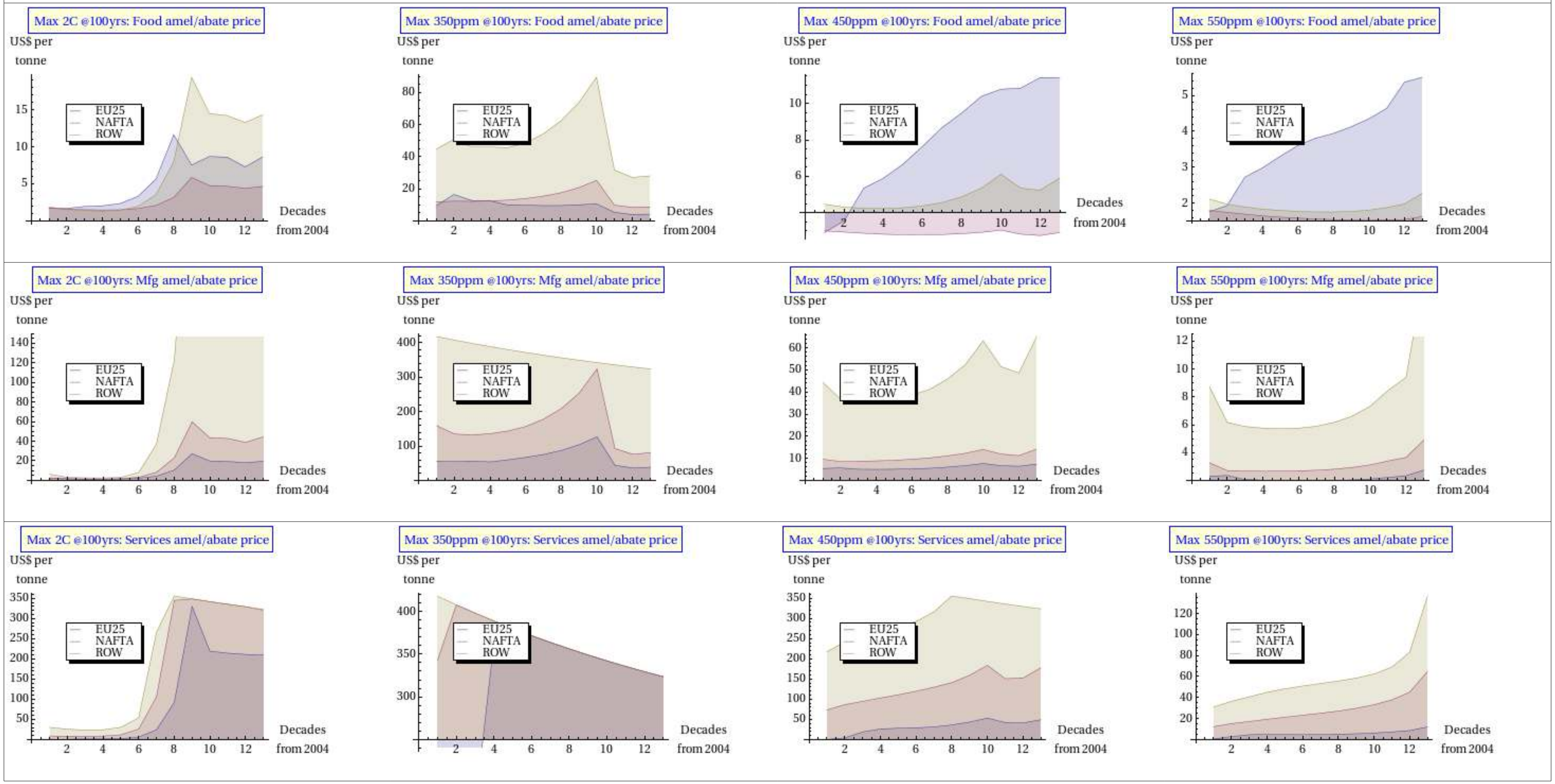
vii m12_13p_350_100.nb
viii m12_13p_450_100.nb
ix m12_13p_550_100.nb
x m12_13p_2C_100.nb

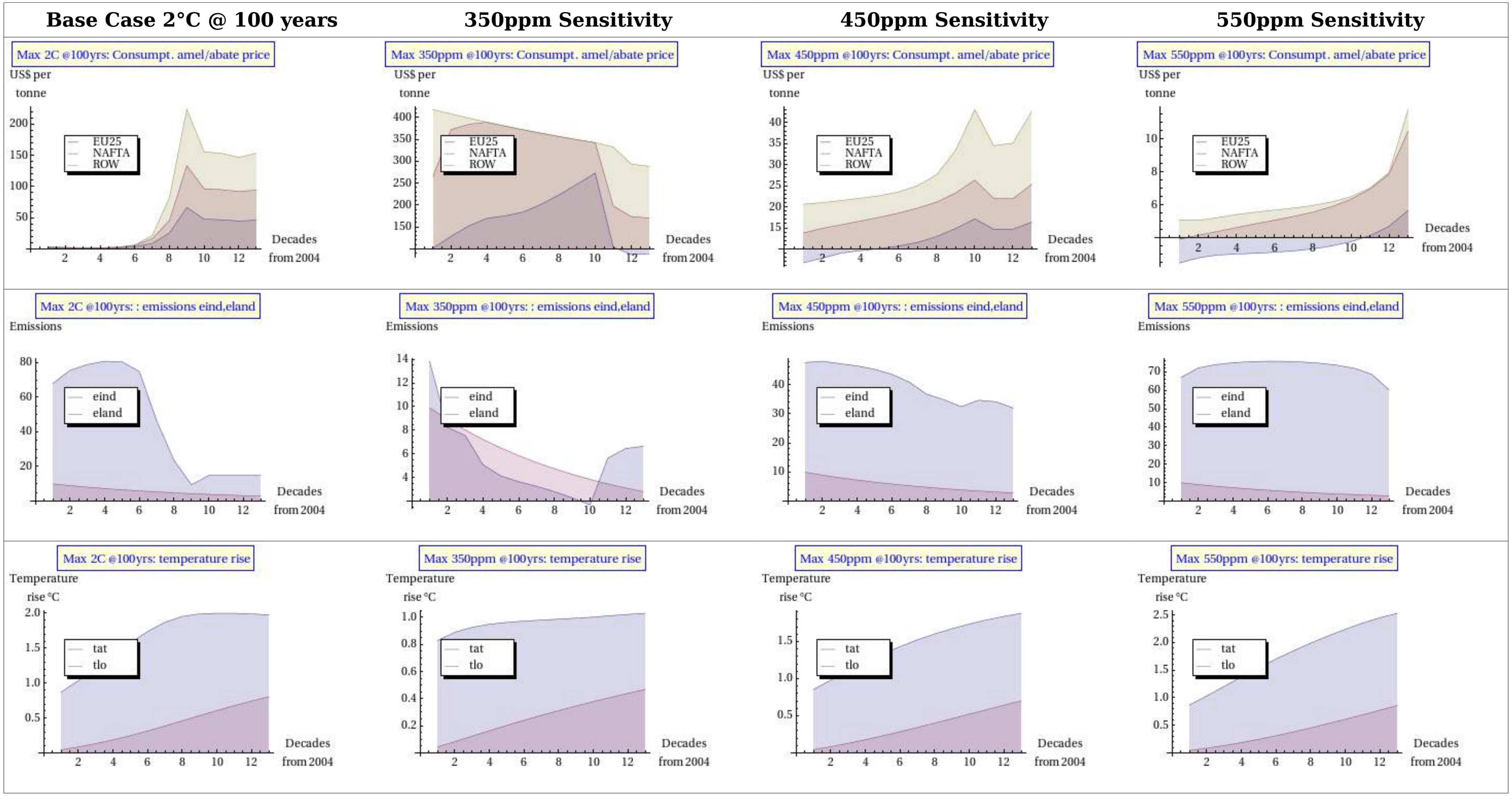
Atmospheric concentration constraint severity sensitivity analysis

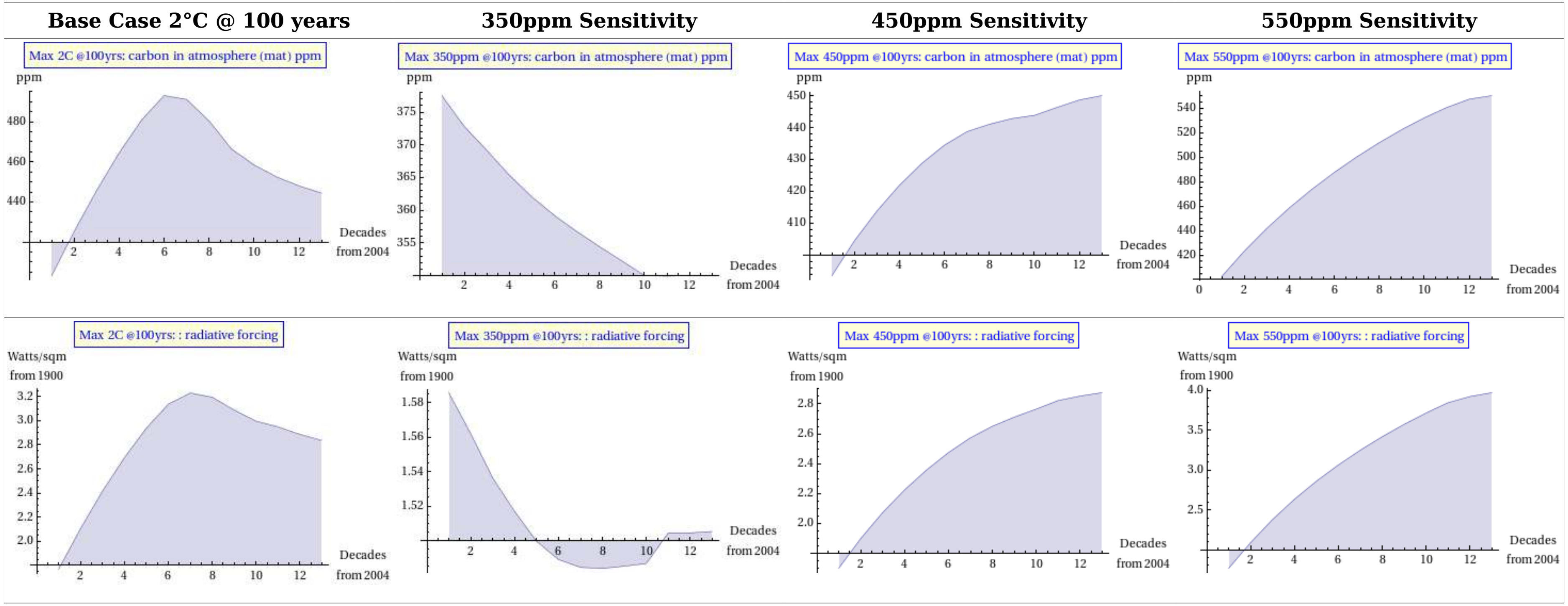


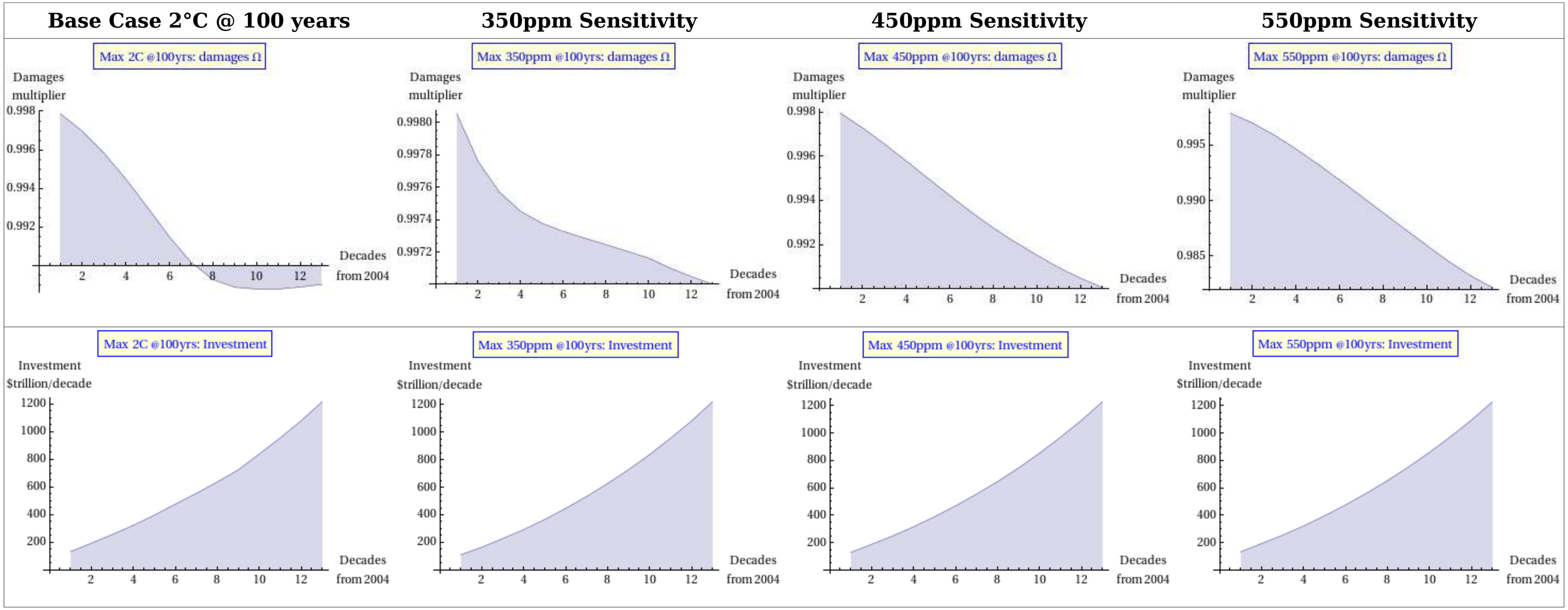

Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: Mfg abate μ
Max 350ppm @100yrs: Mfg abate μ
Max 450ppm @100yrs: Mfg abate μ
Max 550ppm @100yrs: Mfg abate μ
Max 2C @100yrs: Services abate μ
Max 350ppm @100yrs: Services abate μ
Max 450ppm @100yrs: Services abate μ
Max 550ppm @100yrs: Services abate μ
Max 2C @100yrs: amelioration μa
Max 350ppm @100yrs: amelioration μa
Max 450ppm @100yrs: amelioration μa
Max 550ppm @100yrs: amelioration μa
Proportion Abated
Decades from 2004
EU25
NAFTA
ROW

Base Case 2°C @ 100 years	350ppm Sensitivity	450ppm Sensitivity	550ppm Sensitivity

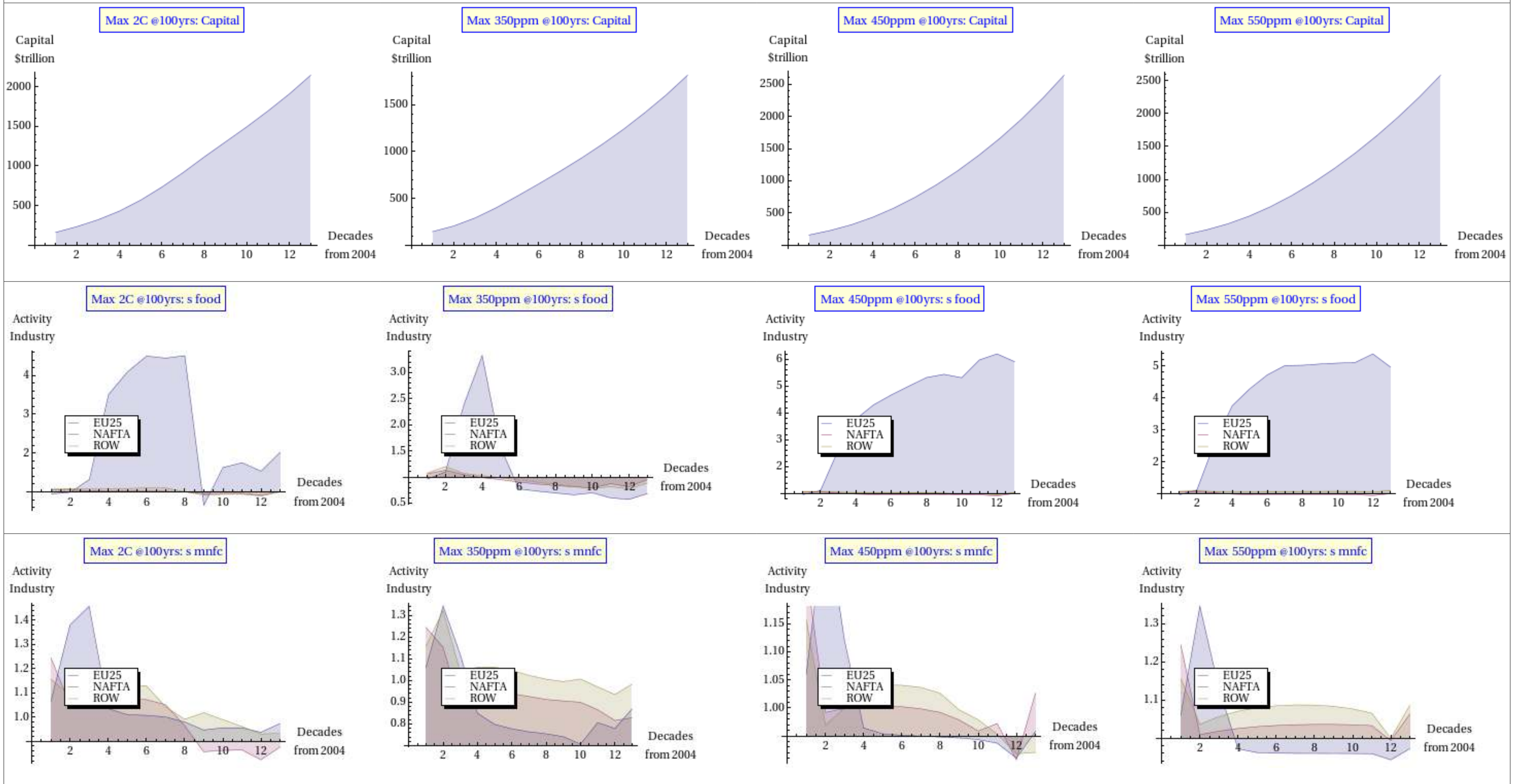


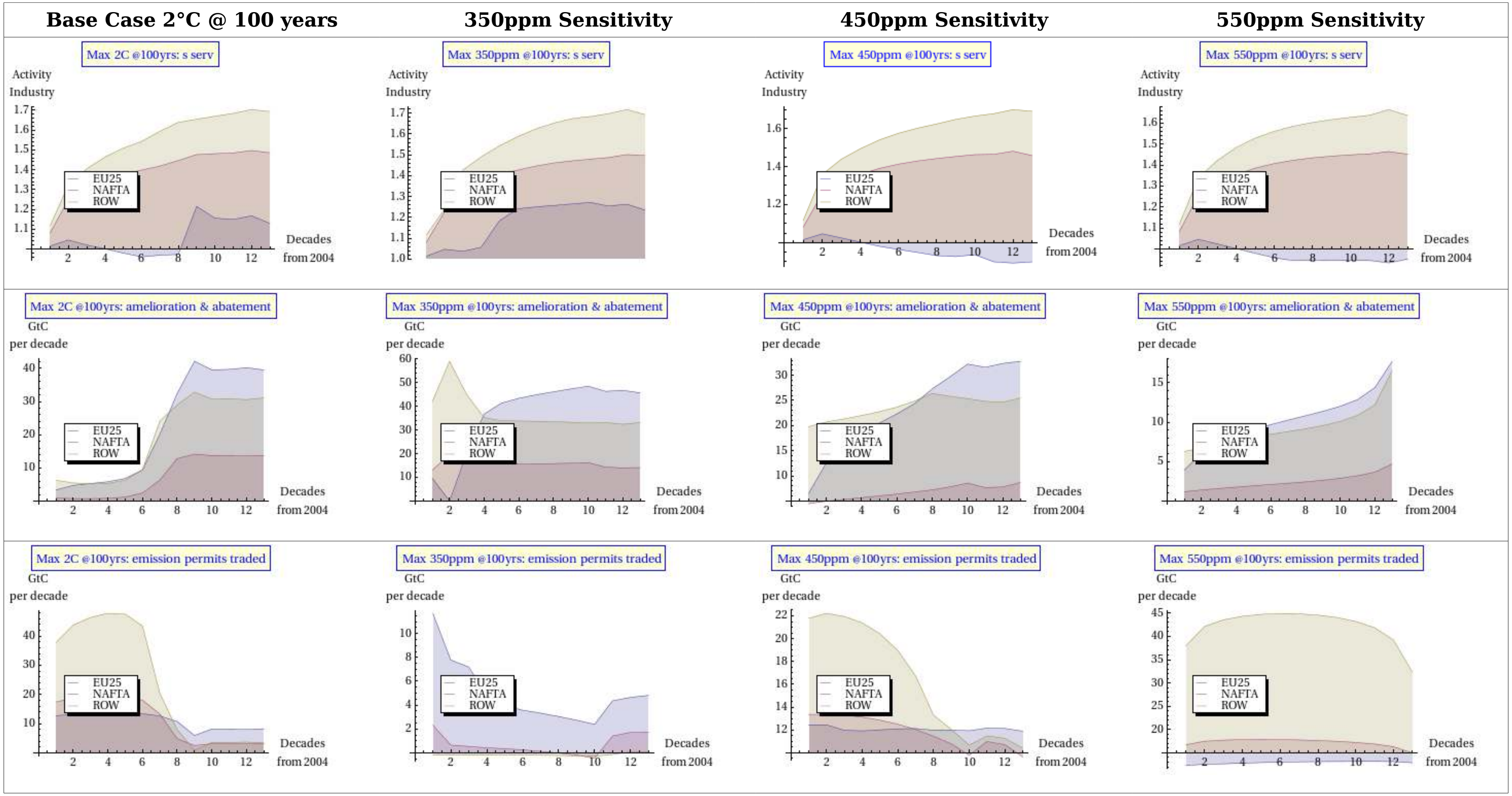

Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: Consumpt. amel/abate price
Max 350ppm @100yrs: Consumpt. amel/abate price
Max 450ppm @100yrs: Consumpt. amel/abate price
Max 550ppm @100yrs: Consumpt. amel/abate price
US$ per tonne
EU25
NAFTA
ROW
Decades from 2004
Max 2C @100yrs: : emissions eind,eland
Max 350ppm @100yrs: : emissions eind,eland
Max 450ppm @100yrs: : emissions eind,eland
Max 550ppm @100yrs: : emissions eind,eland
Emissions
eind
eland
Max 2C @100yrs: temperature rise
Max 350ppm @100yrs: temperature rise
Max 450ppm @100yrs: temperature rise
Max 550ppm @100yrs: temperature rise
Temperature rise °C
tat
tlo


Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: carbon in atmosphere (mat) ppm
Max 350ppm @100yrs: carbon in atmosphere (mat) ppm
Max 450ppm @100yrs: carbon in atmosphere (mat) ppm
Max 550ppm @100yrs: carbon in atmosphere (mat) ppm
ppm
Decades from 2004
Max 2C @100yrs: : radiative forcing
Max 350ppm @100yrs: : radiative forcing
Max 450ppm @100yrs: : radiative forcing
Max 550ppm @100yrs: : radiative forcing
Watts/sqm from 1900
Decades from 2004


Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: damages Ω
Max 350ppm @100yrs: damages Ω
Max 450ppm @100yrs: damages Ω
Max 550ppm @100yrs: damages Ω
Damages multiplier
Decades from 2004
Max 2C @100yrs: Investment
Max 350ppm @100yrs: Investment
Max 450ppm @100yrs: Investment
Max 550ppm @100yrs: Investment
Investment $trillion/decade
Decades from 2004

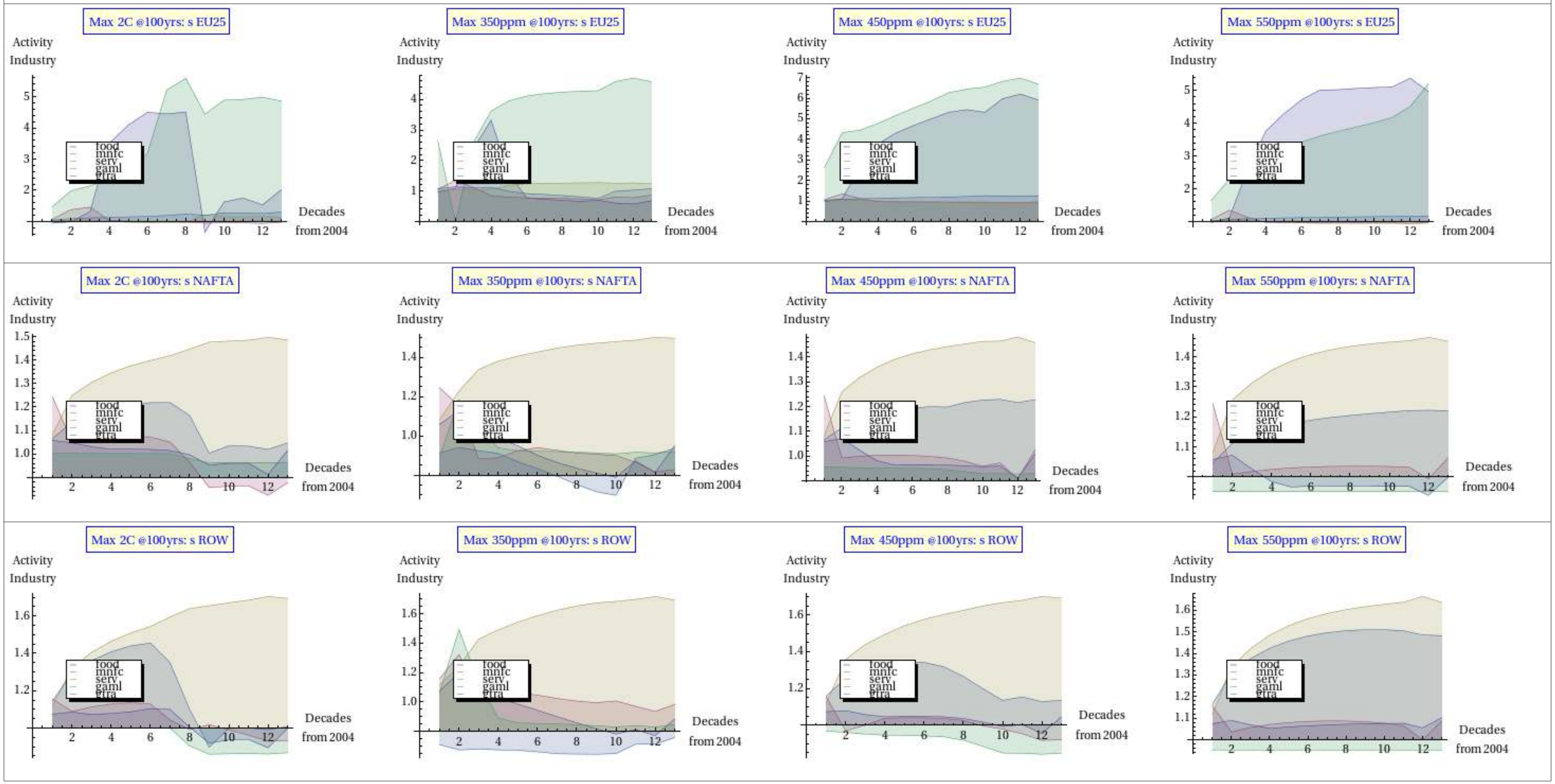
Base Case 2°C @ 100 years	350ppm Sensitivity	450ppm Sensitivity	550ppm Sensitivity

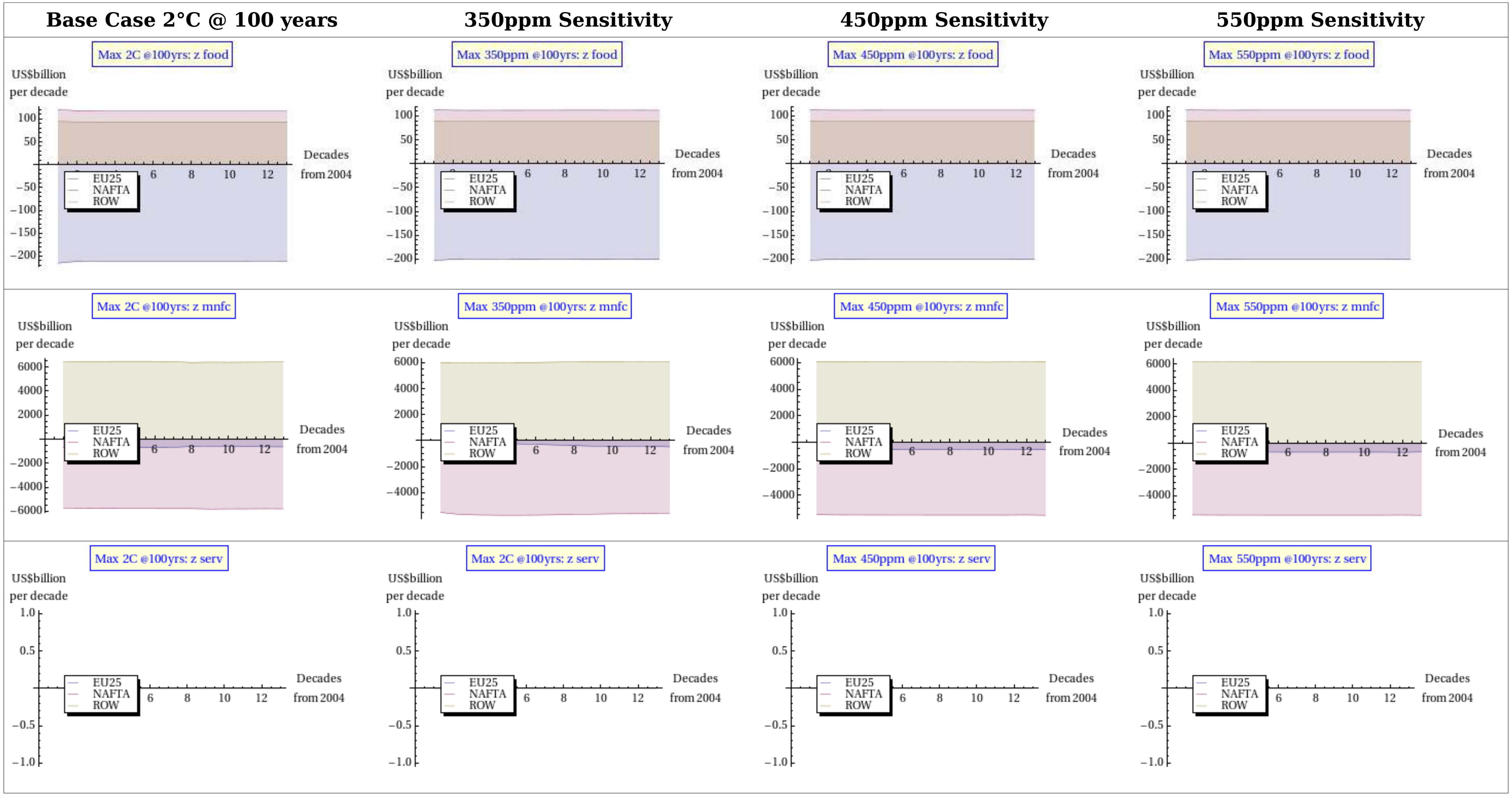


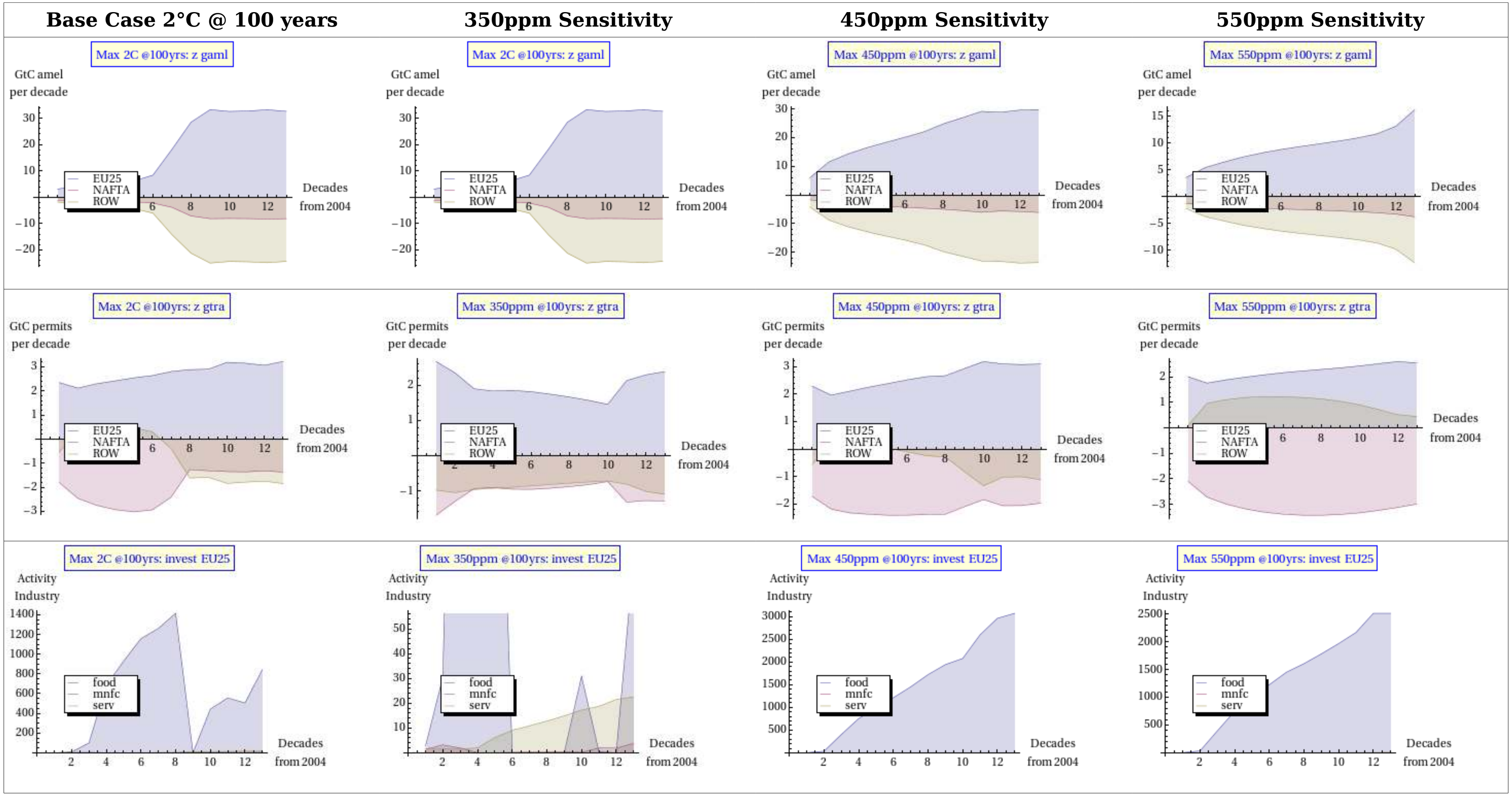


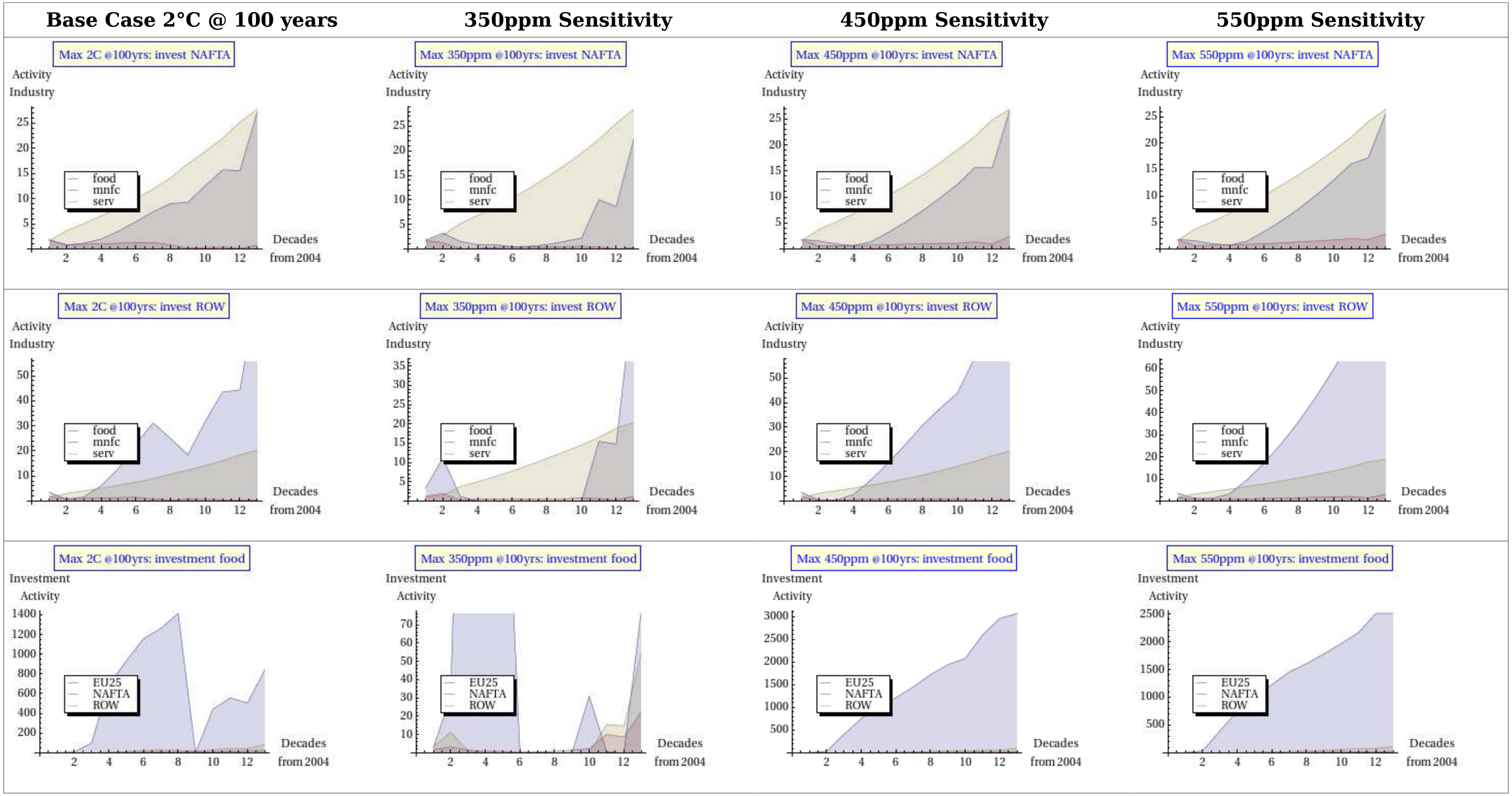
Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: s serv
Max 350ppm @100yrs: s serv
Max 450ppm @100yrs: s serv
Max 550ppm @100yrs: s serv
Activity Industry
Max 2C @100yrs: amelioration & abatement
Max 350ppm @100yrs: amelioration & abatement
Max 450ppm @100yrs: amelioration & abatement
Max 550ppm @100yrs: amelioration & abatement
Max 2C @100yrs: emission permits traded
Max 350ppm @100yrs: emission permits traded
Max 450ppm @100yrs: emission permits traded
Max 550ppm @100yrs: emission permits traded
GtC per decade
Decades from 2004
EU25
NAFTA
ROW

Base Case 2°C @ 100 years	350ppm Sensitivity	450ppm Sensitivity	550ppm Sensitivity

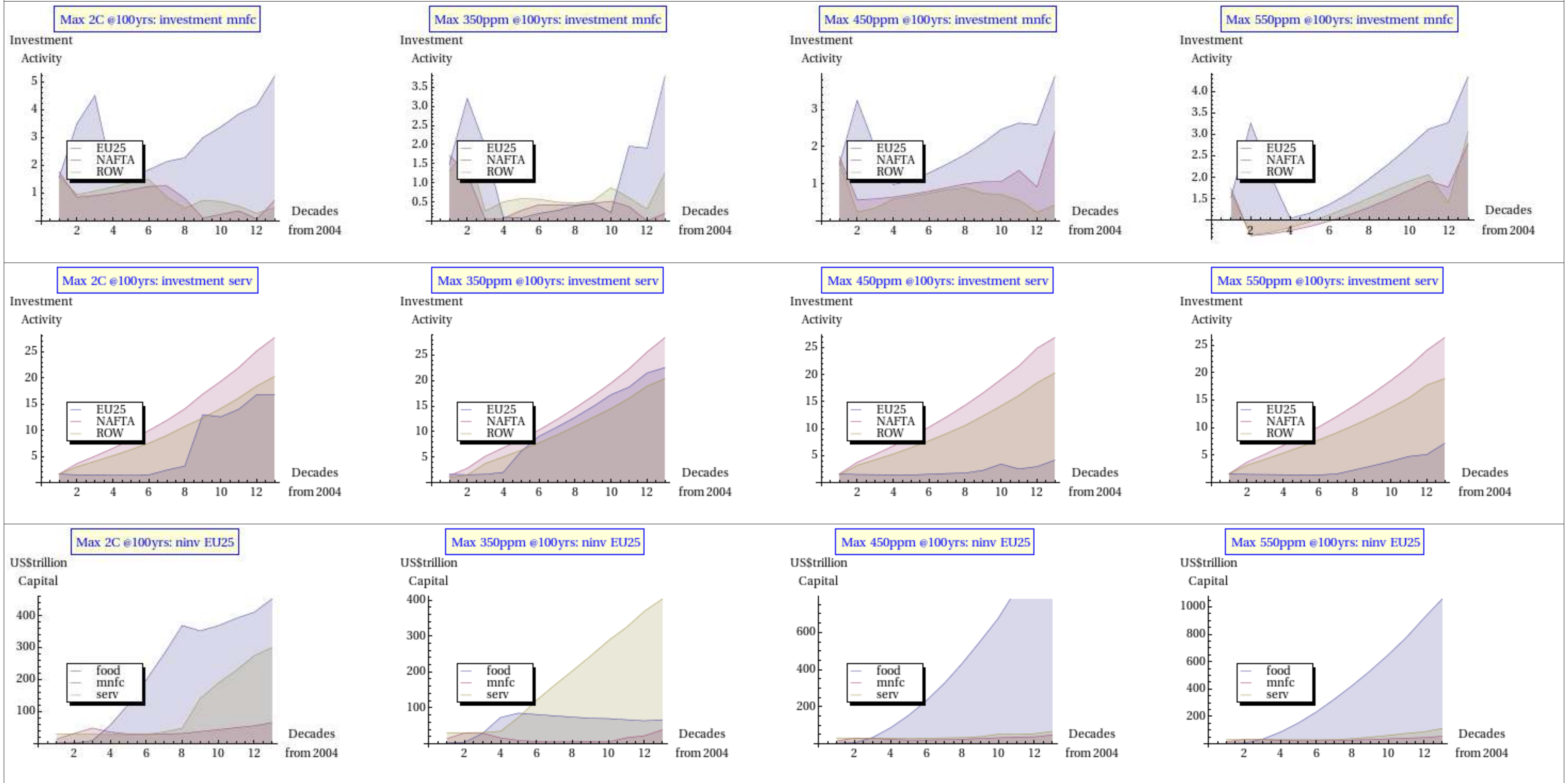



Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: z food
Max 350ppm @100yrs: z food
Max 450ppm @100yrs: z food
Max 550ppm @100yrs: z food
Max 2C @100yrs: z mnfc
Max 350ppm @100yrs: z mnfc
Max 450ppm @100yrs: z mnfc
Max 550ppm @100yrs: z mnfc
Max 2C @100yrs: z serv
Max 2C @100yrs: z serv
Max 450ppm @100yrs: z serv
Max 550ppm @100yrs: z serv
US$billion per decade
Decades from 2004
EU25
NAFTA
ROW

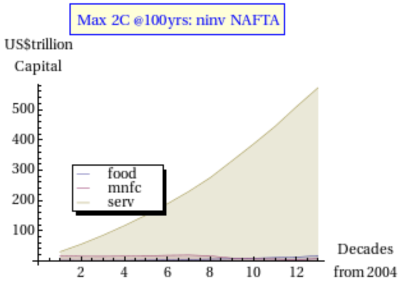

Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: z gaml
Max 2C @100yrs: z gaml
Max 450ppm @100yrs: z gaml
Max 550ppm @100yrs: z gaml
GtC amel per decade
Decades from 2004
EU25
NAFTA
ROW
Max 2C @100yrs: z gtra
Max 350ppm @100yrs: z gtra
Max 450ppm @100yrs: z gtra
Max 550ppm @100yrs: z gtra
GtC permits per decade
Max 2C @100yrs: invest EU25
Max 350ppm @100yrs: invest EU25
Max 450ppm @100yrs: invest EU25
Max 550ppm @100yrs: invest EU25
Activity Industry
food
mnfc
serv

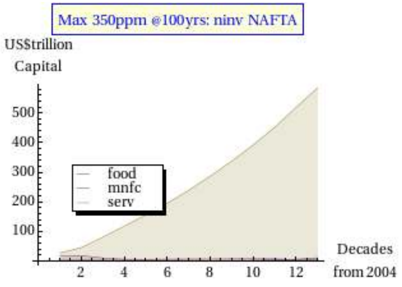

Base Case 2°C @ 100 years
350ppm Sensitivity
450ppm Sensitivity
550ppm Sensitivity
Max 2C @100yrs: invest NAFTA
Max 350ppm @100yrs: invest NAFTA
Max 450ppm @100yrs: invest NAFTA
Max 550ppm @100yrs: invest NAFTA
Max 2C @100yrs: invest ROW
Max 350ppm @100yrs: invest ROW
Max 450ppm @100yrs: invest ROW
Max 550ppm @100yrs: invest ROW
Max 2C @100yrs: investment food
Max 350ppm @100yrs: investment food
Max 450ppm @100yrs: investment food
Max 550ppm @100yrs: investment food
Activity
Industry
Investment
Activity
food
mnfc
serv
EU25
NAFTA
ROW
Decades
from 2004

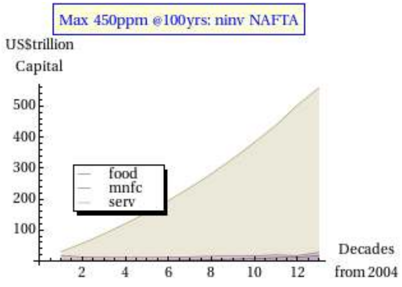
Base Case 2°C @ 100 years	350ppm Sensitivity	450ppm Sensitivity	550ppm Sensitivity

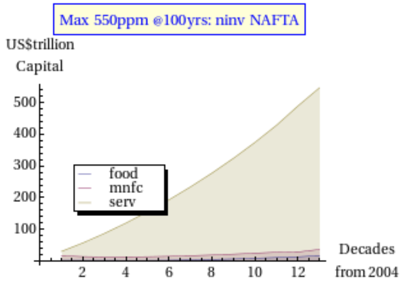


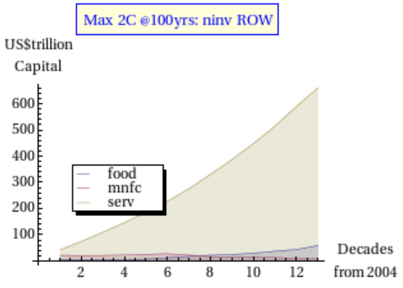
Base Case 2°C @ 100 years	350ppm Sensitivity	450ppm Sensitivity	550ppm Sensitivity

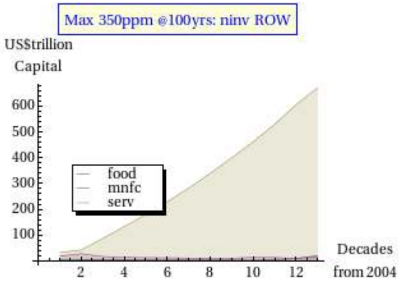


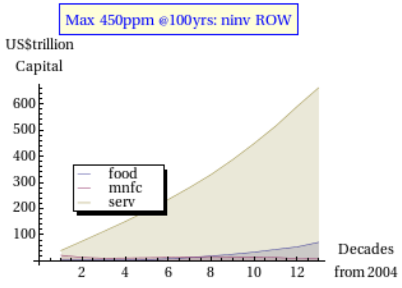


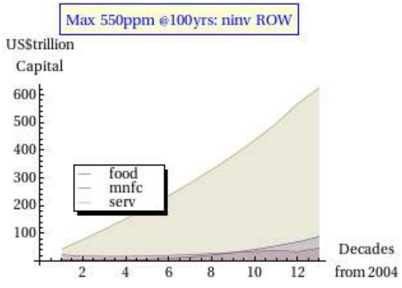












6.1.4 Technology cost sensitivity

In *Chapter 3 Political Economy of the Anglo-American world view of climate change* it was noted that many developing countries including China and India fear that ameliorating emissions will seriously retard economic growth. One concern is that intellectual property royalties for green technologies will lead to major transfer payments from developing economies to industrialised economies. Poor and developing countries know that intellectual property matters are difficult to resolve, as they have found in the ongoing imbroglio over the supply of anti-retroviral (HIV) drugs.

Intellectual property concerns aside, there are situations where the abatement and amelioration task retards economic growth. This is particularly the case for developing countries due to rapidly rising standards of living and in many cases, rapid population growth.

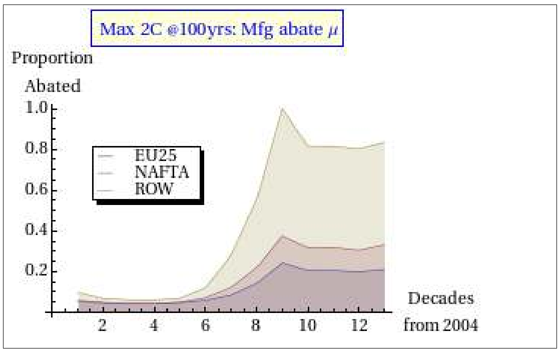
Results and analysis

Base Case 2°C rise[xi]	**2x technology cost**[xii]	**10x technology cost**[xiii]	**20x technology cost**[xiv]
Nordhaus DICE backstop technology cost	Twice Nordhaus DICE cost	10x Nordhaus DICE cost	20x Nordhaus DICE cost

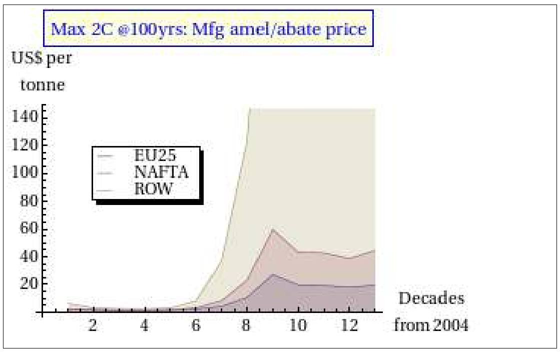
In each case it is found increased technology costs lead to only a small decrease in the value of the objective function of the order of US$18 billion (2004 dollars) (cf. Base Case analysis for method of calculation).

As might be expected, emissions and temperature rise are relatively unaffected by technology cost. The main effects of increasing technology cost is to depress the emissions control rate. However, this proves to be inelastic and the changes are only moderate given the large magnitude of increase in amelioration and abatement prices.

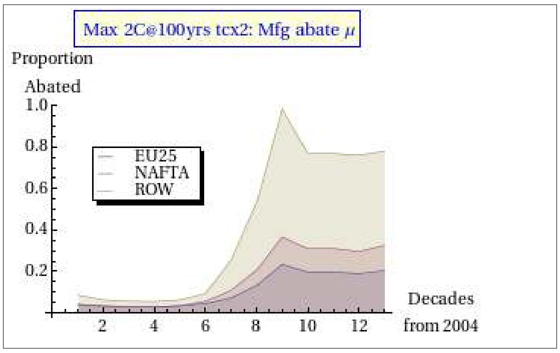
Manufacturing emissions control rate	**Manufacturing emissions control technology price**



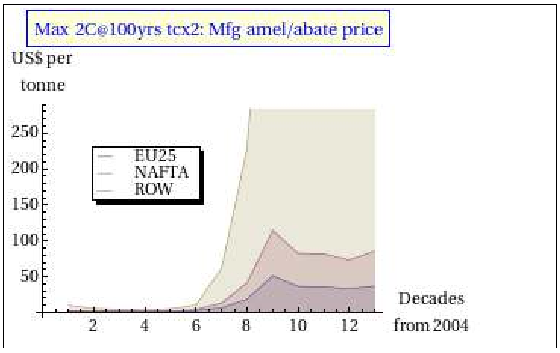
Base Case



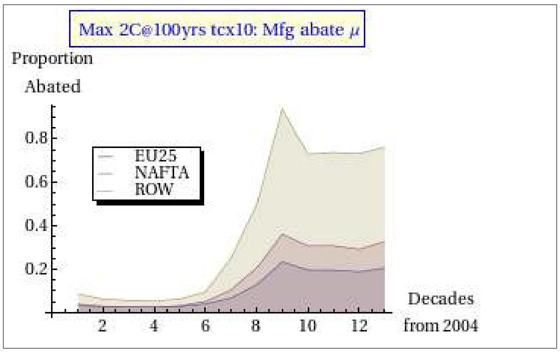
Base Case



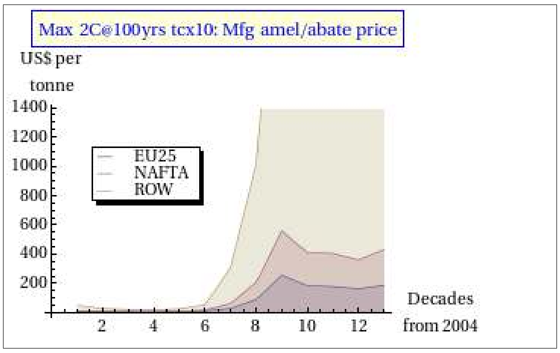
2x increase in technology cost



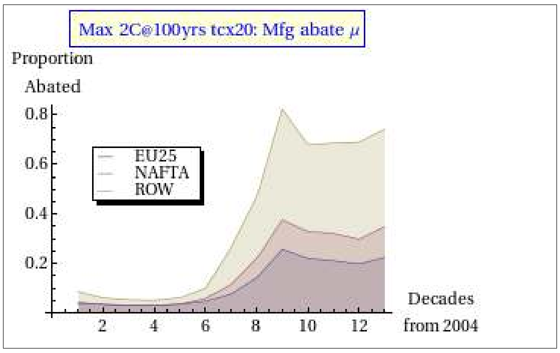
2x increase in technology cost



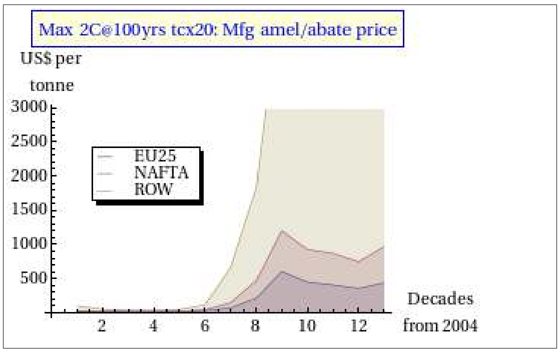
10x increase in technology cost



10x increase in technology cost

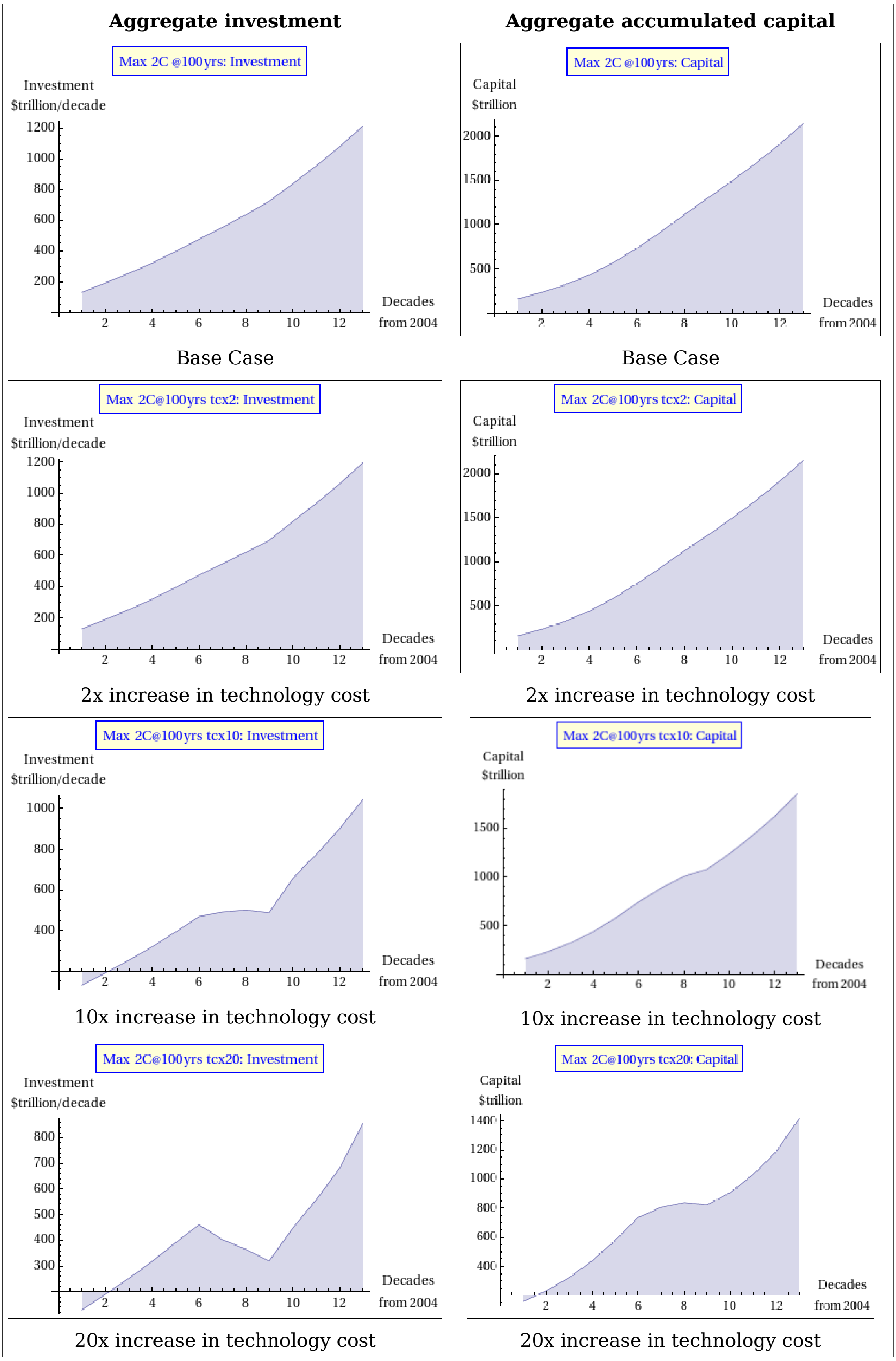


20x increase in technology cost



20x increase in technology cost

Economic investment and capital are sensitive to backstop technology cost:


Aggregate investment
Aggregate accumulated capital
Max 2C @100yrs: Investment
Investment
$trillion/decade
1200
1000
800
600
400
200
2
4
6
8
10
12
Decades
from 2004
Max 2C @100yrs: Capital
Capital
$trillion
2000
1500
1000
500
Base Case
Base Case
Max 2C@100yrs tcx2: Investment
Max 2C@100yrs tcx2: Capital
2x increase in technology cost
2x increase in technology cost
Max 2C@100yrs tcx10: Investment
Max 2C@100yrs tcx10: Capital
10x increase in technology cost
10x increase in technology cost
Max 2C@100yrs tcx20: Investment
700
500
300
Max 2C@100yrs tcx20: Capital
1400
20x increase in technology cost
20x increase in technology cost

As may be seen in the above illustrations, global investment fractures, falling 25% from US$800 billion at decade 10 in the Base Case level to US$600 billion for the 10x technology cost case. The fall is 50% for the 20x technology cost case. There is a similar effect on accumulated capital, which falls from US$1500 trillion at decade 10 to US$1100 trillion for 10x cost and US$800 trillion for 20x cost.

The following section in this Chapter provides the disaggregated results. It may be noted that the main effects continue to be in investment and capital rather than industry activity and trade. The sensitivity of economic performance to backstop technology cost suggests that there will be different stresses on different economies that arise solely as a function of differential technology propagation.

Technology risk

The scale of the task for developing economies in reducing emissions and the situation that they usually do not have primary access to technology intellectual property rights suggests that developing countries appear to face the greatest technology risk. Developing countries have seen this sort of risk before, for example in HIV medication.

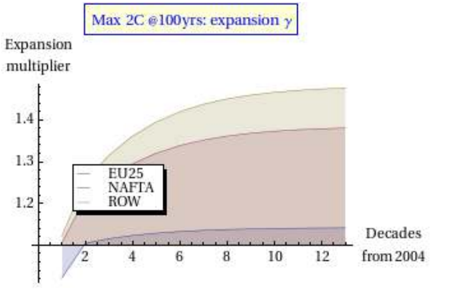
It is also apparent from these projections that industrialised countries need developing countries to participate in ambitious targets for amelioration and abatement. For example, the requirement for ROW participation is considerably in excess of the challenge for NAFTA. This leads to a double risk for developed nations. The first risk is for their own performance. The second is a derivative risk in the performance of developing nations to whose failure they are exposed.

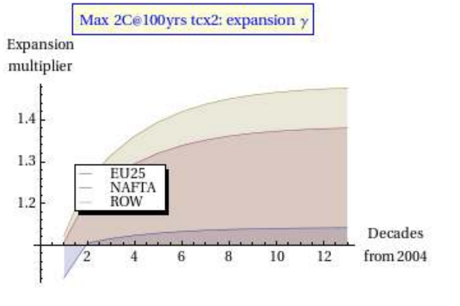
The world view of China and India was discussed in *Chapter 3 Political Economy of the Anglo-American world view of climate change*. This suggests that industrialised nations will need to resolve the uncertainty about technology availability and concern about being exploited by technology providers before they are ready to engage in a common goal.

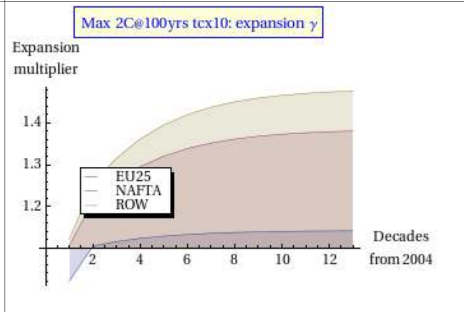
xi m12_13p_2C_100.nb
xii m12_13p_2C_100_tcx2.nb
xiii m12_13p_2C_100_tcx10.nb
xiv m12_13p_2C_100_tcx20.nb

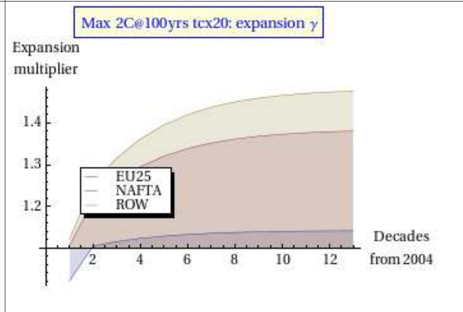
Abatement technology cost sensitivity analysis

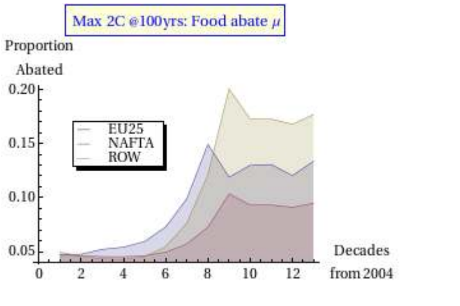
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

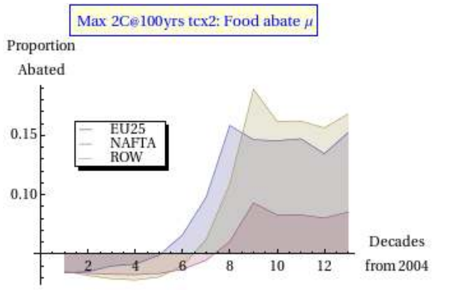


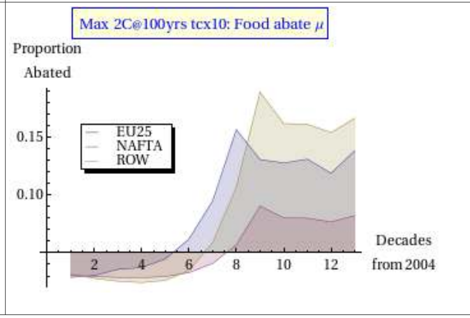


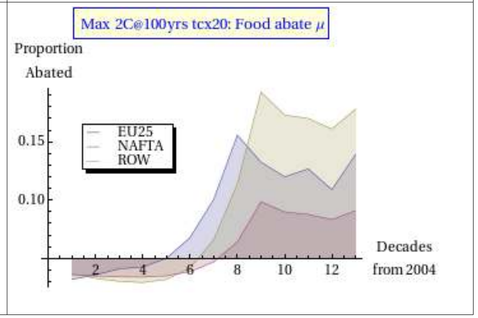


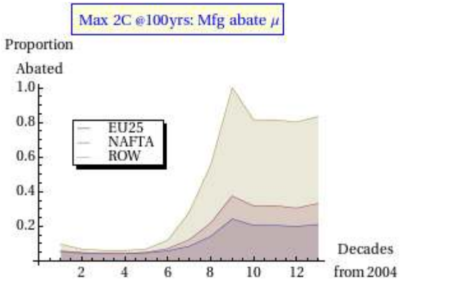
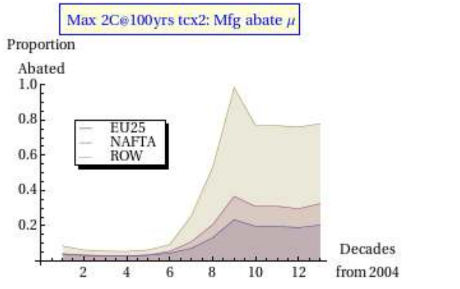
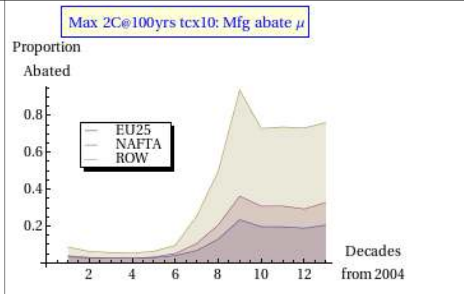
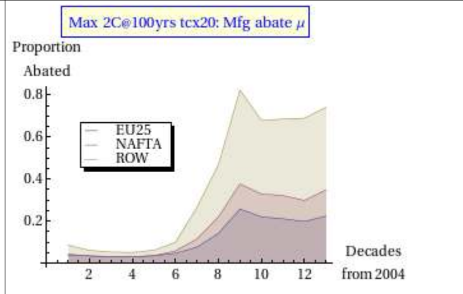
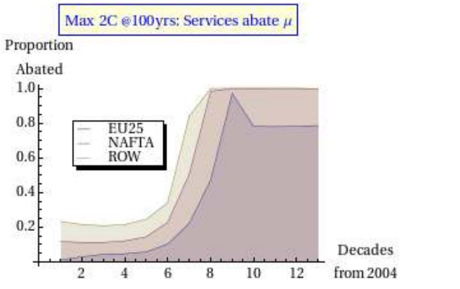
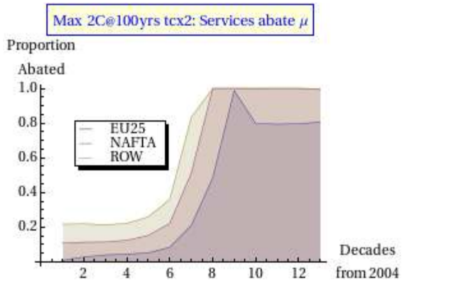
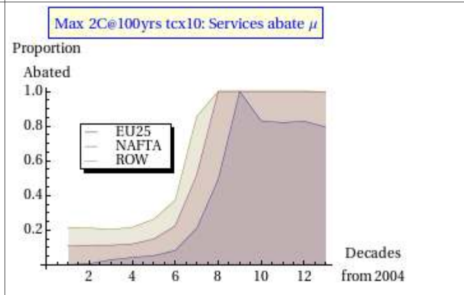
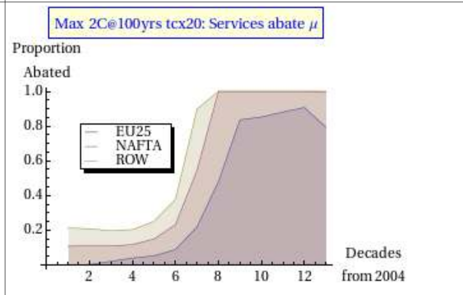
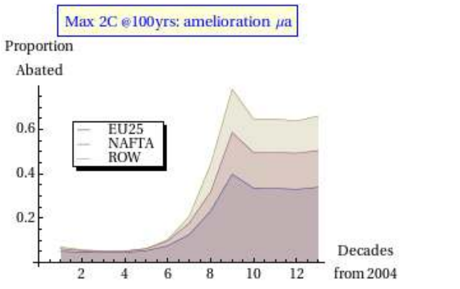
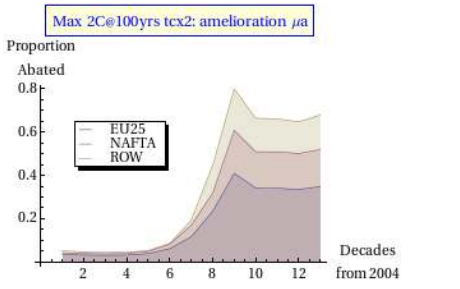
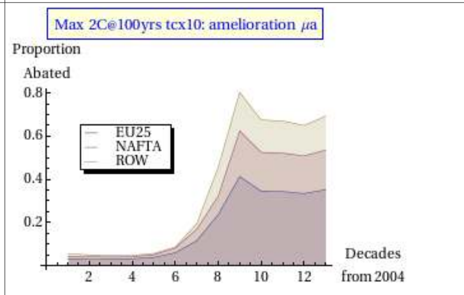
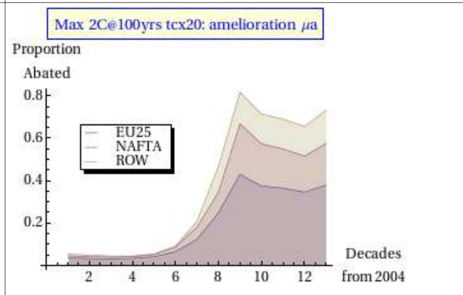




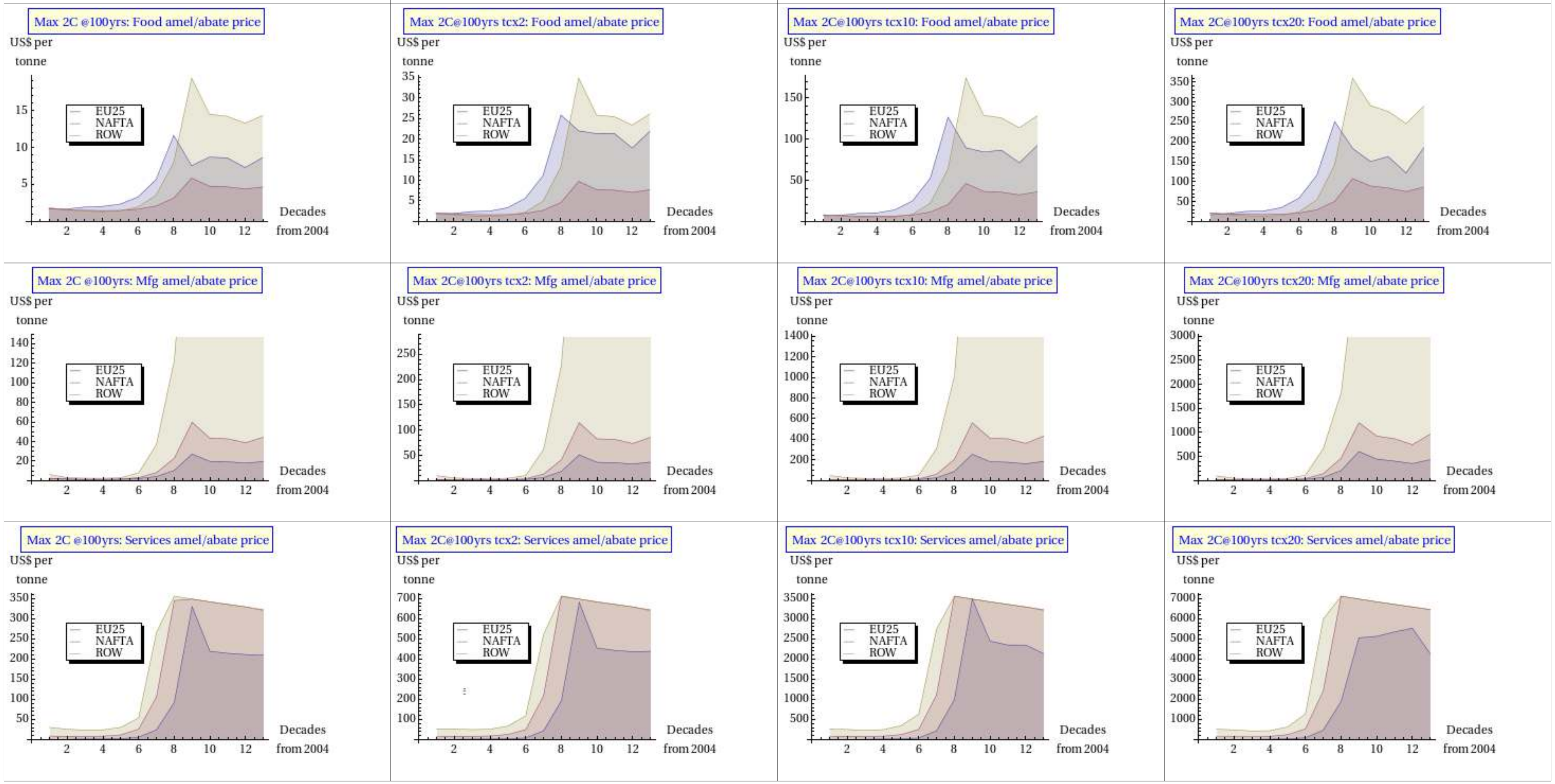




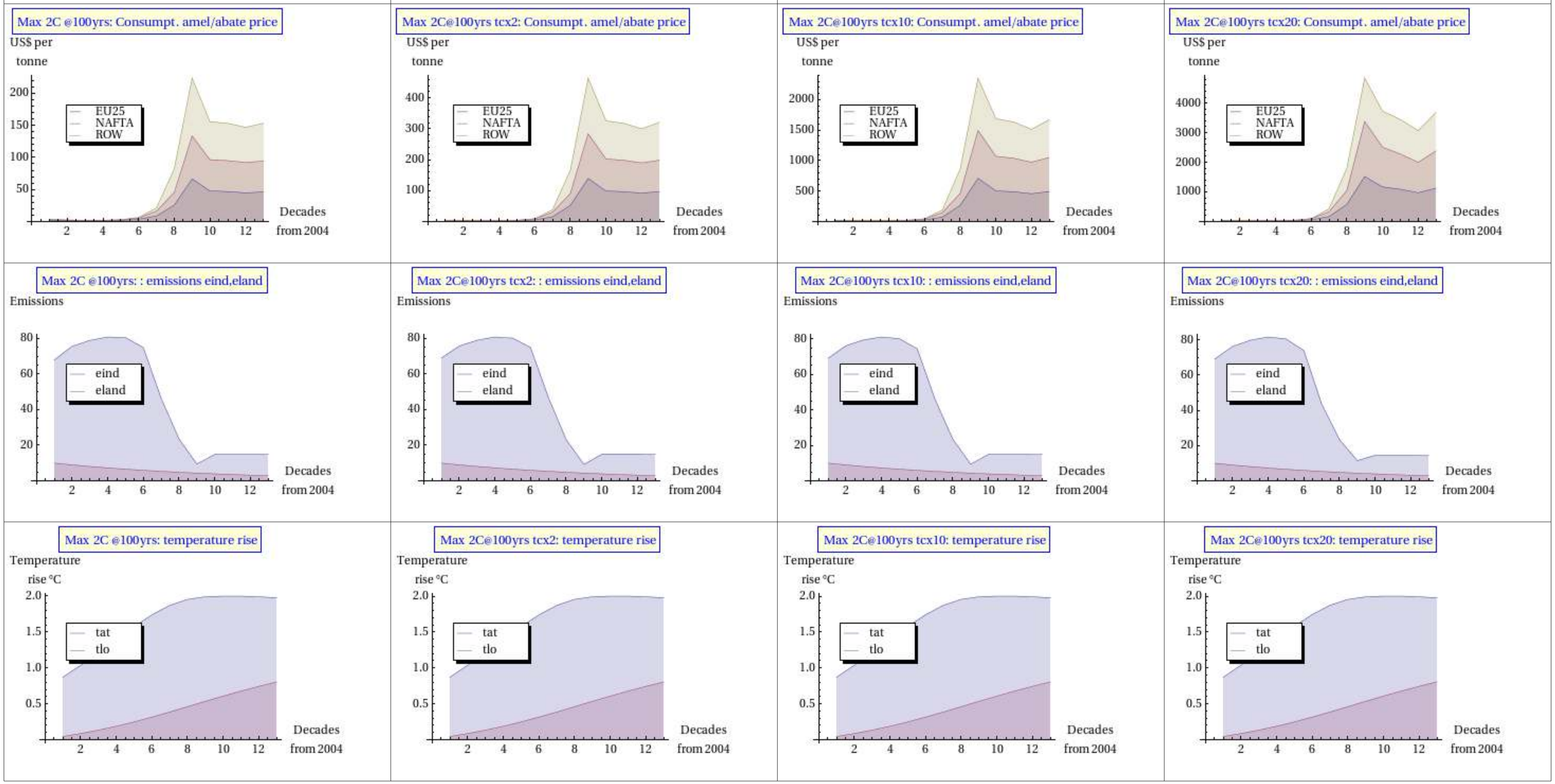


Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology
			
			
			

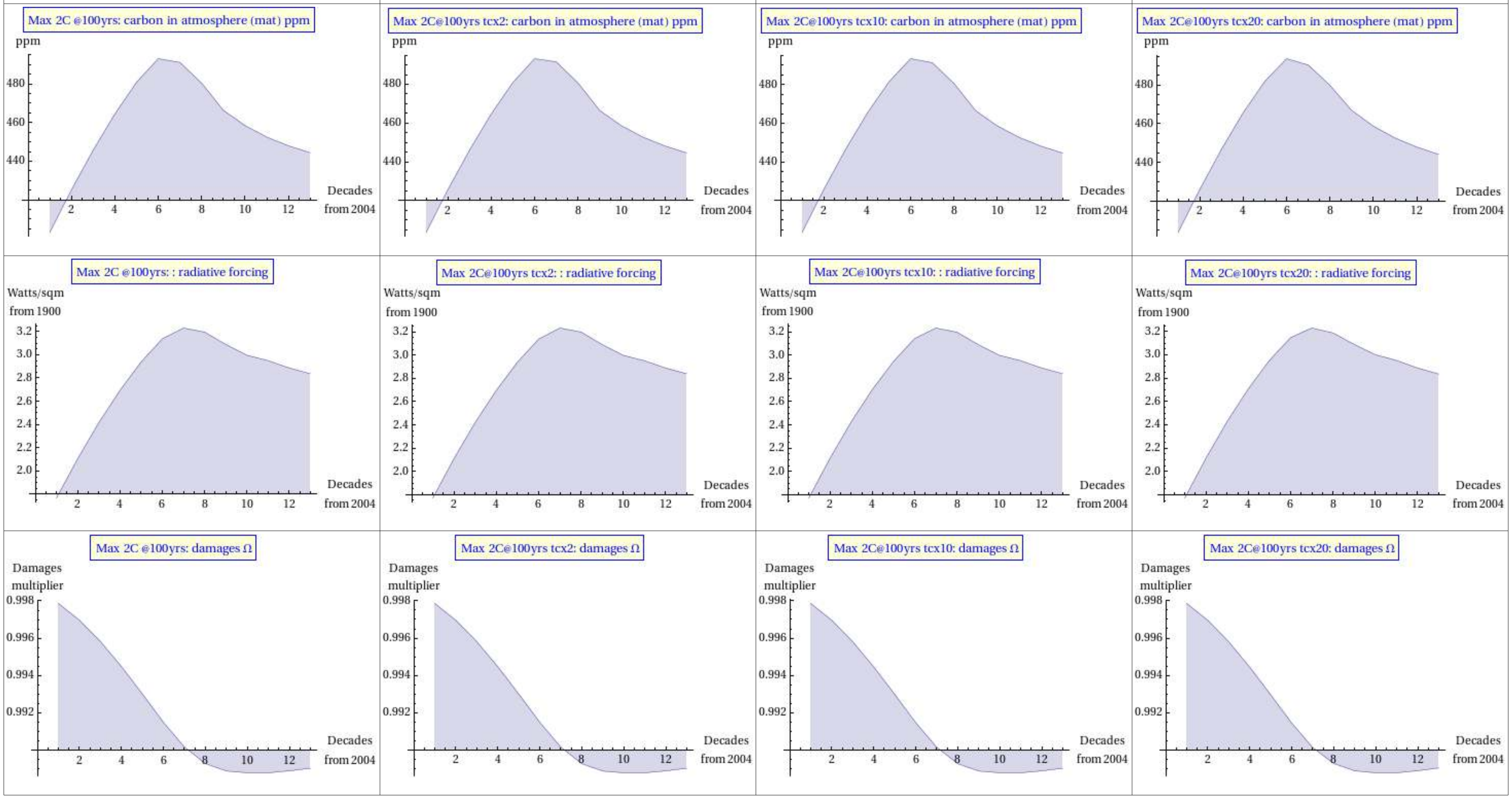
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

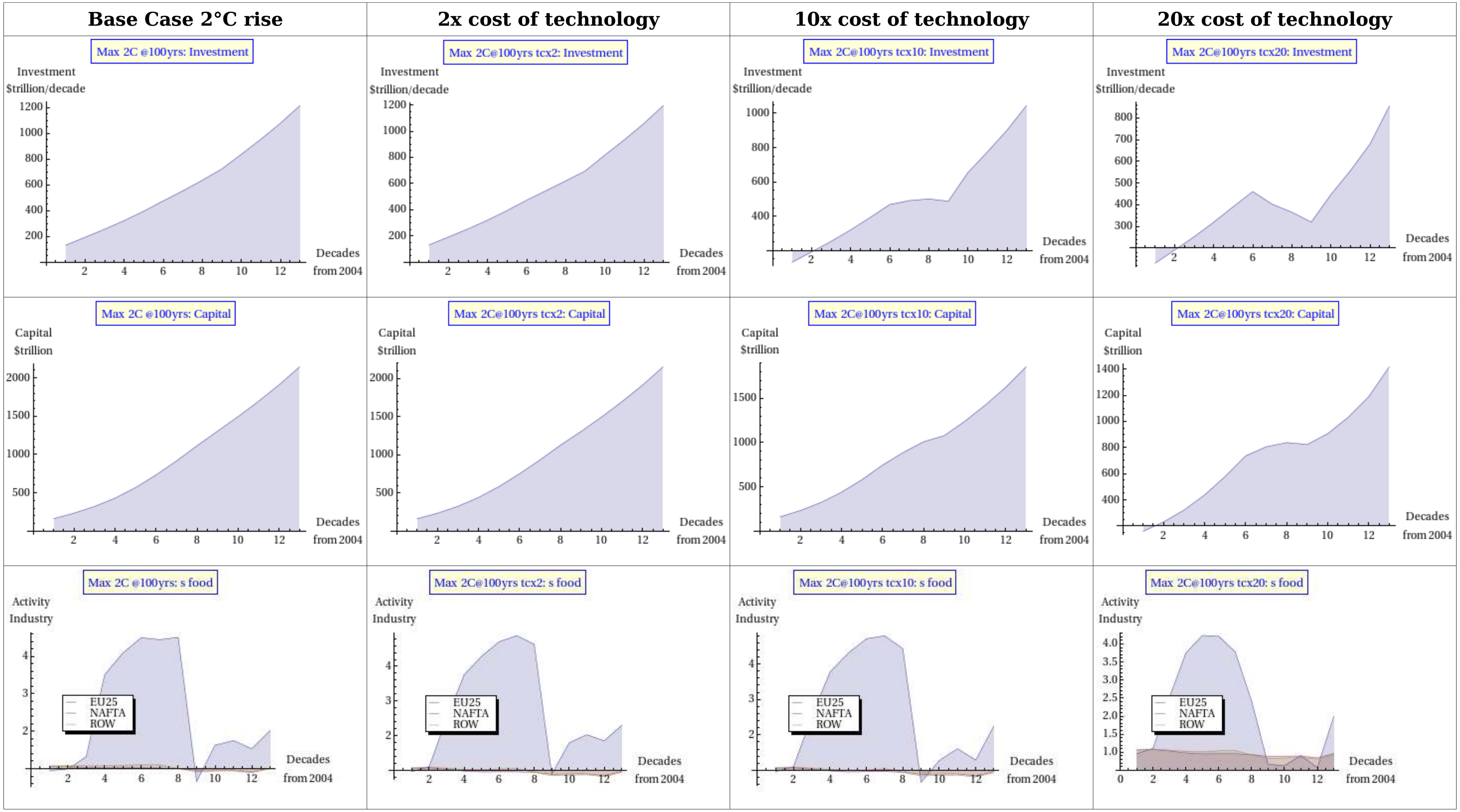


Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology



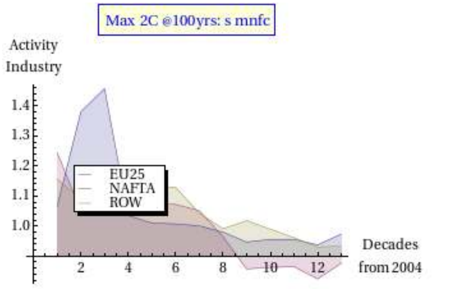
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

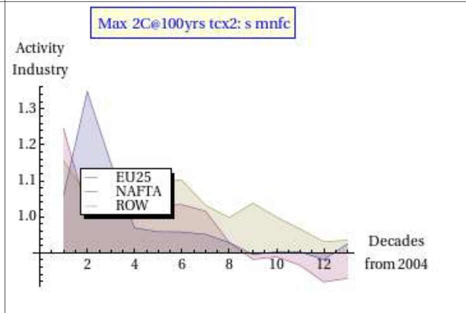


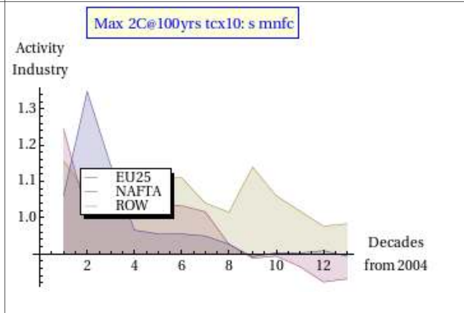


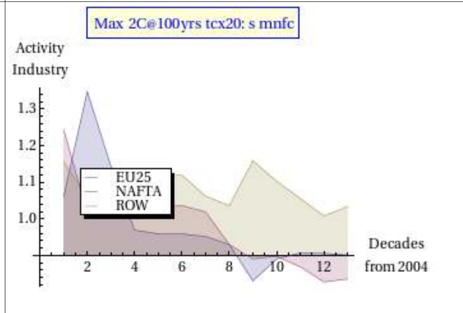
Base Case 2°C rise
2x cost of technology
10x cost of technology
20x cost of technology
Max 2C @100yrs: Investment
Max 2C@100yrs tcx2: Investment
Max 2C@100yrs tcx10: Investment
Max 2C@100yrs tcx20: Investment
Investment
$trillion/decade
Decades
from 2004
Max 2C @100yrs: Capital
Max 2C@100yrs tcx2: Capital
Max 2C@100yrs tcx10: Capital
Max 2C@100yrs tcx20: Capital
Capital
$trillion
Max 2C @100yrs: s food
Max 2C@100yrs tcx2: s food
Max 2C@100yrs tcx10: s food
Max 2C@100yrs tcx20: s food
Activity
Industry
EU25
NAFTA
ROW

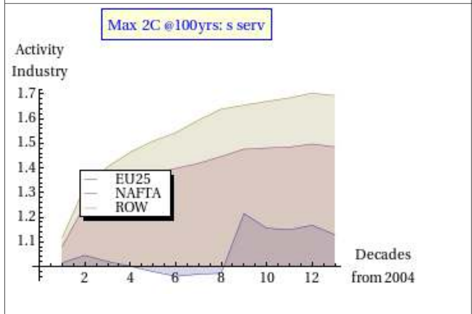
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

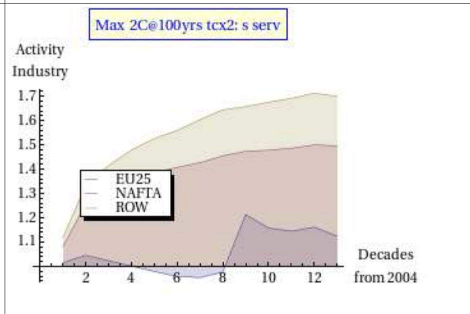


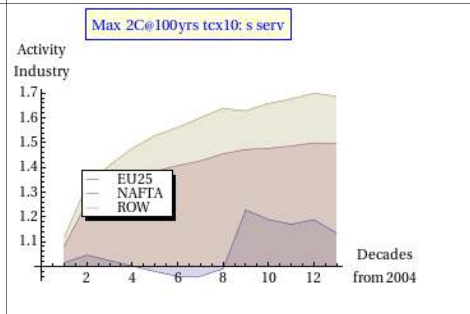


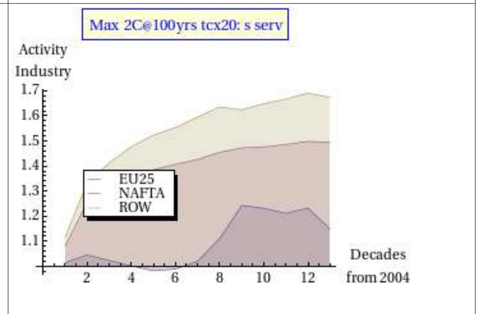


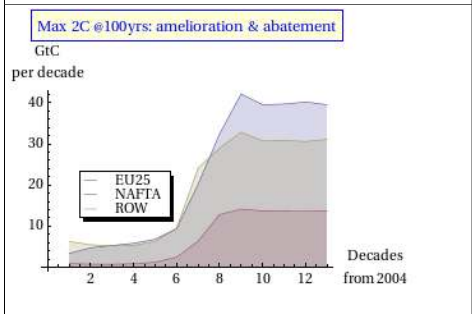


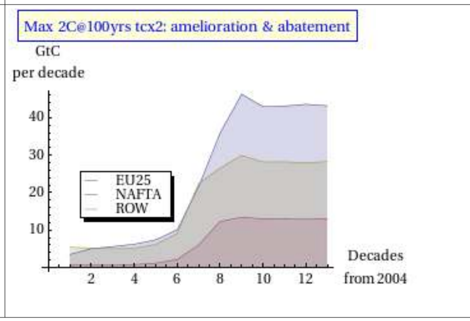


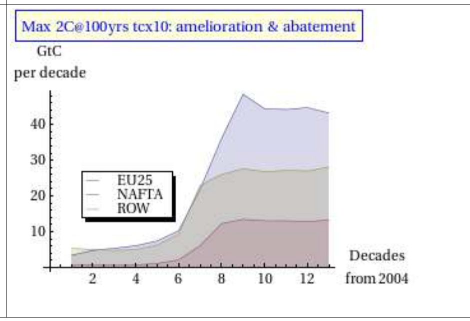


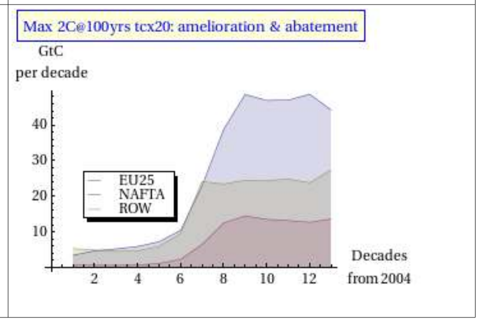




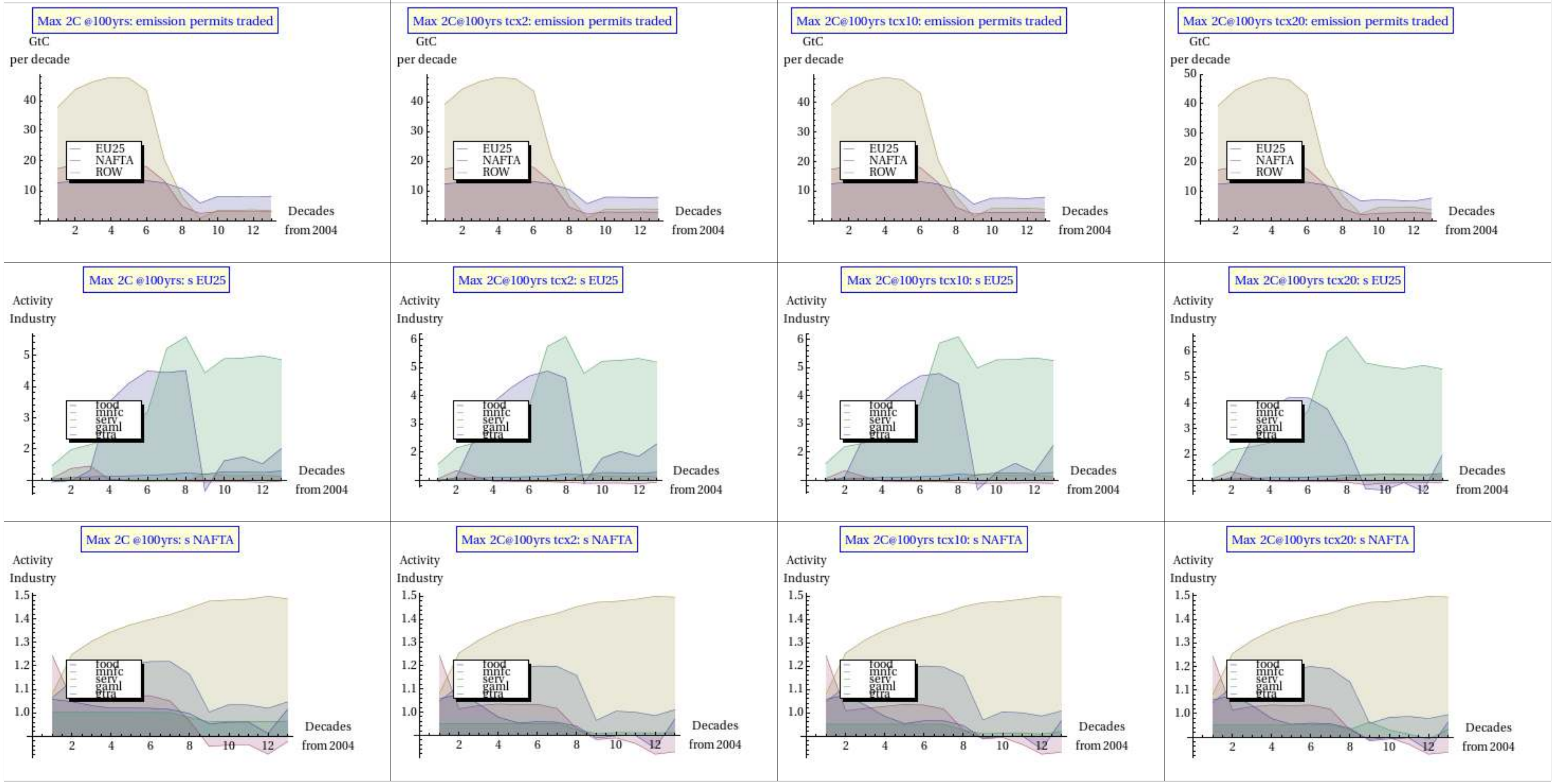


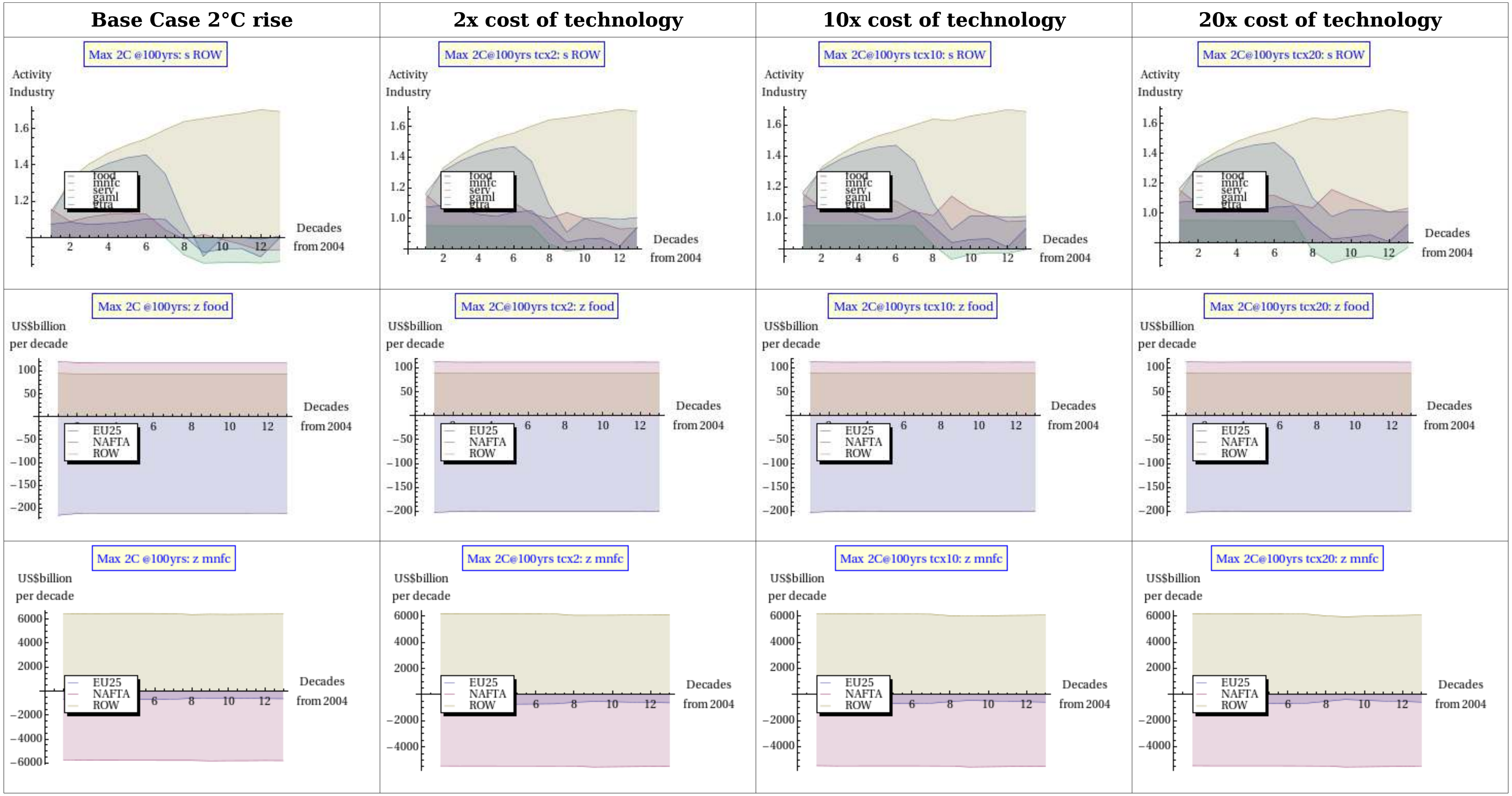


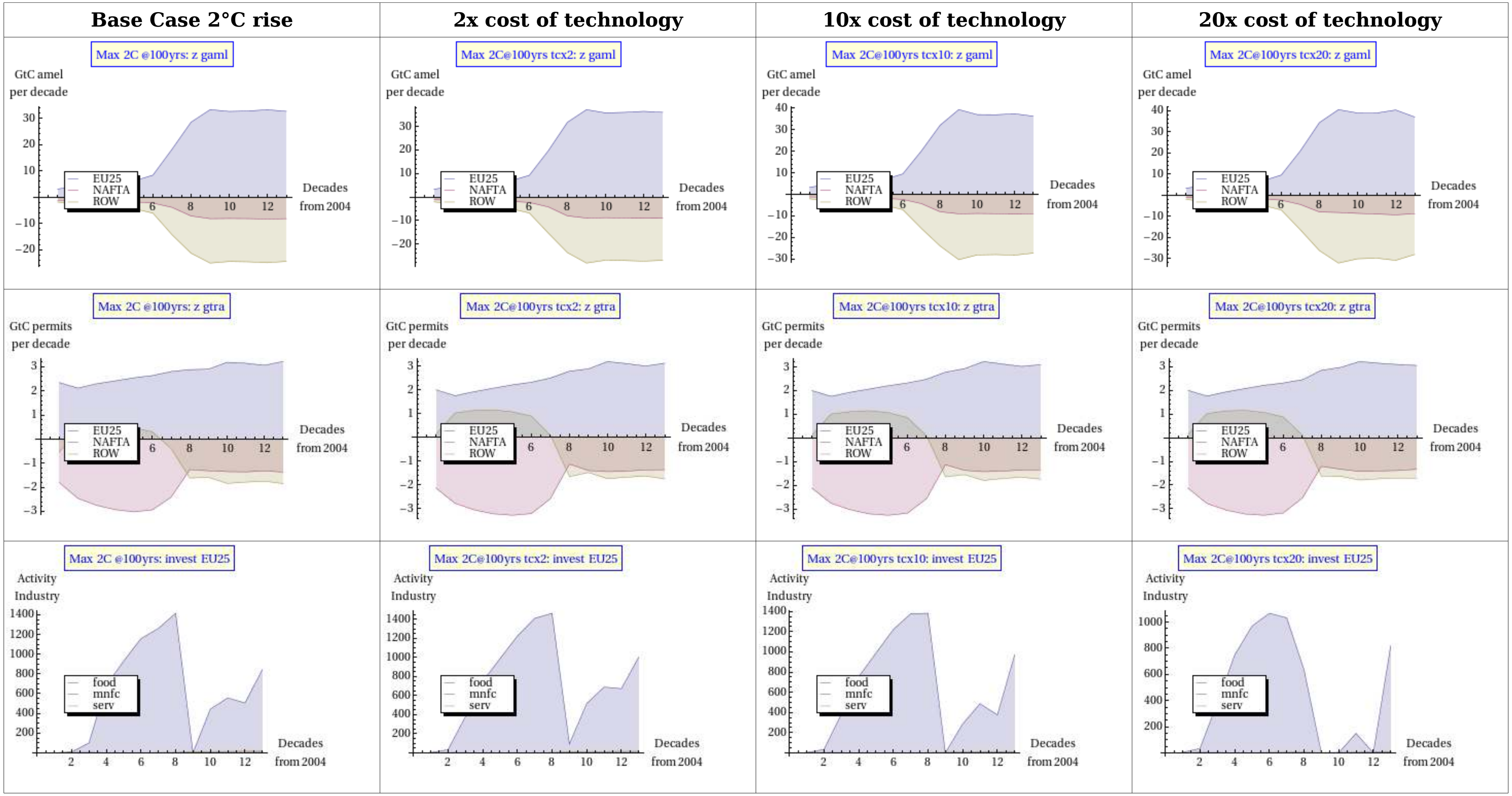




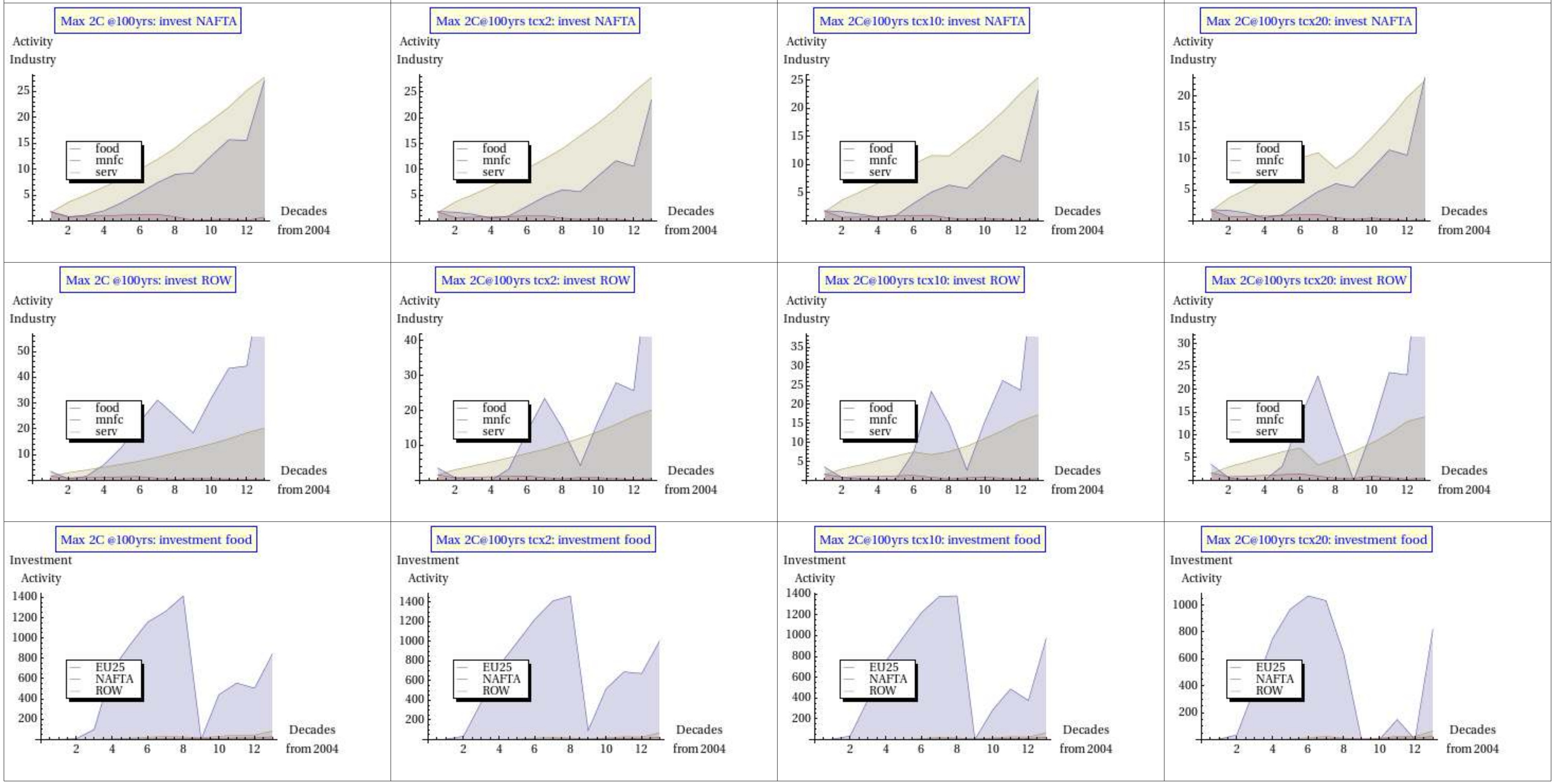
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology



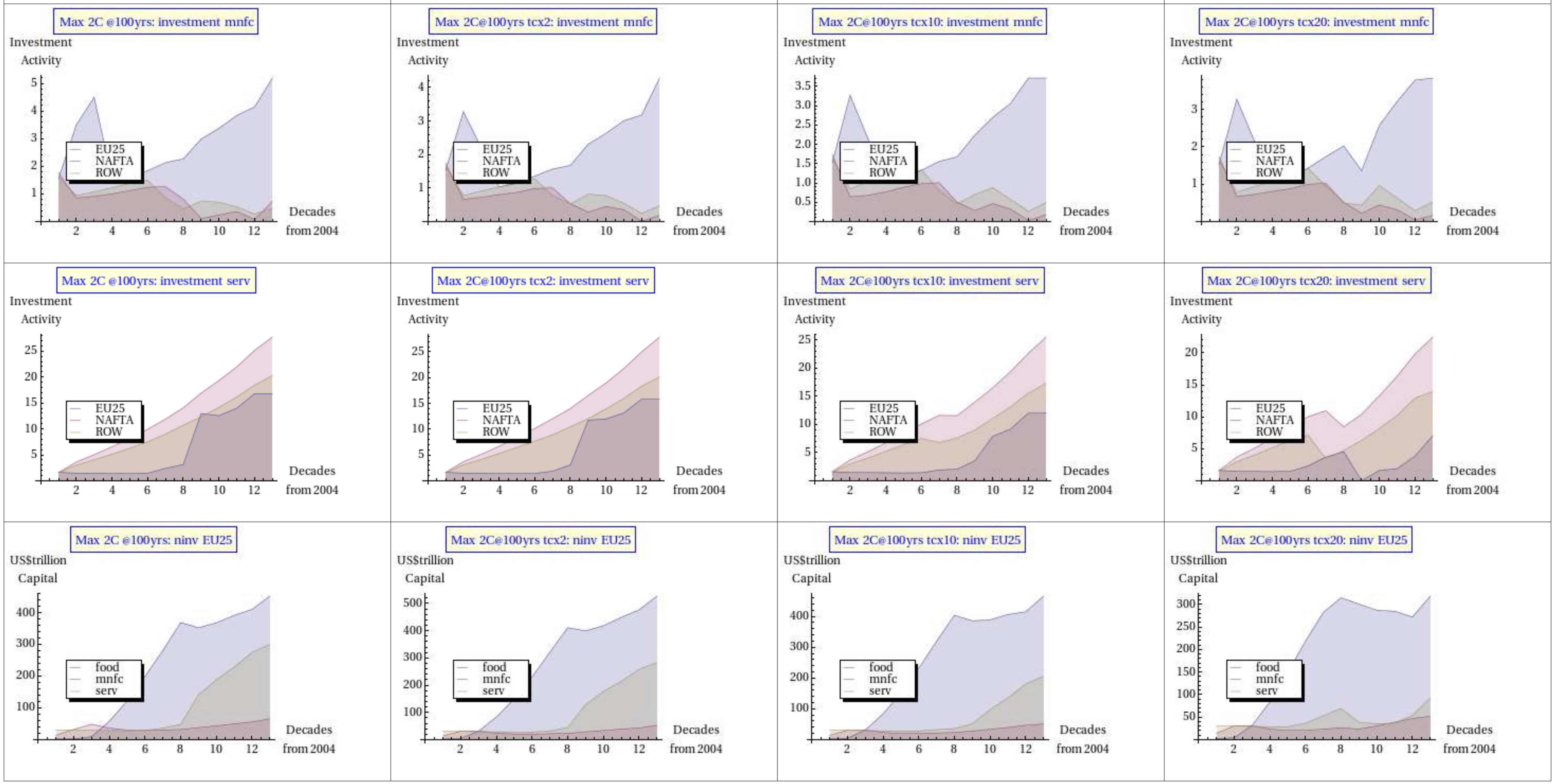

Base Case 2°C rise
2x cost of technology
10x cost of technology
20x cost of technology
Max 2C @100yrs: s ROW
Max 2C@100yrs tcx2: s ROW
Max 2C@100yrs tcx10: s ROW
Max 2C@100yrs tcx20: s ROW
Activity Industry
food
mnfc
serv
gaml
etra
Decades from 2004
Max 2C @100yrs: z food
Max 2C@100yrs tcx2: z food
Max 2C@100yrs tcx10: z food
Max 2C@100yrs tcx20: z food
US$billion per decade
EU25
NAFTA
ROW
Max 2C @100yrs: z mnfc
Max 2C@100yrs tcx2: z mnfc
Max 2C@100yrs tcx10: z mnfc
Max 2C@100yrs tcx20: z mnfc


Base Case 2°C rise
2x cost of technology
10x cost of technology
20x cost of technology
Max 2C @100yrs: z gaml
Max 2C@100yrs tcx2: z gaml
Max 2C@100yrs tcx10: z gaml
Max 2C@100yrs tcx20: z gaml
GtC amel
per decade
EU25
NAFTA
ROW
Decades
from 2004
Max 2C @100yrs: z gtra
Max 2C@100yrs tcx2: z gtra
Max 2C@100yrs tcx10: z gtra
Max 2C@100yrs tcx20: z gtra
GtC permits
per decade
Max 2C @100yrs: invest EU25
Max 2C@100yrs tcx2: invest EU25
Max 2C@100yrs tcx10: invest EU25
Max 2C@100yrs tcx20: invest EU25
Activity
Industry
food
mnfc
serv

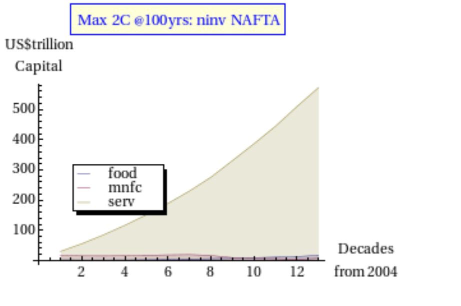
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

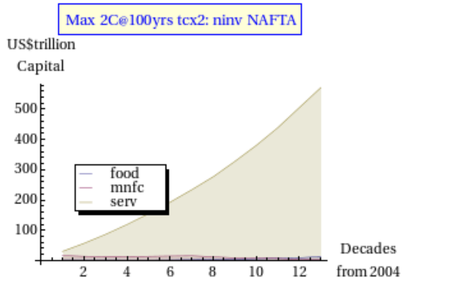


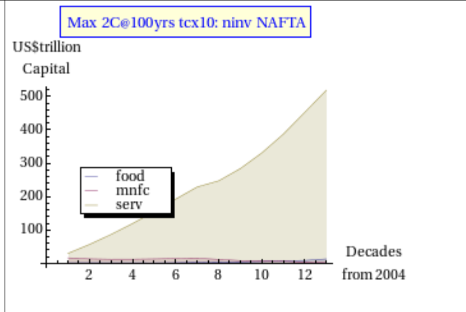
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

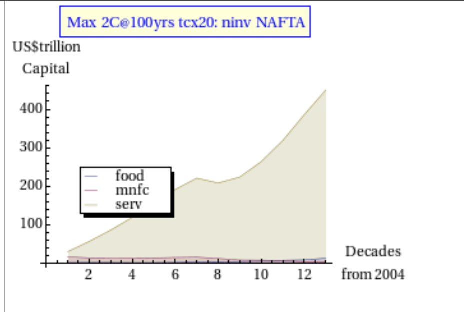


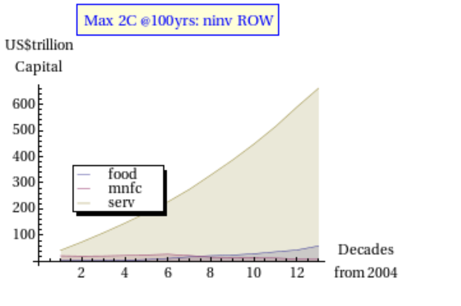
Base Case 2°C rise	2x cost of technology	10x cost of technology	20x cost of technology

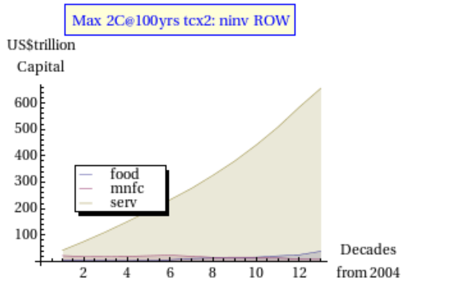


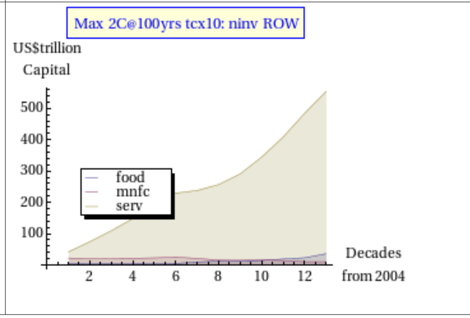


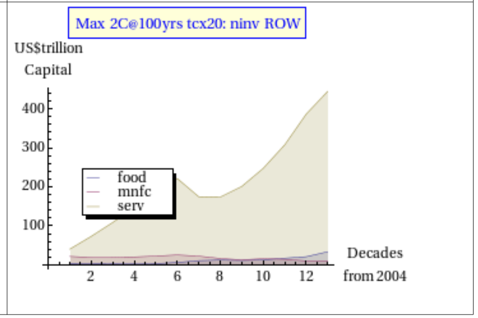












6.1.5 Effect of climate damage on Sales to Assets ratios

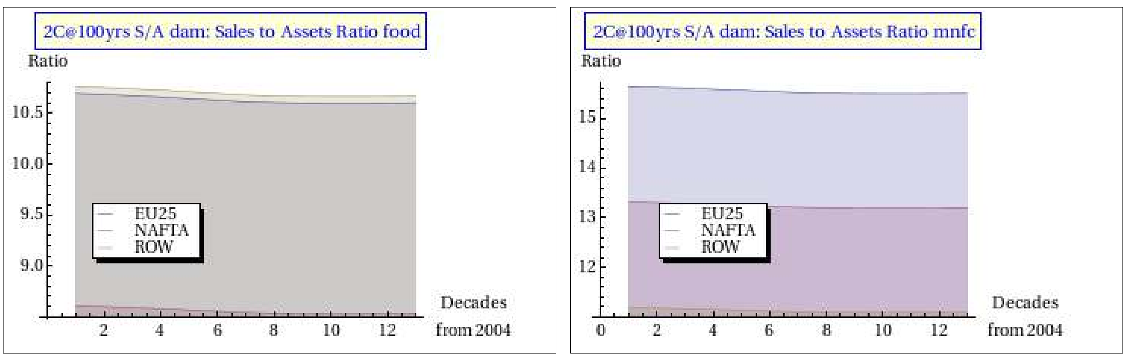
Sceptre has been run with the climate damage function impairing both industrial output and Sales to Asset ratios. This provides a new perspective on climate-economic analysis.

It is reasonable to expect that additional assets are required in each industry as economic-climate damage occurs. This is in addition to the effect of the damage function on production. The first is to “proof” the industry against higher levels of climate stress and the second is dealing with extra risk or volatility associated with climate. More assets for the same amount of sales means that the Sales to Assets ratio decreases. A decrease in the Sales/Assets will divert more resources to accumulated capital.

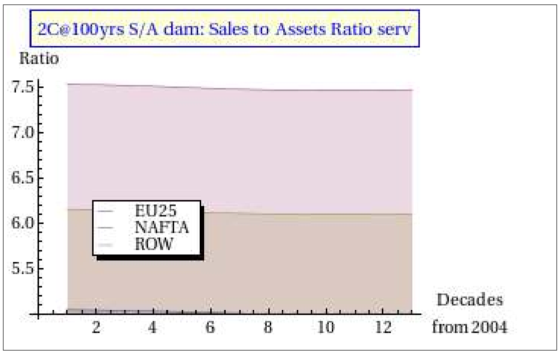
A Sales to Assets ratio for the single year of 2004, which is the base year of GTAP data, is calculated by dividing the V matrix by the opening assets for the 2004 year. The Sales for decade is calculated from the single year figure by applying a multiplier comprising the sum of the population index.

Impaired Sales to Assets ratios are shown in the following illustrations for each commodity of food, manufacturing and services.

Sales to Asset Ratio impairment[xv]



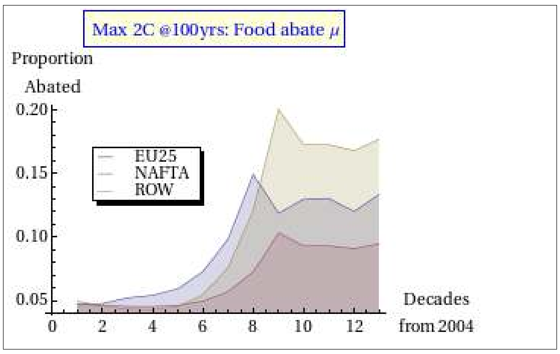
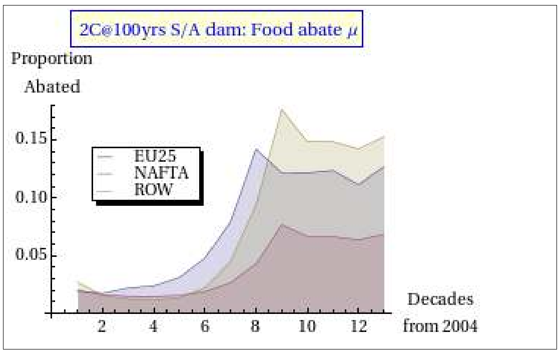
Sales to Asset Ratio impairment

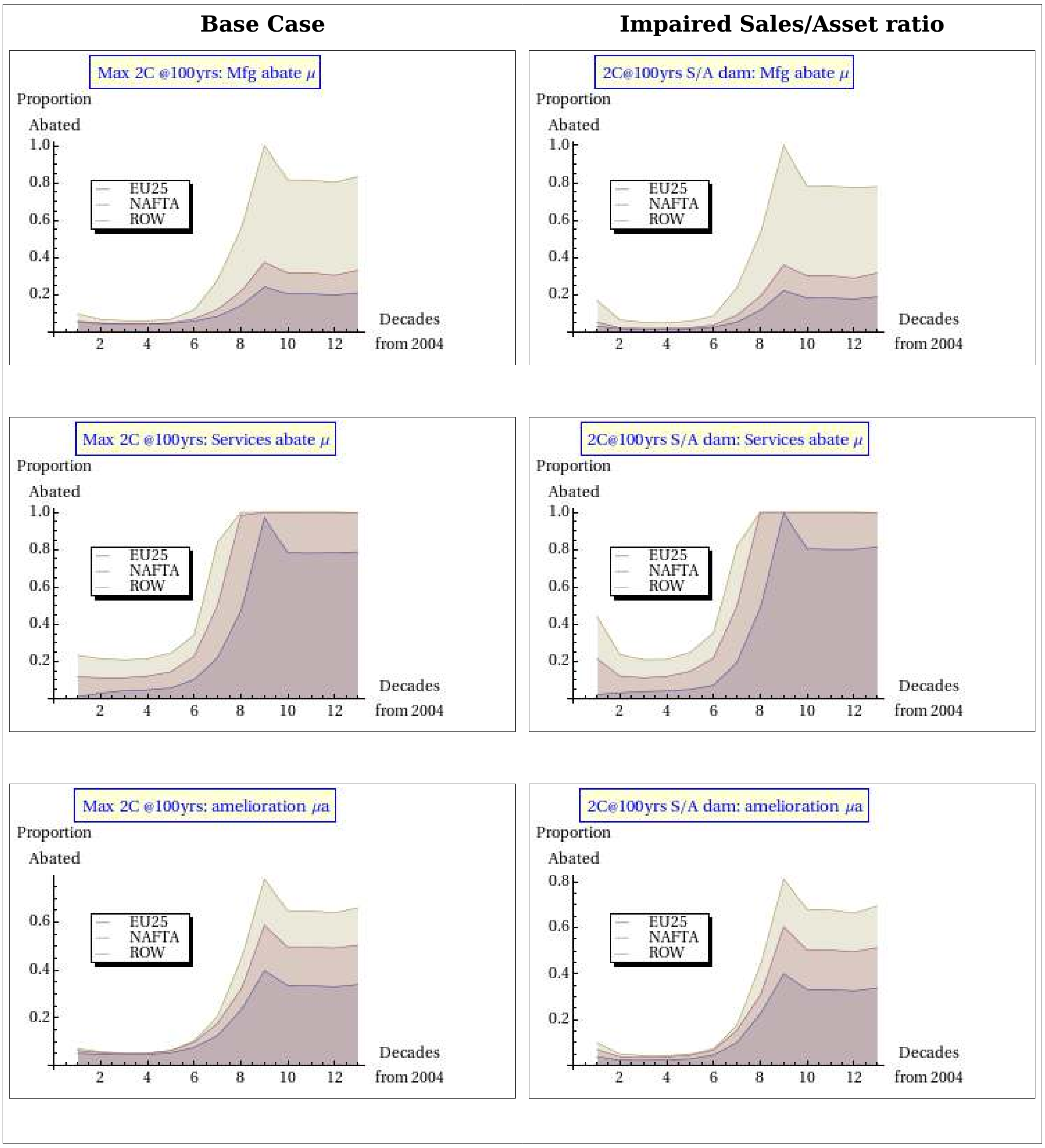


Results and analysis

Impairing the Sales/Assets ratio reduces the value of the objective function by about US$180 billion (2004 dollars) (*cf.* Previous Base Case analysis for method of calculation). As might be expected, the small changes to Sales/Assets ratio result in only minor changes to disaggregated results (see next section of this Chapter).

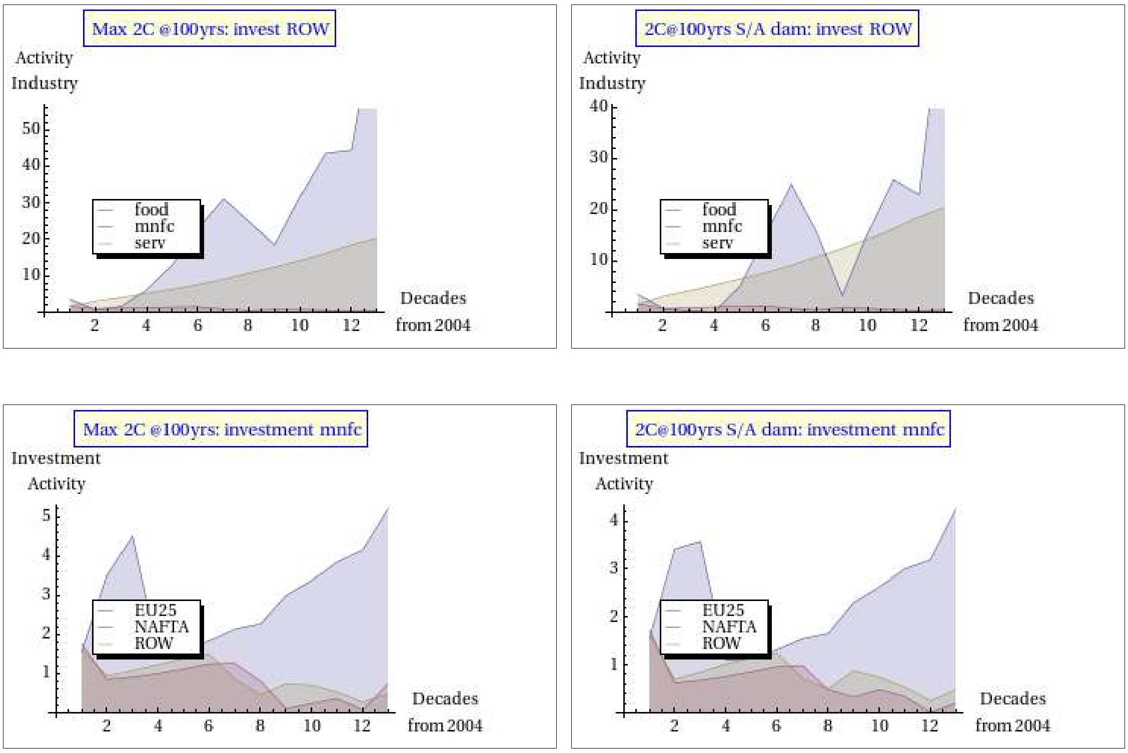
It is notable that the emissions control rate for consumption increases, while that for food and manufacturing decreases slightly. The control requirement for services remains at the maximum. Although the increased responsibility of consumers to ameliorate and abate is only an indicative trend, it demonstrates that as industry needs increased assets to produce the same output then consumers start to bear a greater burden to directly control their emissions.

Base Case	Impaired Sales/Asset ratio
	



EU and NAFTA decrease investment in manufacturing while ROW decreases investment in food production.

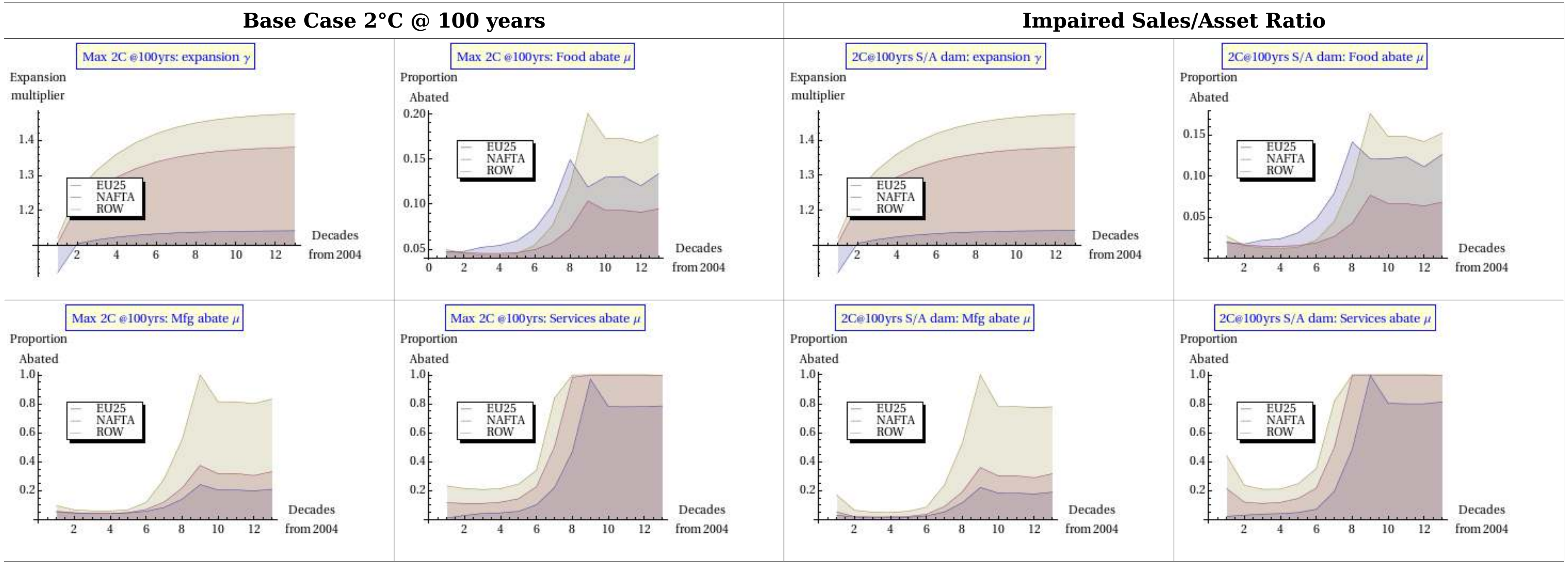
Base Case	Impaired Sales/Asset ratio
disaggregated investment by region	disaggregated investment by region



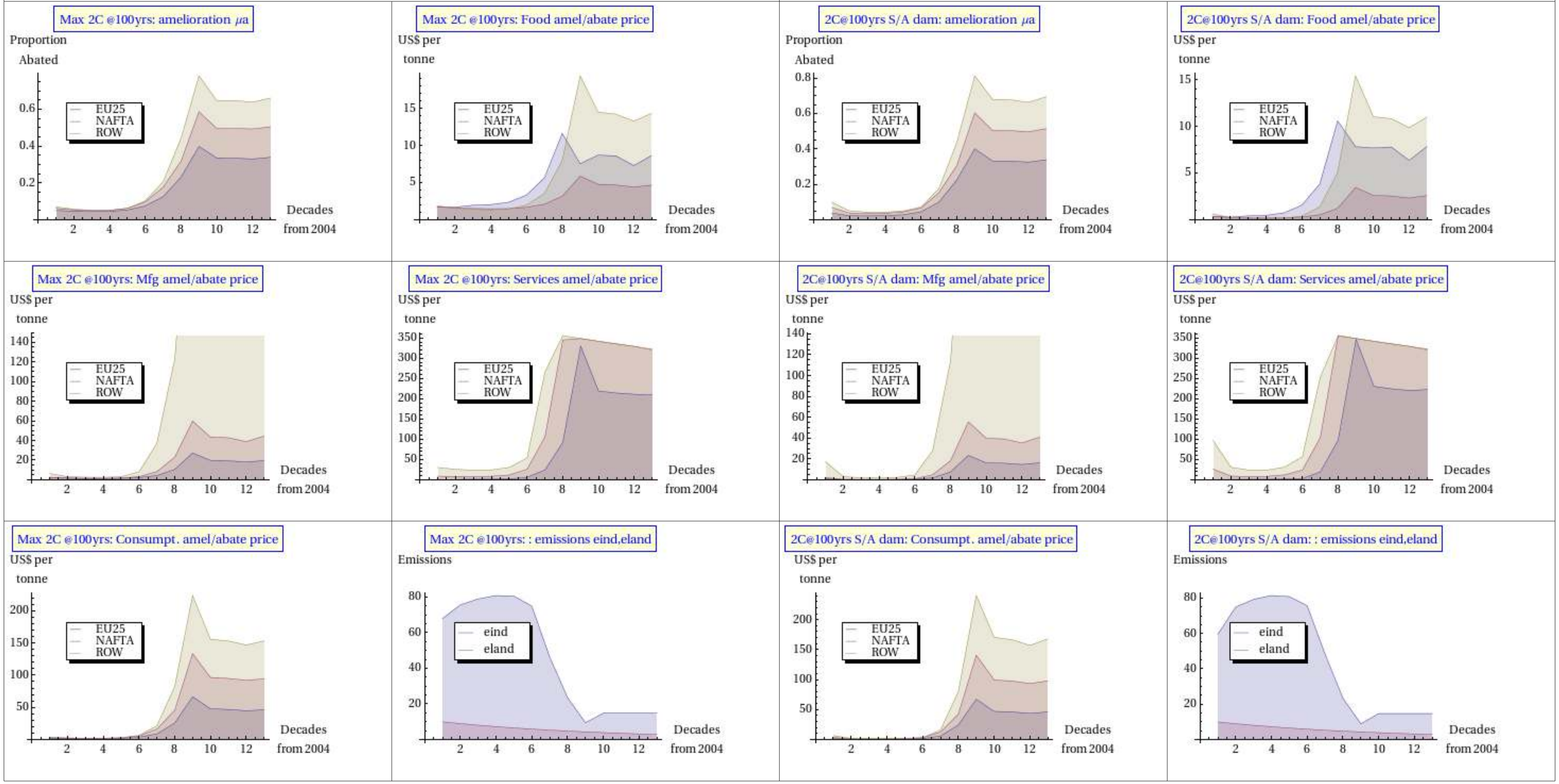
Other sector activities vary in small ways that would be meaningful to investigate for particular regional performance. Fully disaggregated results are provided in the next section of this Chapter.

xv m12_13p_2C_100_s2a.nb

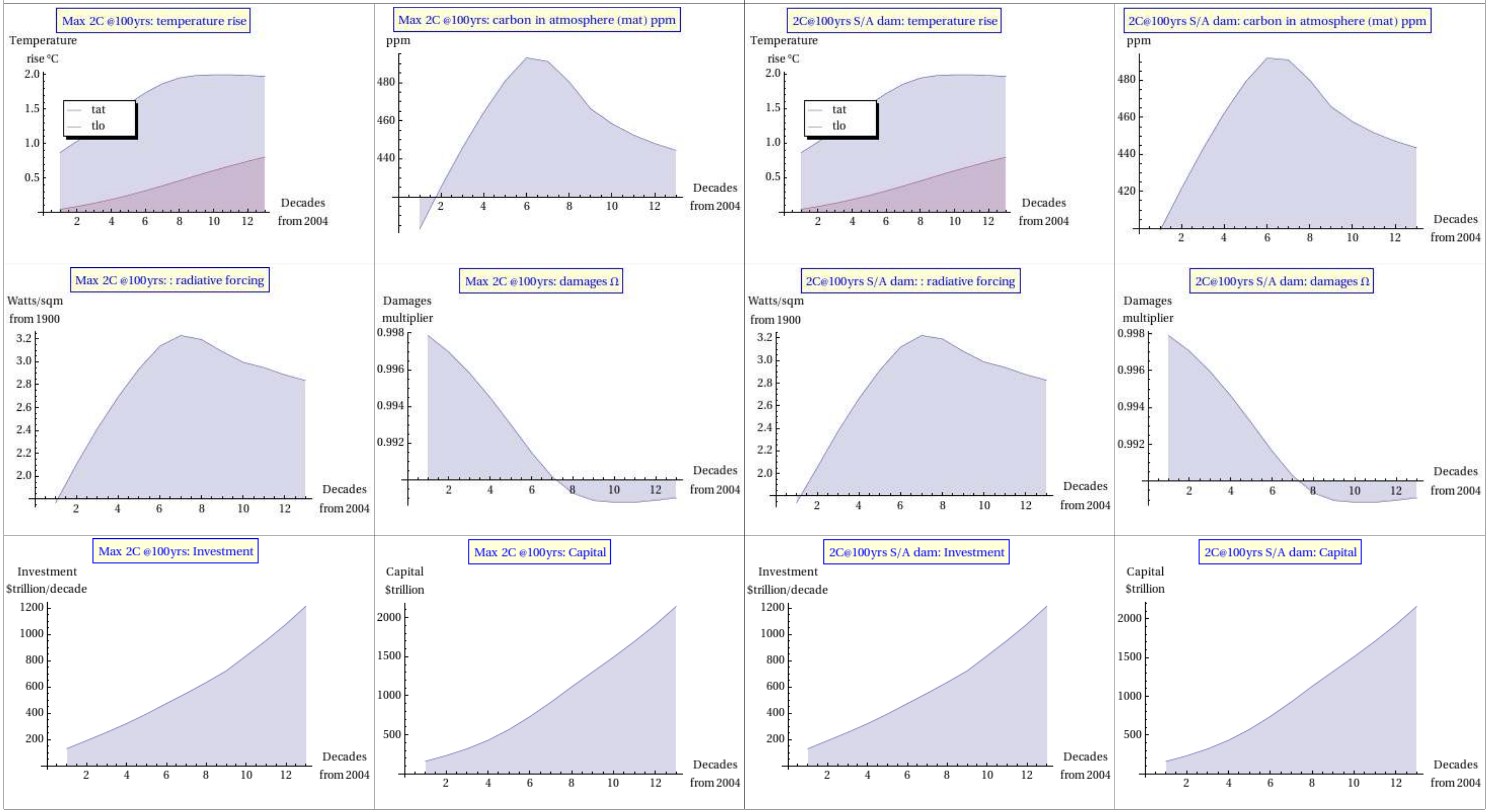
Sensitivity with impaired Sales/Asset ratios



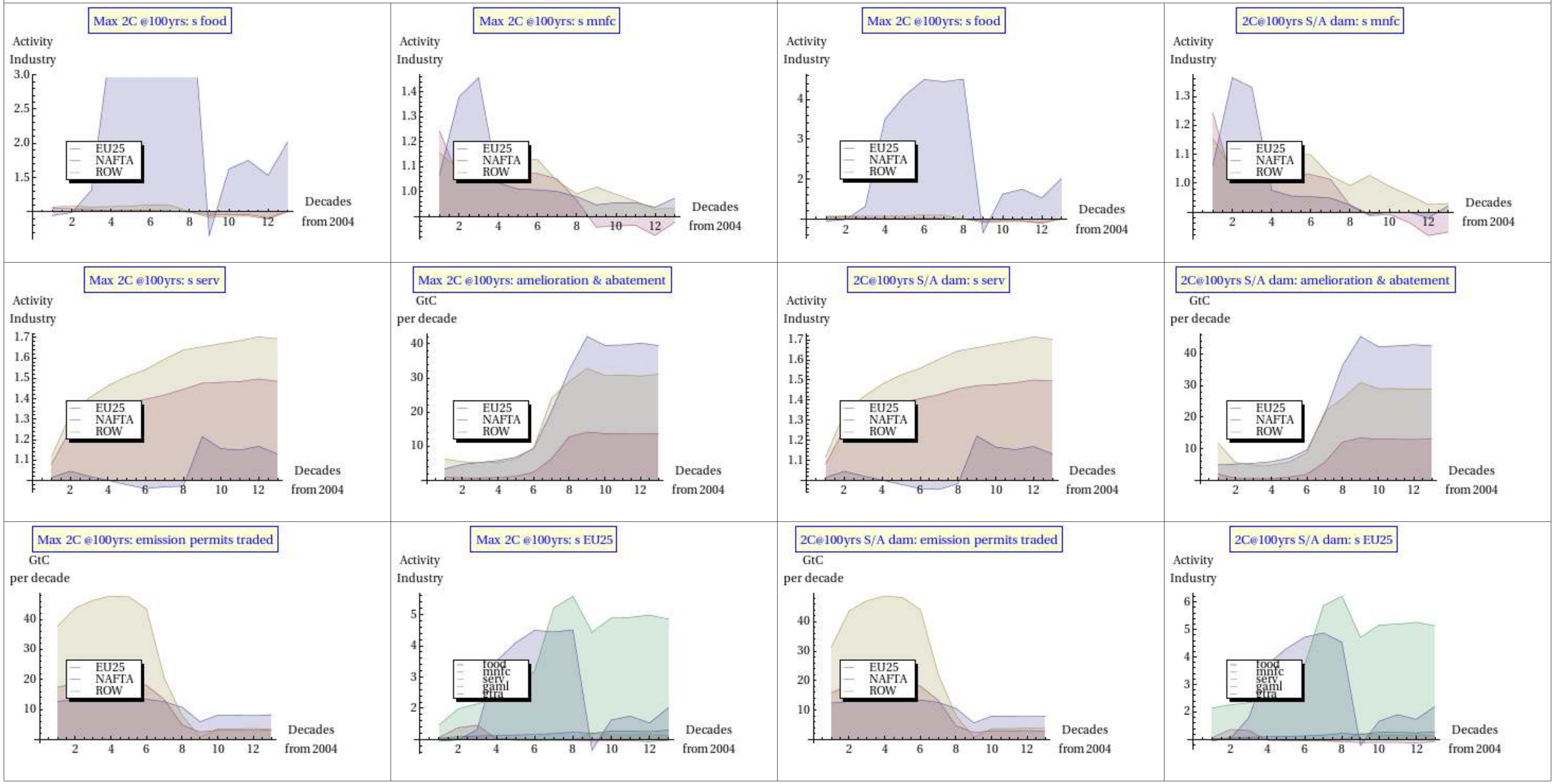
Base Case 2°C @ 100 years	Impaired Sales/Asset Ratio



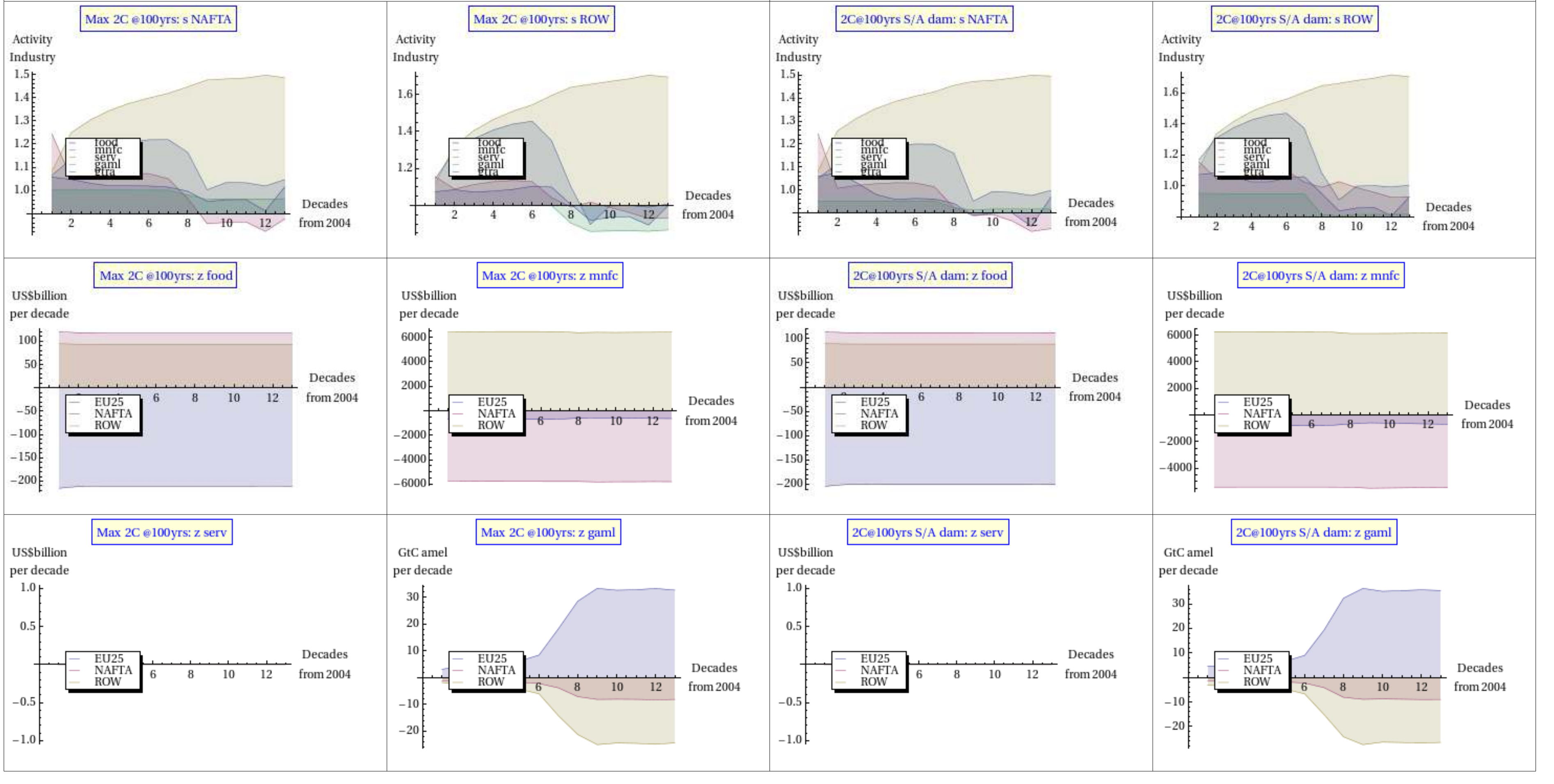
Base Case 2°C @ 100 years	Impaired Sales/Asset Ratio



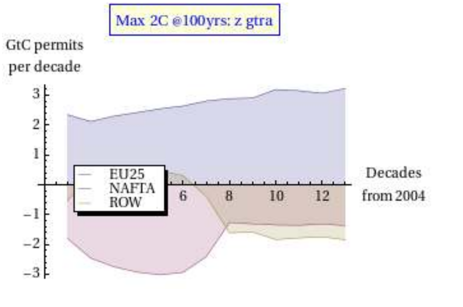
Base Case 2°C @ 100 years	Impaired Sales/Asset Ratio

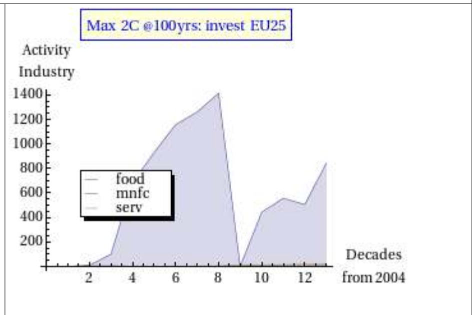


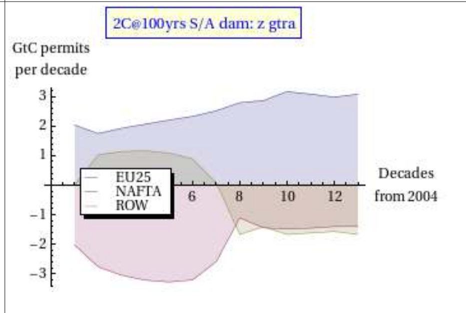
Base Case 2°C @ 100 years	Impaired Sales/Asset Ratio

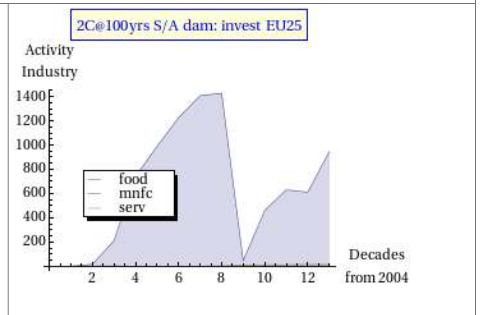


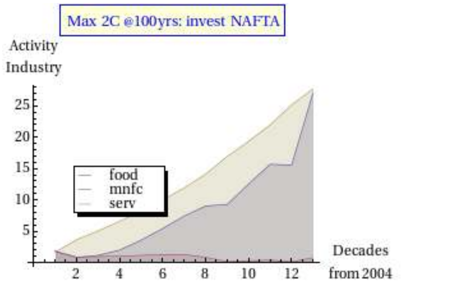
Base Case 2°C @ 100 years	Impaired Sales/Asset Ratio

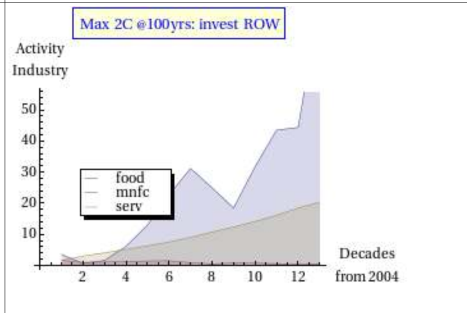


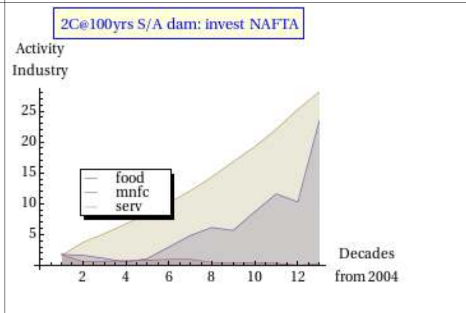


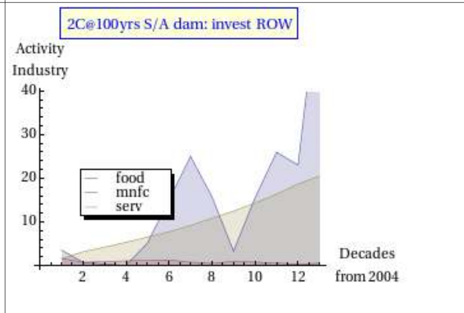


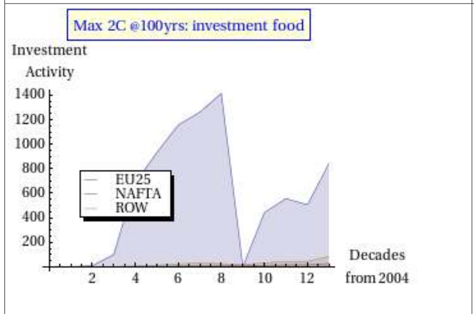


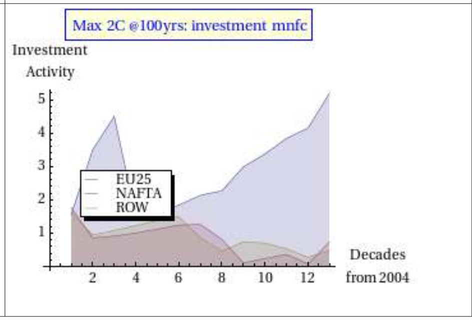


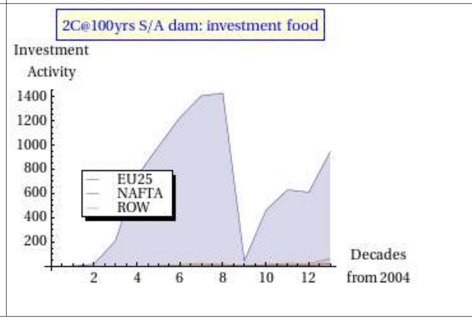


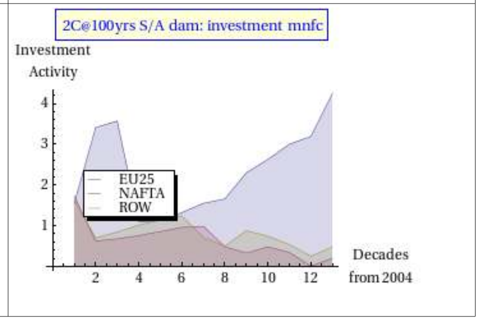




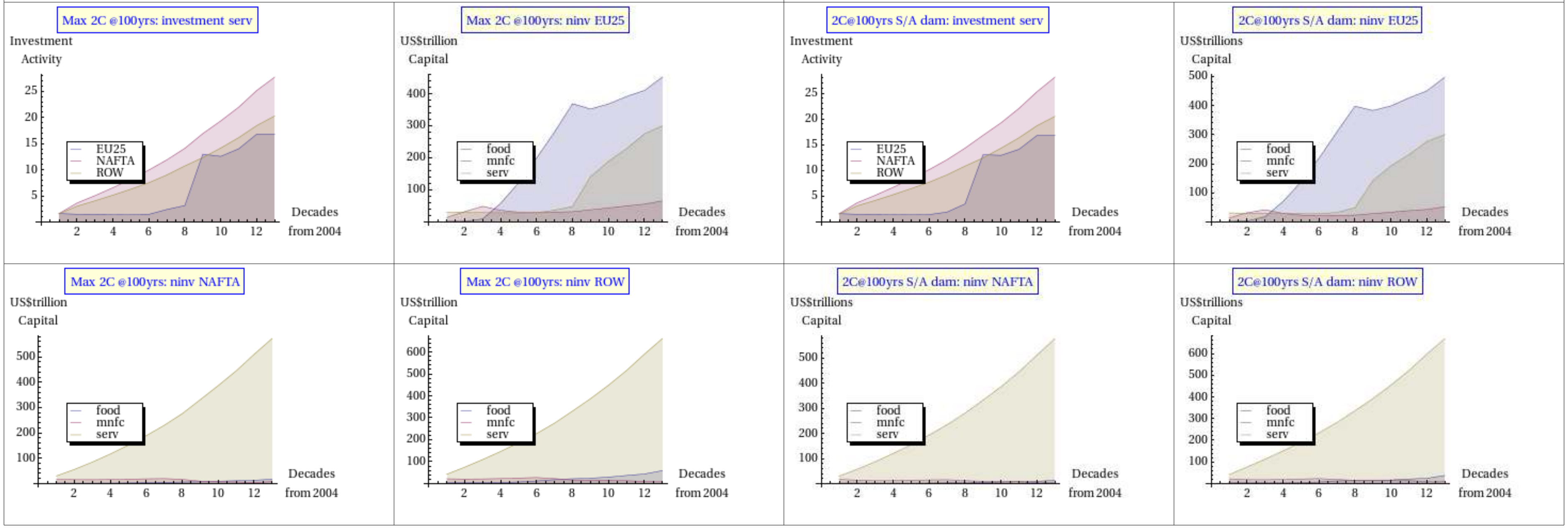








Base Case 2°C @ 100 years	Impaired Sales/Asset Ratio



6.1.6 Effect of carbon commodity trading

In all previous sensitivities, unrestricted international trading in carbon commodities is assumed. This sensitivity case removes the international arbitrage of emission permits and amelioration and abatement services. It is included for the case where international trade in these commodities is limited or absent.

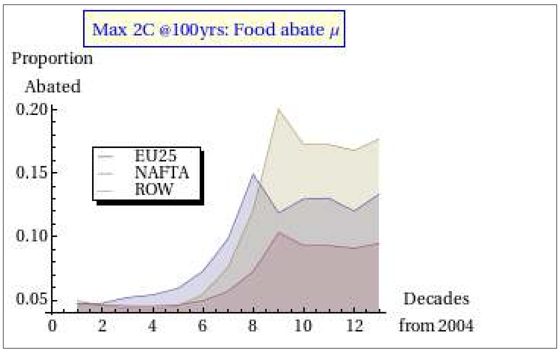
Limited trading of emission permits and amelioration and abatement services is a real scenario. For example, Australia's proposed policy is that no more than 5% of emissions permits may be imported so it would be useful to model Australia's performance with limited trading of permits.

Results and analysis

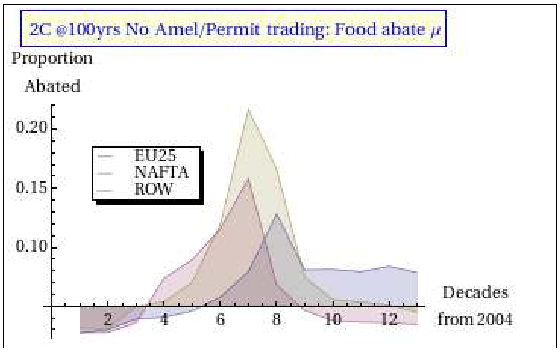
The overall net benefit of international trade in carbon commodities does not appear to be very large. Indeed, there is a negligible US$2 billion (2004 dollars) gain in the objective function if trade is prevented (*cf.* Base Case analysis for method of calculation).

The geophysics of the environment is adequately managed so emissions and temperature rise are unchanged from the Base Case. However, the effects of zero trade in carbon commodities are insightful. The control of emissions from food and manufacturing declines for all regions; services are unaffected; and the demand for consumers to control emissions increases.

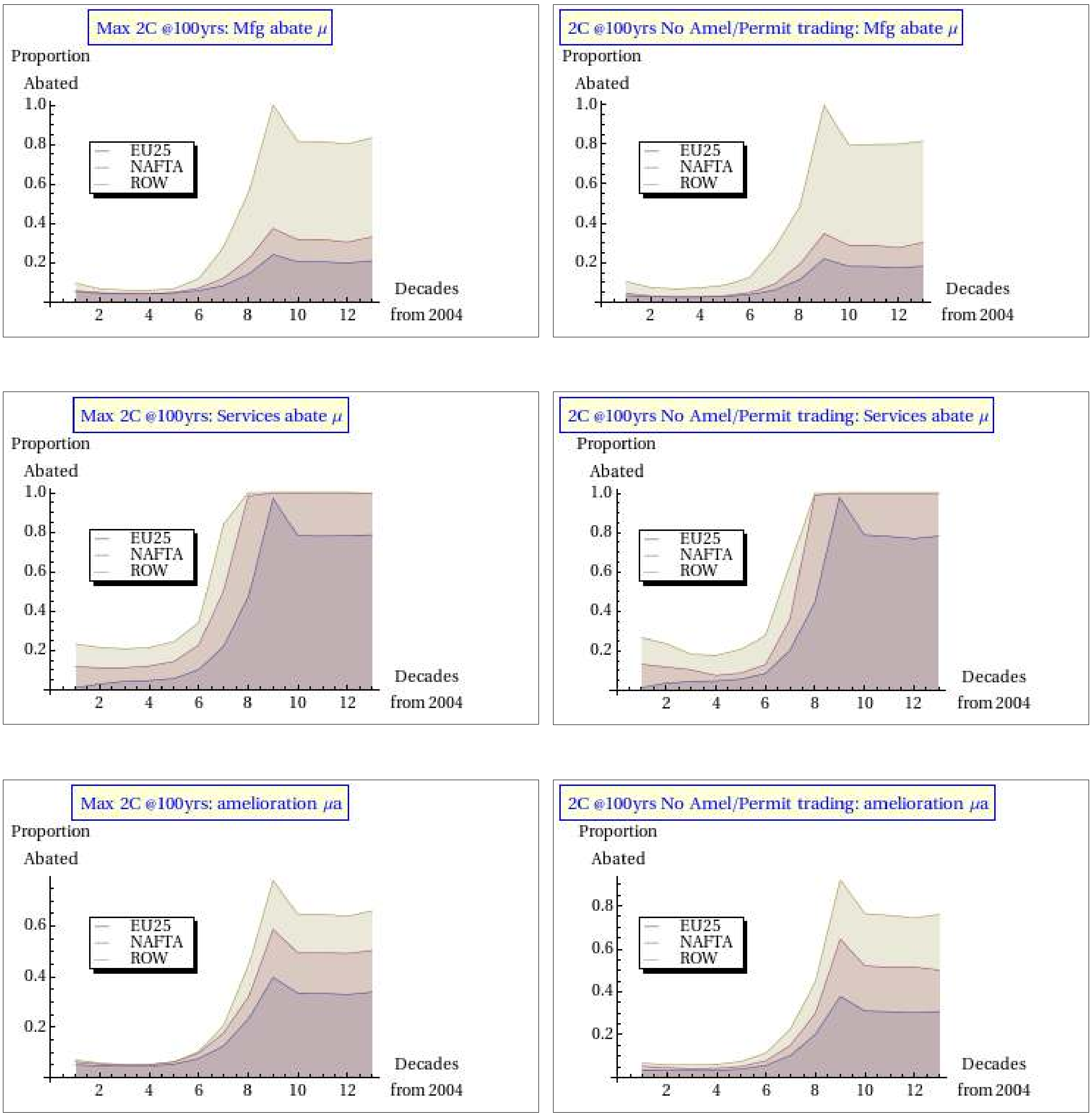
Base Case emissions control rate



No carbon commodity trading emissions control rate

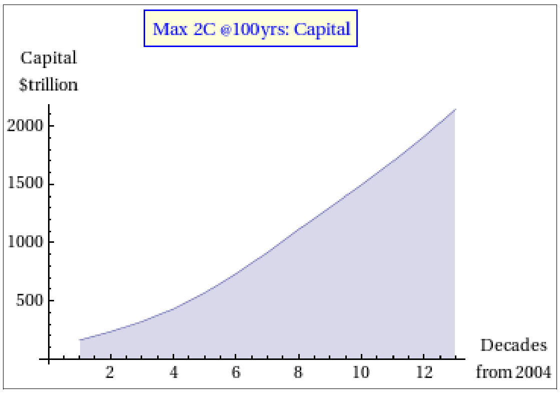


Base Case emissions control rate	No carbon commodity trading emissions control rate

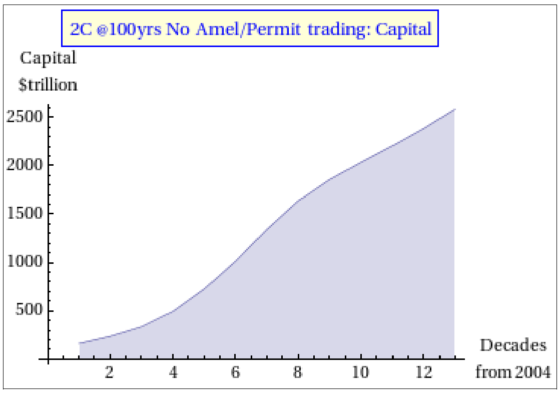


However, global capital increases significantly. At decade 10, Base Case global capital accumulation of US$1,500 trillion (2004 dollars) rises to US$2,000 trillion in the case of no international carbon commodity trading.

Base Case capital accumulation

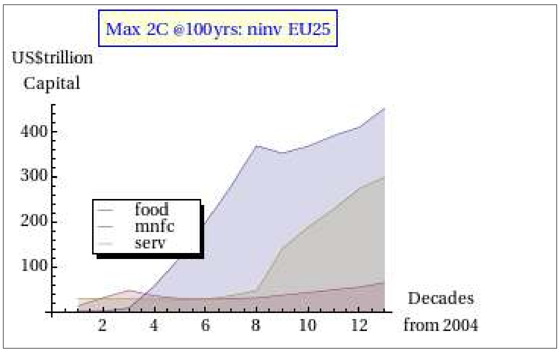


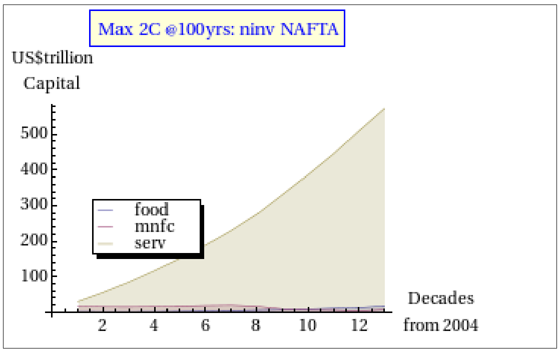
No carbon commodity trading capital accumulation



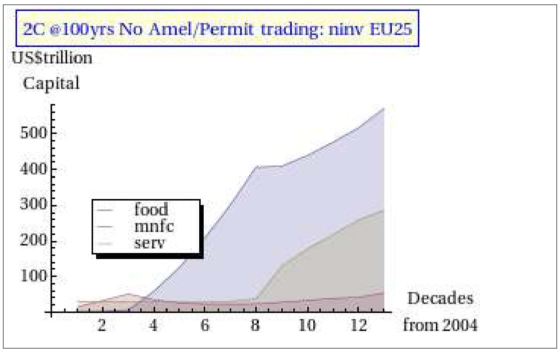
This is reflected in increased accumulated capital profiles at a disaggregated level as shown in the following table.

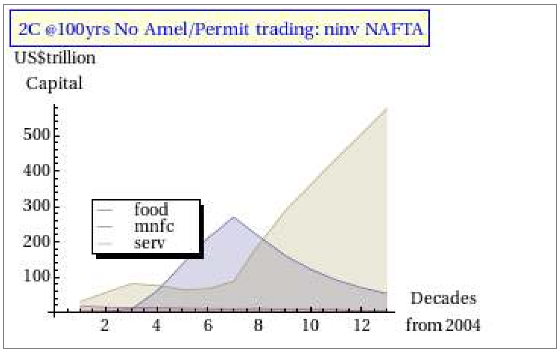
Base Case disaggregated capital accumulation



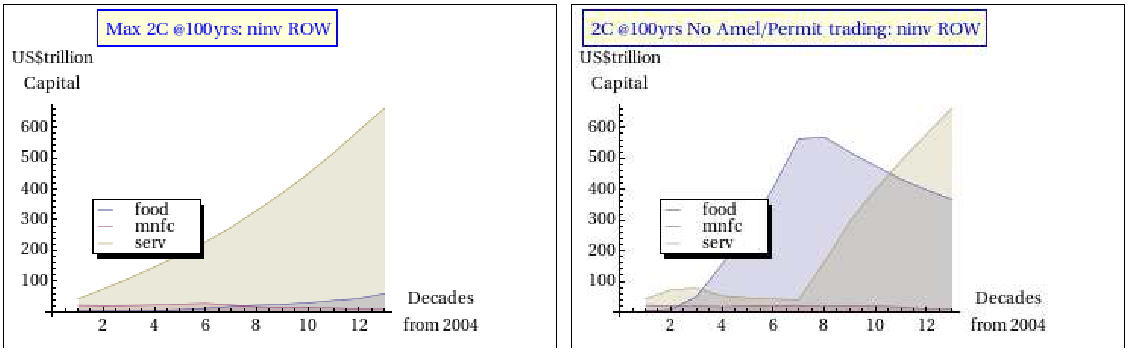


No carbon commodity trading disaggregated capital accumulation



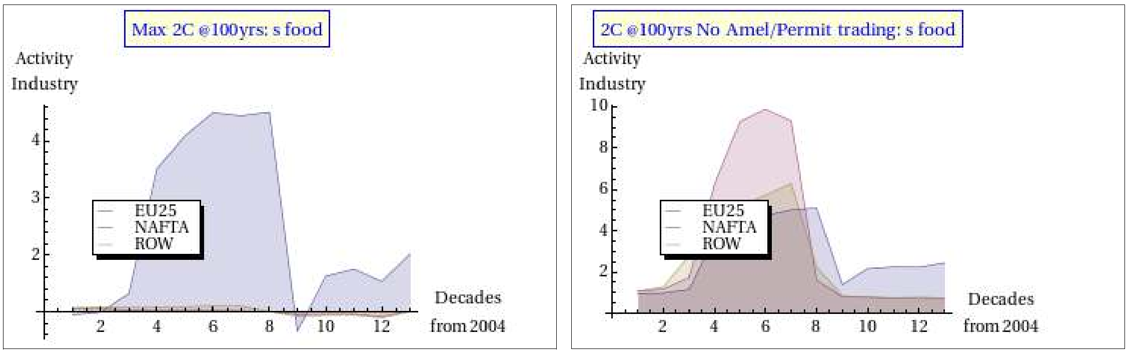


Base Case disaggregated capital accumulation | **No carbon commodity trading disaggregated capital accumulation**



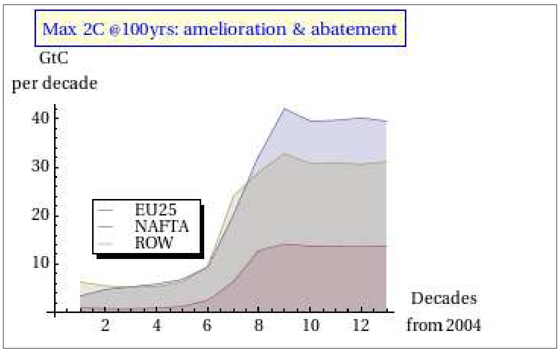
NAFTA and ROW lift their food production significantly and the EU25 resource expansive food production is less pervasive. From this it may be noted that EU25 expansive food production is actually a function of trading carbon commodities.

Base Case food industry activity level | **No carbon commodity trading food industry activity level**

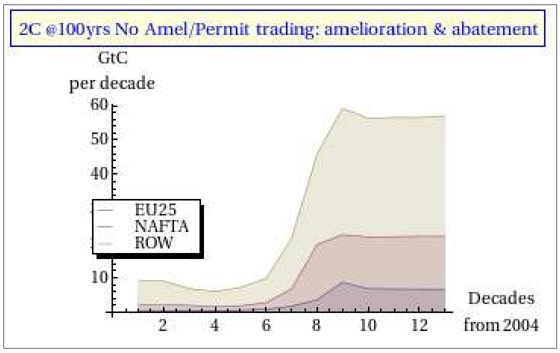


Perhaps the most important effect of all is that zero international carbon commodity trading means that the amelioration and abatement task of ROW rises to almost 60 GtC per decade, which is nearly three times that of NAFTA and five times that of EU25.

Base Case
amelioration and abatement



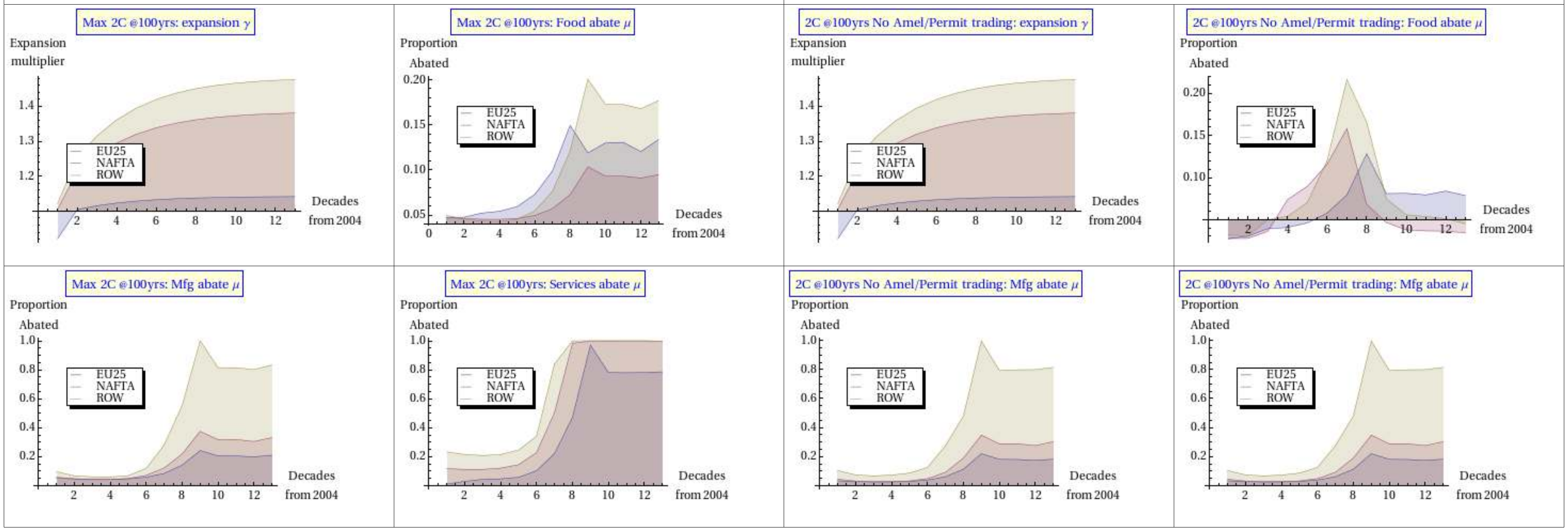
No carbon commodity trading
amelioration and abatement



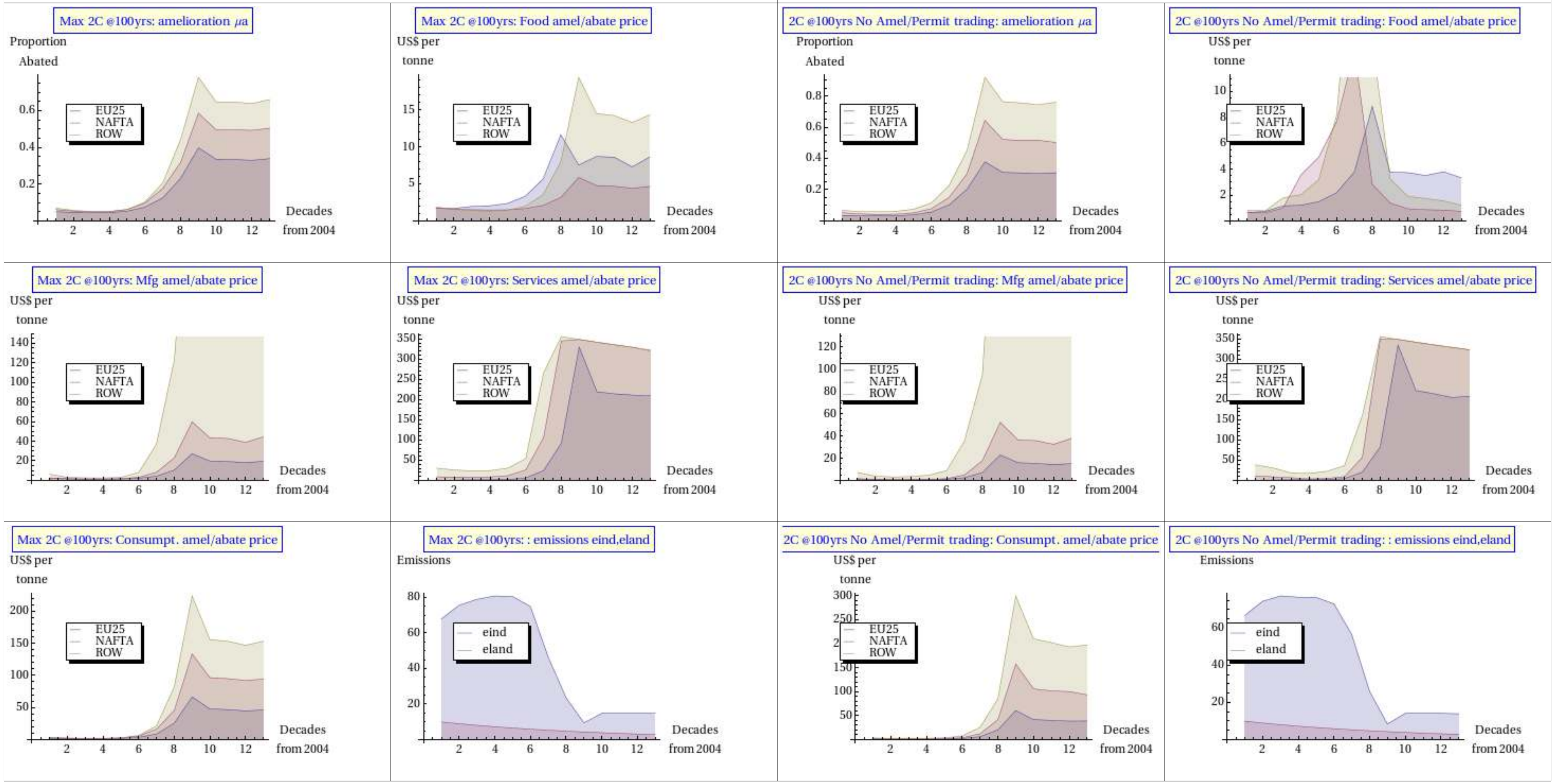
This analysis demonstrates the importance of regional aggregations at the country level. It provides insight in to why the presence of emissions management in each country returns the focus of economic policy to regions.

Sensitivity for no international trading in carbon commodities

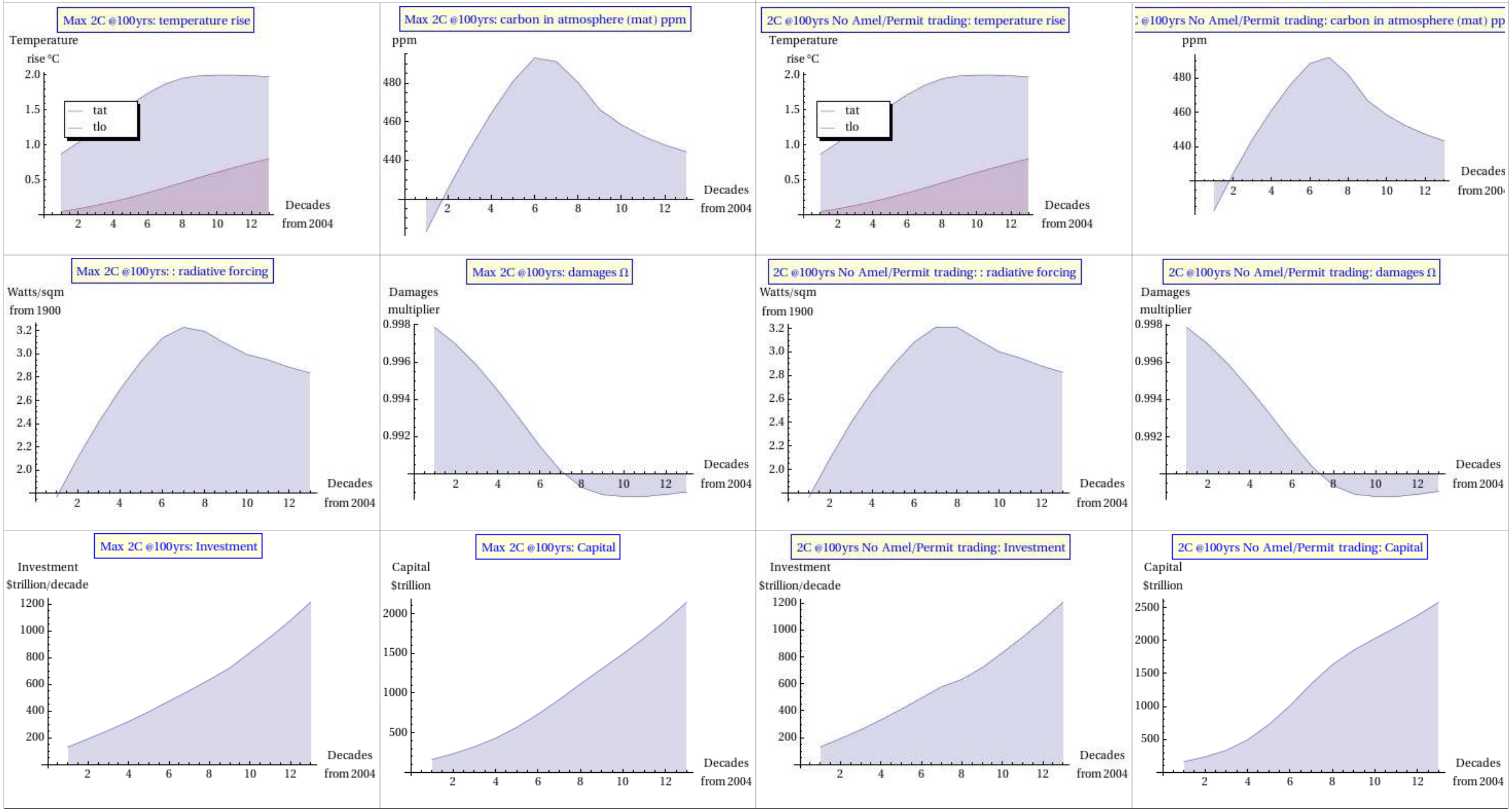
Base Case 2°C rise	No international trading of carbon commodities



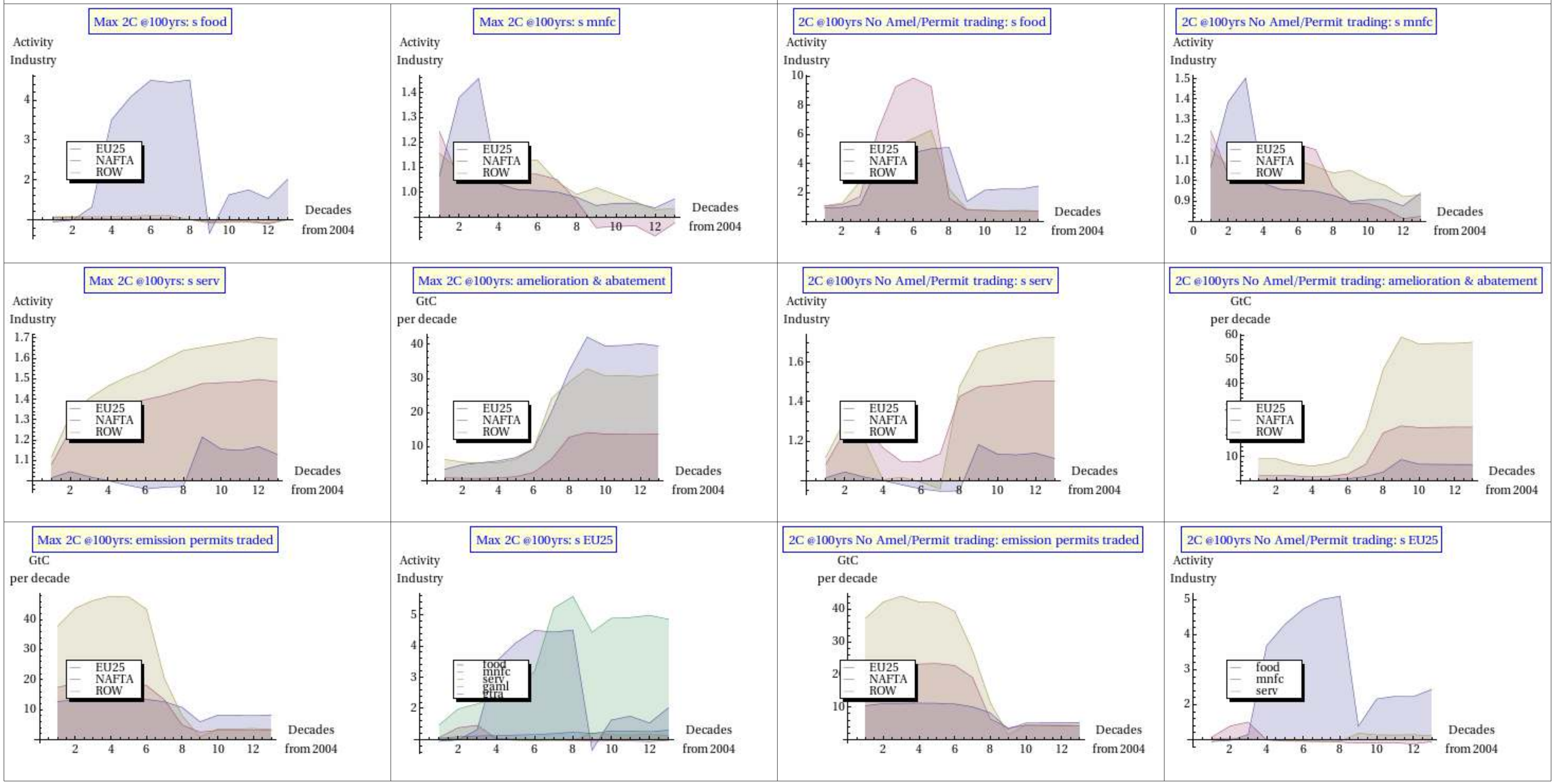
Base Case 2°C rise	No international trading of carbon commodities



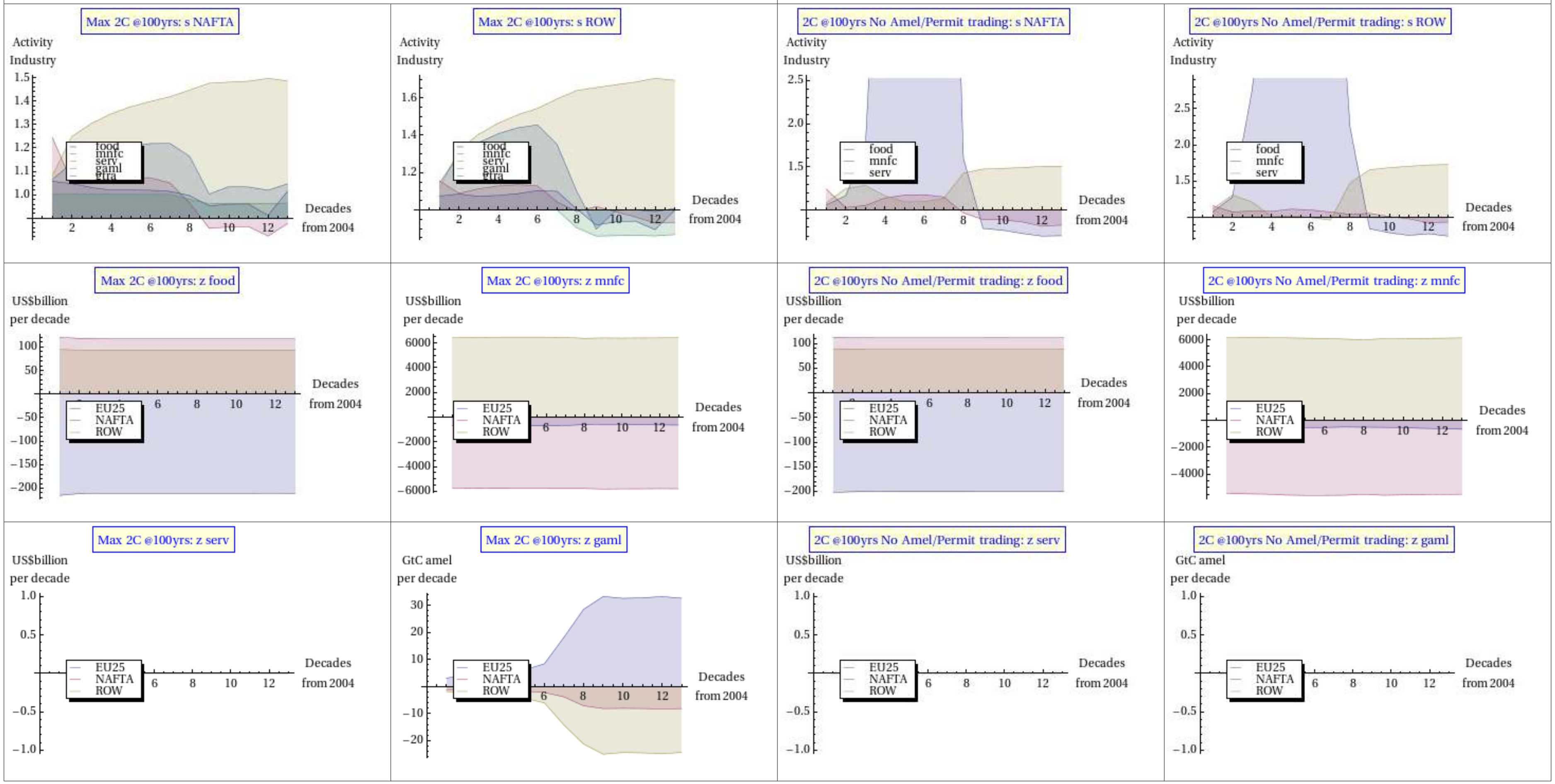
Base Case 2°C rise	No international trading of carbon commodities



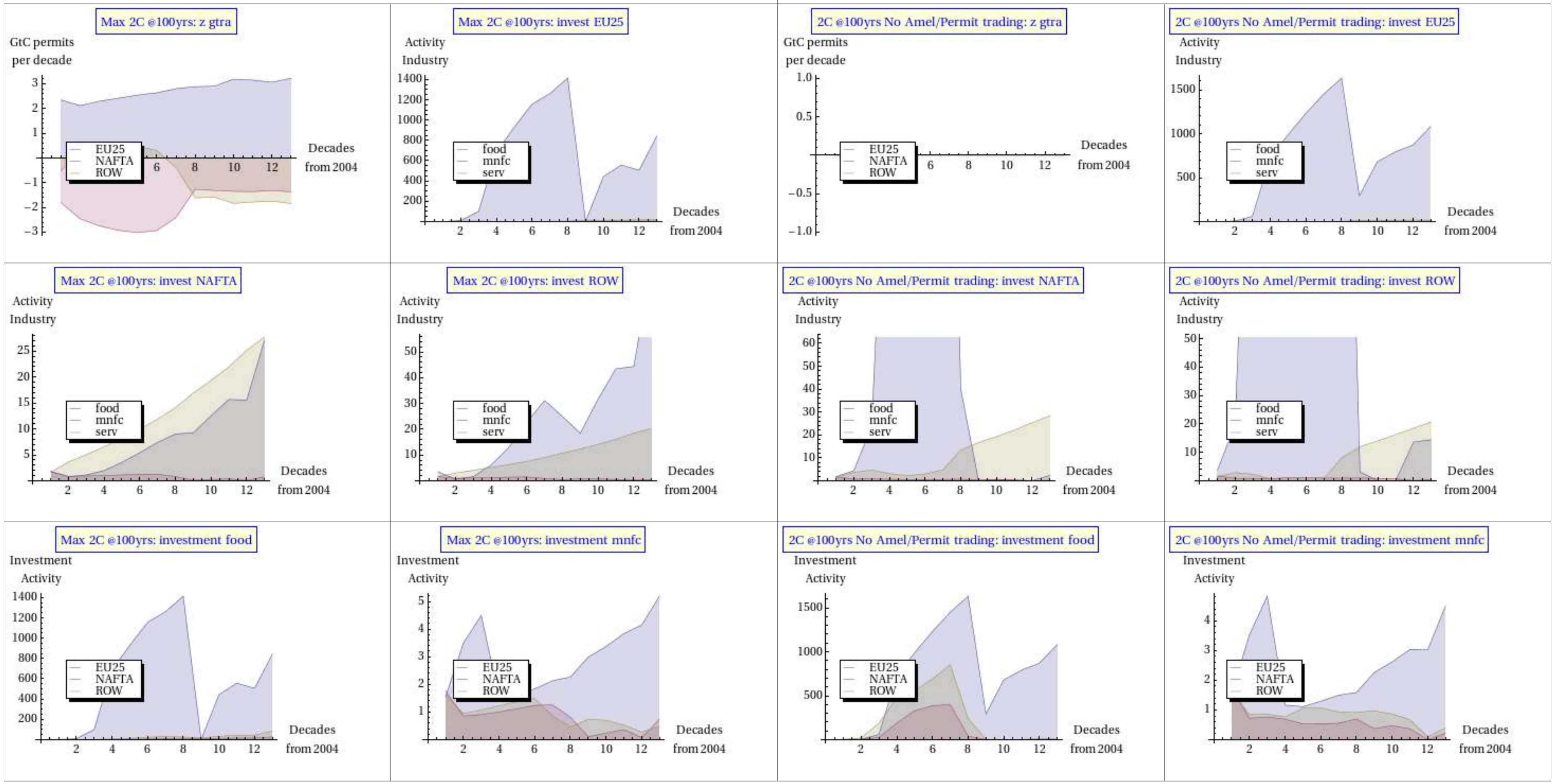
Base Case 2°C rise	**No international trading of carbon commodities**



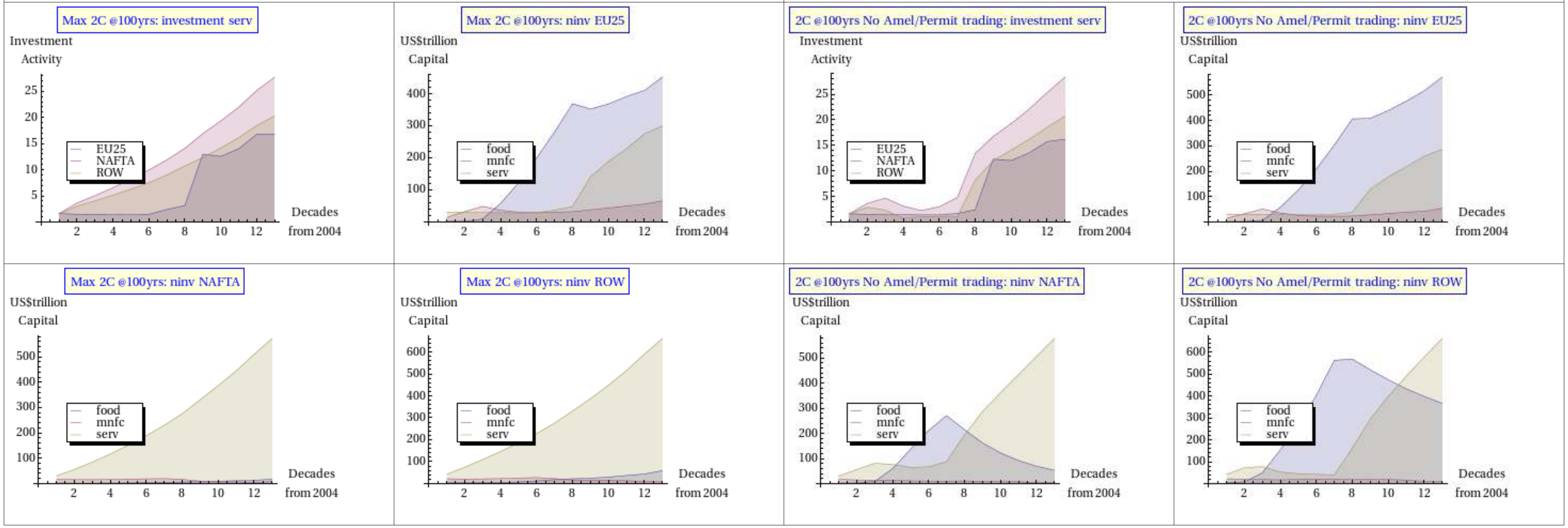
Base Case 2°C rise	No international trading of carbon commodities



Base Case 2°C rise	No international trading of carbon commodities



Base Case 2°C rise	No international trading of carbon commodities



6.2 Conclusion

Based on the results of the political economy analysis, a new benchmarking type of CGE model has been developed and used to investigate a climate-economic Base Case and discriminate five categories of sensitivities as shown in the following table.

Climate Policy Sensitivity Analysis				
Point of View	**Climate Constraint Severity**	**Backstop Technology Cost**	**Sales to Asset Ratio Impairment**	**No Bilateral Carbon Commodity Trading**
Sceptic	350 ppm	Base Case	Base Case	Base Case
Laissez faire	Base Case	2x	Impaired S/A	No Trading
Base Case	450 ppm	10x		
Radical	550 ppm	20x		

The Base Case shows that the IPCC, European Union, Major Economies Forum and G20 policy of limiting temperature rise from pre-industrial times to a maximum of 2°C is feasible.

The Point of View sensitivity demonstrates that the Base Case costs little more than the Sceptic and *Laissez-faire* scenarios, so controlling emissions for the safety of the globe does not incur a prohibitive cost. Indeed, the Radical ultra-risk averse policy option of controlling emissions to 350 ppm has a relatively small net present value premium over the Base Case of US$3.8 trillion. On this basis governments may be advised to reconsider the Radical perspective of strongly limiting emissions through a mix of quantitative regulation, taxes and property rights.

The climate constraint sensitivity shows that the three sensitivity scenarios of 350, 450 and 550 ppm do not have a significant cost over the Base Case. The 450 ppm case and the Base Case are similar, as the IPCC found, although the earlier control of emissions in the 450 ppm case results in a lesser temperature rise of 1.7°C for 450 ppm at decade 10 compared to 2°C for the Base Case.

Increasing the cost of backstop technology ultimately leads to a fracturing of economic performance. While this commences at 20 times current estimates of the backstop technology cost, it is important to note that current cost and availability estimates remain highly speculative. In addition, as has been the case with HIV pharmaceuticals, there may be a disproportionately large risk for countries that do not hold intellectual property rights. The political economy analysis showed that this has led to a situation of considerable anxiety for China, India and other newly developed and developing countries. It has been a key reason that these countries have declined to engage in binding emissions reduction targets. In order to minimise the significant technology risk shown by this sensitivity analysis, governments would be advised to implement strong quantitative limits in concert with robust market price signals. These measures will minimise the market risk from technology development business plans and catalyse immediate technology development. It is unlikely that continuing the current policy of research subsidies for far away technologies like carbon capture and storage can adequately address the technology cost and availability risk.

This model is the first of its type known to use Sales/Assets ratios (instead of resource limits) to mediate capital accumulation in the underlying economic model and price resources. The impairment of Sales to Asset ratios has a subtle influence on the Base Case. As industry struggles with needing more assets for the same output, consumers are also exposed to a greater burden for directly ameliorating or abating their emissions.

The sensitivity of prohibiting international carbon commodity trading demonstrates that countries become more self-sufficient in their own commodity production. In the past, India has shown how broad-based resilience is derived from an open but self-sufficient economy. Conversely, France is seeking exceptional competitiveness in exports as other countries remain entrenched with dirty electricity generation and resist the green revolution. In 2009, 90% of France's electricity generation was from carbon-free sources such as hydro and nuclear. It implemented a carbon tax to give certainty to French industry and spur technological development.

The combination of Base Case and sensitivity analyses using the new spatial benchmarking CGE tool and informed by a deep investigation of political economy, provides a range of policy insights at the global, regional and commodity level. It demonstrates that this tool is appropriate for climate-economic policy research.

6.3 Chapter References

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Chapter 7 Conclusion and Suggestions for Further Research

7.1 Conclusion

Chapter 1 Introduction discussed policy issues in climate change and the way that the evidence-based policy methodology may help address those issues. It identified that policy makers look to evidence-based techniques to confirm policy and instrument feasibility and to understand the sensitivity of proposed policy solutions. Systematic, non-systematic and communication risks of modelling in the policy research process were investigated. The tools of policy research were addressed and it was concluded that for issues with national or global significance policy makers look to computable general equilibrium (CGE) modelling in policy research.

The inadequacies of CGE tools were discussed in general and with reference to developing effective climate change policies. Four research gaps were identified: the difficulty of solving comprehensive general equilibrium with spatial aggregation; the choice of production function; intertemporal consistency; and communication of results. It was proposed that national accounting Use and Make tables could resolve the first shortcoming, benchmarking techniques the second, linking flows to stocks through Sales/Assets ratios the third, and modern data visualisation could address the last gap.

This analysis led to the research aim of this dissertation, which is to answer the question "What changes in regional and industry performance are implied by a change in the Anglo-American world view from unconstrained to climate-constrained resource usage?" The means of achieving this was to develop a new lens through which to understand the spatial and intertemporal effects of climate policy on regions and commodities linked through trade.

A research methodology was proposed that addressed two important issues of evidence-based policy. Firstly, that the political economy of the research question was fully researched. Secondly, that the underlying principles of the new CGE tool, or lens, would have provenance in the political economy of the world view being addressed and, in particular, with regard to the specific policy area being investigated, in this case climate-economic policy.

Chapter 1 Introduction also set out the scope of the research and showed that it was a subject of wide interest to national and international governmental and non-governmental organisations and addressed a number of Australian National Research Priority Areas.

Chapter 2 Political Economy of the Anglo-American economic world view found the Anglo-American world view is premised on the drive to protect freedom and unilateralism. It was concluded that American foreign policy remains in tension, unlike the United Kingdom which has judged that its long term welfare is inextricably linked to multilateral cooperation across the global commons of trade, nuclear non-proliferation, security and the environment.

It was also found that a number of unexpected failures in the Anglo-American world view such as “agency conflict,” “moral hazard” and the Global Financial Crisis of 2008-9 have exacerbated America's declining domestic and international competitiveness. The causes of these challenges was traced to the dominant Anglo-American world view, which finds expression in classical economics and its neoclassical sibling. Important for the development of the neoclassical model in this doctoral research, it was concluded that the classical and neoclassical paradigms may need to adapt but they are not invalidated by internal conflicts and occasional spectacular failures.

The main adjustment to be made is by policy makers that seek ideological assurances from such concepts and models. The unexpected failures have brought the realisation that policy makers need to reconnect to the understanding that beautiful neoclassical solutions based on elegant fictions (such as completely deregulated markets, “enlightened self-interest” and trickled-down economics) are merely points-of-view. The reality is that the greater interconnectedness of the world and increased monitoring of government decisions have led to both policy making and regulation becoming even more complex, messier and visible processes.

Chapter 2 Political Economy of the Anglo-American economic world view also found that President Obama has recognised that America's competitiveness and financial position require immediate action and its future is linked to multilateral cooperation. It was concluded that America may be on the cusp of accepting its new reality of resource constrained growth but is not yet out of the “storming” phase. Plans to reform America may be thwarted by the political conservative psyche, which continues to be driven by dreams of exceptionalism and is ideologically committed to unfettered American unilateralism. The direction America ultimately takes will determine both its future and that of the Anglo-American cohort.

Chapter 3 Political Economy of the Anglo-American world view of climate change investigates climate science and policy and finds overwhelming scientific, United Nations and national government support for measures to limit global atmospheric temperature rise to 2°C (3.6°F) above the pre-industrial level. However, climate change sceptics remain influential and the tension between industrialised and developing nations is palpable. In Hamlet Act 2, Scene 2, Shakespeare's hero soliloquises “the plays the thing wherein I'll catch the conscience of the king.” It is a play within a play, which is very like the intriguing drama of climate change policy formation unfolding before all the world. Although America began to engage with climate change policy in June 2009, the unstable American economic world view and the previous U.S. Senate Byrd Hagel resolution continue to render America's commitment to the 2°C objective tantalisingly close but still beyond reach.

This *Chapter 3* takes forward the investigation of the neoclassical paradigm in *Chapter 2 Political economy of the Anglo-American economic world view* to establish the policy dimensions on which this doctoral research in CGE policy research has been framed. It has established a policy Base Case of 2°C rise, consistent with geophysical modelling of a 750 Gt CO_2 carbon tranche.

Chapter 3 also investigates the three main policy instruments for reducing CO_2 emissions, namely quantitative limits, taxation and property rights. It finds that while all have the same theoretical outcome, in practice each has strengths and weaknesses. It is concluded that with adequate regulatory protections against market abuse and market failure, the introduction of property rights is a feasible and attractive way of pricing pollution and mobilising capital. From this analysis it is concluded that carbon commodity trading is an appropriate means of including amelioration and abatement measures in the policy research model developed in this dissertation.

A policy research CGE tool is not merely a set of equations or optimisations. It is a compound technical solution where the nature of the model, the computing environment and the nature of the source data and the structure of the data are all matched to achieve the research aim. *Chapter 4 Economic models for climate change policy analysis* determined that a new Service Sciences benchmarking-type of neoclassical, intertemporal, multiregional and multi-commodity CGE model using GTAP Input Output data and expressed in Mathematica would provide the most appropriate expression for the requirements established in Chapters 1, 2 and 3 (above).

The blueprint for a new CGE model is described in *Chapter 5 A new spatial, intertemporal CGE policy research tool*. The model is called "Sceptre," which is an acronym for Spatial Climate Economic Policy Tool for Regional Equilibria. It unites CGE modelling with Input Output modelling by generating resource pricing through an optimisation dual solution. This is made possible through recent innovations in nonlinear interior-point techniques. The model employs Thijs ten Raa's approach to using the Make and Use tables of national accounts for benchmarking economies using Input Output data. In order to place this in an intertemporal context, a new approach is introduced to link stocks and flows through Sales/Assets ratios. This creates both a strong underlying intertemporal economic framework for the constraints and allows resource pricing to be generated through these dynamic resource constraints, rather than through static or exogenous commodity resource limits. New commodities are introduced for international carbon trading of permits and amelioration and abatement services. Geophysical feedback is implemented using William Nordhaus' technology functions and proven climate-economic equations. The model was validated using the results of recent geophysical modelling and by comparison with the William Nordhaus DICE model.

Sceptre's suitability for policy research was investigated in *Chapter 6 Assessment of changes in regional and industry performance under resource* *constrained growth*. A Base Case of limiting atmospheric temperature rise to 2C maximum was formulated from the political economy analysis of Chapters 2 & 3. The regional and commodity effects are investigated in detail. In terms of policy makers expectations for CGE modelling in confirming viability, the Base Case policy is found to be “feasible.” A notable outcome is the degree to which the European Union becomes resource expansive under the Base Case policy constraint. This commodity specialisation is an example of the neoclassical model applying knife-edge pricing, which may be unachievable if realistic land use or regional self-sufficiency political constraints were included.

Additional risk appraisal was undertaken through sensitivity cases. Point of view analysis found that the Base Case costs little more than Sceptic and *Laissez-faire* scenarios, which might be expected since environmental taxes are *prima facie* revenue neutral. Even the Radical ultra-risk averse policy option of immediately eliminating emissions has a relatively small net present value premium of US$3.8 trillion over the Base Case. Consistent with this, climate constraint severity sensitivities of 350, 450 and 550 ppm impose little cost over the Base Case and would be selected for policy reasons based on political rather than economic objectives.

Technology cost sensitivity scenarios demonstrated that the anxiety of China, India and other newly developed and developing countries about a mismatched risk between targets and technology availability are not misplaced. Third world experience with HIV pharmaceuticals has demonstrated the disproportionately large risk for countries that do not hold intellectual property rights.

In addition to impairing economic value added for climate damage, Sales/Asset ratios may also be impaired. This means that industry requires more assets for the same output. It was found that this effect, although subtle, also increased the requirements for consumer emissions control.

In a sensitivity of economic growth without international trade in carbon commodities it was found that climate-constrained resource expansiveness, for example of European Union food production, is significantly reduced. This increased the requirement for regional self-sufficiency. The implication of resource expansiveness emerging with climate constraints is a real issue that may pose significant challenges for the industry policy of countries and regions that are struggling to maintain self-sufficiency or an independent industrial base. For example, the political economy analysis showed that countries such as France are well positioned and keen to capitalise on the resource expansive growth. France already derives 90% of its electricity from zero emission sources and is hurrying to make the transition to a fully green economy with measures such as a carbon tax and mandating plug-in hybrid cars. It has recognised that the new climate constraints will provide a magnificent one-time opportunity to use its resource expansive competitiveness to seize global market share.

This dissertation has addressed the research aim of answering the question "What changes in regional and industry performance are implied by a change in the Anglo-American world view from unconstrained to climate-constrained resource usage?" This has been achieved through developing a new CGE policy tool, or lens through which to undertake policy research in both sustainability and international symbiosis for managing the commons across trade, security and the environment.

7.2 Suggestions for further research

Some suggestions for future climate policy research using the Sceptre model include:

Investigating alternative social policy scenarios

Globalisation

The CGE policy research model developed in this dissertation is a unique spatial policy tool for investigating globalisation risks and the sensitivity of economies, societies and political structures to rapid change. It is possible to investigate policies with different aggregations of countries. For example, those subject to sea rise, desertification, crop changes, net food importers, mobility of dislocated peoples, new global trading blocs, different ethno-cultural groups, and perhaps different classifications of moral philosophy such as conservative and liberal.

The model developed in this dissertation may also be used to understand the effect of emerging, binding constraints of scarcity as they replace relative abundance. For example, the transition away from dependence on oil. Other fruitful areas of research may be new security zones, autarchies established to guard primary resources such as food and water, and new multipolar superpower equilibriums. Perhaps these new equilibriums may be based on enlightened democracies or on game theory's mutually assured destruction framework.

Other dimensions of geopolitical research may include a reorientation of emphasis from globalisation toward internal self-reliance, resilience and sustainability of economies. This could include China relaxing its one-child policy, Russia's expanding link with Germany or joining the European Union, or modelling of potential North-South economic alliances such as America uniting with South America, Russia formalising its long-standing relationship with India or perhaps the surprising scenario of a Sino-Australian trade bloc.

Associated with these geopolitical-scenarios is policy research into the future of overpopulated middle-eastern regions that may become “lost in the middle” once their oil revenues decline. Nations in this position include Egypt, Syria, Iraq, Iran and Saudi Arabia.

Industry policy

Investigate local industry policies in the presence of climate constrained specialisation and competitive advantage. Different industry aggregations could include various forms of transport, electricity generation, automobile manufacture, water resources and military security.

Various forms of utility function

Various social policies may be tested using different forms of utility functions. For example, the recently proposed Net National Product (NNP), which is GDP less depletion of natural and human capital (Stiglitz et al. 2009). In addition, the interface of production specialisation and consumer employment could be investigated. This would be of the greatest interest for those countries seeking self-sufficiency in various commodities.

Multiple objective and minimax programming

The exploration of alternative objective functions may be extended to multiple objective optimisation in order to evaluate different social objectives. For example, multiple objective optimisation involves minimising several objective functions under the expectation that no unique optimal solution will exist because a solution that optimises one function often will not optimise the others at the same time. Multiple objective programming would allow optimisation for a range of objectives, such as the United Nations Millennium Development Goals relating to poverty, hunger, education, health etc.

Von Neumann and Rawls' minimax problem is a particular form of multiple objective optimisation where the minimum value of a function is defined as the maximum of several functions. For example, performance of the elementary economic model in Chapter 5 “A new spatial, intertemporal CGE policy research tool” demonstrated that one effect of a minimax objective function was to bring stability to economic performance.

Supplementing data for additional functionality

Include non-CO_2 greenhouse gases

GTAP expects to release data for non-CO_2 greenhouse gas emissions. This data will improve the modelling of climate feedbacks with greater detail for these non-CO_2 emissions.

Include Land Use data

GTAP's land use database and Mathematica' Country database provide the opportunity to investigate other factors. For example, the nexus between economic performance and commodities or factors such as water, fuels, minerals, arable land, crop yield, forests, erosion and changes in biodiversity.

Refine economic damage functions

A generic climate-economic damage function has been applied to economic output in the Make Use format by adjusting the Use table. Additional understanding of the effect of climate damage functions on each of Use and Make matrices separately would be highly insightful. Engineering, industrial ecology and physical science analysis in the next IPCC Assessment Report (AR5), which is due in 2014, can be expected to provide major advances in realism. In addition, to better understanding the effect of damage on Make and Use tables, specific country and industry risk analysis could be undertaken to develop localised climate damage functions.

Refine technology costs

The amelioration and abatement cost used in this policy research is a function of the proportion of emissions ameliorated or abated. At present, Nordhaus' technology cost profile remains speculative. Technology costs will become better known with the commercialisation of geoengineering, geosequestation, wind, solar, hydrogen and nuclear projects. Engineering cost functions may be embedded in the abatement cost function.

Empirical studies of Sale to Assets ratios

Improved data on historical Sales to Asset ratios, appraisal of the new risks and volatility to industrial production of climate damage and estimates of future Sales to Assets ratios would materially improve the reliability of the model for government policy makers and to industry strategists.

Expand the use data in physical units

Input Output tables have the advantage of being clear and consistent. The material balance of commodities based on Input Output table monetary data is common to traditional CGE and benchmarking models. However, the relationship with physical material flows or ecological flows is more tenuous. Commodities are assumed to be homogeneous but are only artificial categories and there are many assumptions made in mapping resources to commodities. The availability of integrated data through the EXIPOL project will allow realism to be improved by substituting key rows and columns with data in physical units such as tonnes of a commodity.

Improve the quality of existing data

Industrial greenhouse gas emissions are already in physical units. However this emissions data is derived from International Energy Agency estimates. As greenhouse gas emissions begin to be measured more accurately around the globe, actual data may be substituted in lieu of the IEA's estimated data to improve realism.

Furthermore, the characteristics of regional labour endowments might be empirically investigated in order to better understand labour constrained growth.

Improving analysis techniques

Improve treatment of trade taxes & freight

The use of net exports has many advantages but alterations in trade flows leads to mismatch with taxes and international freight. Further research into modelling trade taxes in Sceptre would enhance the trade realism of the model.

Introduce more complex forms of production function

Sceptre's carbon commodities are computed with detailed technology functions. The economic commodities of food, manufacturing and services are optimised through a Leontief-type Make Use tableau as the production function. It would be insightful to augment the Leontief tableau with functions having an engineering or ecological foundation for fine grained analysis of specific commodities at country or local levels. As *Occam's Razor* mitigates against additional complexity and assumptions, the alternative generic approaches of Constant Elasticity of Substitution (CES) and Transcendental Logarithmic (Translog) functions may not be so worthwhile.

Endogenous technological change

Implement the propagation of technological change through Use and Make matrices, extending the work of Wilting et al. (2004; 2008) and Pan (2006; Pan & Kohler 2007) in technology diffusion.

Develop acyclic topological processing for nonlinear constraints

An acyclic processor for constraints would significantly enhance interior point optimisation and materially expand the scope of Sceptre.

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Appendix 1 Climate change engagement in Australia

A1.1 Submission to Garnaut Review

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18 April, 2008
Submission to ETS Discussion Paper
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Dear Professor Garnaut,

I am a senior lecturer and climate change researcher in the Faculty of Engineering at the University of Technology, Sydney.

The key points of my submission are:

1. Until the USA commits to an ETS, it may be too early for Australia to do so.
2. Australia can immediately commence reducing emissions through price mechanisms by implementing a moderate carbon tax applied on a carbon-added basis.

Let me more fully explain the rationale for these points.

Until the USA commits to an ETS, it may be too early for Australia to do so.

The European Union implemented its ETS as a differential or relative model in order to avoid an absolute carbon price or tax. A major reason for this was that the concept of an environmental tax had been determined unconstitutional in France. Therefore, the UN and EU sought a self-regulating means to reduce emissions by using market forces and the profit motive. The differential scheme introduced by the EU provides for the emissions of firms to be assessed on a case-by-case basis, quotas determined and carbon permits granted free for these quotas. Approximately 10,000 steel factories, power plants, oil refineries, paper mills, and glass and cement installations were involved, representing approximately half of the EU's emissions. Initially, aluminium producers, the chemicals industry and the transport sector have not been included. Through the ETS, firms can sell surplus emissions permits, or conversely buy permits to offset excess emissions above quota.

The ETS proposed in the Discussion Paper is an absolute scheme quite different to the EU model in at least two respects. Firstly, in being an absolute scheme, each firm is required to purchase sufficient permits through the ETS to acquit all emissions produced by that firm. There is no valuable surplus of permits arising, as the bounty of innovation in the EU model, that may be traded for profit. Secondly, the Discussion Paper ETS causes the market to put a price on carbon, presumably through ASX-type auction and equilibrium price or through authorised dealers tendering for permits from the proposed Carbon Bank and selling these through the ETS in smaller denominations to the firms that need to purchase permits.

Given the difference in the EU and Australian schemes, linking them together as raised on page 69 of the Discussion Paper could prima facie expose the Australian economy and tax base to great risks. While the EU proposes to auction permits in the future, due to the failure of enlightened self-interest amongst generators (leading to high electricity prices for customers because the benefits of the free permits were not passed through to customers), it is by no means certain that an auctioning of permits will be constitutionally possible (Deroubaix & Leveque 2006).

The fabric of an Australian ETS would have a very large cost base, including the Carbon Bank (acting as a Reserve Bank in permits), operators like the ASX, regulators like ASIC, primary dealers, distribution brokers, etc. This fabric would mean the ETS commences its existence from a position of considerably negative value to the Australian economy.

With the introduction of the ETS, there will be a significant risk introduced into industry and for consumers. Following considerable debate at the time of the last Federal election, most Australian stakeholders are expecting a “price on carbon”. The ETS Discussion model above does not provide such a price. Instead, a price is set by the market. As for all commodity spot and futures markets, the price will be extremely volatile as traders and speculators are driven to hoard and liquidate by the usual emotions of greed and fear.

Certainty and stability are key issues. The ability of firms to plan ahead with certainty will be impaired unless they commence sophisticated hedging strategies using futures. This need for thousands of emitters to have new financial departments to manage hedging portfolios could necessitate a burden of financial sophistication on firms that is unwarranted and otherwise costly to have independently managed.

Given the significant costs to efficiency of an Australian ETS and uncertainty about whether the USA will introduce an ETS and its model of doing so, it is submitted that it is premature to implement a particular ETS model in Australia at this time.

Australia can commence reducing emissions using price mechanisms by implementing a moderate carbon tax applied on a carbon-added basis

While the word “tax” is an anathema to most Australians, there is a strong sense of equity in the argument that those who pollute the commons should pay a price for doing so. As Australian firms are accustomed to completing monthly or quarterly BAS statements, it would be of very little additional effort to include a carbon-added tax and for relatively few companies to complete this part of the statement. This would be efficient to administer by standard Australian Tax Office online procedures.

The concept of a carbon-adder very subtly changes the focus from emitters to those firms that extract carbon from the earth or import carbon into Australia. If a company, for example a coal company, sells coal it would need to pay the Government a carbon-added tax. The generator that buys that coal does not need an emission permit or to pay tax. It merely needs to pay the higher cost of the coal including both GST and carbon-added tax.

As upstream companies usually deal in large quantities of commodities, the Australian Tax Office would find it efficient to deal with the limited number of carbon-added firms. Contrast this to the task of dealing with the enormously larger number of emitters in electricity, iron & steel, aluminium, transport, agriculture etc.

One may ask whether the ability to readily pass on higher costs in the form of higher prices to consumers will reduce incentive for generators to seek lower carbon sources of supply. If the National Electricity Market continues to be regulated then reductions in carbon will come from generators seeking cheaper fuel sources and new entrants to the market with lower source costs.

As with GST, in the case where a user is able to successfully capture and store carbon, then the user could claim back the tax on the captured carbon in the same way GST is claimed back. Mining companies already have the necessary expertise for storing carbon. Therefore, carbon storage is naturally a task for the coal miners rather than the generators. As a consequence, coal companies would both pay the carbon tax and claim the carbon tax offset. Presumably, this sort of technically advanced coal company would have skilled financial and accounting personnel and be aware of the risk of re-incurring the tax liability if the sequestered carbon under its stewardship was inadvertently vented to the atmosphere.

Export sales and imports could also operate on the same basis as the GST. Carbon-added tax would not apply to exports as the carbon implications of trade are for the receiving country to deal with. If that country is a signatory to the Kyoto Protocol, then it may in its own discretion charge for embedded emissions. Fortunately from Australia's perspective, having no carbon-tax on exports obviates the need to differentiate between signatory and non-signatory end destinations, which is a task inevitably complicated by transhipment. It is also likely to be politically more palatable than the Government compensating coal and metals exporting companies in cash or otherwise for the cost of their direct and indirect emissions in producing the exports.

In regard to imports, all products brought into Australia would need to pay carbon-added tax. With scientific and economic assistance, formulae for taxable embedded carbon can be readily determined by the Australian Tax Office in conjunction with Customs & Excise. Techniques such as Input output analysis are available to model the flow of carbon emissions through the economy and therefore the vesting in various products.

Government revenues from a carbon-tax will be very large indeed. It is generally argued that environmental taxes should be fiscally neutral. Therefore, these tax revenues would, in the main, be returned into the economy through reducing nineteenth-century Bismarckian labour taxes like payroll tax and personal income tax. This return mechanism can produce an additional benefit, which is indirectly alluded to in the Discussion Paper. The first dividend of the environmental tax is reduced pollution through using the price mechanism to switch consumer preferences. The second dividend is economic growth, particularly through enhancing the competitiveness of labour and increasing the buying power of consumers. Therefore, in contrast to the heavy burden of the fabric of an ETS, a carbon-added tax may well “start in front” due to the positive effect of this fortuitous natural double dividend. Bento & Jacobsen (2007) demonstrate that in real world situations fiscally neutral environmental taxes can produce a double dividend of up to 11% of the saving in pollution.

Availability of carbon, even at escalated prices, will be far less frightening to firms than the prospect of being denied a future supply of permits, due to both the reduction of sales by a Carbon Bank and unpredictable hoarding by traders and speculators. Any potential of being denied a future supply of permits to operate would cause firms to react very negatively to an ETS.

A firm can plan for price but not for being unpredictably denied a key requirement for production. In order to provide certainty to industry, the Government could introduce a carbon tax with a rising profile. For example, this may begin at a moderately low rate and increase over 8-12 years to a high rate. Such a scenario would provide plenty of certainty to firms and give them the time and incentive to innovate in their production processes to reduce costs. In addition, a rising profile would provide the opportunity for the Government to slowly learn about this new paradigm of carbon-added tax and to change the rate as necessary.

Therefore, a carbon tax as the first stage of a market-based scheme is quite different in scale, risk, control and cost to a big bang approach of launching a full ETS as set out in the Discussion Paper. The former would be simple to implement and would not commit Australians to substantial investment in the fabric and operation of an ETS without certainty of first knowing where this very new concept fits into the Australian and international paradigms, with key stakeholder perceptions in the Australian economy based on real experience. I refer again to Deroubaix & Leveque (2006) for an investigation of the importance of bringing stakeholders along in this quite controversial process.

Nevertheless, a carbon tax would be quite straightforward to reformulate into any internationally agreed ETS scheme with a different mechanism for pricing carbon. Perhaps this could be seen as no more difficult than floating the Australian dollar.

Whatever the nature of an international scheme, Australia would be at the forefront through being experienced, proactive and positioned to flexibly adjust to any new scheme. It might be noted that the air quality regulator in the San Francisco Bay Area, with a population of 7.2 million and CO2 emissions of 85.4 million tonnes per year, are currently introducing a small carbon tax on emissions of CO2 in order to learn about the effect of carbon taxes and to recoup the costs of registering and controlling emissions (Barringer 2008).

It is therefore submitted that the first stage of an Australian market-based emissions reduction scheme would be a moderate tax applied on a carbon-added basis. Stage 2 of the market-based scheme would be an ETS developed as greater certainty evolves about the nature of an international model. Further consideration of an Australian ETS could be deferred for a short period of, say, three years.

I would be pleased to expand on any of the points above at your convenience.

Yours faithfully,

(signed)

Stuart J Nettleton

A1.2 Australian climate change policy development

Tim Flannery

In his speech at the the University of Technology's 20th year celebration dinner in May 2008, the indefatigable climate change campaigner and 2007 Australian of the Year, Professor Tim Flannery, noted that the climate change problem is bigger and more urgent than currently being addressed (Flannery 2008). He predicted some form of emissions trading scheme proceeding in Australia but did not hold much expectation of this reducing emissions.

Flannery's reasons were, firstly, that the standard of living of highly populous nations such as China and India is rapidly rising with attendant energy requirements. Developing nations are are not interested in anything to do with carbon taxes as they claim their per-capita emissions are very low, and they will not sacrifice economic growth because of this issue, and the problem was created by the West so the West should pay to fix the problem.[i]

Secondly, approximately fifty percent (50%) of the world's carbon dioxide emissions are from coal-fired power stations. There is a massive installed base and annual increase in coal-fired generation. For example, China has been commissioning around one new 1 gigawatt coal-fired power station per week. Only the so-called clean coal technology of carbon capture and storage (CCS) can reduce the carbon emissions. However, CCS is not currently available and may never be available. The pressurised storage of carbon dioxide is also very dangerous because the gas must be stored forever and we cannot be certain that storage will remain secure. Even though CCS has so many disadvantages and risks, Professor Flannery called for Australia's coal industry to be heavily subsidised at 10 times the current investment to achieve successful CCS so it can be urgently given to China and India.

Thirdly, nuclear fired generation is probably a key technology that is more certain than CCS. It is only used on a small scale at present, for example 2% of China's generation is nuclear, however its share could strongly accelerate. Intrinsically safe nuclear is becoming feasible so there may be no more Chernobyl meltdowns from new reactors but future generations will inherit the growing problem of safely storing nuclear waste and controlling the proliferation of nuclear weapons.

Finally, according the Professor Flannery, the only reasonably foreseeable method of actively reducing atmospheric carbon dioxide is wide scale pyrolytic combustion of crop biomass. This has the potential to reduce the absolute amount of carbon dioxide in the atmosphere by approximately 5% per annum. Biomass such as wheat and corn stalks can be combusted in the absence of oxygen to produce fuel oil while sequestrating the carbon as charcoal. This charcoal may be ploughed back into fields where it will be stable for thousands of years and contribute many beneficial properties to the soils.

Election of Prime Minister Kevin Rudd

It is well known that Australia's Prime Minister Kevin Rudd, in his first act of office, ratified the Kyoto Protocol on 3 December 2007. Kevin Rudd's 2007 election commitment was to introduce an Australian greenhouse gas reduction target of 60% by 2050 (compared to the 2000 level).

Garnaut Climate Change Review

Garnaut Report

The Garnaut Climate Change Review was established by the State and Territory Governments of Australia in July 2007. The Commonwealth Department of Climate Change joined the work in January 2008.

In the interim report (Garnaut Climate Change Review 2008b), Professor Ross Garnaut recommended that emissions and climate change should be decoupled from world economic growth because high world growth is driving Australia and all the world towards high cost downside risks and that this is happening more rapidly than commonly appreciated.

The major recommendation of the interim report is that Australia should press for the strongest possible outcomes in global mitigation. Garnaut saw this as being in Australia's self-interest in avoiding unacceptable levels of risk of dangerous climate change effects on Australia's fragile land, biodiversity and dry climate.

Garnaut says Australia should pursue deeper 2008, 2020 and 2050 emissions cuts than the Rudd Government's single target of a 60% reduction on 2000 levels by 2050 “Waiting until 2020 would be to abandon hope of achieving climate stabilisation at moderate levels.”

Garnaut highlighted that Australia could not remain complacent about being a low emitter relative to the USA and China. Under convergent-contraction principles being developed by the United Nations to ensure developing countries join the reduction program, all reduction targets will switch from the relative basis of improving on current emissions to an absolute target of emissions on a per capita basis. This would greatly impact Australia because it has one of the highest per capita rates of emissions in the world.

Garnaut also noted that Australia was an emerging world leader and role model in setting the post-Kyoto framework of global objectives, greenhouse gas stabilisation, emissions budgets and the principles for allocation of global emissions among countries.

Garnaut et al. (2008) expand on the need for urgency in addressing the climate change phenomena. The reason for Professor Garnaut's continued emphasis on urgency is his hope to justify political expediency in accepting his somewhat utopian concept of an all encompassing emissions trading scheme, where all emissions permits need to be purchased. His ultimately unfulfilled hope was that a cloak of urgency would generate sufficient groundswell to sweep aside all the arguments of equity that have constrained debate in the European Union and America and resulted in inferior forms of emissions schemes.

Emissions Trading Scheme

In the Interim Report (Garnaut Climate Change Review 2008b), Professor Garnaut proposed an emissions trading scheme (ETS). More detail of the proposed scheme was provided in an Emissions Trading Scheme Discussion Paper (Garnaut Climate Change Review 2008a).

The European Union has already implemented a regional ETS. Garnaut proposes that Australia do like-wise with a national scheme. A tradeable permit would provide for a capped quantity of total emissions for a specific time. It could be used immediately or hoarded indefinitely. The Australian Governmental would progressively reduce the volume of permits available to the ETS as Australia's global emissions budget reduces.

Garnaut noted that emissions trading schemes have an implicit assumption that the world can tolerate a certain level of emissions. Therefore, this scarce resource of tolerable emissions needs to be allocated in some way across countries and across emitters within countries.

Garnaut also subscribes to a rather straightforward view of geopolitical equity. He sees that the basis of allocating quotas for emissions needs to be equitable to all countries taking into account population, the need to adjust from current emissions and past emissions, and sufficient time for adjustment etc. This is because all major emitters, both current and future, must take on their obligations in order for the sum of the measures to be sufficient for effective global mitigation.

There are two levels in international ETS schemes. The first is for countries to trade emissions permits. The second is a market that connects local ETS markets and facilitates arbitrage and fungibility.[ii]

Garnaut (p35) makes the point that an international ETS that connects local markets is a long way off “Only a few countries have proposed national targets, and fewer still have sought to ground their targets in a framework based on global emissions budgets derived from explicit mitigation objectives .... All developing countries reject binding targets.”

Connecting local ETS markets has many implications. Firstly, the linked national schemes need to define a carbon unit in the same way and agree on what constitutes a tradeable surplus. Secondly, price and volume fluctuations in one market immediately cause price and volume changes in the other. Therefore regulators in each market need to monitor and enforce minimum standards.

For a local ETS, the first issue is the formula on which quotas are allocated. This is a major issue given countries such as America, China, India and Bangladesh are highly diverse in their life-style, population, degree of industrialisation, current level of emissions, exposure to the effects of climate change and the impact on industry and jobs of compliance with the quotas.

A second issue is level of flexibility permitted to individual governments to respond to the challenge of managing within the quotas. Some argue that each government should then be free to decide how to bring down its own emissions to meet the quota. Others seek a comprehensive prescription on the approach. For example, specification of a common rate of carbon tax.

However, in perhaps his most controversial point, Garnaut argues against the European Union's differential form of ETS where permits are granted free of cost to emitters. Emitters receive the value of the scarcity of the permits, which is not necessarily passed on to the end consumer. Indeed, in a failure of enlightened self-interest, generator profits increased by the amount of the windfall permits so households and people on low incomes suffered considerable injury from the higher prices.

Garnaut's most contentious and perhaps disputed point is that the Government would auction emissions permits and thus the market would set the price on emissions.[iii] He envisages that the Government would apply the proceeds in the same way the proceeds of a revenue neutral environmental tax would be used to reduce labour or other taxes and increase public expenditure.

Garnaut (p45) says of his proposed ETS:

> An ETS relies more completely on market processes, and if properly designed, and allowed to play its role without extraneous interventions to vary the budget or control the price, would be the more direct instrument for securing the Australia's emissions budget. [grammar as in original] …. It is likely that the closest comparator would be the gold market …. The market would set the rate at which Australia's emissions budget was utilised …. If there were high expectations of future progress with new low emissions

> technologies, the market would set a relatively low price curve, allowing relatively high use of Australia's emissions budget in the early years, followed by later rapid reductions in emissions. Low expectations of emissions would generate a higher price curve, a faster decline in emissions in the early years, and a more gradual reduction in later years. Any new information that increased optimism about new, lower-emissions ways of producing some product, whether they were expected to become available immediately or in the future, would shift downwards the whole structure of carbon prices, spot and forward. Any new information that lowered expectations about the future availability of low-emissions alternative technologies would raise the whole structure of carbon prices, spot and forward .... It is important to allow permits to be used when they have greatest value to market participants, to the extent that this is consistent with taking account of any additional climate impacts of early use of permits and with emerging international agreements. The practical way to achieve the desired outcome would be for the Government to define an optimum path for use of permits - ideally based on analysis of the minimum cost path of emissions reduction within the total emissions budget - and to issue permits over time in line with this trajectory of emissions reduction. The fixed schedule for release of permits could then be accompanied by provision for banking permits in excess of current economic use, and borrowing from the future allocations when the value of current relative to future use suggested it. The banking and borrowing would allow the market to modify the rate at which permits were used in a way that minimised the cost of mitigation. It would allow the market to shape and reshape the “depletion curve” in response to new information about emissions-related technology or practices.

Garnaut has also accepted the recommendations in the Report by the Task Group on Emissions Trading (Australian Department of the Prime Minister and Cabinet 2007), established by former Prime Minister Howard, which recommends Government interventions in the ETS to support governance and ameliorate market failures and innovation, R&D, demand-side energy use and provision of network infrastructure to address weaknesses.

The Garnaut Review recommends a form of Reserve Bank to issue and monitor the use of permits:

> In addition, the independent authority could be given the roles of ensuring that Australia met its obligations under international agreements to reach emissions targets (for example, to buy permits on the international market when the private sector was a net borrower from the authority in a year in which Australia was required to meet an international target); and to assess and make payments related to incentives for operation of trade-exposed, emissions-intensive industries.

Garnaut (p50) argues that other firms that suffer because of higher prices on inputs or on what they supply would not be compensated. He says there is no tradition in Australia for compensating other firms for losses associated with economic reforms, particularly because the business community has been able to anticipate the risks of carbon pricing for many years. However, Garnaut does makes the case for assistance to workers and communities who are adversely affected by environmental reforms. He notes:

> Desirably, and typically, these take the form of assistance in preparation for new employment: retraining of workers (as with textile and steel workers in the 1980s after reduction in protection); grants to communities to support improvements in infrastructure that would be helpful to the attraction of alternative industries (the steel towns in the 1980s); or assistance to parts of the industry that have opportunities for survival and expansion in the new, more competitive circumstances (design and export assistance to the passenger motor industry following reductions in protection in the 1980s and 1990s).

The essence of the problem with Garnaut's proposed Australian ETS perhaps lies in the above point. The very reason emissions permits were given to firms in the European Union was to avoid charging for the permits, which would have constituted an environmental tax of the form found unpopular in Germany and determined by the French Constitutional Court to be unconstitutional (Deroubaix & Leveque 2006).

At the heart of addressing greenhouse gas emissions is the principle that the cost of adjusting to climate change should not fall on individual countries, firms or individuals. Garnaut's ETS proposal of auctioning permits is prima facie inequitable because it leads to differential damage to firms. Firms and indeed end consumers will have plenty of reason to object to such damage. They have the right to ask “Why me? Why should I be sacrificed for the good of the planet?” Garnaut's policy of not compensating firms and individuals who suffer has not proven to be a point easily accepted. As in France, inequalities of this nature mean the policy requires a supra-approval under the Constitution's international treaty provisions.

The Australian Government immediately reacted to Garnaut's interim report in ways that Garnaut had recommended against. For example, the Government announced that it was considering excluding petrol from any ETS and eventually proposed that every increase in permits cost would be offset by decreases in excise duty. Garnaut responded immediately, rejecting this type of compensation and arguing “The broader the coverage, the lower the overall cost to the economy.”

The Treasurer of the New South Wales (NSW) State Government, Michael Costa, in the process of privatising NSW's power stations, also reacted immediately to the issue. He said the National Generators Forum was seeking either free emissions permits or A$20 billion compensation from the proceeds of an auction of emissions permits.

In an indication of the direction of debate on this issue, the National Generators Forum issued a polemical statement criticising Garnaut's proposals “It is of serious concern for the security of the future electricity supply in Australia, that for the second time in a month, Professor Ross Garnaut has released a report which demonstrates a fundamental lack of understanding of how Australia’s energy market operates” (Boshier 2008).

The National Generators Forum continues to be perplexed by the simplistic views of such a complex area that Professor Garnaut espouses. It is an indication of the difficulty of national consensus in Australia’s transition to a low carbon economy.

Lastly, due to its unusual structure, another point in Garnaut's proposal has the potential to become a major controversial issue. Garnaut (p48) says that firms such as coal, iron ore and metals exporters, which may not be able pass on price increases, would receive special treatment in the form of cash subsidies:

> For the most part, the distinction is between firms selling into the non-traded domestic sector, which will mostly be in a position largely to pass on the permit price, and firms in the trade-exposed, emissions- intensive sector, which mostly will not be able to pass on the price of permits (in part of in whole) unless and until relevant competitors in global markets are in a comparable position .... In Australia, industries included in this category may include non-ferrous metals smelting, iron and steel-making, and cement .... There are environmental and economic reasons for establishing special arrangements for highly emissions-intensive industries that are trade-exposed and at risk during the transition to effective global carbon pricing arrangements. The case for special arrangements is based on efficiency in international resource allocation. All other factors being equal, if such enterprises were subject to a higher emissions price in Australia than in competitor countries, there could be sufficient reason for relocation of emissions-intensive activity to other countries. The relocation may not reduce, and in the worst case may increase, global emissions. The economic costs to Australia and the lack of a global environmental benefit of such relocation of industry are obvious."

Although this point is analogous to exporters not charging goods and services tax (GST) and reclaiming from the Government any GST paid on inputs, the concept of a subsidy to extremely wealthy multinational resource companies is on the face of it electorally unpalatable.

Australian Whitepaper & Carbon Pollution Reduction Scheme

In December 2008, the Australian Government responded to the Garnaut Review with a White Paper. The key features of the White Paper were confirmation of a 60% reduction in emissions by 2050 (compared to 2000 levels); a unilateral 5% reduction by 2020 (compared to 2000 levels) and up to 15% if necessary to join with other nations in global action to limit CO_2 equivalent emissions to 450ppm or lower by 2050; 20% of Australia's energy being produced from renewable sources by 2020; and an Emissions Trading Scheme (ETS) to operate from 1 July 2011.

The Government noted that a 15% reduction by 2020 (compared to 2000 levels) is equivalent to 27% per capita (or 34% per capita from 1990) because Australia's population is projected to grow by 45% over the same period.

The Whitepaper was subsequently embodied in a Bill called the Carbon Pollution Reduction Scheme (CPRS), which had insufficient support for either its initial passage in the Australian Senate or a second vote in August 2009.

While the CPRS appears to be well designed, it is subject to ongoing political negotiations that will variously exempt, advantage and disadvantage various industries and groups in society. For example, exporters and energy intensive industries subject to import competition have been exempted. The owners of coal fired electricity generation plants have been compensated for the loss of value of their plant. Motorists have been compensated for their extra costs. The deficiency of the scheme is therefore apparent when contrasted to Garnaut's framework. Many believe that the Government will face a century or more of unremitting lobbying from powerful stakeholders.

Lowe (2009, p.48) was particularly dismayed at the Government's response to the Garnaut Review:

> Australia's carbon-dioxide emissions from energy use are now about 40 per cent above the 1990 figure and spiralling out of control. The emissions trading scheme put forward by the Rudd Government in

> December 2008 – for our pollution levels in 2020 to be 5 per cent less than they were in 2000, possibly up to 15 per cent should a global agreement be reached – will not be adequate to promote changes to the way we live and do business. On the contrary, the government has proposed concessions to households and high-emissions industries to ensure that their levels of consumption and pollution remain unaffected by the scheme!

And he sees the magnitude of the task to be daunting (p89) “A rough calculation shows that the eventual carbon budget for each Australian will be about 5 per cent of the present level of emissions.”

The 5% unilateral and 15% negotiable targets proved to be very controversial with environmental groups. In May 2009, under parliamentary pressure from the Green Party, the negotiable cap was increased to a range between 15% and 25%; the ETS was delayed 1 year until 1 July 2012; and a interim price of A$10 per emissions permit was fixed.

Minister for Climate Change & Water, Penny Wong, noted that the Government would meet the maximum 25% target through the CPRS, the 20% renewable energy target and from 2015 by purchasing international credits for up to 5% of the target.

Australian Renewable Energy Target

The Australian Government's 20% renewable energy target (RET) will be achieved by substantial investment in renewable energy, energy efficiency and carbon capture and storage (CCS). In August 2009, the RET Bill was finally passed by the Australian Parliament after the Government agreed to separate it from the controversial Carbon Pollution Reduction Scheme.

However, it was a foregone conclusion in any case. The Council of Australian Governments (COAG) had already given its support for the new RET to take over from the existing Mandatory Renewable Energy Target (MRET), which runs from 2001 to 2010. The MRET requires wholesale purchasers of electricity to proportionally contribute to an additional 9,500 GWh of renewable energy per year by 2010. The RET expanded target is 45,000 GWh by 2020. The new RET now absorbs all existing and proposed state and territory renewable energy schemes.

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i Nevertheless, it is possible for the West to impute a carbon tax on imports from countries that do not levy emissions.

ii Fungibility is the ability to trade a permit in different markets. For example, the ready sale of an American emission permit on the Australian ETS market

iii Garnaut dismisses outright a carbon tax or capped-price at which the Australian Government would sell any number of permits, which Garnaut says is the same as a carbon tax

Appendix 2 CGE Modelling

A2.1 Elementary CGE modelling

Embedded within every CGE model are neoclassical consumer utility and production functions.

Consumer utility function

Chapter 5 Sceptre model development discussed the consumer utility function often used in general equilibrium studies and its interrelationship with the pure intertemporal discount rate. The single commodity consumer utility function described there is:

$$u(c) = \frac{-c^{1-\alpha}}{(1-\alpha)}$$

where c is per capita consumption and the constant elasticity of intertemporal substitution of $\varepsilon = 1/\alpha$.

However, there are many approaches to multi-commodity utility functions. There are three main types of neoclassical utility function, in order of ascending flexibility: Cobb-Douglas, Constant Elasticity of Substitution (CES) and transcendental logarithmic (Translog) with coefficients estimated through econometrics.

The simplest form of all utility functions that satisfies conditions for regularity (i.e. monotonicity and convexity) is the Cobb-Douglas (1928) or log-linear function

$$U = \prod_{i=1}^{n} q_i^{\beta_i}$$

where u is utility in pure units, q_i is the i_{th} commodity with a share factor of β_i .

The log-linear form of the utility function is (Chung 1994, p.8):

$$u = \ln(U) = \sum_{i=1}^{n} \beta_i q_i$$

Criticisms of the log-linear function are that partial elasticity of substitution is unity for all pairs of commodities and the shares of each commodity in the consumer's budget are independent of the size of the budget. These assumptions of additivity and homotheticity introduce distortions and limit the value of log-linear utility functions for empirical studies.

The constant elasticity of substitution (CES) model is a generalisation of the log linear function, which removes some of the restrictive assumptions. Chung (1994, p.58) defines the CES utility function as:

$$u = \left[\sum_{i=1}^{n} \beta_i q_i^{-\rho}\right]^{\frac{-1}{\rho}}$$

where u is utility in pure units, q_i is the i_{th} commodity with a share factor of β_i and ρ is related to the elasticity of substitution by

$$\rho = \frac{1-\sigma}{\sigma} < 1 \quad .$$

While the CES function remains highly popular, it is limited by the assumption of constant elasticities of substitution and it cannot model inferior goods. The transcendental logarithmic (Translog) functions for price and quantity developed by Christensen et al. (1975) provide a model free of these restrictions. However, there are still deficiencies. The price and quantity functions are approximated to the second order. Furthermore, demand functions fitted to time-series data are not homogeneous and probably not symmetric (Chung 1994, p.76 & 81). A Translog function can become unstable if it takes a homothetic and separable form, whereupon it collapses to a Cobb-Douglas function of Translog sub-aggregates (or the reverse).

Production function

Analogous to the three forms of utility function, there are three main types of neoclassical production functions: Cobb-Douglas, Constant Elasticity of Substitution (CES), transcendental logarithmic (Translog). In addition, the Leontief Input-Output table of proportions is a special form or schema for a neoclassical production function.

The most commonly used production function in computable general equilibrium modelling is Constant Elasticity of Substitution (CES). Following identification of the CES function by Arrow et. al. (1961), the CES production function is often shown as:

$$U(x_{1,}x_2) = A(\alpha x_1^{\rho} + (1-\alpha)x_2^{\rho})^{\frac{1}{\rho}}$$

where, for example, x_1 may be capital, x_2 labour and A the factor productivity (i.e. the technology multiplier). The elasticity of substitution between x_1 and x_2 is σ where $\sigma = \frac{1}{1-\rho}$ or, alternatively,

$$\rho = \frac{\sigma - 1}{\sigma} \quad .$$

It may be noted that it is possible to keep $U(x_{1,}x_2)$ as a fixed amount (an "isoquant") using different proportions of x_1 and x_2 . The degree to which one input can substitute for the other is governed by either of the parameters $\{\alpha, \rho\}$.

The CES production function is often nested so that pairs of composite inputs (goods or factors), prices and conditional demand functions lead to composite outputs. For example, labour and capital produce value added, and the combination of value-added with commodities A & B produces commodity C. Commodities A & B may have both been produced by other processes. The same sort of nesting is used for consumer utility: commodities X & Y are consumed, and this consumption together with savings produces the consumer utility.

The deficiencies of the CES form are similar to those discussed above in relation to utility. These are that the factor shares do not vary with total output and the elasticity of substitution is the same for all input pairs (Chung 1994, p.110).

The CES production function has three special cases, where the elasticity of substitution σ approaches one, zero or infinity.

As $\sigma \rightarrow 1$, $\rho \rightarrow 0$ and the CES function becomes the Cobb-Douglas production function:

$$U = A x_i^{\alpha} x_2^{1-\alpha}$$

When $\sigma \rightarrow 0$ the CES function becomes the Leontief function of perfect complements, where factors are contemporaneously used in fixed proportions $\{a, b\}$. No substitution is possible. Therefore, an isoquant q is L-shaped and the bottom left-hand corner of the isoquant is the minimum resource usage of each input to achieve the output level q .

$$U = Min[\frac{x_1}{a}, \frac{x_2}{b}] = q$$

When $\sigma \rightarrow \infty$, the CES production function becomes a simple linear formulation with substitution remaining feasible, albeit rarely observed in reality:

$$U = A\left(\sum_{i=1}^{n} x_i\right)$$

For example, the producer's behaviour is to minimise the total cost of inputs subject to the constraint of achieving a minimum output of q (the isoquant):

$$Min \; p_1 x_1 + p_2 x_2$$
subject to:
$$A(\alpha x_1^{\rho} + (1-\alpha) x_2^{\rho})^{\frac{1}{\rho}} = q$$

where p_1 and p_2 are the prices of the respective inputs.

Let $\delta_1 = \alpha$ and $\delta_2 = (1-\alpha)$

Taking logarithms of each side of the constraint to facilitate analysis, the Lagrangian equation becomes:

$$L = (p_1 x_1 + p_2 x_2) - \lambda[\rho \log(q/A) - \log(\delta_1 x_1^\rho + \delta_2 x_2^\rho)]$$

Setting the partial differentials $\{\frac{\partial L}{\partial x_1} = 0, \frac{\partial L}{\partial x_2} = 0, \frac{\partial L}{\partial \lambda} = 0\}$ to zero provides the equations:

$$\{p_1 + \frac{x_1^{\rho-1}\delta_1 \lambda \rho}{\delta_1 x_1^\rho + \delta_2 x_2^\rho} = 0,\ p_2 + \frac{x_2^{(-1+\rho)}\delta_2 \lambda \rho}{\delta_2 x_2^\rho + \delta_1 x_1^\rho} = 0\ ,\ -\rho \log[\frac{q}{A}] + \log[\delta_1 x_1^\rho + \delta_2 x_2^\rho] = 0\}$$

From the first two equations, the ratio of prices can be calculated as:

$$\frac{p_1}{p_2} = \frac{\delta_1 x_1^{\rho-1}}{\delta_2 x_2^{\rho-1}}$$

Upon rearranging into equations $\{x_{1,} x_2\}$:

$$\{x_1 = \left[\frac{x_2^{1-\rho}\delta_2 p_2}{\delta_1 p_1}\right]^{\frac{1}{1-\rho}}, x_2 = \left[\frac{x_1^{1-\rho} p_1 \delta_2}{\delta_1 p_2}\right]^{\frac{1}{1-\rho}}\}$$

Substituting each of these equations for $\{x_{1,} x_2\}$ in the CES constraint $A(\delta_1 x_1^\rho + \delta_2 x_2^\rho)^{\frac{1}{\rho}} = q$ and solving for the other provides the solutions:

$$\{x_1 = (\frac{q}{A}) k^{-1/\rho} (\frac{\delta_1}{p_1})^{\frac{1}{1-\rho}},\ x_2 = (\frac{q}{A}) k^{-1/\rho} (\frac{\delta_2}{p_2})^{\frac{1}{1-\rho}}\}$$

Where:

$$k = \left[\delta_1^{\frac{1}{1-\rho}} p_1^{\frac{-\rho}{1-\rho}} + \delta_2^{\frac{1}{1-\rho}} p_2^{\frac{-\rho}{1-\rho}} \right]$$

The CES function exhibits constant returns to scale, therefore a single unit numéraire cost function for demand of 1 unit c can be defined as the ratio of input value to output quantity. Here it is given at the minimum value:

$$c = \frac{p_1 x_1 + p_2 x_2}{q}$$

Substituting the equations above for $\{x_{1,} x_2\}$ in the unit cost function provides:

$$\{c = (\frac{1}{A}) k^{\frac{\rho-1}{\rho}}\}$$

Therefore, the factor $k^{\frac{-1}{\rho}}$ appearing in the equations for $\{x_{1,} x_2\}$ is given by:

$$k^{\frac{-1}{\rho}} = (A c)^{\frac{-1}{1-\rho}}$$

Substituting this in the conditional demand equations for $\{x_{1,} x_2\}$:

$$\{x_1 = q A^{\frac{\rho}{1-\rho}} \left[\frac{\delta_1 c}{p_1} \right]^{\frac{1}{1-\rho}}, \; x_2 = q A^{\frac{\rho}{1-\rho}} \left[\frac{\delta_2 c}{p_2} \right]^{\frac{1}{1-\rho}}\}$$

Using $\sigma = \frac{1}{1-\rho}$ for the elasticity of substitution between x_1 and x_2 ,

the conditional demand equations $\{x_i\}$ become functions of $\left[\frac{\delta_i c}{p_i} \right]^{\sigma}$:

$$\{x_1 = q A^{\sigma-1} \left[\frac{\delta_1 c}{p_1} \right]^{\sigma}, \; x_2 = q A^{\sigma-1} \left[\frac{\delta_2 c}{p_2} \right]^{\sigma}\}$$

Generalised multi-input CES production function

This provides a specification for the multi-input CES function used in many CGE models, where the share parameters $\{\delta_i\}$ are defined slightly differently to facilitate removal from the power function, for example, with $\{\delta_1^{\rho-1} = \alpha,\ \delta_2^{\rho-1} = (1-\alpha)\}$:

$$q = A\left(\sum_{i=1}^{n} \delta_i^{\rho-1} x_i^{\rho}\right)^{\frac{1}{\rho}} \quad \text{or} \quad q = A\left(\sum_{i=1}^{n} \delta_i^{\frac{1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

The numéraire unit cost function c for demand of 1 unit is:

$$c = \frac{1}{A}\left(\sum_{i=1}^{n} \delta_i\, p_i^{1-\sigma}\right)^{1/\sigma-1}$$

and the conditional demand function x_i for are relative prices of p_i is:

$$x_i = q\, A^{\sigma-1} \delta_i \left[\frac{c}{p_i}\right]^{\sigma}$$

Mathematica CGE model

Noguchi (1991; 1992) provides an elementary single period, multi-sector, multi-factor CGE model in Mathematica. The model has ten equations, which are retained at a high level for flexibility rather than being analytically reduced for efficiency. A modified version of Noguchi's model is provided below. It is possible to select either a Cobb-Douglas or CES for each of the consumer utility function and production function. There is also the facility for intermediate products.

There are two conditions for equilibrium. The first is that the total consumption of each commodity equals the total production:

$$C_i = X_i - \sum_{k=1}^{n} X_k m_{i,k}$$

Where $m_{i,k}$ is the proportion if the i^th commodity requisite for producing the X_k product.

The second is that the marginal rates of substitution of each commodity in consumption and production are identical, which means the prices of consumed commodities equals the prices of produced commodities.

```
Clear[equations, Assign, Equilibrium, X, w, U, p, Y, Co, vp];
TSectors = 2; TFactors = 2;
(**Production Function**)
(*Cobb Douglas Prodn*)
Do[X[i] = A[i] Product[L[i, j]^a[i, j], {j, TFactors}], {i, TSectors}];
(*CES Prodn*)
(*Do[X[i]=A[i] Sum[a[i,j]L[i,j]^-a[i,TFactors+1],{j,1,TFactors}]^(-
1/a[i,TFactors+1]),{i,TSectors}];*)
Do[w[i, j] = D[X[i], L[i, j]], {i, TSectors}, {j, Tfactors}];

(**Utility Function**)
(*Cobb Douglas*)
U = Product[Co[i]^s[i], {i, TSectors}];
(*CES*)
(*U=Sum[s[i]Co[i]^-s[TSectors+1],{i,1,TSectors}]^(-1/s[TSectors+1]);*)
(**Price Functions**)
Do[p[i] = D[U, Co[i]]/D[U, Co[1]], {i, TSectors}];
Y = Sum[p[i] Co[i], {i, Tsectors}];

(**No intermediate products**)
Do[Co[i] = X[i], {i, TSectors}];
Do[vp[i] = w[i, 1] p[i], {i, Tsectors}];

(**Intermediate products present**)
(*Table[Co[i]=X[i]-Sum[X[k] ic[i,k],{k,1,TSectors}],{i,TSectors}];
Table[vp[i]=w[i,1]( p[i]-Sum[p[k] ic[k,i],{k,TSectors}]),{i,TSectors}];*)
(**Constraints**)
equations = Flatten[{
    (**Resource Limits**)
    Table[Ltot[j] == Sum[L[i, j], {i, TSectors}], {j, TFactors}],
    (**Production Equilibrium Condition (relative marginal productivities
are equal**)
    Table[w[1, 1] w[i, j] == w[1, j] w[i, 1], {i, 2, TSectors}, {j, 2,
       Tfactors}],

    (**Marginal Value Productivities (same across all sectors**)
    Table[vp[1] == vp[i] , {i, 2, TSectors}]
    }];

(**Allocate Parameters**)
Assign[{unitspars_, prodpars_, intcoffs_, utilpars_, extpars_}] :=
  Join[
   Thread[Array[A, TSectors] -> unitspars],
   (*TFactors increased by 1 in prodpars for Production X CES
elasticities*)

   Thread[Flatten[Array[a, {TSectors, TFactors + 1}]] ->
Flatten[prodpars]],
   Thread[Flatten[Array[ic, {TSectors, TSectors}]] -> Flatten[intcoffs]],

   (*TSectors increased by 1 in utilpars for Utility CES elasticity*)
```

```
      Thread[Array[s, TSectors + 1] -> utilpars],
   Thread[Array[Ltot, TFactors] -> extpars]
   ];

(**Equilibrium Function**)
Equilibrium[pars_] := Solve[equations /. Assign[pars]];

(**Execute Equilibrium**)
pars = {{1, 1}, {{0.8, 0.2, 0.3}, {0.2, 0.8, 0.5}}, {{.1, .3}, {.4, .1}},
{0.6, 0.4, 0.5}, {400, 600}};
Assign[pars]
Equilibrium[pars]
```

Using Cobb-Douglas for each of the consumer utility and production functions, the output with no intermediate inputs becomes:

```
(**The result of Assign[mypars1] – dummy parameters have been removed**)
{A[1] → 1, A[2] → 1, a[1, 1] → 0.8, a[1, 2] → 0.2, a[2, 1] → 0.2, a[2, 2]
→ 0.8, s[1] → 0.6, s[2] → 0.4, Ltot[1] → 400, Ltot[2] → 600}

(**The result of Equilibrium[mypars1]**)
{{L[1, 1] → 342.857, L[1, 2] → 163.636, L[2, 1] → 57.1429, L[2, 2] →
436.364, vp[1] → 0.689991, vp[2] → 0.689991, Co[2] → 290.584, Co[1] →
295.71}}
```

The above formulation processes very quickly for both consumer utility and producer production functions having the Cobb-Douglas form, and where there is no intermediate inputs. However, if CES functions are used or intermediate inputs are allowed then execution becomes laborious.

Linearisation of conditional demand functions

As noted in the previous section, nonlinear CGE equations become very difficult to solve with direct optimisation techniques. Therefore, industrial models such as GTAP usually linearise the equations using a presolver algorithm. Gohin & Hertel (2003, p.5-10) show how linearisation rules may be used in such an algorithm with proportional changes of the form $\hat{A} = \frac{dA}{A}$:

$$
\begin{aligned}
\widehat{AB} &= \hat{A} + \hat{B} \\
\widehat{A/B} &= \hat{A} - \hat{B} \\
\widehat{B^{\sigma}} &= \sigma \hat{B} \\
\widehat{A+B} &= \frac{A}{A+B}\hat{A} + \frac{B}{A+B}\hat{B}
\end{aligned}
$$

For example, the analytically reduced nonlinear equation for x_1 in the CES function derived above is:

$$x_1 = q\,A^{\sigma-1}\left[\frac{\delta_1 c}{p_1}\right]^{\sigma}$$

Upon transformation using the linearisation rules, this becomes the simple linear equation:

$$\hat{x}_1 = \hat{q} + \sigma(\hat{\alpha} + \hat{c} - \hat{p}_1) + (\sigma - 1)\hat{A}$$

It is interesting to note that this equation shows four dynamic effects on demand:

$$\begin{array}{ll} \hat{q} & \textit{expansion effect (change of output level)} \\ \sigma(\hat{c}-\hat{p}_1) & \textit{substitution effect (change of relative prices)} \\ \sigma\,\hat{\alpha} & \textit{factor biased technological change} \\ (\sigma-1)\hat{A} & \textit{neutral technological change} \end{array}$$

A2.2 Economic Equivalence of Competitive Markets and Social Planning

Sargent (1987) and Ljungqvist & Sargent (2000) have described the discrete time analysis of non-linear stochastic neoclassical growth in great detail. Uhlig (1999, pp.7-12) uses this benchmark model to demonstrate that the same allocation of resources occurs under competitive equilibrium and social planners welfare optimisation.

Uhlig's formulation is elegant consisting of preferences, technologies, endowments and information as follows.

Preferences

In the neoclassical growth model, utility of the representative agent is a time discounted function of the expectation of consumption in the presence of risk aversion η :

$$U = E[\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\eta} - 1}{1-\eta}]$$

where:
C_t consumption
β the time discount factor
η the coefficient of risk aversion

Technologies

Technology is represented with a Cobb-Douglas production function as follows:

$$C_t + K_t = Z_t K_{t-1}^{\rho} N_t^{1-\rho} + (1-\delta) K_{t-1}$$

where:
K_t capital
N_t labour
ρ share of capital and $0 < \rho < 1$
δ depreciation rate and $0 < \delta < 1$
Z_t total factor productivity

with Z_t evolving according to the equation as::

$$\log Z_t = (1-\psi) \log \bar{Z} + \psi \log Z_{t-1} + \epsilon_t$$

where:
ϵ $i.i.d. N(0;\sigma^2)$
ψ parameter and $0 '<' \psi < 1$
$\bar{Z}$ parameter

Endowments

The representative agent is endowed with:

N_t *each period has one unit of time so* $N_t = 1$
K_{-1} *the initial capital of the time period before* $t = 0$

Information

The variables C_t, N_t and K_t are chosen according to information available at each time period t.

Social planners problem

Social planners objective function is maximisation of the Preferences utility function subject to the Technologies constraint, with the consumer as representative agent:

$$\max_{(C_t, K_t)_{t=0}^{\infty}} E\left[\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\eta}-1}{1-\eta}\right]$$

$$\begin{aligned}
&s.t. \quad K_{-1}, Z_0 \\
&C_t + K_t = Z_t K_{t-1}^{\rho} N_t^{1-\rho} + (1-\delta) K_{t-1} \\
&\log Z_t = (1-\psi) \log \bar{Z} + \psi \log Z_{t-1} + \epsilon_t
\end{aligned}$$

which has the Lagrangian function:

$$L = \max_{(C_t, K_t)_{t=0}^{\infty}} E\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\eta}-1}{1-\eta} - \lambda_t \left(C_t + K_t - Z_t K_{t-1}^{\rho} - (1-\delta) K_{t-1}\right)\right)\right]$$

The partial differential Euler equations:

$$\begin{aligned}
&\frac{\partial L}{\partial \lambda_t} : 0 = C_t + K_t - Z_t K_{t-1}^{\rho} - (1-\delta) K_{t-1} \\
&\frac{\partial L}{\partial C_t} : 0 = C_t^{-\eta} - \lambda_t \\
&\frac{\partial L}{\partial K_t} : 0 = -\lambda_t + \beta \; E_t\left[\lambda_{t+1} \left(\rho Z_{t+1} K_t^{\rho-1} + (1-\delta)\right)\right]
\end{aligned}$$

provide first order condition approximations. The Kuhn-Tucker limiting condition is introduced by summing to T rather than infinity ∞ and substituting C_t with:

$$C_t = Z_t K_{t-1}^{\rho} - (1-\delta) - K_t$$

A transversality condition prevents unstable solutions. This is obtained by setting the differential of the Kuhn-Tucker limiting condition to zero, as follows:

$$0 = \lim_{T \to \infty} E_0 [\ \beta^T\ C_T^{-\eta}\ K_T\ ]$$

In order to provide a set of equations from which a steady state solution can be determined, Lucas' asset pricing equation can be used (Lucas 1978):

$$1 = E_t [\beta\ (\frac{C_t}{C_{t+1}})^{\eta}\ R_{t+1}]$$

where R_{t+1} is the return on the capital in purchasing an additional unit of next year's resources.

Collecting the equations for a steady state solution:

$$\begin{aligned} C_t &= Z_t\ K_{t-1}^{\rho} + (1-\delta)\ K_{t-1} - K_t \\ R_t &= \rho\ Z_t\ K_{t-1}^{\rho-1} + (1-\delta) \\ 1 &= E_t [\beta\ (\frac{C_t}{C_{t+1}})^{\eta}\ R_{t+1}] \\ \log\ Z_t &= (1-\psi)\ \log\ \bar{Z} + \psi\ \log\ Z_{t-1} + \epsilon_t \end{aligned}$$

which can be rearranged and restated without time indices as:

$$\begin{aligned} \bar{C} &= \bar{Z}\ \bar{K}^{\rho} + (1-\delta)\ \bar{K} - \bar{K} \\ \bar{R} &= \rho\ \bar{Z}\ \bar{K}^{\rho-1} + (1-\delta) \\ 1 &= \beta\ \bar{R} \end{aligned}$$

or alternatively as:

$$\begin{aligned} \bar{R} &= \frac{1}{\beta} \\ \bar{K} &= (\frac{\rho\ \bar{Z}}{\bar{R} - 1 + \delta})^{\frac{1}{1-\rho}} \\ \bar{Y} &= \bar{Z}\ \bar{K}^{\rho} \\ \bar{C} &= \bar{Y} - \delta\ \bar{K} \end{aligned}$$

which may further be reduced to just one equation in K_t or to a popular formulation in two variables C_t and K_{t-1} .

Competitive equilibrium

Analogous to the social planners objective function, competitive equilibrium in markets needs to be defined in terms of the market powers. For example, if competitive equilibrium is the sequence:

$$(C_t, N_t, K_t, R_t, W_t)_{t=0}^{\infty}$$

where, in addition to the previous definitions, W_t is market wages and R_t is returns.

The representative agent maximises the same Preferences utility equation as the social planner, albeit from a suppliers perspective so the superscript (s) is used in $K_t^{(s)}$ and $N_t^{(s)}$:

$$\max_{(C_t, K_t^{(s)})_{t=0}^{\infty}} E[\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\eta}-1}{1-\eta}]$$

$$s.t. \quad N_t^{(s)},$$
$$C_t + K_t^{(s)} = W_t N_t^{(s)} + R_t K_{t-1}^{(s)}$$

and the intertemporal budgetary restraint that, over time, returns will pay for capital (and any borrowings will be paid for from returns) such that at time ∞ there is neither surplus capital nor borrowings (known as the “no-Ponzi-game condition”):

$$0 = \lim_{t \to \infty} E_0 \Pi R_t^{-1} K_t$$

The representative agent, the firm, demanding labour will pay wages and receive returns in the equilibrium function $(W_t, R_t)_{t=0}^{\infty}$. Using the superscript (d) for demand as we did (s) for supply:

$$\max_{K_{t-1}^{(d)}, N_t^{(d)}} Z_t \left(K_{t-1}^{(d)}\right)^{\rho} \left(N_t^{(d)}\right)^{(1-\rho)} + (1-\delta)\, K_{t-1}^{(d)} - W_t\, N_t^{(d)} - R_t\, K_{t-1}$$

where Z_t is exogenous :
$\log Z_t = (1-\psi) \log \bar{Z} + \psi \log Z_{t-1} + \epsilon_t$, ϵ_t is $i.i.d.\, N(0;\sigma^2)$

Markets clear as follows, although Walras' Law is that only two of these three equations are needed:

$$N_t^{(d)} = N_t^{(s)} = N_t \quad \text{in the labour market}$$
$$K_{t-1}^{(d)} = K_{t-1}^{(s)} = K_{t-1} \quad \text{in the capital market}$$
$$C_t + K_t = Z_t\, K_{t-1}^{\rho} + (1-\delta)\, K_{t-1} \quad \text{in the goods market}$$

The demand curves for wages and capital return as first order approximations are:

$$W_t = (1-\rho)\, Z_t \left(K_{t-1}^{(d)}\right)^{\rho} \left(N_t^{(d)}\right)^{-\rho}$$
$$R_t = \rho\, Z_t \left(K_{t-1}^{(d)}\right)^{\rho-1} \left(N_t^{(d)}\right)^{1-\rho} + (1-\delta)$$

The “no-Ponzi-game” condition can be shown to be equivalent to the social planners problem transversality condition.

Dropping the (d) superscript, the Cobb-Douglas function is:

$$Y_t = Z_t\, K_{t-1}^{\rho}\, N_t^{1-\rho}$$

Applying the Cobb-Douglas function to the Euler equations above:

$$W_t\, N_t = (1-\rho)\, Y_t$$
$$R_t\, K_{t-1} = \rho\, Y_t + (1-\delta)\, K_{t-1}$$

Therefore, the income share of labour is just wages and the income share of capital is the return on capital plus depreciation.

The rate of return r_t is given by:

$$\begin{aligned} r_t &= R_t - 1 \\ &= \rho \frac{Y_t}{K_{t-1}} - \delta \end{aligned}$$

For the representative agent the Lagrangian is:

$$L = \max_{(C_t, K_t)_{t=0}^{\infty}} E\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\eta} - 1}{1-\eta} - \lambda_t \left(C_t + K_t - W_t - R_t K_{t-1}\right)\right)\right]$$

Again, the partial differential Euler equations provide first order condition approximations:

$$\begin{aligned} \frac{\partial L}{\partial \lambda_t} &: 0 = C_t + K_t - W_t - R_t K_{t-1} \\ \frac{\partial L}{\partial C_t} &: 0 = C_t^{-\eta} - \lambda_t \\ \frac{\partial L}{\partial K_t} &: 0 = -\lambda_t + \beta \; E_t[\lambda_{t+1} R_{t+1}] \end{aligned}$$

Collecting the equations and substituting for W_t and R_t provides the same equations as for the social planners problem:

$$\begin{aligned} C_t &= Z_t K_{t-1}^{\rho} + (1-\delta) K_{t-1} - K_t \\ R_t &= \rho Z_t K_{t-1}^{\rho-1} + (1-\delta) \\ 1 &= E_t\left[\beta \left(\frac{C_t}{C_{t+1}}\right)^{\eta} R_{t+1}\right] \\ \log Z_t &= (1-\psi) \log \bar{Z} + \psi \log Z_{t-1} + \epsilon_t \end{aligned}$$

From the preceding analysis, Uhlig (1999, p.13) concludes:

> These are the same equations as for social planners problem! Thus, whether one studies a competitive equilibrium or the social planners problem, one ends up with the same allocation of resources.

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i Uhlig uses capital letters to denote variables and small letters to denote log-deviations. This notation is pursued in this analysis but is different to the usual use of capital letters to represent aggregate variables and small letters to represent individual variables.

Appendix 3 Input Output Tables

A3.1 Input Output tables from the Australian Bureau of Statistics

Input output tables can be compiled as either industry-by-industry or product-by-product. The Australian Bureau of Statistics (2000, Chapter 9; 2008) prefers the former because detailed information on inputs is not normally available for products, the assumption that goods have the same input structure wherever they are produced can be expensive to resolve as SNA93 recommends and the difference from a product-by-product table is only as a result of any secondary production. Therefore, industry-by-industry tables are suitable for the analysis of changes in factor costs, productivity, taxes and imports

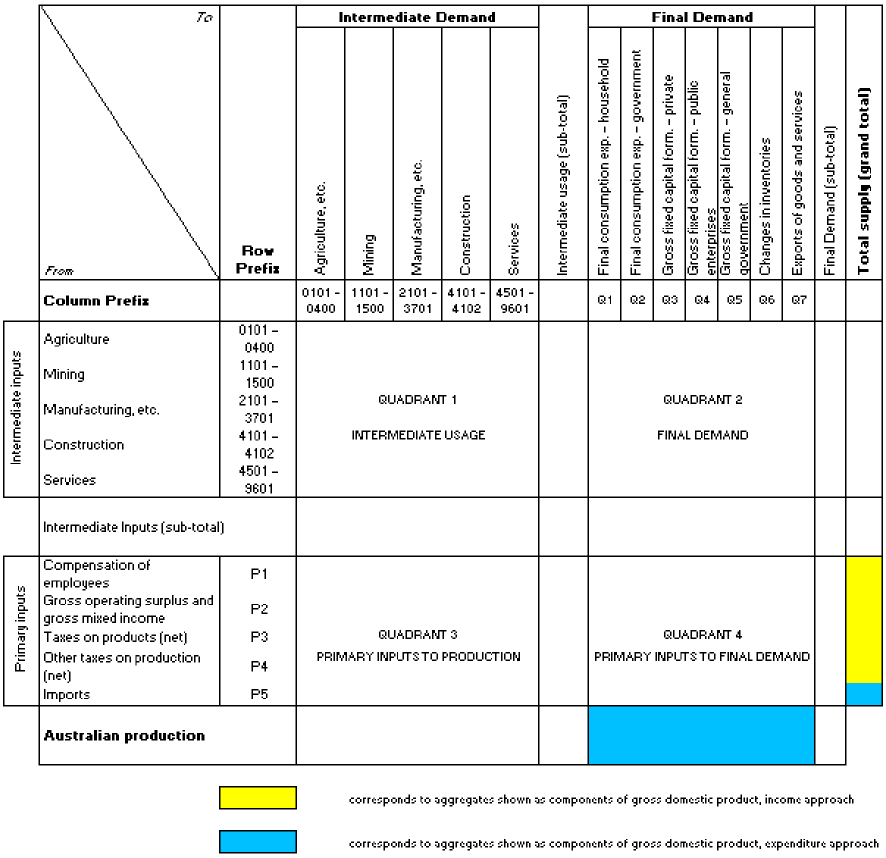

Illustration 37: Australian Bureau of Statistics Input Output TableSource: Table 9.1 Industry-by-Industry Matrix, ABS 2000 Paragraph 9.23, with direct allocation of inputs

The Illustration above shows an industry-by-industry input output matrix. Coefficients taken by row represent the distribution of an industry's output. Columns provide the sources of inputs for an industry. The total of outputs in a row is equal to the sum of its inputs in a column, including gross operating surplus.

Quadrant 1 is called the inter-industry quadrant because it shows the intermediate goods and services traded between industries. Each coefficient represents the proportion of industry i's output used by industry j for its current domestic production.

Quadrant 2 shows the distribution of output for consumption by the public and private sector and individuals. It also includes changes in inventories. Quadrants 1 and 2 together show the total usage of the goods and services supplied by each industry, which is also equal to total supply.

Quadrant 3, the primary inputs, represents employee wages, profits and imports, which are not part of the output of current domestic production in the same way as intermediate goods and services traded by industries. The sum of the inputs in Quadrants 1 and 3 produce the total outputs, that is the total supply, of each industry.

In the Illustration, imports are shown as a distinct row in the Value Added area across Quadrants 3 and 4. This is called a direct allocation of imports. It assumes that each using sector draws on imports and domestic production in the average proportions established for the total supply of each product.

Technology matrix

It is also possible to have an indirect allocation of imports where the total output from each industry includes both Australian and imported content. Imports are recorded as adding to the supply of the sector to which they are primary and then this supply is allocated along the corresponding row of the table.

This means that the coefficients reflect both domestic and imported supply. It permits substitution between imports and domestic production without affecting the size of the coefficients.

As materials coming into the system must be equal to the flows of materials out of the system (plus any material accumulated within the system during the period) then the law of conservation of mass is met.

Therefore, coefficients built from total dollar requirements also reflect the actual technological relationship between industries. The same applies to energy intensities and greenhouse emissions. For this reason, an input output table with indirect allocation of imports is called a technology matrix.

However, the technology assumption implicitly requires that in the short run products of the same type are homogeneous with the same input structure wherever produced, there are no changes in relative input prices (unless specific behavioural models are included to separately modify the coefficients), technological structures are fixed, output is a linear function of inputs, so there is neither increasing returns to scale nor other constraints in the system and products are made in fixed proportions to each other.

Symmetric input output tables

Symmetric Leontief-type input output matrices are produced from the above Sources and Uses tables, as either product by product or industry by industry tables.

Direct Requirements Coefficients

The matrix of Leontief $A(a_{ij})$ coefficients is called the direct requirements coefficients matrix. It can be used to calculate input requirements for any given output of an industry. In all Australian Bureau of Statistics input output tables, 100% always represents total Australian production. This is notwithstanding whether imports are allocated directly or indirectly.

Total Requirements Coefficients

The matrix of Leontief Inverse $(1-A)^{-1}$ coefficients is called the total requirements coefficients matrix. Each coefficient represents the units of industry i's output required both directly and indirectly for industry j to produce 100 units of output. It needs to be remembered that the answers obtained by applying these coefficients are in terms of the output of industries and include the flows of products not primary to these industries.

It is also important to recognise the way imports have been allocated. With direct allocation of imports the total requirements coefficients in Quadrant 1 refer only to the domestic production. Any use of the total requirements matrix necessarily has the caveat assumption that imports are unchanged.

Indirect allocation of competing imports means that the total requirements coefficients of Quadrant 1 implicitly include the usage of both imported and domestically produced products. Therefore, substitution can take place between imports and domestic production without affecting the size of the coefficients. However, the implicit assumption is that the usage of a product by a particular industry remains unchanged. There is also a need to complete a separate assessment of the proportion satisfied by import.

Primary data tables of Sources and Uses

The input data from which symmetric input output matrices are derived from Sources and Uses tables for the economy as a whole. These tables show the total resources in terms of domestic output and imports, and the uses of goods and services in terms of intermediate consumption, final consumption, gross capital formation and exports. They also provide information on the generation of income from production.

Supply Table

$$Supply\ x\ Product\ x\ Industry\ \&\ Imports$$

The columns represent output of domestic industries and imports. Rows contain the output of products primary to these industries. Typically the matrix is predominantly diagonal because industries mainly produce those products primary to it.
Table 1 of Australian Bureau of Statistics cat. no. 5209.0.55.001 Australian National Accounts: Input-Output Tables - Electronic Publication provides supply by product group by industry and imports.

Use Table

$$Input\ x\ Industry\ \&\ Final\ Use\ Category\ \&\ Supply\ x\ Product\ Group$$

Rows contain product groups and primary inputs, whether locally produced or imported. Rows designated by prefix ‘P’ show the primary inputs which have been purchased by industries and by final demand.

Columns show the composition of intermediate and primary inputs into each industry and final demand category.

ABS cat. no. 5209.0.55.001 Australian National Accounts: Input-Output Tables - Electronic Publication provides the Use Table as “Table 2”. This table comprises indirect allocation of imports, basic prices and records intra-industry flows across 109 industries. As imports are neither directly nor indirectly allocated, it is not suitable for calculating Leontief and Leontief Inverse matrices.

Imports table

This table is used to reallocate imports, which may be substituted from domestic production, into the columns to which they would have been primary if they were produced in Australia. These are called competing imports.

Imports that are not produced in Australia, called complementary imports, are recorded in separate columns. Coffee and natural rubber are examples of complementary imports. Imports for re-export are treated the same way.

Margins table

This table relates the basic price and purchasers’ price of all flows in the use table.

A3.2 Leontief Matrix

Mathematical Derivation

The output of the Selling Sectors $X_1, X_{2,} \ldots X_n$ is given by:

$$X_i = z_{i1} + z_{i2} + \ \dots \ + z_{ii} + Y_i$$

Where the variables are defined as:

$$\begin{aligned} X_i &= output\ of\ Selling\ Sector\ i \\ z_{ij} &= output\ of\ Selling\ Sector\ i\ becoming\ inflow\ of\ Purchasing\ Sector\ j \\ Y_i &= final\ demand\ of\ Selling\ Sector\ i \end{aligned}$$

In addition to purchasing goods from the Selling Sectors, the Purchasing Sectors also buy imports and value adding sources as follows:

$$\begin{aligned} L &= labour\ services \\ N &= \left\{ \begin{array}{l} government\ services\ (paid\ for\ as\ taxes) \\ +\ capital\ costs\ (interest\ payments) \\ +\ land\ (rental\ payments) + entrepreneurship\ (profits) \end{array} \right\} \\ M &= imports \end{aligned}$$

So the Purchasing Sectors have total inflows of:

$$P_j \ = \ z_{1j} + z_{2j} + \dots + z_{nj} + L_j + N_j + M_j$$

where Pj is the Total Australian Production (after value added items)

The Leontief "Direct Requirement Coefficients" a_{ij} are given by:

$$a_{1j} \ = \ z_{1j} / P_j \quad \text{etc, so} \quad a_{ij} \ = \ z_{ij} / P_j$$

Where:

$$\begin{aligned} P_j &= input\ of\ Purchasing\ Sector\ j \\ L_j &= labour\ of\ Purchasing\ Sector\ j \\ N_j &= other\ value\ added\ services \\ M_j &= imports\ of\ Purchasing\ Sector\ j \end{aligned}$$

Since $inflows = outflows,\ X_i = P_j$ and therefore over all rows i and columns j:

$$z_{i1} + z_{i2} + \ldots + z_{in} + Y_i = z_{1j} + z_{2j} + \ldots z_{nj} + L_j + N_j + M_j$$

The z_{ij} elements cannot be eliminated against the reverse z_{ji} elements because $z_{ij} \neq z_{ji}$. For example, the value of steel that goes into a car is not equal to the value of cars that go to make steel. However, from the definition of gross profit $GP = Sales - Raw\ Materials$, we know that the value of all materials purchased by a firm for its output is only different to the sales value by gross profit (which in turn, represents the value add of $labour + overheads + profit$). Therefore the sum of the products $z_{i1} + z_{i2} + \ldots + z_{in}$ is logically equal to $z_{1j} + z_{2j} + \ldots + z_{nj}$. So we can eliminate each side respectively leaving:

$$Y_1 = L_1 + N_1 + M_1$$

and upon rearranging and eliminating subscripts to indicate aggregates

$$L + N = Y - M$$

and since:

$$Y = C + I + G + E$$

then:

$$L + N = C + I + G + (E - M)$$

Where:

$$\begin{aligned} C &= final\ consumer\ consumption \\ I &= investment\ consumption \\ G &= government\ consumption \\ E &= exports \end{aligned}$$

which means:

$$\left\{ \begin{matrix} \text{Factor Payments in} \\ \text{the economy for labour,} \\ \text{rent, interest, profit,} \\ \text{indirect taxes, etc.} \end{matrix} \right\} = \left\{ \begin{matrix} \text{Total spent on} \\ \text{consumption,} \\ \text{investment} \\ \text{and net exports} \end{matrix} \right\}$$

In other words,

$$\text{Gross National Income} = \text{Gross National Product}$$

and

$$\left\{ \begin{matrix} \text{Gross National Product} \\ \text{at Factor Prices} \\ \text{including Indirect Taxes} \end{matrix} \right\} = \left\{ \begin{matrix} \text{Gross National Product} \\ \text{at Market Prices} \end{matrix} \right\}$$

Leontief Inverse

On a per unit basis:

$$a_{ij} = z_{ij} / P_j$$

Where:

$$\begin{aligned} P_j &= \left\{ \begin{matrix} \text{the column total for Australian Production after} \\ \text{value added items such as wages, taxes \& profits} \end{matrix} \right\} \\ a_{ij} &= \text{technical coefficients} \end{aligned}$$

so

$$X_j = a_{j1} X_1 + a_{j2} X_2 + \ldots + a_{jn} X_n + Y_j$$

and therefore:

$$X_j - a_{j1} X_1 - a_{j2} X_2 - a_{jj} X_j \ldots - a_{jn} X_n = Y_j$$

upon rearranging:

$$-a_{j1}X_1 - a_{j2}X_2 + (1 - a_{jj}X_j) \ldots - a_{jn}X_n = Y_j$$

to provide the matrix:

$$(I - A)X = Y$$

and the Leontief Inverse is given:

$$X = (I - A)^{-1} Y$$

A-1 can be rather tediously calculated using the formula:

$$A^{-1} = (1 / |A|)(adj\ A)$$

where:

$$
\begin{aligned}
A_{ij} &= \textit{the independence coefficients (cofactors) of element } a_{ij} \\
A_{ij} &= (-1)(i + j)|a_{ij}| \\
|A| &= \textit{the determinant of } A \\
adj\,A &= \left\{ \begin{array}{l} \textit{the adjoint whose element } (i,j) \textit{ is the cofactor of the element } (i,j) \\ \textit{of the transpose of } A \textit{ where the minor } |a_{ij}| \textit{ is the determinant of} \\ \textit{the square that remains when row } i \textit{ \& column } j \textit{ are removed} \end{array} \right\}
\end{aligned}
$$

To avoid this calculation, a computer can be used or $(I - A)^{-1}$ approximated by using the first few elements of a power series:

$$(I - A)^{-1} = (I + A + A^2 + A^3 + \ldots)$$

As all parts of A are less than 1, the elements of the power series quickly approach zero (for example $0.3^2 = 0.09$), then it is usually only necessary to iterate 3 times to capture most of the effects.

The Leontief Inverse derived above:

$$X = (I - A)^{-1} Y$$

can be interpreted as:

$$X_i = - A_{i1} Y_1 - A_{i2} Y_2 - A_{ij} Y_j \ \ldots - A_{in} Y_n$$

or, alternatively, as:

$$X_i = f(Y_1, Y_2, Y_j, \ldots Y_n)$$

Therefore, every one dollar of final demand for industries $Y_1, Y_2, Y_j, \ldots Y_n$ leads to the output of each sector i (X_i) in proportion to the A_{ij} independence coefficients.

Calculation of the Leontief and Leontief Inverse matrices

Table 5 of Australian Bureau of Statistics cat. no. 5209.0.55.001 Australian National Accounts: Input-Output Tables - Electronic Publication provides an Industry-by-Industry flow table with direct allocation of imports and basic prices across 109 industries. The technical coefficients (Leontief A) matrix can be derived from it by dividing each number in the table by the column total of Australian Production (T2), which is prior to imports (P2). The Leontief Inverse matrix $(I-A)^{-1}$ can be derived from A by dividing each coefficient of A by 100 and calculating the necessary inverse $(I-A)^{-1}$.[i]

In the case of direct allocation of imports, the Leontief A matrix derived from Table 5 can be compared to ABS Table 6 and the Leontief Inverse to ABS Table 7. In addition, the output vector Y is provided by the column Final Uses (T5). From this, the input vector X can be calculated as the matrix multiplication of the total requirements coefficients matrix $(I-A)^{-1}$ and the output vector Y.[ii]

Similar tables to the foregoing are provided for the main case of indirect allocation of imports. Table 8 provides an Industry-by-Industry flow table with indirect allocation of imports and basic prices, across 109 industries. The

Leontief A matrix can be compared to ABS Table 9 and the Leontief Inverse to ABS Table 10.[iii]

It needs to be noted that the Leontief A matrix is only for Industry Uses in Tables 6 and 9, for direct and indirect allocation of imports respectively. The Leontief A matrix excludes Intermediate Input rows in the ABS tables, which aggregates with the Leontief A matrix of Industry Uses to produce Australian Production Compensation of employees (P1), Gross operating surplus & mixed income (P2), Taxes less subsidies on products (P3) and Other taxes less subsidies on production (P4).

The Leontief A matrix also excludes the following Final Use columns in the ABS tables, which aggregates with the Leontief matrix of Industry Uses to produce total supply Final consumption expenditure of the household (Q1) and government (Q2) sectors, Gross fixed capital formation of private (Q3), public enterprise (Q4) and general (Q5) government sectors, Changes in inventories (Q6) and Exports (Q7).

A3.3 World Multiregional Input Output Model

The presentation of an IRIO model is quite different to that of an MRIO model. An IRIO model is conceptually an expansion of the regional Z matrix. For example, a two region model (L & M) would have money flows represented as:

$$Z = \begin{bmatrix} Z^{LL} & Z^{LM} \\ Z^{ML} & Z^{MM} \end{bmatrix}$$

Analogously, the IRIO coefficient matrix is:

$$A = \begin{bmatrix} A^{LL} & A^{LM} \\ A^{ML} & A^{MM} \end{bmatrix}$$

where, as usual:

$$a_{ij}^{LM} = \frac{z_{ij}^{LM}}{X_j^M} \quad \text{and} \quad X = (1-A)^{-1} Y \quad .$$

In contrast to the full integration of an IRIO model, the MRIO approach seeks to simplify the modelling paradigm by representing data in regional tables and interregional trade tables.

MRIO Regional Model

In lieu of IRIO's regional inputs coefficient matrix A^{LL} , a MRIO model uses a regional technical coefficients matrix A^{L} . In essence, this ignores the source of the imported inputs. MRIO makes the assumption that inputs per unit of output are constant across regions at a fine level of industrial classification (called the “product-mix approach”).

The input coefficient matrix of regions is assumed to be the average of the detailed coefficients of the supra-entity (in our case the world) weighted by the proportions of sub-sector outputs to total sector output in each region.

Miller & Blair (1985, Appendix 3.2, pp.91-3) describe the method to build trade tables as follows:

Total supply of commodity i in region M is:

$$T_i^M = Z_i^{1M} + Z_i^{2M} + \ldots + Z_i^{LM} + \ldots + Z_i^{pM}$$

$$T_i^M = \sum_{L=1}^{p} z_i^{LM}(L \neq M) + z_i^{MM}$$

where the total production of commodity i by region L is:

$$X_i^L = \sum_{M=1}^{p} z_i^{LM}$$

and the amount supplied from within the region is z_i^{MM} .

Since the interregional trade coefficients are defined as the proportion of all commodity i used in M that comes from L :

$$c_i^{LM} = \frac{z_i^{LM}}{T_i^M}$$

then rearranging and substituting z_i^{LM} into the above leads to:

$$X_i^L = \sum_{M=1}^{p} c_i^{LM} T_i^M$$

As the demand for commodity i in region M is:

$$T_i^M = \sum_{j=1}^{n} a_{i\,j}^M X_j^M + Y_i^M \quad ,$$

substituting T_i^M into X_i^L leads to:

$$X_i^L = \sum_{M=1}^{p} c_i^{LM} \left(\sum_{j=1}^{n} a_{i\,j}^M X_i^M + Y_i^M\right)$$

Using matrix notation:

$$X_i^L = \sum_{M=1}^{p} \hat{C}^{LM} \left(A^M . X^M + Y^M\right)$$

$$X = C\left(A.X + Y\right)$$

so:

$$X = \left(I - CA\right)^{-1} CY$$

where the expanded matrices definitions are:

$$A = \begin{bmatrix} A^1 \ldots & 0 \ldots & 0 \\ \vdots & \vdots & \vdots \\ 0 \ldots & A^M \ldots & 0 \\ \vdots & \vdots & \vdots \\ 0 \ldots & 0 \ldots & A^p \end{bmatrix}, \quad A^M = \begin{bmatrix} a^M_{i1} & \ldots & a^M_{1n} \\ \vdots & & \vdots \\ a^M_{n1} & & a^M_{nn} \end{bmatrix} ,$$

$$C = \begin{bmatrix} \hat{C}^{11} \ldots & \hat{C}^{1M} \ldots & \hat{C}^{1p} \\ \vdots & \vdots & \vdots \\ \hat{C}^{L1} \ldots & \hat{C}^{LM} \ldots & \hat{C}^{Lp} \\ \vdots & \vdots & \vdots \\ \hat{C}^{p1} \ldots & \hat{C}^{pM} \ldots & \hat{C}^{pp} \end{bmatrix}, \quad \hat{C}^{LM} = \begin{bmatrix} C^{LM}_1 & 0 & \ldots & 0 \\ 0 & C^{LM}_2 & & \\ \vdots & & & \\ 0 & & & C^{LM}_n \end{bmatrix}$$

$$C^{LM} = \begin{bmatrix} c^{LM}_1 \\ \vdots \\ \vdots \\ c^{LM}_n \end{bmatrix}, \quad c^{LM}_i = \frac{z^{LM}_i}{T^M_i}, \quad X^L = \begin{bmatrix} X^L_1 \\ \vdots \\ \vdots \\ X^L_n \end{bmatrix}, \quad X^M {}'=' \begin{bmatrix} X^M_1 \\ \vdots \\ \vdots \\ X^M_n \end{bmatrix}, \quad Y^M = \begin{bmatrix} Y^M_1 \\ \vdots \\ \vdots \\ Y^M_n \end{bmatrix}$$

Technological change

Solow's technological change

Robert M. Solow (1957) separated the effects of technological change and capital in the aggregate production function of the United States. In 1987, Solow was awarded the Nobel Prize in Economics "for his contributions to the theory of economic growth".

Solow found that aggregate American data 1909-1949 demonstrated that technical change in the period was on average neutral, the production function shifted upwards at 0.5%pa for the first two decades and 2%pa for the second two decades, gross output per man doubled over the period, with 87.5% attributable to technological change and 12.5% due to increased use of capital and after correcting for technological change, the aggregate production function suggests diminishing returns.

Solow assumed that factors are paid their marginal products such that:

$$Q = f(K, L; t)$$

He further assumed that technical change A is neutral because marginal rates of substitution remain unaltered even though the production function shifts then:

$$Q = A\, f(K, L)$$

Differentiating with respect to time and dividing by Q:

$$\begin{aligned}
\dot{Q} &= \dot{A} f(K,L) + A \dot{f}(K,L) \\
&= \dot{A} f(K,L) + A \left(\dot{K} \frac{\partial f}{\partial K} + \dot{L} \frac{\partial f}{\partial L} \right) \\
\frac{\dot{Q}}{Q} &= \frac{\dot{A}}{A} + \frac{A}{Q} \left(\dot{K} \frac{\partial f}{\partial K} + \dot{L} \frac{\partial f}{\partial L} \right) \\
&= \frac{\dot{A}}{A} + w_k \frac{\dot{K}}{K} + w_l \frac{\dot{L}}{L} \\
&\textit{where}: \\
w_k &= \left(\frac{AK}{Q}\right) \frac{\partial f}{\partial K} \\
w_l &= \left(\frac{AL}{Q}\right) \frac{\partial f}{\partial L}
\end{aligned}$$

Furthermore, dividing by labour L and simplifying provides:

$$\begin{aligned}
&\frac{\dot{q}}{q} = \frac{\dot{A}}{A} + w_k \frac{\dot{k}}{k} \\
&\textit{where}: \\
&\frac{Q}{L} = q \\
&\frac{K}{L} = k \\
&w_l = 1 - w_k
\end{aligned}$$

Solow assumed that constant returns to scale was unavoidable. This being the case:

$$\begin{aligned}
Q &= A\, f(K,L) \\
q &= A\, f(k,l)
\end{aligned}$$

Using labour and capital statistics from *The Economic Almanac* , Solow reconstructed A by replacing time derivatives with year-to-year changes as follows:

$$\frac{\Delta A(t)}{A(t)} = \frac{\Delta q}{q} - w_k \frac{\Delta k}{k}$$

From his empirical investigation, Solow determined that a Cobb-Douglas log linear function best fitted the plot of data:

$$\log q = \alpha + \beta \log k$$

In order to determine a generic relationship, the static aggregate Cobb-Douglas production function is developed to a continuous function and thence to a discrete function:

$$\begin{aligned} y &= \Pi \, (A_i x_i)^{\beta_i} \\ &= (A_1 x_1)^{\beta_1} \, . \, (A_2 x_2)^{\beta_2} \, . \, (A_3 x_3)^{\beta_3} \ldots \end{aligned}$$

$$\begin{aligned} &where: \\ &y &&= output \\ &x_i &&= input \\ &A_i &&= productivity\ effect\ that\ augments\ x \\ &\sum \beta_i &&= 1 \end{aligned}$$

Taking the natural logarithm:

$$\begin{aligned} \ln y &= \ln(A_1 x_1)^{\beta_1} + \ln(A_2 x_2)^{\beta_2} + \ln(A_3 x_3)^{\beta_3} \ldots \\ &= \ln A_1^{\beta_1} + \ln A_2^{\beta 2} + \ln A_3^{\beta 3} \ldots + \ln x_1^{\beta_1} + \ln x_2^{\beta_2} + \ln x_3^{\beta 3} + \ldots \\ &= \Sigma \, \beta_i \, \ln A_i + \Sigma \, \beta_i \, \ln x_i \end{aligned}$$

According to Solow (1957, p.313) the learning effect is reflected with the exponential:

$$A_i = e^{r_i t}$$

This may be approximated by the discrete function $A(t) = (1 + r_i)^t$ so:

$$
\begin{aligned}
\sum \beta_i \ln A_i &= \sum \beta_i r_i t \\
&= t \sum \beta_i r_i \\
&= t \beta_0 \\
&\textit{where}: \\
\beta_0 &= \sum \beta_i r_i \\
&= \textit{measure of the growth of technology (i.e. technological progress)}
\end{aligned}
$$

Substituting in the above equation for $\ln y$ leads to the log linear identity:

$$\ln y = t \beta_0 + \sum \beta_i \ln x_i$$

Differentiating x with respect to time leads to the following growth frontier:

$$
\begin{aligned}
\frac{\dot{y}}{y} &= \beta_0 + \sum \beta_i \frac{\dot{x}}{x} \\
&\textit{where}: \\
z &= \ln y \\
\dot{z} &= \frac{dz}{dy} \cdot \frac{dy}{dt} \\
&= \frac{\left(\frac{dy}{dt}\right)}{y} \\
\dot{x} &= \frac{dx}{dt} \\
\dot{y} &= \frac{dy}{dt}
\end{aligned}
$$

Extension with Total Factor Productivity

If it is assumed that there is only a single compound factor of production F (Denny et al. 1981; Diewert 1981; Sengupta 2004) then the growth frontier can be expressed in terms of the elasticity ε :

$$
\begin{aligned}
\frac{\dot{y}}{y} &= \beta_0 + \varepsilon^{-1} \frac{\dot{F}}{F} \\
&\textit{So}: \\
\beta_0 &= \frac{\dot{y}}{y} - \varepsilon^{-1} \frac{\dot{F}}{F}
\end{aligned}
$$

$$
\begin{aligned}
&where: \\
&F && = the\ compound\ factor\ of\ production \\
&\dot{F}/F && = \beta_0 + \sum w_i x_i \frac{\dot{x}}{(c x_i)} \\
&w_i && = \text{is the price of input } x_i \\
&c && = \sum w_i\ x_i,\ the\ total\ cost\ of\ inputs \\
&\varepsilon && = \frac{(\frac{\partial c}{c})}{(\frac{\partial y}{y})},\ the\ output\ cost\ elasticity
\end{aligned}
$$

Now considering Total Factor Productivity TFP as a function of output y and the compound factor of production F :

$$
\begin{aligned}
&TFP && = \frac{y}{F} \\
&T\dot{F}P && = \frac{d(TFP)}{dt} \\
& && = \frac{y}{F} - y F^{-2} \dot{F} \\
&\frac{T\dot{F}P}{TFP} && = \frac{(\frac{y}{F} - y F^{-2} \dot{F})}{(\frac{y}{F})} \\
& && = \frac{y}{y} - \frac{\dot{F}}{F} \\
&So: \\
&\frac{\dot{y}}{y} && = \frac{T\dot{F}P}{TFP} + \frac{\dot{F}}{F}
\end{aligned}
$$

Substituting in the above equation for β_0 :

$$
\begin{aligned}
\beta_0 &= \frac{\dot{y}}{y} - \epsilon^{-1} \frac{\dot{F}}{F} \\
&= (\frac{T\dot{F}P}{TFP} + \frac{\dot{F}}{F}) - \epsilon^{-1} \frac{\dot{F}}{F} \\
&= \frac{T\dot{F}P}{TFP} + (1 - \epsilon^{-1}) \frac{\dot{F}}{F}
\end{aligned}
$$

For Solow's assumption of constant returns to scale $\epsilon = 1$:

$$
\begin{aligned}
\beta_0 &= \frac{T\dot{F}P}{TFP} + (1 - \epsilon^{-1})\frac{\dot{F}}{F} \\
&= \frac{T\dot{F}P}{TFP}
\end{aligned}
$$

It may be seen that for the case of constant returns to scale technological progress β_0 is simply the proportional rate of change in Total Factor Productivity.

The parameterised formulation for constant returns to scale is finalised by substituting β_0 in the growth frontier:

$$
\begin{aligned}
\frac{\dot{y}}{y} &= \beta_0 + \sum \beta_i \frac{\dot{x}}{x} \\
&= \frac{T\dot{F}P}{TFP} + \sum \beta_i \frac{\dot{x}}{x}
\end{aligned}
$$

Incorporation of technological change in input output models

One criticism of input output models is that this technique is only suitable for short run studies. This is because technology is already installed (i.e. *ex-post*) and does not allow substitution among inputs. This may be corrected in two ways. The first is to incorporate production functions where future choices are made between several technologies that may be installed (i.e. *ex-ante*). The second way is to complement this by generally allowing substitution of inputs between industries, which is discussed in *Chapter 4 Economic Models for Climate Change Policy Analysis* and *Appendix 6 Benchmarking with Linear Programming.*

In each sector, there is a relationship between production, consumption and emissions. The input output coefficients represent technology. In order to project, the technology coefficients need to be constructed for future periods. This has the effect of influencing production, balance of trade and emissions in future years.

In an input output context there are two ways to propagate changes in technology. The first is to extrapolate past trends into the future. While this is relatively easy to do, it is little better than guessing. Using the popular management example, the best place to *find a drunk in a cornfield* is to look in the place where he was left. Analogously, the best estimate of future technology is today's best technology. Investigations in the United Kingdom and the Netherlands have found innovative changes in environmental technology are very difficult to project.

Wilting et al. (2004; 2008) are critical that traditional approaches such as Miller & Blair's (1985) use of marginal input coefficients and the University of Maryland's extension of logistic growth curves in its INFORUM model fare no better.

The second approach for including technological change is to construct future technical coefficients based on expert knowledge of future technologies (Rose 1984). For example, it may be assumed that today's best practice becomes tomorrow's mid-level performance.
It is important to focus on the underlying causes of technology change, rather than the symptoms of this, which is how the technical coefficients change.

Wilting et. al. (2004; 2008) use trend extrapolation to generate an autonomous reference path. They combine this with expert analysis of specific technology life cycles along this reference path.

$$a(R)_p = a_{00} + \Delta a(R)$$

where:

p	$=$ *the number of projection periods*
R	$=$ *the Reference scenario*
$a(R)_p$	$=$ *final year technical coefficient based on reference scenario R*
a_{00}	$=$ *original technical coefficient*
$\Delta a(R)$	$=$ *absolute change of the technical coefficient across projection horizon*
	$= a_{00}\,\delta(R)$

The authors suggest there are two types of change that lead to technology diffusion through technical coefficients. The first is changes to primary production processes, for example lower demand for herbicides due to a change from common to organic agriculture. The second is a more general technological changes due to better information and communication, or substitutions between inputs.

Wilting et. al. prepare future technical coefficients by surveying the mix of existing primary technologies that provide the current coefficients of input output tables and developing new coefficients for alternative technologies. The difference between these coefficient sets is projected as a changing mix of technologies independent of the existing primary technology.

The original mix of existing technologies is given by:

$$a_{00} = \sum_i \alpha_{00}^i \, a_{00}^i$$

subject to:

$$\sum_i \alpha_{00}^i = 1$$

$where:$

$a_{00} \quad = input\ output\ technical\ coefficient$

$a_{00}^i \quad = original\ technical\ coefficient\ for\ technology\ i$

$\alpha_{00}^i \quad = original\ proportion\ of\ technology\ i$

All coefficients are then related to the new technologies. The implicit assumptions are that pace of technological change in all industries is the same and that the share of each technology in total production remains constant. The ratio of coefficients for technologies i and 1 is constant as follows:

$$a_{00}^i = \gamma^i * a_{00}^1$$

$where:$

$\gamma^i \quad = ratio\ of\ technical\ coefficents\ of\ i\ \&\ 1$

Therefore:

$$a_{00} = \sum_i \alpha_{00}^i \, \gamma^i \, a_{00}^1$$

$$a_{00}^1 = \frac{a_{00}}{\sum_i \alpha_{00}^i \, \gamma^i}$$

Changes in non-primary technologies are assumed to lead to an improvement factor ϕ :

$$a(S)_p^i = \phi(S)\, a(R)_p^i$$

$$\begin{aligned} &where: \\ &\phi(S) = general\ change\ coefficient\ of\ scenario\ S \end{aligned}$$

Therefore:

$$\begin{aligned} a(S)_p &= \sum_i \alpha(S)_p^i\, a(S)_p^i \\ &= \sum_i \alpha(S)_p^i\, \phi(S)\, a(R)_p^i \\ &= \sum_i \alpha(S)_p^i\, \phi(S)\, \gamma^i\, a(R)_p^i \\ &= \sum_i \alpha(S)_p^i\, \phi(S)\, \gamma^i\, [\delta(R)\, a_{oo}^i + a_{00}^i] \end{aligned}$$

$$\begin{aligned} &where: \\ &\alpha(S)_p^i = \phi(S)\, [\delta(R)\, a_{oo}^i + a_{00}^i] \sum_i \alpha(S)_p^i\, \gamma^i \\ &\qquad = technology\ i\ share\ of\ sector\ total\ production\ for\ scenario\ S \\ &\sum_i \alpha(S)_p^i = 1 \end{aligned}$$

The diffusion changes in labour, capital and emissions can be carried out in the same way as this projection of technical change.

A3.4 Appendix references

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i With each element multiplied by 100 to comply with ABS scaling

ii With each element divided by 100 to comply with ABS scaling

iii As a “round trip” check on ABS data and computation, process the Table 9 Leontief matrix to the Leontief Inverse and compares the result with Table 10. R-package code for this comparison is:

```
# load the ABS Table 9 Leontief dataset (technical coefficients) into
matrix L_ABS:
L_ABS <- read.table("table09_L_indirect_imports.csv", header=FALSE,
sep=",", na.strings="", strip.white=TRUE)
# load the ABS Table 10 Leontief Inverse dataset (technical coefficients)
into matrix LI_ABS:
LI_ABS <- read.table("table10_LI_indirect_imports.csv", header=FALSE,
sep=",", na.strings="", strip.white=TRUE)
# create the Leontief inverse (total requirements coefficients) by using
solve to invert the identity matrix less A
# note that L_ABS and LI_ABS both arrive scaled up by 100
LI_CALC <- solve(diag(nrow(L_ABS))-L_ABS/100)
# compare the calculated Leontief Inverse with ABS Table 10:
LI_CALC-LI_ABS/100
```

Appendix 4 Nordhaus DICE Model

A4.1 Basic scientific model

William Nordhaus' (2008, Appendix A, pp.205-8) scientific equations are based on the United Nations IPCC Report *The Physical Science Basis* (2007). Damage feedback increases the inputs required for production, while technological change acts in the opposite direction, reducing production inputs through growth in Total Factor Productivity.

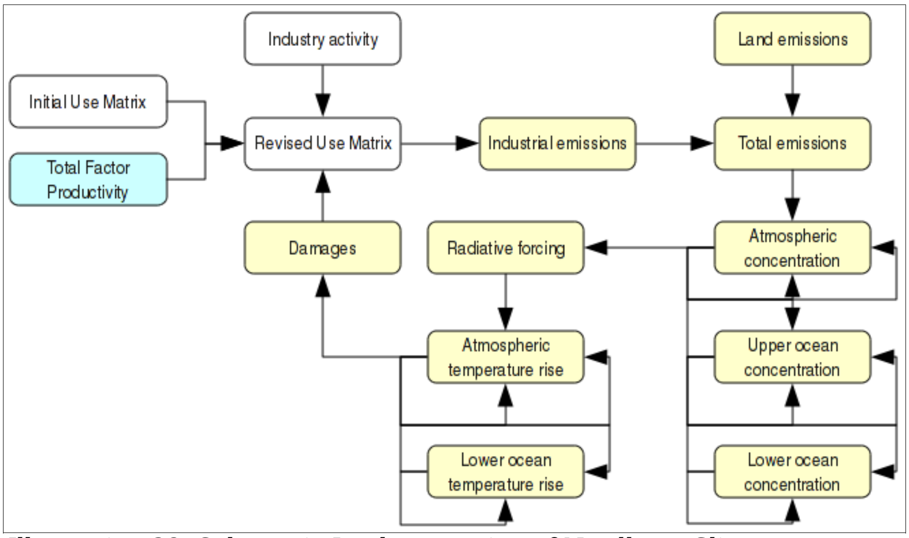

Illustration 38: Schematic Implementation of Nordhaus Climate Equations

A4.2 Model equations

The equations for the economic and climate models are:

A.01	W	$= \sum_{t=1}^{T_{max}} u[c_t , L_t] \, R_t$
A.02	R_t	$= (1 - \rho)^{-t}$
A.03	$U[c_t , L_t]$	$= L_t \dfrac{c_t^{1-\alpha}}{(1-\alpha)}$
A.04	Q_t	$= \Omega_t \, [1 - \Lambda_t] \, A_t \, K_t^{\gamma} \, L_t^{1-\gamma}$
A.05	Ω_t	$= \dfrac{1}{[1 + \psi_1 \, T_{AT,t} + \psi_2 \, T_{AT,t}^2]}$

$$
\begin{array}{lll}
A.06 & \Lambda_t & = \pi_t \ \theta_t \ \mu_t^{\theta_2} \\
A.07 & Q_t & = C_t + I_t \\
A.08 & c_t & = \dfrac{C_t}{L_t} \\
A.09 & K_t & = I_t + (1-\delta_K) K_{t-1} \\
A.10 & E_{ind,t} & = \sigma_t \, [1-\mu_t] \, A_t \, K_t^{\gamma} \, L_t^{1-\gamma} \\
A.11 & CCum & \geq \sum_{t=0}^{T_{max}} E_{ind}(t) \\
A.12 & E_t & = E_{ind,t} + E_{land,t} \\
A.13 & M_{AT,t} & = E_t + \phi_{11} \, M_{AT,t-1} + \phi_{21} \, M_{UP,t-1} \\
A.14 & M_{UP,t} & = \phi_{12} \, M_{AT,t-1} + \phi_{22} \, M_{UP,t-1} + \phi_{32} \, M_{LO,t-1} \\
A.15 & M_{LO,t} & = \phi_{23} \, M_{UP,t-1} + \phi_{33} \, M_{LO,t-1} \\
A.16 & F_t & = \eta \log_2 [\dfrac{M_{AT,t}}{M_{AT,1750}}] + F_{EX,t} \\
A.17 & T_{AT,t} & = T_{AT,t-1} + \xi_1 \, [F_t + \xi_2 \, T_{AT,t-1} - \xi_3 [T_{AT,t-1} - T_{LO,t-1}]] \\
A.18 & T_{LO,t} & = T_{LO,t-1} + \xi_4 [T_{AT,t-1} - T_{LO,t-1}] \\
A.19 & \pi_t & = \varphi_t^{1-\theta_2}
\end{array}
$$

Where:

$$
\begin{array}{ll}
\phi_{11} & = 1 - \phi_{12} \\
\phi_{21} & = \dfrac{587.473 \, \phi_{12}}{1143.894} \\
\phi_{22} & = 1 - \phi_{21} - \phi_{23} \\
\phi_{32} & = \dfrac{1143.894 \, \phi_{23}}{18340} \\
\phi_{33} & = 1 - \phi_{32}
\end{array}
$$

$$
\begin{array}{ll}
\xi_2 & = \dfrac{\eta}{t2xco2} \\
gfacpop_t & = \dfrac{(e^{pop_g * (ord_t - 1)} - 1)}{e^{pop_g * (ord_t - 1)}} \\
l_t & = pop_0 (1 - gfacpop_t) + gfacpop_t \, pop_a \\
ga_t & = ga_0 * e^{-dela * 10 * (ord_t - 1)} \\
a_{t+1} & = \dfrac{a_t}{1 - ga_t}, \ a_{t=1} = a_0
\end{array}
$$

where ord_t is the ordinate of t :

$$g\sigma_t = g\sigma_0\, e^{-d\sigma_1 * 10 * (ord_t - 1) - d\sigma_2 * 10 * (ord_t - 1)^2}$$

$$\sigma_{t+1} = \frac{\sigma_t}{1 - g\sigma_{t+1}}, \sigma_1 = \sigma_0$$

$$\theta_{1,t} = \frac{pback\,\sigma_t}{\theta_2} \cdot \frac{backrat - 1 + e^{-gback*(ord_t - 1)}}{backrat}$$

$$E_{land,t} = E_{land,0}\,(1 - 0.1)^{ord(t) - 1}$$

$$r_t = (1+\rho)^{-10*(ord_t - 1)}$$

$$fex_t = If\,(ord_t \geq 12\ then\ (fex_0 + 0.36)\ else\ (fex_0 + 0.1\,(fex_1 - fex_0)))$$

$$\varphi_t = If\,(ord_t > 25 \text{ then } \varphi_{21} + (\varphi_2 - \varphi_{21})\, e^{-d\varphi*(ord_t - 2)} \text{ else } \varphi_{21})$$

$$\varphi_{t=1} = \varphi_1$$

$$\pi_t = \varphi_t^{1-\theta_2}$$

Supplementary model equations:

$$ygross_t = a_t\, k_t^{\gamma}\, l_t^{1-\gamma}$$

$$damages_t = ygross_t\,(1 - \Omega_t)$$

$$ynet_t = ygross_t\, \Omega_t$$

$$abate_t = ygross_t\, \Lambda_t$$

$$cpc_t = \frac{1000\, c_t}{l_t}$$

$$y_t = \Omega_t\,(1 - \Lambda_t)\, ygross_t$$

$$ypc_t = \frac{1000\, q(t)}{l_t}$$

$$s_t = \frac{i_t}{q_t + 0.001}$$

$$ri_t = \frac{\gamma\, q_t}{k_t} - \frac{1 - (1 - \delta_k)^{10}}{10}$$

Boundary conditions:

$$k.lo_t = 100$$

$$mat.lo_t = 10$$

$$mup.lo_t = 100$$

$$mlo.lo_t = 1000$$

$$c.lo_t = 20$$

$$
\begin{aligned}
&tlo.up_t && = 20 \\
&tlo.lo_t && = -1 \\
&tat.up_t && = 20 \\
&mu.up_t && = \mu_{limit} \\
&mu.fx_{t=1} && = \mu_0 \\
&ccum.up_{t=tlast} && = ccumm
\end{aligned}
$$

Preferences:

$$
\begin{aligned}
&\alpha && = 2.0 && \textit{elasticity of marginal utility of consumption} \\
&\rho && = 0.015 && \textit{pure rate of social time preference per unit time}
\end{aligned}
$$

Population and technology:

$$
\begin{aligned}
&pop_0 && = 6514 && \textit{world population } 2005 \textit{ millions} \\
&pop_g && = 0.35 && \textit{population growth rate per decade} \\
&pop_a && = 8600 && \textit{asymptotic population (was popasym)} \\
&a_0 && = 0.02722 && \textit{initial level of total factor productivity} \\
&ga_0 && = 0.092 && \textit{initial growth rate for technology per decade} \\
&dela && = 0.001 && \textit{decline rate of technological change per decade} \\
&\delta_k && = 0.10 && \textit{capital depreciation rate per period} \\
&\gamma && = 0.30 && \textit{elasticity of output with respect of capital (a pure number)} \\
&q_0 && = 61.1 && \textit{initial world gross output, trillion } 2005 \textit{ US dollars} \\
&k_0 && = 137 && \textit{initial capital, trillion } 2005 \textit{ US dollars}
\end{aligned}
$$

Emissions:

$$
\begin{aligned}
&\sigma_0 && = 0.13418 && \textit{initial } CO_2 \textit{ equivalent emissions} - \textit{GNP ratio } 2005 \\
&g\sigma_0 && = -0.0730 && \textit{initial growth of sigma per decade} \\
&d\sigma_1 && = 0.003 && \textit{decarbonization decline rate per decade} \\
&d\sigma_2 && = 0.0 && \textit{decarbonization quadratic term} \\
&eland_0 && = 11.0 && \textit{land clearing carbon emissions } 2005, \textit{ GtC per decade}
\end{aligned}
$$

Carbon cycle:

$$
\begin{array}{lll}
mat_{1750} & = 596.4 & atmospheric\ concentration\ mat(1750)\,GtC \\
mat_0 & = 808.9 & atmospheric\ concentration\ 2005\ GtC \\
mup_0 & = 1255 & upper\ ocean\ concentration\ 2005\ GtC \\
mlo_0 & = 18365 & lower\ ocean\ concentration\ 2005\ GtC
\end{array}
$$

Carbon cycle transfer parameters:

$$
\begin{array}{ll}
\phi_{11} & = 0.810712 \\
\phi_{12} & = 0.189288 \\
\phi_{21} & = 0.097212 \\
\phi_{22} & = 0.852787 \\
\phi_{23} & = 0.05 \\
\phi_{32} & = 0.003119 \\
\phi_{33} & = 0.996881
\end{array}
$$

Climate model:

$$
\begin{array}{lll}
t2xco2 & = 3 & equilibrium\ temperature\ impact\ of\ CO_2 doubling,\ deg C \\
\eta & = 3.8 & estimated\ forcings\ of\ equilibrium\ CO_2\ doubling,\ deg C/watt/m^2 \\
fex_0 & = -0.06 & estimate\ of\ 2000\ forcings\ of\ non-CO_2\ GHG \\
fex_1 & = 0.30 & estimate\ of\ 2100\ forcings\ of\ non-CO_2\ GHG
\end{array}
$$

$$
\begin{array}{lll}
tlo_0 & = 0.0068 & 2000\ lower\ ocean\ temp\ change\ deg\ C\ since\ 1900 \\
tat_0 & = 0.7307 & 2000\ atmospheric\ temp\ change\ deg\ C\ since\ 1900 \\
\xi_1 & = 0.220 & parameter\ of\ the\ climate\ equation\ flows\ per\ period \\
\xi_3 & = 0.300 & parameter\ of\ the\ climate\ equation\ flows\ per\ period \\
\xi_4 & = 0.050 & parameter\ of\ the\ climate\ equation\ flows\ per\ period
\end{array}
$$

Climate damage function parameters calibrated for quadratic at 2.5C in 2105:

$$
\begin{array}{ll}
\psi_1 & = 0.0000 \\
\psi_2 & = 0.0028388 \\
\psi_3 & = 2.00
\end{array}
$$

Abatement cost parameters:

$\theta_2 \quad = 2.8 \quad$ *control cost function exponential parameter*
$pback \quad = 1.17 \quad$ *cost of backstop technology* 2005 *US$'000 per tC*
$backrat \quad = 2 \quad$ *ratio of initial/final backstop cost*
$gback \quad = 0.05 \quad$ *initial cost decline backstop percent per decade*
$mu_{limit} \quad = 1 \quad$ *upper limit on control rate*

Participation parameters:

$\varphi_0 \quad = 0.25372 \quad$ *initial value of* φ
$\varphi_1 \quad = 1 \quad$ *fraction of emissions under control regime* 2005
$\varphi_2 \quad = 1 \quad$ *fraction of emissions under control regime* 2015
$\varphi_{21} \quad = 1 \quad$ *fraction of emissions under control regime* 2205
$d\varphi \quad = 0 \quad$ *participation decline rate*

$\mu_0 \quad = 0.005 \quad$ *initial value of* μ *determined by Kyoto Protocol*
$ccumm \quad = 6000 \quad$ *maximum cumulative consumption of fossil fuels GtC*

Objective function scaling coefficients:

$scale_1 \quad = 194$
$scale_2 \quad = 381800$

Other parameters:

$a_t \quad$ *total factor productivity, units of productivity*
$eland_t \quad$ *land clearing emissions of carbon, GtC per period*
$fex_t \quad$ *other greenhouse gases exogenous radiative forcing, watts/metre*^{2} *since* 1900
$ga_t \quad$ *productivity growth rate upto period t*
$gfacpop_t \quad$ *population growth factor*
$gl_t \quad$ *labour growth rate upto period t*
$g\sigma_t \quad$ *energy efficiency cumulative improvement*

$\theta_{1,t} \quad$ *adjustment cost for backstop technology, parameter of the abatement cost function*
$\varphi_t \quad$ *participation rate = controlled fraction of emissions*
= proportion of emissions included by policy
$\xi_2 \quad$ *climate model parameter*

l_t	*population labour inputs, millions*
π_t	*participation cost markup, abatement cost with incomplete participation as proportion of abatement cost with complete participation*
r_t	*average utility social time preference discount factor per time period*
σ_t	*ratio of uncontrolled industrial CO_2 equivalent emissions / output, metric tons of carbon per unit of output* 2005 *prices*
mlo_t	*mass of carbon for lower ocean reservoir, GtC at beginning of period*
μ_t	*emissions control rate = proportion of uncontrolled emissions*
mup_t	*mass of carbon for upper (shallow) ocean reservoir, GtC at beginning of period*
Ω_t	*damage function climate damages as proportion of world output*
q_t	*gross world product (output of goods, services) net of damages* and *abatement costs* 2005 *US trillion dollars*
ri_t	*real interest rate*
s_t	*gross savings rate as fraction of gross world product*

tat_t	*global mean surface temperature deg C increase since* 1900
tlo_t	*global mean lower ocean temperature deg C increase since* 1900
u_t	*instantaneous utility function (utility per period)*
w	*objective function (present value of utility, pure units)*
y_t	*gross world product net of abatement* and *damages*
$ygross_t$	*gross world product gross of abatement* and *damages*
$ynet_t$	*output net of damages*
ypc_t	*income per capita, thousands US dollars*

Variables:

$abate_t$	*abatement cost*
c_t	*consumption of goods* and *services, trillions of* 2005 *US dollars*
$ccum_t$	*cumulative emissions*
cpc_t	*per capita consumption of goods and services, thousands* 2005 *US dollars*
$damages_t$	*damages*
e_t	*total of industrial* and *land CO_2 equivalent emissions, GtC per period*
$eind_t$	*industrial carbon emissions, GtC per period*
f_t	*total radiative forcing, watts per metre*^{2} *since* 1900
i_t	*investment, trillions of* 2005 *US dollars*
k_t	*capital stock, trillions of* 2005 *US dollars*

Λ_t	$abatement\ cost\ function, cost\ of\ emissions\ reductions\ as\ proportion\ of\ world\ output$
mat_t	$mass\ of\ carbon\ in\ atmosphere\ reservoir\ at\ beginning\ of\ period, GtC$
$matav_t$	$average\ atmospheric\ concentration\ GtC$
mlo_t	$mass\ of\ carbon\ in\ lower\ ocean\ reservoir, at\ beginning\ of\ period, GtC$
μ_t	$emissions\ control\ rate = proportion\ of\ uncontrolled\ emissions$
mup_t	$mass\ of\ carbon\ in\ upper\ (shallow)\ ocean\ reservoir, at\ beginning\ of\ period, GtC$
Ω_t	$damage\ function, climate\ damages\ as\ proportion\ of\ world\ output$
q_t	$gross\ world\ product\ output\ of\ goods\ and\ services\ net\ of\ abatement\ and\ damages, trillions\ of\ 2005\ US\ dollars$

ri_t	$real\ interest\ rate$
s_t	$gross\ savings\ rate\ as\ fraction\ of\ gross\ world\ product$
tat_t	$global\ mean\ surface\ temperature\ deg\ C\ increase\ since\ 1900$
tlo_t	$global\ mean\ lower\ ocean\ temperature, deg\ C\ increase\ since\ 1900$
u_t	$instantaneous\ utility\ function, utility\ per\ period$

y_t	$gross\ world\ product\ net\ of\ abatement$ and $damages$
$ygross_t$	$gross\ world\ product\ gross\ of\ abatement$ and $damages$
$ynet_t$	$output\ net\ of\ damages$
ypc_t	$income\ per\ capita, thousands\ US\ dollars$

A4.3 Implementation issues

Preference for consumption over investment

The most important implementation issue is DICE's preference for consumption over investment, which arises because consumption is maximised with respect to capital. This can be seen by examining the equations for the Cobb-Douglas production function, consumption and capital:

$$A.04 \quad Q_t = \Omega_t [1 - \Lambda_t]\, A_t\, K_t^{\gamma}\, L_t^{1-\gamma}$$
$$A.07 \quad Q_t = C_t + I_t$$
$$A.09 \quad K_t = I_t + (1 - \delta_K) K_{t-1}$$

For a particular period t , $\Omega_t [1 - \Lambda_t] A_t L_t^{1-\gamma}$ is an equilibrium settled factor with both exogenous and endogenous components but having only a second order feedback effect and no effect at all if the emissions control rate μ is constant. Depreciation of capital in the previous period $(1 - \delta_K) K_{t-1}$ is constant because K_{t-1} is predetermined by time t . Therefore, the three equations above may be simplified by substituting $\{\alpha, \beta\}$ for the two constants respectively:

$$
\begin{aligned}
&A.04 \quad Q_t &&= \alpha\, K_t^{\gamma} \\
&A.07 \quad Q_t &&= C_t + I_t \\
&A.09 \quad K_t &&= I_t + \beta
\end{aligned}
$$

Rearranging and simplifying:

$$C_t = \alpha\, K_t^{\gamma} - K_t + \beta$$

Maximising C_t by differentiating with respect to K_t and equating to zero provides the maximum condition:

$$
\begin{aligned}
&\alpha \gamma\, K_t^{\gamma - 1} - 1 = 0 \\
&K_t = \{\alpha \gamma\}^{1-\gamma} \\
&K_t = k \\
&where: \\
&k = \{\alpha \gamma\}^{1-\gamma}
\end{aligned}
$$

From this, it may be noted that K_t is just the constant k . Substituting back for the value of C_t and Q_t at the maximum, we find that each is also just a constant:

$$
\begin{aligned}
&C_t = \alpha\, k^{\gamma} - k + \beta \\
&Q_t = \alpha\, k^{\gamma}
\end{aligned}
$$

For the period, the increments of production, capital and consumption $\{Q_t, K_t, C_t\}$ are all constant and predetermined by the values of various factors and starting capital. Indeed, if the emissions control factor μ is constant and does not give rise to changes in abatement and economic damages $\{\Omega_t, \Lambda_t\}$ respectively, then the whole economic model is also predetermined.

However, it is not the case that the emissions control rate μ is a constant. Therefore, over the intertemporal space of the projection period DICE optimises with respect to μ as the primary optimisation factor and capital K_t as an important albeit now secondary factor. Other aspects of DICE performance are discussed in *Appendix 5 Acyclic solver for unconstrained optimisation*.

Equation A.9

Nordhaus' implementation of his economic-climate model in the General Algebraic Modelling System (GAMS) has a number of aberrations from the equations presented above.

This equation for K_t is specified as a function of I_t .

$$A.09 \quad K_t = I_t + (1 - \delta_K) K_{t-1}$$

However, equation A.9 is implemented with I_{t-1} as follows:

$$A.09 \quad K_t = I_{t-1} + (1 - \delta_K) K_{t-1}$$

This alternative formulation changes the interpretation of K_t from the capital at the end of period t to the capital at the beginning of the period t . This is an inconsistent treatment between normal interpretation of the equations and the manner in which they are implemented.

Utility function

The utility function formula U_t is different in two ways:

(a) Population L_t is used in the instantaneous utility function U_t rather than in the summation objective function 2.. However, this is merely a rearrangement and has little effect on the outcome.

For example, the equations A.1 and A.3 are provided above as:

$$A.01 \quad W \quad = \sum_{t=1}^{T_{max}} u[c_t, L_t] R_t$$

$$A.03 \quad U[c_t, L_t] \quad = L_t \frac{c_t^{1-\alpha}}{(1-\alpha)}$$

However, the implementation is in the form:

$$A.01 \quad W \quad = \sum_{t=1}^{T_{max}} L_t u[c_t, L_t] R_t$$

$$A.03 \quad U[c_t, L_t] \quad = \frac{c_t^{1-\alpha}}{(1-\alpha)}$$

(b) There is an extra term in equation A.03, which is implemented as:

$$A.03 \quad U[c_t, L_t] \quad = \frac{c_t^{1-\alpha}-1}{(1-\alpha)}$$

As shown in *Chapter 5 Model development*, the reason often given for introducing this additional term is that the function reduces to $\ln(c)$ in the special case of $\alpha = 1$. Nordhaus uses $\alpha = 2$ and so does not make this simplification. However, the discussion in Chapter 5 also shows that the effective discount rate is relatively unstable in the initial formulation and it is likely that this supplementary form of the welfare function provides more stability. The stability could be assessed in the same way as the initial formulation has been readily investigated in Chapter 5.

Equations A.11 and A.12

These equations are specified as:

$$A.11 \quad CCum \geq \sum_{t=0}^{T_{max}} E_{ind,t}$$
$$A.12 \quad E_t = E_{ind,t} + E_{land,t}$$

There are two differences in the implemented model. The first difference is that Equation A.11 uses $E_{ind,t}$, whereas the model implementation uses E_t :

$$A.11 \quad CCum = \sum_{t=0}^{T_{max}} E_t$$
$$A.12 \quad E_t = E_{ind,t} + E_{land,t}$$

While the output $CCum$ is used only in the sense of setting a maximum constraint, there is a major inconsistency in subjecting maximum total emissions (of industrial and land) to the maximum conceived for industrial emissions. Secondly, the use of $CCum$ in further discussion and analysis is inconsistent and likely to be highly confusing.

The second difference is am alternative formulation regarding $CCum_{t+1}$ as carried forward forward amount in period t , and equivalently $CCum_t$ at the brought forward amount in period t :

$$A.11 \quad CCum_{t+1} = E_t + CCum_t$$

Normally, this would be implemented in a more straightforward manner using the sum of current period emissions and accumulated emissions at the end of the previous year.

$$A.11 \quad CCum_{t+1} = E_{t+1} + CCum_t$$

There is an inconsistency in Nordhaus' interpretation of $CCum$ because the constraint of a maximum is applied to the brought forward quantity rather than the usual understanding of the carried forward quantity.

Equation A.13

This equation is specified as:

$$A.13 \quad M_{AT,t} \quad = E_t + \phi_{11}\, M_{AT,t-1} + \phi_{21}\, M_{UP,t-1}$$

However, it is implemented inconsistently with E_{t-1} instead of E_t as follows:

$$A.13 \quad M_{AT,t} \quad = E_{t-1} + \phi_{11}\, M_{AT,t-1} + \phi_{21}\, M_{UP,t-1}$$

Nordhaus DICE Brief (GAMS code version)

The following Nordhaus DICE model is translated from William Nordhaus' GAMS model (Nordhaus 2007). The model uses the Phase III acyclic topological processor described in *Appendix 5:Acyclic solver for unconstrained optimisation*.

```
(* Nordhaus Brief Climate Change Policy Model May 2008 *)
(* Note: periods are decades, with the decade to 2005 being period zero
*)
(* Stuart Nettleton Topological Model September 2008 *)
(* Nordhaus Brief Code equations modified only in respect of rendering
acyclic *)
(* Note: Nordhaus Brief Code differs from the Nordhaus Book Code *)

starttime=AbsoluteTime[];
periods = 5; (* projection periods *)
optimpenalty=0; (* optimisation return if iteration non-real *)
<<Combinatorica`

(* objective function *)
(* this program always minimises, so negative for maximisation *)
obj = {-cumu[periods]};

(* optimisation variables: topology start nodes ... *)
(* .. to have FindMinimum use the fast & robust Brent's Method by *)
(* default, which avoids the use of derivatives, make sure there *)
(* are no constraints and set two start variables. If possible *)
(* make sure there is one on either side of the zero crossing. *)
(* If formal constraints are present, FindMinimum will use the Interior
*)
(* If constraints are present, FindMinimum will use the Interior *)
(* Point Method and only one start variable should be present. *)
(* This should be your best estimate of the solution. While *)
(* Brent's Method is much faster than Interior Point, both execute *)
(* much faster and use considerable less memory than NMinimize. *)
(* Note that if an optimisation variable is set here but later *)
(* is defined as an initial variable, the latter is used. *)
```

```
opt ={
(* emissions control rate, fraction of uncontrolled emissions *)
{ μ[t],0.01,0.5},
(* capital stock *) {k[t],300, 2000}
};

(* exogenous parameters *)
exogparams={
(* population 2005 millions *) pop0 → 6514,
(* population growth rate per decade *) popg → 0.35,
(* population asymptote *) popa → 8600,
(* technology growth rate per decade *) ga0 → 0.092,
(* technology depreciation rate per decade *) dela → 0.001,
(* equivalent carbon growth parameter *) gσ0 → -0.0730,
(* decline rate of decarbonisation per decade parameters*) dσ1 → 0.003,
dσ2 → 0.000,
(* backstop technology cost per tonne of carbon 2005 *)  pback → 1.17,
(* backstop technology, final to inital cost ratio *) backrat → 2,
(* backstop technology, rate of decline in cost *) gback → 0.05,
(* pure rate of social time preference *) ρ → 0.015,
(* radiative forcing of non-carbon gases in 2000 & 2001 *) fex0 → -0.06,
fex1 → 0.30,
(* emissions in control regime parameters for 2005, 2015, 2205 *) κ1->1,
κ2 → 1, κ21 → 1,
(* emissions in control regime decline rate*) dκ → 0,
(* abatement cost control parameter *) θ → 2.8,
(* carbon emissions from land use 2005 *) eland0 → 11};

(* initial exogvars *)
exoginitial ={
gfacpop[1] → 0,gfacpop[0] → 0,
ga[0] → ga0,gσ[0] → gσ0,
a[1] → 0.02722, a[0] → 0.02722,
σ[1] → 0.13418, σ[0] → 0.13418,
eland[0] → eland0,
fex[0] → fex0, fex[1] → fex1,
κ[1] → 0.25372, κ[0] → 0.25372
};

(* exogenous equations *)
exogeqns ={
(* population growth factor *)  gfacpop[t]==(Exp[popg*(t-1)]-
1)/Exp[popg*(t-1)],
(* population level *)  l[t]== pop0*(1-gfacpop[t])+gfacpop[t]*popa,
(* productivity growth rate *) ga[t] == ga0*Exp[-dela*10*(t-1)],
(* total factor productivity *) a[t] ==a[t-1]/(1-ga[t-1]),
(* energy efficiency cumulative improvement *) gσ[t] ==gσ0*Exp[-
dσ1*10*(t-1)-dσ2*10*(t-1)^2],
(* carbon emissions output ratio *) σ[t] == σ[t-1]/(1-gσ[t]),
(* backstop technology adjusted cost *) Θ[t] ==(pback* σ[t]/
θ)*((backrat-1+Exp[-gback*(t-1)])/backrat),
(* carbon emissions from land use sources *)  eland[t] ==eland0*(1-
0.1)^(t-1),
(* social time preference discount factor *)  r[t] ==1/(1+ ρ)^(10*(t-1)),
(* radiative forcing of other greenhouse gases *)  fex[t] ==fex0 + If[ t
≤ 12,0.36, 0.1*(fex1-fex0)*(t-1)],
(* fraction of emissions in control regime *)  κ[t] ==If[ t ≥ 25, κ21,
κ21 + ( κ2- κ21)*Exp[-dκ*(t-2)]],
(* ratio of abatement cost with incomplete participation to that with
complete participation *) Π[t] == κ[t]^(1- θ)
};

(* endogenous parameters *)
```

```
endogparams={
(* elasticity of marginal utility of consumption *)  α → 2.0,
(* elasticity of output with respect to capital in production function *)
γ → 0.30,
(* depreciation rate of capital *) δ → 0.1,
(* temperature forcing parameter *) η → 3.8,
(* temperature change with carbon doubling *) t2xco2 → 3,
(* damage function parameters *) ψ1 → 0, ψ2 → 0.0028388, ψ3 → 2,
(* climate equation parameters *)  ξ1 → 0.22, ξ2 → η/t2xco2, ξ3 → 0.3, ξ4
→ 0.05,
(* carbon cycle parameters *) ϕ11 → 1- ϕ12a, ϕ12 → 0.189288, ϕ12a →
0.189288,
(* carbon cycle parameters *) ϕ21 → 587.473* ϕ12a/1143.894, ϕ22 → 1- ϕ21
— ϕ23a,
(* carbon cycle parameters *) ϕ23 → 0.05, ϕ23a → 0.05, ϕ32 → 1143.894*
ϕ23a/18340, ϕ33 → 1- ϕ32,
(* mass of carbon in atmosphere, pre-industrial *)  mat1750 → 596.4,
(* μlim → 1, *)
(* ceindlim → 6000, *)
(* scaling factor *) scale1 → 194
};

(* endogenous initial *)
endoginitial = {
y[0] → 61.1, c[0] → 30,
inv[0] → 31.1,
k[1] → 137, k[0] → 137,
ceind[1] → 0, ceind[0] → 0,
Λ[1] → 0.66203, Λ[0] → 0.66203,
Ω[1] → 0.99849, Ω[0] → 0.99849,
mat[1] → 808.9, mat[0] → 808.9,
mup[1] → 1255, mup[0] → 1255,
mlo[1] → 18365, mlo[0] → 18365,
tat[1] → 0.7307, tat[0] → 0.7307,
tlo[1] → 0.0068, tlo[0] → 0.0068,
μ[1] → 0.005, μ[0] → 0.005,
cumu[1] → 381800, cumu[0] → 381800
};

(* endogenous variables *)
(* sn modifications of Nordhaus to render acyclic *)
endogeqns={
(* net present value of utility, the objective function *)  cumu[t] ==
cumu[t-1]+(l[t]*u[t]*r[t]*10)/scale1,
(* utility function *)  u[t] == ((c[t]/l[t])^(1- α)-1)/(1- α),
(* consumption of goods and services *) c[t] == y[t]-inv[t],
(* output of goods and services, net of abatement and damages *)  y[t] ==
Ω[t]*(1- Λ[t])*ygr[t],
(* ratio of abatement to world output *)  Λ[t] == Π[t] * θ[t] * μ[t]^ θ,
(* output of goods and services, gross *)  ygr[t] == a[t]* k[t]^ γ
*l[t]^(1- γ),
(* ratio of climate damages to world output *) Ω[t] == 1/(1+ \
[Psi]1*tat[t]+ ψ2*(tat[t]^ ψ3)),
(* global mean terrestrial temperature *)  tat[t] == tat[t-1]+
ξ1*(for[t]- ξ2*tat[t-1]- ξ3*(tat[t-1]-tlo[t-1])),
(* global mean lower ocean temperature *)  tlo[t] ==tlo[t-1]+ ξ4*(tat[t-
1]-tlo[t-1]),
(* radiative forcing total *)  for[t] == η*Log[2,((mat[t]+mat[t-
1])/2)/mat1750]+fex[t],
(* mass of carbon in atmosphere *)  mat[t] == eind[t] + ϕ11*mat[t-1] +
ϕ21*mup[t-1],
(* carbon emissions *)  eind[t] == 10 * σ[t] *(1- μ[t]) *ygr[t]
+eland[t],
```

```
(* mass of carbon in lower oceans *)  mlo[t] == ϕ23*mup[t-1]+ ϕ33*mlo[t-1],
(* mass of carbon in upper oceans *)  mup[t] == ϕ12*mat[t-1]+ ϕ22*mup[t-1] + ϕ32*mlo[t-1],
(* carbon emissions cumulative *)  ceind[t] == eind[t]+ceind[t-1],
(* capital stock as function of investment *)  k[t] == 10*inv[t]+((1-δ)^10)*k[t-1]
(* (* climate damages, gross *) dam[t] == ygr[t]*(1- Ω[t]),*)
(* (* savings ratio *) s[t] == inv[t]/y[t],*)
(* (* interest rate *) ri[t] == γ*y[t]/k[t] -(1-(1- δ)^10)/10,*)
(* (* consumption of goods and services, per capita *)  cpc[t] == c[t]*1000/l[t],*)
(* (* output of goods and services, net per capita *)  pcy[t] == y[t]*1000/l[t],*)
};

(* endogenous constraints *)
endogcons={(*
k[t] ≤ 10*inv[t]+((1- δ)^10)*k[t-1],
0.02*k[periods] ≤ inv[periods],
100 ≤ k[t],
20 ≤ c[t],
0 ≤ mat[t],
100 ≤ mup[t],
1000 ≤ mlo[t],
-1 ≤ tlo[t]<= 20,
tat[t] ≤ 20,
ceind[t] ≤ ceindlim,
0 ≤ q[t],
0 ≤ inv[t],
0 ≤ ygr[t],
0 ≤ eind[t],
0 ≤ μ[t] ≤ μlim *)
};

(* solve topological equations *)

toponodes[eqns_]:=Module[
{eqnvars,flatvars,eqnlist,mysource,mysink,edges1,edges2,edges3,edges,vertices2,vertices,forwardgraph,networkflows,forwardflows,forwardedges,revisededges,revisedgraph,toposort,sortedequations,
sortedvertices,posfirstequation,startvertices},
eqnvars=Map[Cases[eqns[[#]],_Symbol[_Integer],Infinity]&,Range[Length[eqns]]];
flatvars=Union[Flatten[eqnvars]];
eqnlist=Range[Length[eqns]];
f1[a_,b_]:={a,b};
edges1=Map[f1[mysource,flatvars[[#]]]&,Range[Length[flatvars]]];
edges2=Flatten[Map[Outer[f1,eqnvars[[#]],{eqnlist[[#]]}]&,eqnlist],2];
edges3=Map[f1[eqnlist[[#]],mysink]&,eqnlist];
edges=Join[edges1,edges2,edges3];
vertices2= Join[flatvars,eqnlist];
vertices=Join[{mysource},vertices2,{mysink}] ;
forwardgraph=MakeGraph[vertices,(MemberQ[edges,{#1,#2}])&,Type->Directed,VertexLabel->True];
If[!AcyclicQ[forwardgraph],Print["*** ERROR: FORWARD GRAPH IS NOT ACYCLIC SO CHECK THE EQUATIONS ***"]];
networkflows=NetworkFlow[forwardgraph,1,Length[vertices],Edge];
forwardflows=Cases[networkflows[[All,1,All]],
{x_/;x>1,y_/;y<Length[vertices]}];
forwardedges = Map[vertices[[#]]&,forwardflows];
revisededges =
Join[Complement[edges2,forwardedges],Map[Reverse,forwardedges]];
```

```
revisedgraph=MakeGraph[vertices2,(MemberQ[revisededges ,{#1,#2}])&,Type-
>Directed,VertexLabel->True];
If[!AcyclicQ[revisedgraph],Print["*** ERROR: REVISED GRAPH IS NOT ACYCLIC
SO CHECK THE EQUATIONS ***"];Exit[]];
(* Print[ShowGraph[revisedgraph]];*)
toposort=TopologicalSort[revisedgraph];
(*Print[toposort];*)
sortedvertices=Cases[vertices2[[toposort]],_Symbol[_Integer],1];
sortedequations = Cases[vertices2[[toposort]],_Integer,1];
posfirstequation=Apply[Plus,First[Position[vertices2[[toposort]],_Integer
,1]]];
startvertices = vertices2[[toposort[[Range[posfirstequation-1]]]]];
(*startvertices
=vertices2[[Select[vertices,InDegree[revisedgraph,#]==0&]]];*)
Return[{sortedequations,sortedvertices, startvertices}]
];

(* calculate exogenous variables *)
exoginitialextended = Cases[Union[Flatten[Map[exoginitial/.t → # &,
Range[periods]]]]//.exogparams /.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];
exogextended= Cases[Union[Flatten[Map[exogeqns/.t → # &,
Range[periods]]]]//.Join[exogparams, exoginitialextended]
/.x_Symbol[i_Integer /;i < 0] → 0 ,Except[False|True|Null]];

exogtoposolver[equations_]:=Module[
{eqnorder,soleqn,solvar,outputs={},soltest1,soltest2},
eqnorder = toponodes[equations/.Equal->Subtract][[1]];
For[i=1,i<=Length[eqnorder],i++,
soleqn =equations[[eqnorder[[i]]]]//.outputs;
solvar = Cases[soleqn,_Symbol[_Integer],Infinity];
If[Length[solvar]!=0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** ERROR: DURING EXOGENOUS CALCULATIONS A VARIABLE HAD NO
SOLUTION ***"];Exit[],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
];
outputs
];

exogaugmented=Join[exoginitialextended,exogtoposolver[exogextended]];
Print["The exogenous variables calculate as: ", Sort[exogaugmented]];

(* calculate endogenous variables *)
interimparams = Join[exogparams, exogaugmented, endogparams];
endoginitialextended=endoginitial//.interimparams ;
allparams = Join[interimparams , endoginitialextended];
endogextended= Cases[Union[Flatten[Map[endogeqns/.t -> # &,
Range[periods]]]]//.allparams /.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];
endogtoponodes= toponodes[endogextended/.Equal->Subtract];
endogeqnorder =endogtoponodes[[1]];
Print["Directed acyclic graphs and topological processing have been
completed.... optimisation commencing..."];
(*Print["Topological order of variables:" ,endogtoponodes[[2]]];*)
```

```
Print["Please note that start vertices of the endogenous equation
tolopogy have not been automatically included as optimisation variables.
This is for flexibility as you may wish to use a surrogate based on your
observation of an alternative topological sort order. So please check the
endogenous start vertices here to confirm that these variables (or your
surrogates) have been included with optimisation variables at the start:
",
endogtoponodes[[3]]
];
lenendogeqnorder=Length[endogeqnorder];
endogextendedordered= endogextended[[endogeqnorder]];

(* calculate endogenous constraints *)
endogconextended= Cases[Union[Flatten[Map[endogcons/.t → # &,
Range[periods]]]]//.allparams /.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];
endogconextvars= Union[Cases[endogconextended,_Symbol[_Integer]
,Infinity]];

(* calculate objective vars *)
objvar= Cases[Union[Flatten[Map[obj/.t → # &,
Range[periods]]]]//.allparams/.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];

(* prepare the independent optimising variables *)
optimous=Union[Cases[Apply[List,Map[opt /.t → # //.allparams
&,Range[periods]]],
{_Symbol[_Integer],_Integer|_Real}|
{_Symbol[_Integer],_Integer|_Real,_Integer|_Real}|
{_Symbol[_Integer],_Integer|_Real,_Integer|_Real,_Integer|_Real},
Infinity]];
optimousvars= Union[Cases[optimous//.allparams,_Symbol[_Integer]
,Infinity]];

(* include any additional optimising variables arising from the leaves
and endogenous constraints *)
variables=Union[Join[optimous,Partition[Complement[endogconextvars,optimo
usvars],1]]];
Print["The optimising variables being used are: ",variables];
finalvars=Union[Cases[variables,_Symbol[_Integer] ,Infinity]];

(* commence solve *)
(* objective function ... *)
endogoptimsolver[nmvars_]:=Module[
{soleqn,solvar,outputs={},soltest1,soltest2},
For[i=1,i<=lenendogeqnorder,i++,
soleqn =endogextendedordered[[i]]/.outputs;
solvar = Cases[soleqn,_Symbol[_Integer],Infinity];
If[Length[solvar]!=0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** Warning: during optimisation ",solvar," became complex or null
in the equation ",soleqn," so the specified optimisation penalty of
",optimpenalty," was applied ***"];Return[optimpenalty],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
];
```

```
Apply[Plus,objvar/.outputs]
]/; VectorQ[nmvars,NumberQ];

(* optimisation phase ... *)
(* ... use FindMinimim to optimise the endogenous equations .. NMinimize
exhausts 16Gb of memory *)
endogoptimsolution=If[(Length[endogconextvars]==0),
FindMinimum[endogoptimsolver[finalvars],variables],
FindMinimum[{endogoptimsolver[finalvars],endogconextended},variables]
];

Print["The solution to the endogenous optimising variables is: ",
endogoptimsolution];

(* calculate final outputs by back substitution *)
endogoutputsolver[nmvars_]:=Module[
{soleqn,solvar,outputs=nmvars, soltest1,soltest2},
For[i=1,i<=lenendogeqnorder,i++,
soleqn =endogextendedordered[[i]]/.outputs;
solvar = Cases[soleqn,_Symbol[_Integer],Infinity];
If[Length[solvar]!=0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** ERROR: DURING BACKSUBSTITUTION A VARIABLE HAD NO SOLUTION
***"];Exit[],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
];
outputs
];

endogaugmented =
Join[endoginitialextended,endogoutputsolver[endogoptimsolution[[2]]]];
Print["The final outputs of the endogenous equations are: "
,Sort[endogaugmented]];

Print["Execution time: ",Round[N[AbsoluteTime[]-starttime]/60,0.01],"
minutes using ", Round[N[MaxMemoryUsed[]/10^6],0.01]," Mb; with ",
Length[finalvars]," optimising variables and ",
Length[exogaugmented]+Length[endogaugmented], " final variables in total;
",
Length[exogparams]," exogenous parameters; ",
Length[exoginitial]," exogenous initial variables; ",
Length[exogeqns]," exogenous equations; ",
Length[exogaugmented]," final exogenous variables; ",
Length[endogparams]," endogenous parameters; ",
Length[endoginitial]," endogenous initial variables; ",
Length[endogeqns]," endogenous equations; ",
Length[endogaugmented], " final endogenous variables"
 ];
```

Nordhaus DICE Brief (Book version)

The following Nordhaus DICE model is built from equations in *A Question of Balance: Weighing the Options on Global Warming Policy* (2008). The model uses the Phase III acyclic topological processor described in *Appendix 5 Acyclic solver for unconstrained optimisation*.

```
(* Nordhaus Brief Climate Change Policy Model May 2008 *)
(* Note: periods are decades, with the decade to 2005 being period zero
*)
(* Stuart Nettleton September 2008 *)
(* Nordhaus Book equations modified only in respect of rendering acyclic
*)
(* Note: Nordhaus Book differs from the Nordhaus Brief Code *)

starttime=AbsoluteTime[];
periods = 4; (* projection periods *)
optimpenalty=0; (* optimisation return if iteration non-real *)
<<Combinatorica`

(* objective function *)
(* this program always minimises, so negative for maximisation *)
obj = {-cumu[periods]};

(* optimisation variables: topology start nodes ... *)
(* .. to use the fast & robust Brent's Method by default, *)
(* which avoids the use of derivatives, make sure there *)
(* are no constraints and set two start variables. If possible *)
(* make sure there is one on either side of the zero crossing. *)
(* If formal constraints are present, FindMinimum will use the Interior
*)
(* Point Method and only one start variable should be present. *)
(* This should be your best estimate of the solution. While *)
(* Brent's Method is much faster than Interior Point, both execute *)
(* much faster and use considerable less memory than NMinimize. *)
(* Note that if an optimisation variable is set here but later *)
(* is defined as an initial variable, the latter is used. *)
opt ={
(* emissions control rate, fraction of uncontrolled emissions *)
{ μ[t],0.05,0.2},
(* capital stock *) {k[t],80, 150}
};
(* exogenous parameters *)
exogparams={
(* population 2005 millions *) pop0 → 6514,
(* population growth rate per decade *) popg → 0.35,
(* population asymptote *) popa → 8600,
(* technology growth rate per decade *) ga0 → 0.092,
(* technology depreciation rate per decade *) dela → 0.001,
(* equivalent carbon growth parameter *) gσ0 → -0.0730,
(* decline rate of decarbonisation per decade parameters*) dσ1 → 0.003,
dσ2 → 0.000,
(* backstop technology cost per tonne of carbon 2005 *) pback → 1.17,
(* backstop technology, final to initial cost ratio *) backrat → 2,
(* backstop technology, rate of decline in cost *) gback → 0.05,
(* pure rate of social time preference *) ρ → 0.015,
(* radiative forcing of non-carbon gases in 2000 & 2001 *) fex0 → -0.06,
fex1 → 0.30,
(* emissions in control regime parameters for 2005, 2015, 2205 *) κ1 → 1,
κ 2->1, κ21->1,
(* emissions in control regime decline rate*) dκ → 0,
(* abatement cost control parameter *) θ → 2.8,
(* carbon emissions from land use 2005 *) eland0 → 11
};
```

```
(* initial exogvars *)
exoginitial ={
gfacpop[1] → 0,gfacpop[0] → 0,
ga[0] → ga0, gσ[0] → gσ0,
a[1] → 0.02722, a[0] → 0.02722,
σ[1] → 0.13418, σ[0] → 0.13418,
eland[0] → eland0,
fex[0] → fex0, fex[1] → fex1,
κ[1] → 0.25372, κ[0] → 0.25372
};
(* exogenous equations *)
exogeqns ={
(* total factor productivity *) a[t] ==a[t-1]/(1-ga[t-1]),
(* social time preference discount factor *) r[t] == 1/(1+ ρ)^(10*(t-1)),
(* carbon emissions from land use sources *) eland[t] == eland0*(1-
0.1)^(t-1),
(* radiative forcing of other greenhouse gases *) fex[t] == fex0 + If[ t
≤ 12, 0.36, 0.1*(fex1-fex0)*(t-1)],
(* ratio of abatement cost with incomplete participation to that with
complete participation *) Π[t] == κ[t]^(1-θ),
(* population growth factor *) gfacpop[t]==(Exp[popg*(t-1)]-
1)/Exp[popg*(t-1)],
(* population level *) l[t] == pop0*(1-gfacpop[t])+gfacpop[t]*popa,
(* productivity growth rate *) ga[t] == ga0*Exp[-dela*10*(t-1)],
(* energy efficiency cumulative improvement *) gσ[t] == gσ0*Exp[-
dσ1*10*(t-1)-dσ2*10*(t-1)^2],
(* carbon emissions output ratio *) σ[t] == σ[t-1]/(1-gσ[t]),
(* backstop technology adjusted cost *) Θ[t] ==(pback*σ[t]/θ)*((backrat-
1+Exp[-gback*(t-1)])/backrat),
(* fraction of emissions in control regime *) κ[t] ==If[t ≥ 25, κ21, κ21
+ (κ2- κ21)*Exp[-dκ*(t-2)]]
};
(* endogenous parameters *)
endogparams={
(* elasticity of marginal utility of consumption *) α →2.0,
(* elasticity of output with respect to capital in production function *)
γ → 0.30,
(* depreciation rate of capital *) δ → 0.1,
(* temperature forcing parameter *) η → 3.8,
(* temperature change with carbon doubling *) t2xco2->3,
(* damage function parameters *)  ψ1 → 0, ψ2 → 0.0028388, ψ3 → 2,
(* climate equation parameters *)  ξ1 → 0.22, ξ2 → η/t2xco2, ξ3 → 0.3, ξ4
→ 0.05,
(* carbon cycle parameters *)  ϕ11 → 1- ϕ12a, ϕ12 → 0.189288, ϕ12a →
0.189288,
(* carbon cycle parameters *)  ϕ21 → 587.473* ϕ12a/1143.894, ϕ22 → 1- ϕ21
– ϕ23a,
(* carbon cycle parameters *) ϕ23 → 0.05, ϕ23a → 0.05, ϕ32 → 1143.894*
ϕ23a/18340, ϕ33 → 1- ϕ32,
(* mass of carbon in atmosphere, pre-industrial *)  mat1750->596.4,
(* scaling factor *) scale1 → 194
};

(* endogenous initial *)
endoginitial = {
y[0] → 61.1, c[0] → 30, inv[0] → 31.1,
ygr[1] → 55.667, ygr[0] → 55.667,
k[1] → 137, k[0] → 137,
ceind[1] → 0, ceind[0] → 0,
Λ[1] → 0.66203, Λ[0] → 0.66203,
Ω[1] → 0.99849, Ω[0] → 0.99849,
mat[1] → 808.9, mat[0] → 808.9,
mup[1] → 1255, mup[0] → 1255,
```

```
mlo[1] → 18365, mlo[0] → 18365,
tat[1] → 0.7307, tat[0] → 0.7307,
tlo[1] → 0.0068,tlo[0] → 0.0068,
μ[1] → 0.005, μ[0] → 0.005,
cumu[1] → 381800, cumu[0] →381800
};
(* endogenous variables *)
(* sn modifications of Nordhaus to render acyclic *)
endogeqns={
(* utility function *) u[t] == l[t]*((c[t] / l[t])^(1- α))/(1- α),
(* capital stock as function of investment *) k[t] == 10*inv[t]+((1-
δ)^10)*k[t-1],
(* output of goods and services, net of abatement and damages *) y[t] ==
Ω[t]*(1- Λ[t])*ygr[t],
(* output of goods and services, gross *) ygr[t] == a[t]* (k[t]^γ)
*(l[t]^(1- γ)),
(* ratio of climate damages to world output *) Ω[t] == 1/(1+ ψ1*tat[t]+
ψ2*(tat[t]^ ψ3)),
(* ratio of abatement to world output *) Λ[t] == Π[t] * θ[t] * μ[t]^ θ,
(* consumption of goods and services *) c[t] == y[t]-inv[t],
(* carbon emissions from industrial sources *) eind[t] == 10 * σ[t] *(1-
μ[t]) *ygr[t],
(* carbon emissions from industrial sources cumulative  *) (*ceind[t] ==
eind[t]+ceind[t-1],*)
(* carbon emissions total *) e[t]==eind[t]+eland[t],
(* mass of carbon in atmosphere *) mat[t] == e[t] + ϕ11*mat[t-1] +
ϕ21*mup[t-1],
(* mass of carbon in upper oceans *) mup[t] == ϕ12*mat[t-1]+ ϕ22*mup[t-1]
+ ϕ32*mlo[t-1],
(* mass of carbon in lower oceans *) mlo[t] == ϕ23*mup[t-1]+ ϕ33*mlo[t-
1],
(* radiative forcing total *) for[t] == η*Log[2,mat[t]/mat1750]+fex[t],
(* global mean terrestrial temperature *) tat[t] == tat[t-1]+ ξ1*(for[t]-
ξ2*tat[t-1]- ξ3*(tat[t-1]-tlo[t-1])),
(* global mean lower ocean temperature *) tlo[t]  ==tlo[t-1]+ ξ4*(tat[t-
1]-tlo[t-1]),
(* net present value of utility, the objective function *) cumu[t] ==
cumu[t-1]+(u[t]*r[t]*10)/scale1
};
posteqns={
(* climate damages, gross *) dam[t] == ygr[t]*(1- Ω[t]),
(* savings ratio *) s[t] == inv[t]/y[t],
(* interest rate *) ri[t] == γ*y[t]/k[t] -(1-(1- δ)^10)/10,
(* consumption of goods and services, per capita *) cpc[t] ==
c[t]*1000/l[t],
(* output of goods and services, net per capita *) pcy[t] ==
y[t]*1000/l[t]
};
(* endogenous constraints *)
endogcons={(*
k[t] ≤ 10*inv[t] + ((1- δ)^10)*k[t-1],
0.02*k[periods] ≤ inv[periods],
100 ≤ k[t],
20 ≤ c[t],
0 ≤ mat[t],
100 ≤ mup[t],
1000 ≤ mlo[t],
-1 ≤ tlo[t] ≤ 20,
tat[t] ≤ 20,
ceind[t] ≤ 6000,
0 ≤ q[t],
0 ≤ inv[t],
0 ≤ ygr[t],
```

```
0 ≤ eind[t],
0 ≤ μ[t] ≤ 1 *)
};

(* solve topological equations *)
toponodes[eqns_]:=Module[
{eqnvars,flatvars,eqnlist,mysource,mysink,edges1,edges2,edges3,edges,vert
ices2,vertices,forwardgraph,networkflows,forwardflows,forwardedges,revise
dedges,revisedgraph,toposort,sortedequations,
sortedvertices,posfirstequation,startvertices},
eqnvars=Map[Cases[eqns[[#]],_Symbol[_Integer],Infinity]&,Range[Length[eqn
s]]];
flatvars=Union[Flatten[eqnvars]];
eqnlist=Range[Length[eqns]];
f1[a_,b_]:={a,b};
edges1=Map[f1[mysource,flatvars[[#]]]&,Range[Length[flatvars]]];
edges2=Flatten[Map[Outer[f1,eqnvars[[#]],{eqnlist[[#]]}]&,eqnlist],2];
edges3=Map[f1[eqnlist[[#]],mysink]&,eqnlist];
edges=Join[edges1,edges2,edges3];
vertices2= Join[flatvars,eqnlist];
vertices=Join[{mysource},vertices2,{mysink}] ;
forwardgraph=MakeGraph[vertices,(MemberQ[edges,{#1,#2}])&,Type-
>Directed,VertexLabel->True];
If[!AcyclicQ[forwardgraph],Print["*** ERROR: FORWARD GRAPH IS NOT ACYCLIC
SO CHECK THE EQUATIONS ***"]];
networkflows=NetworkFlow[forwardgraph,1,Length[vertices],Edge];
forwardflows=Cases[networkflows[[All,1,All]],
{x_/;x>1,y_/;y<Length[vertices]}];
forwardedges = Map[vertices[[#]]&,forwardflows];
revisededges =
Join[Complement[edges2,forwardedges],Map[Reverse,forwardedges]];
revisedgraph=MakeGraph[vertices2,(MemberQ[revisededges ,{#1,#2}])&,Type-
>Directed,VertexLabel->True];
If[!AcyclicQ[revisedgraph],Print["*** ERROR: REVISED GRAPH IS NOT ACYCLIC
SO CHECK THE EQUATIONS ***"]; Exit[]];
(* Print[ShowGraph[revisedgraph]];*)
toposort=TopologicalSort[revisedgraph];
(*Print[toposort];*)
sortedvertices=Cases[vertices2[[toposort]],_Symbol[_Integer],1];
sortedequations = Cases[vertices2[[toposort]],_Integer,1];
posfirstequation=Apply[Plus,First[Position[vertices2[[toposort]],_Integer
,1]]];
startvertices = vertices2[[toposort[[Range[posfirstequation-1]]]]];
(*startvertices
=vertices2[[Select[vertices,InDegree[revisedgraph,#]==0&]]]; *)
Return[{sortedequations,sortedvertices, startvertices}]
];
(* calculate exogenous variables *)
exoginitialextended = Cases[Union[Flatten[Map[exoginitial/.t → # &,
Range[periods]]]]//.exogparams /.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];
exogextended= Cases[Union[Flatten[Map[exogeqns/.t → # &,
Range[periods]]]]//.Join[exogparams, exoginitialextended]
/.x_Symbol[i_Integer /;i < 0] → 0 ,Except[False|True|Null]];

exogtoposolver[equations_]:=Module[
{eqnorder,soleqn,solvar,outputs={},soltest1,soltest2},
eqnorder = toponodes[equations/.Equal->Subtract][[1]];
For[i=1,i<=Length[eqnorder],i++,
soleqn =equations[[eqnorder[[i]]]]//.outputs;
solvar = Cases[soleqn,_Symbol[_Integer],Infinity];
If[Length[solvar]!=0,
```

```
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** ERROR: DURING EXOGENOUS CALCULATIONS A VARIABLE HAD NO
SOLUTION ***"];Exit[],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
];
outputs
];

exogaugmented=Join[exoginitialextended,exogtoposolver[exogextended]];
Print["The exogenous variables calculate as: ", Sort[exogaugmented]];

(* calculate endogenous variables *)
interimparams = Join[exogparams, exogaugmented, endogparams];
endoginitialextended=endoginitial//.interimparams ;
allparams = Join[interimparams , endoginitialextended];
endogextended= Cases[Union[Flatten[Map[endogeqns/.t → # &,
Range[periods]]]]//.allparams /.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];
endogtoponodes= toponodes[endogextended/.Equal → Subtract];
endogeqnorder =endogtoponodes[[1]];
Print["Directed acyclic graphs and topological processing have been
completed.... optimisation commencing..."];
(*Print["Topological order of variables:" ,endogtoponodes[[2]]];*)
Print["Please note that start vertices of the endogenous equation
tolopogy have not been automatically included as optimisation variables.
This is for flexibility as you may wish to use a surrogate based on your
observation of an alternative topological sort order. So please check the
endogenous start vertices here to confirm that these variables (or your
surrogates) have been included with optimisation variables at the start:
",
endogtoponodes[[3]]
];
lenendogeqnorder=Length[endogeqnorder];
endogextendedordered= endogextended[[endogeqnorder]];

(* calculate endogenous constraints *)
endogconextended= Cases[Union[Flatten[Map[endogcons/.t → # &,
Range[periods]]]]//.allparams /.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];
endogconextvars= Union[Cases[endogconextended,_Symbol[_Integer]
,Infinity]];

(* calculate objective vars *)
objvar= Cases[Union[Flatten[Map[obj/.t → # &,
Range[periods]]]]//.allparams/.x_Symbol[i_Integer /;i < 0] → 0
,Except[False|True|Null]];

(* prepare the independent optimising variables *)
optimous=Union[Cases[Apply[List,Map[opt /.t → # //.allparams
&,Range[periods]]],
{_Symbol[_Integer],_Integer|_Real}|
{_Symbol[_Integer],_Integer|_Real,_Integer|_Real}|
{_Symbol[_Integer],_Integer|_Real,_Integer|_Real,_Integer|_Real},
Infinity]];
```

```
optimousvars= Union[Cases[optimous//.allparams,_Symbol[_Integer]
,Infinity]];

(* include any additional optimising variables arising from the leaves
and endogenous constraints *)
variables=Union[Join[optimous,Partition[Complement[endogconextvars,optimo
usvars],1]]];
Print["The optimising variables being used are: ",variables];
finalvars=Union[Cases[variables,_Symbol[_Integer] ,Infinity]];

(* commence solve *)
(* objective function ... *)
endogoptimsolver[nmvars_]:=Module[
{soleqn,solvar,outputs={},soltest1,soltest2},
For[i=1,i<=lenendogeqnorder,i++,
soleqn =endogextendedordered[[i]]/.outputs;
solvar = Cases[soleqn,_Symbol[_Integer],Infinity];
If[Length[solvar] ≠ 0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** Warning: during optimisation ",solvar," became complex or null
in the equation ",soleqn," so the specified optimisation penalty of
",optimpenalty," was applied ***"];Return[optimpenalty],
soltest2 = Select[soltest1,(solvar/.#) >0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
];
Apply[Plus,objvar/.outputs]
]/; VectorQ[nmvars,NumberQ];

(* optimisation phase ... *)
(* ... use FindMinimim to optimise the endogenous equations .. NMinimize
exhausts 16Gb of memory *)
endogoptimsolution=If[(Length[endogconextvars]==0),
FindMinimum[endogoptimsolver[finalvars],variables],
FindMinimum[{endogoptimsolver[finalvars],endogconextended},variables]
];

Print["The solution to the endogenous optimising variables is: ",
endogoptimsolution];

(* calculate final outputs by back substitution *)
endogoutputsolver[nmvars_]:=Module[
{soleqn,solvar,outputs=nmvars, soltest1,soltest2},
For[i=1,i<=lenendogeqnorder,i++,
soleqn =endogextendedordered[[i]]/.outputs;
solvar = Cases[soleqn,_Symbol[_Integer],Infinity];
If[Length[solvar]!=0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** ERROR: DURING BACKSUBSTITUTION A VARIABLE HAD NO SOLUTION
***"];Exit[],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
```

```
];
];
];
outputs
];

endogaugmented =
Join[endoginitialextended,endogoutputsolver[endogoptimsolution[[2]]]];
Print["The final outputs of the endogenous equations are: "
,Sort[endogaugmented]];

Print["Execution time: ",Round[N[AbsoluteTime[]-starttime]/60,0.01],"
minutes using ", Round[N[MaxMemoryUsed[]/10^6],0.01]," Mb; with ",
Length[finalvars]," optimising variables and ",
Length[exogaugmented]+Length[endogaugmented], " final variables in total;
",
Length[exogparams]," exogenous parameters; ",
Length[exoginitial]," exogenous initial variables;",
Length[exogeqns]," exogenous equations; ",
Length[exogaugmented]," final exogenous variables; ",
Length[endogparams]," endogenous parameters; ",
Length[endoginitial]," endogenous initial variables; ",
Length[endogeqns]," endogenous equations; ",
Length[endogaugmented], " final endogenous variables"
 ];
```

A4.4 Appendix references

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Appendix 5 Acyclic Solver for Unconstrained Optimisation

A5.1 Overview

In order to undertake the research in this dissertation a new flexible model for optimising systems of nonlinear equations was developed using Mathematica. The achievements in this model are:

- Climate change models: a new platform for investigating climate change policy based on a widely available computer algebra system and therefore opening up the area to a wider body of researchers than those with specialised software such as GAMS and AMPL
- Climate change policy: Nordhaus equation modelling in an environment with modern interior point solver, directed acyclic model and removal of constraints. Nordhaus uses GAMS with the CONOPT solver. CONOPT approximates nonlinear functions with straight line segments and then uses the simplex method for linear functions. Miller (2000, Section 11.3.1, pp595-602) demonstrates the solution method of separable functions, which are functions with multiple variables that can be deconstructed into a number of single variable functions. A solution can be found very quickly but it is only an approximate solution to the original problem. However, Nordhaus has confidence in CONOPT through usage but may not achieve the correct solution
- Operations research perspective: a new platform for solving nonlinear discrete period optimisation problems employing recent Mathematica interior point optimisation and Combinatorica combinatorial geometry. Secondary but important advantages include being able to define problems using Greek characters and that solutions remain in the Mathematica environment for visualisation and post-processing.

A5.2 Modelling factors that affect performance

Arguably, nonlinear optimisation is as much an art as a science because of the considerable number of factors that need to be controlled to achieve a successful result.

- the solution algorithm: for example Nelder-Mead, differential evolution, Brent's method or interior point are discussed below
- the complexity of the equations and treatment of roots: the Fundamental Theorem of Algebra is that any non zero polynomial of n-degree always has at least one. This may be a real number or a conjugate pairs of complex numbers. Usually only real roots are of interest and minimising functions like NMinimize and FindMinimum declare an error with complex objective outcomes. The advantage of a topological method is that learning may be introduced through a penalty function, which moves the optimiser away from complex roots
- starting points for the optimising variables: may be more or less appropriate for the optimisation
- selection of the best optimisation variables: *prima facie* it is tempting to set the optimisation variables as the starting vertices of the DAG, as suggested by the topological sort. For example, in solving a model with the equation $ygr[t]=fn(k[t]^{0.3})$ the topological sort may suggest that $ygr[1], ygr[2], ygr[3]$ etc are the starting vertices. However, it can be observed that an inverse function also exists $k[t]=ifun(ygr[t]^{3.33})$ and a small change in $ygr[t]$ can produce a very large change in $k[t]$. Although $ygr[t]$ has become an unruly optimising variable, optimisations are possible given sufficient control of the starting estimates. Tight control of a small number of starting vertices, such as $ygr[1], ygr[2]... ygr[10]$ is certainly feasible using closely positioned constants. Unfortunately, as the number of optimising variables expands, say $ygr[1], ygr[2]... ygr[60]$ it becomes difficult to know in advance how to customise starting estimates. If the tight starting conditions cannot be maintained for an unruly starting variable like $ygr[t]$ then stability in the optimisation is materially enhanced by using $k[t]$ as a desensitised optimisation variable
- hardware factors: the CPU clock speed, amount of RAM, operating system (Linux or Windows) and 32-bit or 64-bit processing are well known parameters affecting performance.[i] However, there are other issues to consider that make comparing absolute execution times on various machines somewhat tenuous. For example whether multiple

processors have only one memory bus and calculations are CPU-bound or memory-bound

Mathematica optimisation algorithms

Numerical algorithms for constrained nonlinear optimisation either use direct search or gradient search. Direct search is often used for global optimisation and gradient search for local optimisation.

Direct search methods for global optimisation

Direct search methods include Nelder & Mead (1965), genetic algorithm, differential evolution and simulated annealing. A “simplex” of values of the objective function is kept for each iteration of optimising variables. The data set is interpreted in order to “roll downhill” to the optimal solution. While tolerant to noise in the objective function and constraints, steepest descent is a strategy that tends to converge relatively slowly and the method is at the same time very expensive in memory because each for n-dimensional iteration maintains $n+1$ points. The method is sometimes called the “downhill simplex” and is unrelated to George Dantzig's well known simplex method (Dantzig 2002).

By default Mathematica's NMinimize uses the Nelder-Mead method for problems requiring a global minimum. However, NMinimize reverts to the Differential Evolution algorithm if necessary. As described above, Nelder-Mead is computationally intense and therefore slow and memory intensive. Although more robust, Differential Evolution is even slower.

Even though NMinimize is nominally a global minimising function, it may only find a local minimum unless the objective function and constraints are linear. Other issues suggest that it may be more effective to directly use a fast local optimising function, such as FindMinimum. For example, NMinimize usually requires the problem domain to be bounded with constraints, which makes the problem computationally intensive; a starting interval may need to be specified to help achieve a better local minimum; and NMinimize often needs to call a local minimising function in any case, in order to polish the end result.

Gradient search methods for local minimisation

Gradient search methods include sequential quadratic programming (SQP), the augmented Lagrangian, and the modern interior point. The method may employ first derivatives or second derivatives, which are called Hessians.

The local optimisation function FindMinimum is significantly faster than NMinimize, particularly for large problems with few local minima such as climate change policy equations.

FindMinimum's specific settings for method are Brent's principal axis, Gradient, Conjugate Gradient, Levenberg Marquardt, Newton, Quasi Newton, Interior Point and Linear Programming.

In the case where the method is left to default, FindMinimum selects a different method based on whether constraints are present (the interior point method is selected); there is one starting value for each variable (the Broyden-Fletcher-Goldfarb-Shannon (BFGS) quasi-Newton method, with a limited memory variant for large systems); or there are two starting values given for the optimising variables and the objective function is real (Brent's principal axis method).

Line search

Local minimising functions are based on quadratic models.[ii]

$$q_k(p) = f(x_k) + \nabla f(x_k)^T + 1/2\, p^T B_k\, p$$

where k is the kth iterative step
and the step is $x_{k+1} = x_k + s_k$
which is guaranteed to converge to a local minimum
if x_k is sufficiently close to a local minimum

Newton's method uses the exact Hessian:

$$B_k = \nabla^2 f(x_k)$$

with the step $x_{k+1} = x_k + s_k$
and is guaranteed to converge to a local minimum
if x_k is sufficiently close to a local minimum

However, the method is valid only insofar as the Newton quadratic model reflects the function. Where the Hessian is not explicitly known, the system of linear equations is solved by numerical approximation:

$$B_k s_k = -\nabla f(x_k)$$

where s_k is a trial step.

Usually B_k is an inaccurate approximation to the Hessian and the starting value x_k is rarely close enough to guarantee convergence.

Line search and trust region are two methods to improve the rate of optimisation convergence and chance of success by controlling the sequence of steps. The idea of a line search is to use the direction of the chosen step, but to control the length, by solving a one-dimensional problem at each s_k of $x_{k+1} = x_k + \alpha_k s_k$ such that certain optimisation conditions are satisfied. Mathematica uses Wolfe's conditions to require sufficient decrease in value and slope of $f(x_{k+1})$ that guarantees the convergence of B_k.[iii]

Brent's principal axis method

Brent's derivative-free univariate method seeks a minimum regardless of the decrease and curvature factors. The first phase is bracketing the root. The second phase is combining interpolation and golden section to find the minimum. The advantage of this line search is that it does not require, as the other two methods do, that the step be in a descent direction, since it will look at both directions in an attempt to bracket the minimum.

In essence it is a safeguarded secant method, which keeps a point where the function is positive and one where it is negative so that the root is always bracketed. This special geometry of the zero-axis crossing means that at each step, FindMinimum chooses between an interpolated (secant) step and a bisection to ensure convergence. This means that Brent's method is a very robust algorithm, which even provides a good estimate where functions are very steep at the zero crossing or perhaps even discontinuous.

Brent's principal axis method uses the two staring points u_1 and u_2 to commence a line search.[iv] Starting at a point x_0 , the algorithm undertakes a line search from a point x_{i-1} to a point x_i that minimises the objective function along the search $u_1, u_2 ... u_n$ directions. Then u_i is replaced with u_{i+1} and at the end, u_n is replaced with $x_0 - x_i$. Brent's method then realigns the values (that are assumed to be not entirely independent) to the principal directions for the local quadratic model. For efficiency, Brent uses singular value decomposition of the matrix $u_1, u_2 ... u_n$ instead of resolving eigenvalues. The resulting u_i can then be used for the next iteration.

Computing derivatives with finite differences is disadvantaged by significant computing overhead and reduced the reliability of derivatives. Where symbolic derivatives are not available, the alternative is to build a model using only values from function evaluations.

With FindMinimum, it is advisable to provide two start estimates for the optimising variables that (ideally) bracket the root i.e. one starting value gives a positive value and the other a negative value. Notwithstanding whether or not these two starting values do bracket the root, the fact that there are two stating values means that FindMinimum will use Brent's method as default.

Starting estimates of optimising variables are, for example, provided as follows:

$$opt = \{\{\mu[t], 0.1, 0.2\}, \{k[t], 300, 1000\}\};$$

Start estimates automatically provide scoping for the variables; facilitate compact, high performance unconstrained optimisation; facilitate removal of constraints that might have been otherwise needed to position the optimising process (as usually required with NMinimize). For example, instead of setting constraints such as $constraints = \{0 \le \mu[t] \le 1, k[t] \ge 100\}$.

Nevertheless, if a constraint such as $\mu[t] \le 1$ is violated in execution, then a penalty function can be used to teach the optimiser to seek in the correct range. For example, when $\mu[t]>1$ the following penalises the objective function $-Clip[(\mu[t]-1),0,1]10^6$.

Although Brent's algorithm is efficient in terms of its quadratic convergence rate it is quite expensive because of the derivative-free line search that requires a substantial number of function evaluations. The directions given to the line search (especially at the beginning) are not necessarily descent directions so the line search has to be able to search in both directions. For problems with many variables, the individual linear searches in all directions become very expensive, so this method is typically better suited to problems without too many variables.

To make effective use of Brent's method it is necessary to have a way of reducing the number of optimising variables. A major advantage of the topological method described later in this appendix is that the number of variables is significantly reduced to a small number of input vertices of the network of the equations. For example, a network that adds 30 new nodes per period may have only two new input vertices per period requiring optimisation.

Interior point

Over recent decades, interior point development has generated considerable excitement in operations research because it permits nonlinear optimisation comparable with Dantzig's (2002) extraordinarily efficient “simplex” method used for linear programming. Dantzig's “simplex” method works around the surfaces bounding the problem. In contrast, interior point seeks to pass through the solid defined by the problem. It does this by constructing a sequence of strictly feasible points lying in the solid interior that converge to the solution.

Precedents for interior point are found as early as the 1960s in the use of barrier functions. However, the method was not formalised until Karmarkar (1984) and most modern implementations use the Mehrotra (1992) predictor-corrector technique. Mehrotra's interior point method generally converges in polynomial time, which is similar to George Dantzig's simplex method (although both can become exponential under certain conditions).

Commencing with Mathematica version 6.0 (2006), the only method for constrained optimisation in Mathematica's FindMinimum function is interior point. It is based on the COIN Project IPOPT optimiser. In Mathematica 5.2 and earlier, there are no standard functions for nonlinear constrained optimisation, although some functionality was possible with the older approach of using penalty functions to enforce constraints.

FindMinimum requires the first and second derivatives of the objective and constraints. The second derivative (or Hessian) permits Newton's method to be employed, which is a convergence strategy that is much faster than just using first derivative downhill functions.

As its first approach, FindMinimum seeks to symbolically differentiate the objective function and constraints. If this fails it calculates derivatives by finite differences. While Newton's method may take fewer steps due to the information it has about the curvature of the function, the execution time can be longer because the symbolic Hessian is re-evaluated at each step.

One issue with interior point is that it may be unable to converge if the first derivative at the optimal point is not continuous.

Over the last decade, large advances in nonlinear optimisation have been achieved with the interior point method. An industrial solver IPOPT is available as open source but the only convenient interfaces remain in AMPL and GAMS.

Mathematica 6 has benefited from the commoditisation of formerly proprietary operations research optimisation knowhow.[v] The interior point method solves a constrained optimisation by forming a barrier function from the constraints and the objective function. Miller (2000, Section 9.1-9.5, pp494-529) explains the interior point method in considerable detail

Minimise $f(x)$
subject to: $h(x) = 0$
for $x \geq 0$

becomes:

$$\text{Minimise } \psi(x) - \mu \sum_i \ln(x_i)$$
$$\text{subject to } h(x) = 0$$
$$\text{where } \mu \geq 0 \text{ is a barrier function}$$

and such that the Karush-Kuhn-Tucker boundary condition is:

$\nabla \psi_\mu - y^T A(x) = 0$, where $A(x) = (\nabla h_1(x), ..., \nabla h_m(x))^T$ is dimension $n x m$.

Which can be summarised as:

$$\begin{aligned} g(x) &= \mu X^{-1} e - y^T A(x) = 0 \\ h(x) &= 0 \\ Zeta\, X\, e &= \mu e \end{aligned}$$

Newton's Method can be used to solve this nonlinear system:

$$L(x, y) = f(x) - h(x)^T y$$
$$H(x, y) = \nabla^2 L(x, y) = \nabla^2 f(x) - \sum_{i=1}^{m} y_i \nabla^2 h_i x$$

and the Jacobi matrix is:

$$\begin{pmatrix} H(x,y) & -A(x)^T & -I \\ -A(x) & 0 & 0 \\ Z & 0 & X \end{pmatrix} \begin{pmatrix} \delta x \\ \delta y \\ delta z \end{pmatrix} = - \begin{pmatrix} g(x) - z - y^T A(x) \\ -h(x) \\ Z X e - \mu e \end{pmatrix} = - \begin{pmatrix} d_\psi \\ -d_h \\ d_{xz} \end{pmatrix}$$

As

$$\delta z,\ \delta z = X^{-1} Z \delta x + d_{xz}$$

then:

$$(H(x, y) + X^{-1}) \delta x - A(x)^T \delta y = - d_\psi - X^{-1} d_{xz}$$

so:

$$\begin{pmatrix} H(x,y) + X^{-1}Z & -A(x)^T \\ -A(x) & 0 \end{pmatrix}\begin{pmatrix}\delta x \\ \delta y\end{pmatrix} = -\begin{pmatrix} d_\psi + X^{-1} d_{xz} \\ -d_h \end{pmatrix} = -\begin{pmatrix} g(x) - A(x)^{Ty} - \mu X^{-1} e \\ -h(x) \end{pmatrix}$$

Therefore the nonlinear equations can be solved iteratively with:

$$x := x + \delta x, t := y + \delta y, z := z + \delta z$$

and the search direction given by solving the Jacobi system as:

$$\delta x, \delta y, \delta z$$

The augmented Langrangian merit function is defined as:

$$\phi(x, \beta) = f(x) - \mu \sum_i \ln(x_i) - h(x)^T \lambda + \beta \|h(x)\|^2$$

where $\mu > 0$ is the barrier parameter and $\beta > 0$ is a penalty parameter.

The matrix is positively definite:

$$N(x,y) = H(x,y) + X^{-1} Z$$

So the search direction given by solving the Jacobian is a descent direction for the Langrangian merit function. This means x, y, μ satisfies the Karush-Kuhn-Tucker (KKT) condition, which is a necessary condition for nonlinear optimality (Karush 1939; Kuhn & Tucker 1951; Miller 2000, Section 4.4.5, pp 210-9)

While the constraints are positive, a line search can be commended along the initial search direction with a step of 1. A backtracking procedure is then used until the merit function satisfies the Armijo condition:[vi]

$$\phi(x + t\delta x, \beta) \leq \phi(x, \beta) + \gamma \nabla \phi(x, \beta)^T \delta x \quad \text{with} \quad y \in (0, 1/2) \ .$$

Convergence is given by:

$$\|g(x) - z - t^T A(x)\| + \|h(x)\| + \|Z X e - \mu e\| \leq tol$$

where tol is set by default to $10^{-MachinePrecision/3}$.

Both the accuracy condition and number of iterations are critical in finding a solution to problems with significant complexity.

A5.3 Phases of model development

Phase I Model

In the first phase of developing an acyclic solver an abstraction layer was used for the equations with direct and simultaneous optimisation of all independent and dependent variables. While the “blunt instrument” approach of optimising every variable simultaneously is perfectly suitable for small problems, it is rather naïve to believe it can scale to thousands of variables and equations. Indeed, a high performance cluster node with 4Gb RAM (Orion) exceeds memory after just 9 periods and one with 16Gb RAM (Titan) fails after 14 periods, both falling far short of the 60 period goal. Projections of increasing RAM to 64Gb indicated that the additional memory would only achieve one or two more periods.

In the simplest presentation, each of the exogenous variables (scalars), endogenous variables (model equations) and constraints, are elements of a list:

```
(* Exogenous variables *)
equations = {
gfacpop[t] == (Exp[popg*(t - 1)] - 1)/Exp[popg*(t - 1)],
l[t] == pop0*(1 - gfacpop[t]) + gfacpop[t]*popa,
ga[t] == ga[0]*Exp[-dela*10*(t - 1)],
a[t] == If[t == 1, a[0], a[t - 1]/(1 - ga[t - 1])],
gσ[t] == gσ[0]*Exp[-dσ1*10*(t - 1) – dσ2*10*(t - 1)^2],
σ[t] == If[t == 1, σ[0], σ[t - 1]/(1 – gσ[t])],
θ[t] == (pback* σ[t]/θ)*((backrat - 1 + Exp[-gback*(t - 1)])/backrat),
eland[t] == eland[0]*(1 - 0.1)^(t - 1),
r[t] == 1/(1 + ρ)^(10*(t - 1)),
fex[t] == fex0 + If[ t < 12, 0.1*(fex1 - fex0)*(t - 1), 0.36],
κ[t] == If[ t == 1, κ[0], If[ t ≥ 25, κ21, κ21 + ( κ2 – κ21)*Exp[-dκ*(t –
2)]]],
Π[t] == κ[t]^(1 – θ),
s[t] == sr,
(* Exogenous variables *)
ceind[t] == eind[t - 1] + ceind[t - 1],
```

```
k[t] ≤ 10*inv[t - 1] + ((1 – δ)^10)*k[t - 1],
0.02*k[periods] ≤ inv[periods],
eind[t] == 10 * σ[t] *(1 – μ[t]) *ygr[t] + eland[t],
for[t] == η*(Log[(matav[t] + 0.000001)/mat1750]/Log[2]) + fex[t],
mat[t] == eind[t - 1] + ϕ11*mat[t - 1] + ϕ21*mup[t - 1],
matav[t] == (mat[t] + mat[t + 1])/2,
mlo[t] == ϕ23*mup[t - 1] + ϕ33*mlo[t - 1],
mup[t] == ϕ12*mat[t - 1] + ϕ22*mup[t - 1] + ϕ32*mlo[t - 1],
tat[t] == tat[t - 1] + ξ1*(for[t] – ξ2*tat[t - 1] – ξ3*(tat[t - 1] -
tlo[t - 1])),
tlo[t]  == tlo[t - 1] + ξ4*(tat[t - 1] - tlo[t - 1]),
ygr[t] == a[t]* k[t]^ γ *l[t]^(1 – γ),
dam[t] == ygr[t]*(1 - 1/(1 + ψ1*tat[t] + ψ2*(tat[t]^ ψ3))),
Λ[t] == ygr[t] * Π[t] * Θ[t] * μ[t]^ θ,
y[t] == ygr[t]*(1 – Π[t]* Θ[t]* μ[t]^ θ)/(1 + ψ1*tat[t] + ψ2*(tat[t]^
ψ3)),
s[t] == inv[t]/(0.001 + y[t]),
ri[t] == γ*y[t]/k[t] - (1 - (1 – δ)^10)/10,
c[t] == y[t] - inv[t],
(*cpc[t] == c[t]*1000/l[t],*)
(*pcy[t] == y[t]*1000/l[t],*)
u[t] == ((c[t]/l[t])^(1 – α) - 1)/(1 – α),
cumu[t] == cumu[t - 1] + (l[t]*u[t]*r[t]*10)/scale1,
100 ≤ k[t],
20 ≤ c[t],
10 ≤ mat[t],
100 ≤ mup[t],
1000 ≤ mlo[t],
-1 ≤ tlo[t] ≤ 20,
tat[t] ≤ 20,
ceind[t] ≤ ceindlim,
0 ≤ q[t],
0 ≤ inv[t],
0 ≤ ygr[t],
0 ≤ eind[t],
0 ≤ matav[t],
0 ≤ μ[t] <= μlim
};
```

The solution algorithm is very simple:

```
eqextended= Cases[Union[Flatten[Map[Join[objvars,equations] /.t → # &,
Range[periods]]]]//.parametervals//.initialvalues
/.x_Symbol[i_Integer /;i ≤ 0] -> 0 ,Except[False|True]];
variables = Union[Cases[eqextended, _Symbol[_Integer], Infinity]] ;
soln=NMinimize[eqextended, variables]
```

Phase II model

The second phase of acyclic modeller used the symbolic recursion of equations as functions and direct optimisation of resultant independent variables. A recursed approach is far more elegant than using NMinimize (or FindMinimum) as a blunt instrument for solving thousands of equations and variables.

Recursion is not an abstraction structure. Instead it directly employs the equations as active functions that form an auto-topology. This means the optimising function need only solve for the independent variables, which can either be specified exogenously or Mathematica can automatically calculate using symbolic algebra.

The equations are given as functions, with scalars having a memory function, shown in the exogenous equations. Endogenous functions (model equations) are each optimised so cannot have a memory function in the same way as scalars. Starting variables are associated with each function as a limit values of the function:

```
(* exogenous equality constraints *)
gfacpop[t_] := gfacpop[t] = (Exp[popg*(t - 1)] - 1)/Exp[popg*(t - 1)];
l[t_] := l[t] = pop0*(1 - gfacpop[t]) + gfacpop[t]*popa;
ga[t_] := ga[t] = ga[0]*Exp[-dela*10*(t - 1)]; ga[0] = 0.092;
a[t_] := a[t] = a[t - 1]/(1 - ga[t - 1]); a[1] = a[0] = 0.02722;
gσ[t_] := gσ[t] = gσ[0]*Exp[-dσ1*10*(t - 1) − dσ2*10*(t - 1)^2]; gσ[0] =
-0.0730;
σ[t_] := σ[t] = σ[t - 1]/(1 − gσ[t]); σ[1] = σ[0] = 0.13418;
θ[t_] := θ[t] = (pback* σ[t]/θ )*((backrat - 1 + Exp[-gback*(t -
1)])/backrat);
eland[t_] := eland[t] = eland[0]*(1 - 0.1)^(t - 1); eland[0] = 11;
r[t_] := r[t] = 1/(1 + ρ)^(10*(t - 1));
fex[t_] := fex[t] = fex0 + If[ t < 12, 0.1*(fex1 - fex0)*(t - 1), 0.36];
κ[t_] := κ[t] = If[t ≥ 25, κ21, κ21 + ( κ2 − κ21)*Exp[-dκ*(t - 2)]]; κ[1]
= κ[0] = 0.25372;
Π[t_] := Π[t] = κ[t]^(1 − θ);
s[t_] := s[t] = sr;

(* endogenous equality constraints *)
ceind[t_] := eind[t - 1] + ceind[t - 1];
ceind[1] = ceind[0] = ceind0;
eind[t_] := 10 * σ[t] *(1 − μ[t]) *ygr[t] + eland[t];
for[t_] := η*(Log[(matav[t] + 0.000001)/mat1750]/Log[2]) + fex[t];
mat[t_] := eind[t - 1] + ϕ11*mat[t - 1] + ϕ21*mup[t − 1]; mat[1] = mat[0]
= mat0;
matav[t_] := (mat[t] + mat[t + 1])/2;
mlo[t_] := ϕ23*mup[t - 1] + ϕ33*mlo[t - 1]; mlo[1] = mlo[0] = mlo0;
mup[t_] := ϕ12*mat[t - 1] + ϕ22*mup[t - 1] + ϕ32*mlo[t − 1];
mup[1] = mup[0] = mup0;
tat[t_] := tat[t - 1] + ξ1*(for[t] − ξ2*tat[t - 1] − ξ3*(tat[t - 1] -
tlo[t - 1]));
tat[1] = tat[0] = tat0;
tlo[t_] := tlo[t - 1] + ξ4*(tat[t - 1] - tlo[t - 1]); tlo[1] = tlo[0] =
tlo0;
ygr[t_] := a[t]* k[t]^ γ *l[t]^(1 − γ);
dam[t_] := ygr[t]*(1 - 1/(1 + ψ1*tat[t] + ψ2*(tat[t]^ ψ3)));
Λ[t_] := ygr[t] * Π[t] * θ[t] * μ[t]^ θ;
y[t_] := ygr[t]*(1 − Π[t]* θ[t]* μ[t]^ θ)/(1 + ψ1*tat[t] + ψ2*(tat[t]^
ψ3)); y[0] = y0;
inv[t_] := (y[t] + 0.001)*s[t];
k[t_] := 10*inv[t - 1] + ((1 − δ)^10)*k[t - 1];
k[1] = k[0] = k0;
```

```
ri[t_] := γ*y[t]/k[t] - (1 - (1 – δ)^10)/10;
c[t_] := y[t] - inv[t]; c[0] = 30;
cpc[t_] := c[t]*1000/l[t];
pcy[t_] := y[t]*1000/l[t];
u[t_] := ((c[t]/l[t])^(1 – α) - 1)/(1 – α);
cumu[t_] := cumu[t - 1] + (l[t]*u[t]*r[t]*10)/scale1; cumu[1] = cumu[0] =
cumu0;
μ[1] = μ[0] = μ0;
```

Solution is quite straightforward, using symbolic or numeric evaluation of the objective function and optimisation with NMinimize of FindMinimum. If the functions are restricted to numerical evaluation then the functions need to have a ?NumberQ filter to curtail symbolic evaluation, for example:

```
ceind[t_?NumberQ] := eind[t - 1] + ceind[t - 1];
```

Notwithstanding its impressive “grunt” in processing recursed equations, Mathematica eventually fails in the same way as other algebraic processors when dealing with recursion. Recursion memory/stack space issues issues are well documented.

Projection Periods	**Compilation Time (mins)**	**Execution Time (mins)**	**Memory Usage Mbytes**
5	1.0 sec	1.2	34
6	2.4 secs	2.4	535
7	8.9 secs	24.8**	1234
8	0.5	12.8	572
9	2.3	40.9	943
10	9.4	66.3	8908
11	33.5*	NA	Exhausted 16Gb RAM

Notes:

* 10.5Gb used in compilation phase;

** this result looks odd but it was retested and therefore due to the shape of the curve.

Scalar exogenous variables that are not optimisation may be precalculated rather than left to be calculated in the recursion process. This creates significant time savings in compilation prior to optimisation. It takes only 0.4 seconds and 6Mb to calculate either up to 60 periods. However, memory remains a limiting factor in the optimising phase. Ten periods is the maximum projection that can be evaluated in 16Gb.

Comparison statistics for recursed and precalculated scalars are:

Exogenous Variable Calculation Approach	**Projection Periods**	**Compilation Time (mins)**	**Execution Time (mins)**	**Memory Usage Mbyte**
Recursed	10	8.3	66.8	8901
Pre-calculated	10	6	21.8	9051
Pre-calculated	11	23.9	NA	Exhausted 16Gb RAM

One way of scaling-up the recursion approach to maximise and minimise memory is to alternately store and clear intermediate iteration variables. The three key limitations to pursuing this approach are:

- memory usage: the memory usage of this technique in storing a set of parameters for each instance of optimisation variables can be overwhelming. In addition to this there is always a very high memory usage associated with NMinimize because it stores a vast simplex of values to create its downhill roll. For the latter reason, I have found myself moving toward using FindMinimum and particularly to Brent's method (which is derivative free like NMinimize Nelder-Mead). In fact, while the topological method can now solve very large problems of 40 periods (and I am testing more), the use of NMinimize causes machines to run out of memory with only 4 periods!
- platform structure: it is quite important to not only solve the problem but to separate the model from the solver code in order to have a repeatable system for solving different sets equations. Hard coded customised methods can make it very hard to rapidly change the model once it moves into policy analysis. For example, Nordhaus proceeds to solve many different configurations of his equations
- complex roots: when the number of periods is large, the model can stray into complex numbers. This is a real “model wrecker”. It is necessary to intricately customise the model by modifying equations with powers and logarithms that can experience negative bases. The model is then

customised to avoid complex numbers, selecting only the real part of complex numbers and introducing additional constraints as necessary

Phase III model approach

A third more poised and erudite approach uses neither massive optimisation nor recursion. Using graph theory to produce a topological set of variables that can be solved in sequence avoids the “one big objective calculation” of massive optimisation or recursion by substituting an ordered set of incremental calculations. This model relies on an abstraction layer for equations and solver using directed acyclic graphs, and topological sort and a learning function.

Directed Acyclic Graphs

Graph theory formally commenced with Euler (1736) solution of the puzzling Königsberg Bridge Problem. A directed graph, or “digraph”, is one in which each graph edge is directional between two vertices. If there are no internal cycles in the graph, where following a directed path one can return to the start vertex, the graph is known as a directed acyclic graph or a "DAG" (Weisstein 2008).

Each vertex has a number if directed edges arriving and a number of directed edges leaving. These are called “degrees” or “valencies”. The number of directed edges arriving is the indegree and leaving is the outdegree. A vertex with indegree of zero and any non-zero out degree is one of the DAG start vertexes analogous to a leaf of a tree.

DAGs can be sorted in a topological way to provide a sequence of vertices that can be visited in order to ensure that the requirements of each vertex have been satisfied before the vertex is evaluated. This adopts the strengths and deftly avoids the weaknesses of the previous two methods. For example, limiting optimisation variables only to the start nodes is the same as in the recursion method; and keeping the equations to be solved at an abstraction level is similar in approach to the massive optimisation method.

The illustrations below show that topological sorts have quite complex acyclic directed graphs for even three periods:

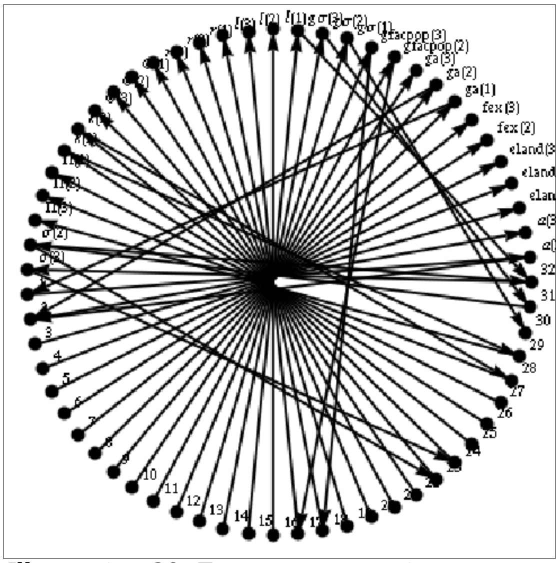


Illustration 39: Exogenous equations

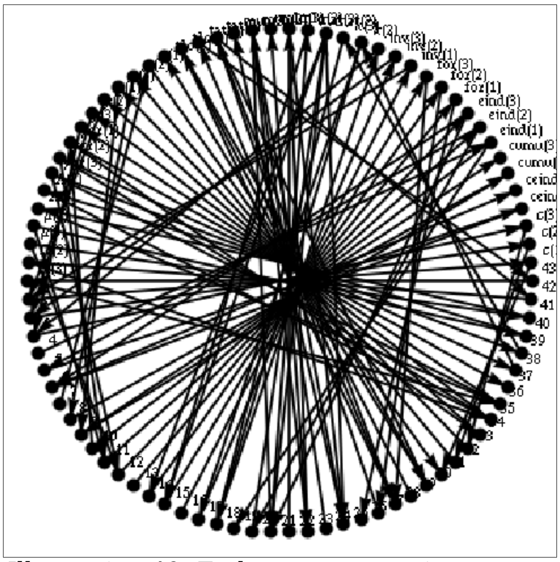


Illustration 40: Endogenous equations

Non-acyclic system and circular references

Part of the difficulty in solving Nordhaus' equations using Mathematica lies in the structure of the equations, which are not directionally acyclic; and require many constraints to condition the solver.

A directed acyclic graph can be best understood by analogy to a spreadsheet that has a logical cell by cell layout. For example, the cell $c1 = a1 + b1$ means that cells $a1$ and $b1$ need to be found before $c1$ can be determined. Of course, associating this logical layout with a geographical layout has proven to be a major feature in the adoption of spreadsheets. This is because it uses behavioural conventions and cultural intuitions to keep things clear to the user. For example, in Western cultures, printed words and logic progress to the right. Using the same example, $a1$ and $b1$ come before $c1$ and so the logical layout is clarified by the geographical layout.

Most users of spreadsheets have also experienced circular references, for example, in the calculation of interest on a loan or overdraft. It is apparently logical to calculate interest as the interest rate times the average of the opening balance of the loan and the closing balance. Novice analysts do not realise that the closing balance is dependent upon the cash flow, which is in turn dependent upon the interest paid.

Circular references can sometimes be solved by immense iteration. Nevertheless, it cannot be guaranteed that the output is indeed the same solution that would be achieved if the equations were to be better structured.

Circular references need to be “deconstructed” so that the circular reference is removed. In the case of interest on a loan, this can be done by calculating the cash flow and refinancing the loan each month or quarter.

In graph theory, circular references are referred to as cycles and a graph with cycles as non-acyclic. A DAG cannot have any internal cycles and graphs can be topologically processed only if they are DAGs. While cycles can be removed with graphical techniques, the system of underlying equations means that it is better to manually resolve any circular references.

Using the new topological model it has been possible to check the for the DAG property in Nordhaus' equations and to rationalise where necessary to render the model acyclic. This has also facilitated the removal of constraints, which are very expensive on computing time.

Mathematica's Combinatorica is a modern and highly efficient graph package. The code developed for pre-solving is complex but its implementation belies this complexity.

It may be seen in the program code that the topological presolver requires two DAGs, a Network flow analysis and a topological sort. The technique has been investigated since Dinic (1970) developed an algorithm for maximum flow in a network.

Subsequently, groups at McGill University pursued the implementation of algorithms with causality assignment for the µModelica, δModelica and MuPAD languages, described by (Xu 2005; Indrani 2003; Casey 2008a; Casey 2008b).

Casey provides the causality assignment implementation of Dinic’s algorithm in µ- and δModelica as:

- create a vertex for each variable, each equation, the source and sink

- add an edge from the source to each equation
- add an edge from each equation to each variable it contains
- add an edge from each variable to the sink
- assign unit weight to each edge
- find the maximum network flow using Dinic’s breadth-first search to determine the path from the source to sink. If such a path exists, each edge in the path is reversed and repeat this step
- topologically sort the causally assigned dependency graph using a double depth-first search to produce a topologically sorted list of strongly-connected components and sets of internal cycles where equations have circular dependencies
- solve for each variable using the topological sort order. Where a circular dependency exists, the equations are solved simultaneously rather than sequentially.

The method developed and implemented in this dissertation reverses the direction of flow in order to use the standard Combinatorica functions in Mathematica for network flow and topological sort:

- create a vertex for each variable, together with a source and a sink
- add an edge from the source to each variable
- create a vertex for each equation
- add an edge from each variable in an equation to the equation
- add an edge from each equation to the sink
- prepare a directed forward graph and check the forward graph is acyclic
- determine the edges that have positive flow in the maximum flow from source to sink
- prepare a revised graph excluding the source and sink and with the direction of the positive flow edges reversed
- check the revised graph is acyclic
- topologically sort the revised graph
- select the independent variables, which are those in the topological sort order before the occurrence of the first equation vertex
- provide the independent variables with values. Substitute these independent variables as they occur in all succeeding equations

- proceeding by topological sequence, solve each equation for the dependent variable implicit within it. Substitute the newly determined variable as they occur in all succeeding equations.

Only acyclic graphs (that is, graphs with no internal cycles) may be topologically sorted. Therefore the researcher needs to manually edit equations having internal cycles to eliminate these circular references. This is an accepted procedure for those familiar with spreadsheets.

Learning

As the number of variables approaches thousands with hundreds of optimising variables, the search travels into complex numbers. Returning a complex number as the result of an objective function causes an error in the solver. As previously explained, this causes major issues for recursive solvers.

A topological model has the major advantage of being able to observe the status of each intermediate variable during the evaluation of the objective function. A penalty function can be used to return a real value when a complex number is encountered.

This penalty function communicates "don't go there" to the solver. In the current structure of equations the solver is seeking a minimum at approximately -250,600. Therefore, the return value of the penalty function is set to zero when a complex number is encountered. The FindMinimum function does indeed learn and a solution is found.

Complex roots requires the use of numerical rather than symbolic variable evaluation

With up to approximately twenty periods, a very fast solution can be achieved using Mathematica's symbolic solvers such as Solve and Reduce that use fast evaluation with techniques like the Gröbner Basis. However, it is not possible to detect complex outcomes with Solve because it can return roots that are symbolic (neither real nor complex) and there can be more than one root provided as an OR alternative that can't be further processed.

Reduce and FindInstance allow domains to be controlled. For example, a root can be requested in the domain of Reals. These functions fail if no real root actually exists.

Mathematica's NSolve function is an efficient numerical solver, whose output can be tested for complex variables and for multiple real roots. This obviates the need for domain control and allows positive roots to be selected over negative roots.

Topological processor for Phase III model

The topological processor was developed as a stand-alone package in Mathematica and relies extensively on Combinatorica graph processing (Pemmaraju & Skiena 2003).

```
BeginPackage["Topofunctions`",{"Combinatorica`"}]
toponodes::usage = "toponodes provides sequence of nodes."
optimsolver::usage="optimsolver solves systems of equations."
outputsolver::usage="outputsolver performs backsubstitution."

Begin["`Private`"]
toponodes[eqns_]:=
Module[{eqnvars,eqnvarsninvt,invt,flatvars,eqnlist,mysource,mysink,edges1
,edges2,
edges3,edges,vertices2,vertices,forwardgraph,networkflows,forwardflows,
forwardedges,revisededges,revisedgraph,toposort,sortedequations,
sortedvertices, posfirstequation,startvertices,f1},
eqnvars=Map[Cases[eqns[[#]],x_Symbol[_Integer..],Infinity]&,Range[Length[
eqns]]];
(*Print[eqnvars];*)
flatvars=Union[Flatten[eqnvars]];
eqnlist=Range[Length[eqns]];
f1[a_,b_]:={a,b};
edges1=Map[f1[mysource,flatvars[[#]]]&,Range[Length[flatvars]]];
edges2=Flatten[Map[Outer[f1,eqnvars[[#]],{eqnlist[[#]]}]&,eqnlist],2];
edges3=Map[f1[eqnlist[[#]],mysink]&,eqnlist];
edges=Join[edges1,edges2,edges3];
vertices2= Join[flatvars,eqnlist];
vertices=Join[{mysource},vertices2,{mysink}] ;
(*Print[vertices];*)
forwardgraph = MakeGraph[vertices, (MemberQ[edges,{#1,#2}])&, Type →
Directed, VertexLabel → True];
(* ShowGraph[forwardgraph]; *)
If[!AcyclicQ[forwardgraph],Print["*** ERROR: FORWARD GRAPH IS NOT ACYCLIC
SO CHECK THE EQUATIONS ***"]];
networkflows=NetworkFlow[forwardgraph,1,Length[vertices],Edge];
forwardflows=Cases[networkflows[[All,1,All]],
{x_/;x>1,y_/;y<Length[vertices]}];
forwardedges = Map[vertices[[#]]&,forwardflows];
revisededges =
Join[Complement[edges2,forwardedges],Map[Reverse,forwardedges]];
revisedgraph= MakeGraph[vertices2, (MemberQ[revisededges ,{#1,#2}])&,
Type → Directed, VertexLabel->True];
```

```
(*ShowGraph[revisedgraph]*)
If[!AcyclicQ[revisedgraph], Print["*** ERROR: REVISED GRAPH IS NOT
ACYCLIC SO CHECK THE EQUATIONS ***"]; (*Print[ShowGraph[revisedgraph]];*)
Return[{{},{},{}}]];
(*ShowGraph[revisedgraph];*)
toposort=TopologicalSort[revisedgraph];
sortedvertices=Cases[vertices2[[toposort]],x_Symbol[_Integer..],1];
(*Print[vertices2[[toposort]]];*)
sortedequations = Cases[vertices2[[toposort]],_Integer,1];
posfirstequation=Apply[Plus,First[Position[vertices2[[toposort]],_Integer
,1]]];
startvertices = vertices2[[toposort[[Range[posfirstequation-1]]]]];
(*startvertices
=vertices2[[Select[vertices,InDegree[revisedgraph,#]==0&]]];*)
Return[{sortedequations,sortedvertices, startvertices}]
];

optimsolver[nmvars_,objtopo_,eqnordered_,leneqnorder_,optimpenalty_]:=
Module[{soleqn,solvar,outputs={},soltest1,soltest2,optimout},
For[i=1,i<=leneqnorder,i++,
soleqn =eqnordered[[i]]/.outputs;
solvar = Cases[soleqn,x_Symbol[_Integer..],Infinity];
If[Length[solvar]!=0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0,
Print["*** infomessage: optimpenalty applied with ",soleqn," ***"];
Return[optimpenalty],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
optimout=objtopo/.outputs;
If[NumericQ[optimout],Return[optimout]]
];
Return[optimout]
]/; VectorQ[nmvars,NumberQ];

outputsolver[nmvars_,eqnordered_,leneqnorder_]:=
Module[ {soleqn,solvar,outputs=nmvars, soltest1,soltest2},
For[i=1,i<=leneqnorder,i++,
soleqn =eqnordered[[i]]/.outputs;
solvar = Cases[soleqn,x_Symbol[_Integer..],Infinity];
If[Length[solvar]!=0,
soltest1 =Select[Chop[NSolve[soleqn,solvar]],(FreeQ[solvar/.#,Complex] )
&];
If[Length[soltest1]==0, Print["*** ERROR: DURING BACKSUBSTITUTION A
VARIABLE HAD NO SOLUTION ***"];Return[{}],
soltest2 = Select[soltest1,(solvar/.#)>0 &];
If[Length[soltest2]==0,
outputs=Join[outputs,First[Sort[soltest1,solvar/.# &]]],
outputs=Join[outputs,Last[Sort[soltest2,solvar/.# &]]]
];
];
];
];
outputs
];

End[]
```

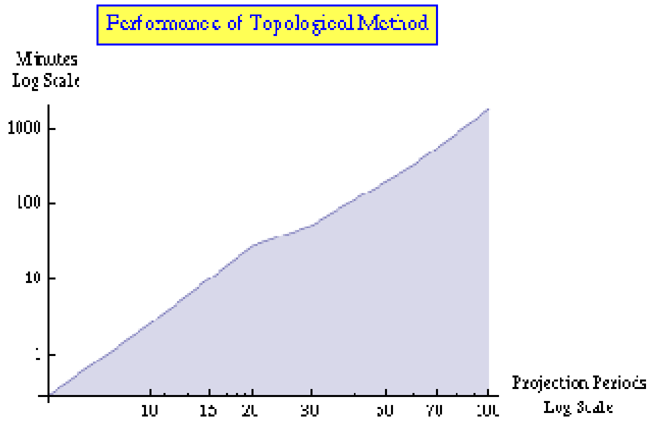
```
EndPackage[]
```

Phase III model performance

The Nordhaus DICE models incorporating the topological processor are provided in *Appendix 4 Nordhaus DICE model*. Its exceptional performance is shown by the following table:

Periods	Minutes	Mbytes	Variables
5	0.28	14	172
10	2.5	15	322
20	28	20	622
30	53	28	922
60	339	68	1822
100	1855	159	3022

This model is very successful as 60 periods solves in just 339 minutes (approximately 5.5 hours) with 120 optimising variables, which is quite a task. The increase of calculation time with periods modelled is shown in the following log-log graph.

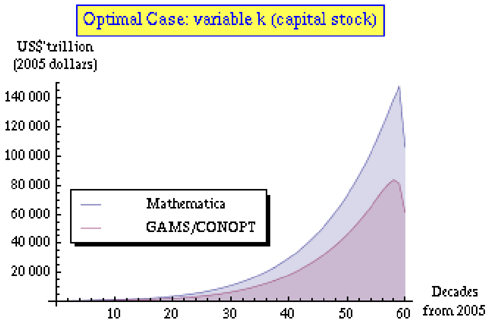


Comparison of DICE Models

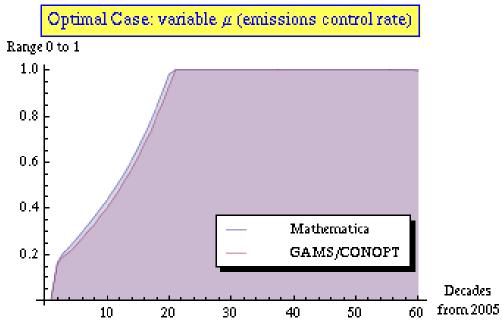
The results of Nordhaus' GAMS/CONOPT non-acyclic/constrained approach and the Mathematica acyclic/unconstrained topological approach are compared below.

Constrained μ

The optimising variables, k and μ, are the independent variables in the model. The nonlinear solver adjusts the two variables in order to maximise the objective function of cumulative social welfare. In a way, the final value of these variables is the major “output” of the optimisation.



Mathematica's capital formation is almost double that of GAMS/CONOPT.

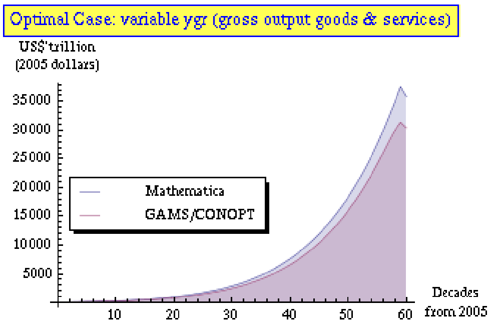


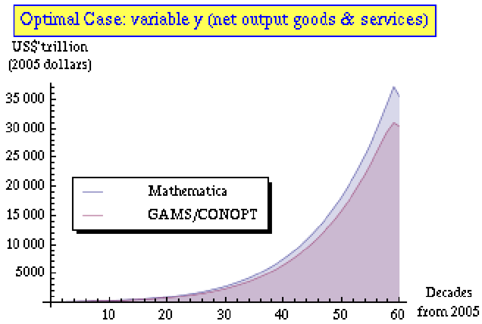
The optimised emissions control rate variable is similar in each model.

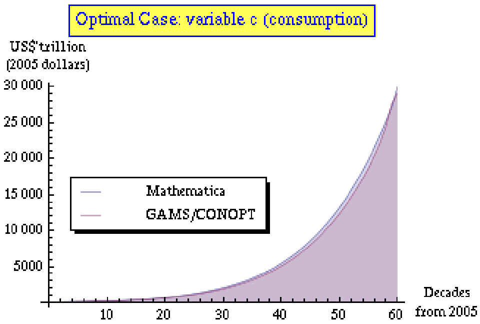
Firstly, the optimised value of the objective function, cumulative social welfare, for each method is significantly different.

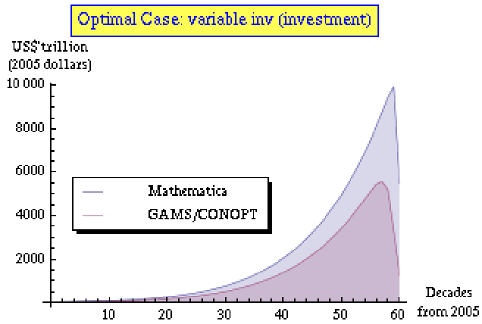
GAMS/CONOPT: 150,240
Mathematica constrained μ: 212,611
Mathematica unconstrained μ: 212,614

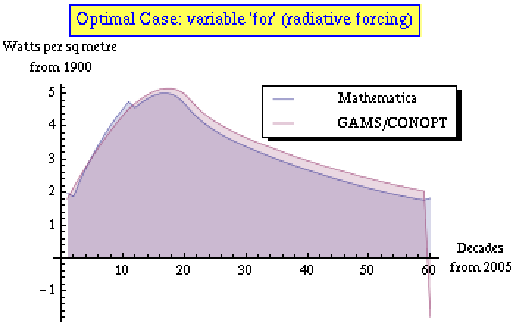
Endogenous variables are the variables determined in the model albeit directly or indirectly dependent upon the optimising variables. These variables illuminate the environmental, economic and technological ecosystem and provide the rich meaning of the model. The effect of differences in the GAMS/CONOPT and Mathematica optimisation approach intermediate variables are illustrated below:

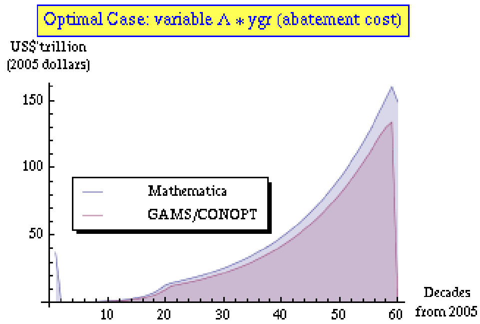


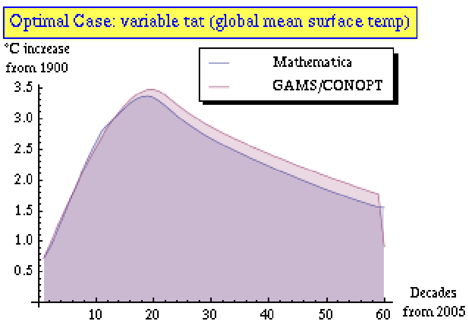


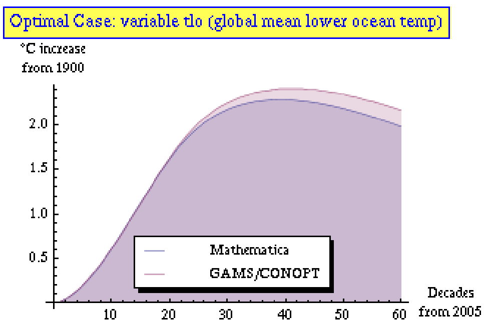






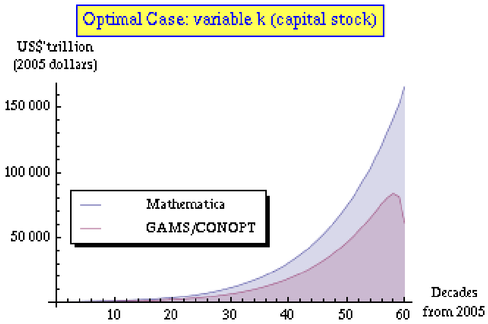




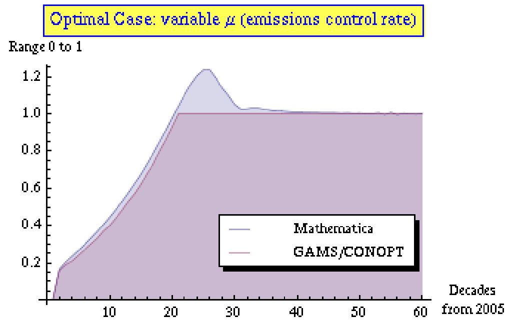


Unconstrained μ

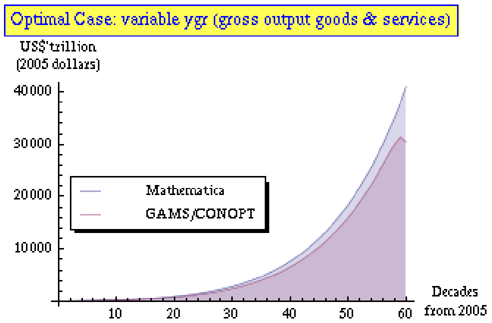
Relaxing the constraint of μ less than 1 indicates the importance of finding a means to remove CO_2 from the atmosphere. The overshoot of μ at the critical point when it would otherwise level off has materially positive effects on temperature reduction, net output of goods and services (that is, net of abatement costs and damages) and social welfare.

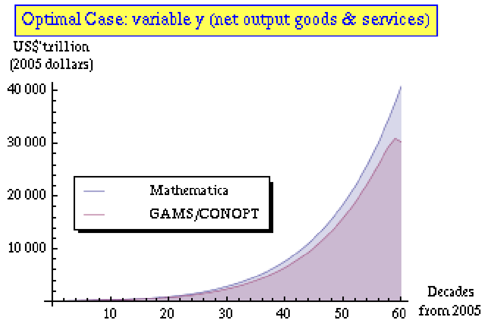


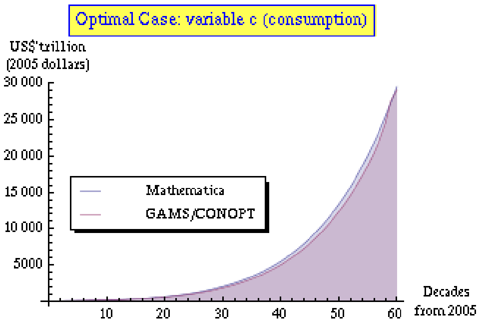
In the Mathematica model, capital stock increases to almost twice GAMS/CONOPT' level. The “drop off” at the sixtieth decade is due to it being the last year of the model and is the same in a hundred decade model.

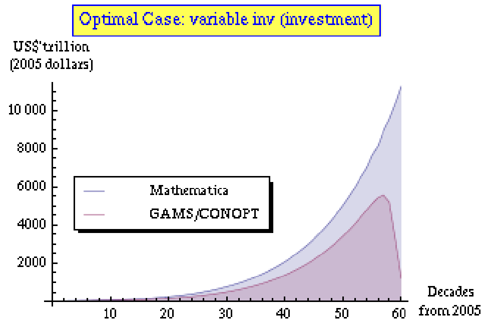


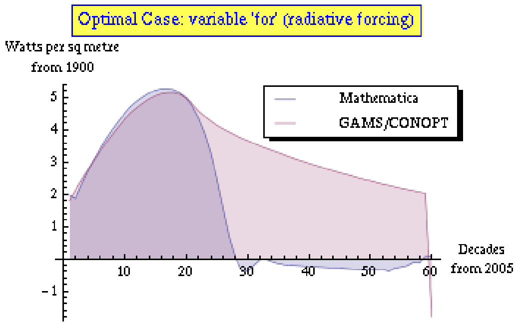
Mathematica's unconstrained emissions control rate rises with Nordhaus but then remains above 1 for 6 decades, suggesting a period of over control (i.e. removing carbon) is required for maximum welfare.



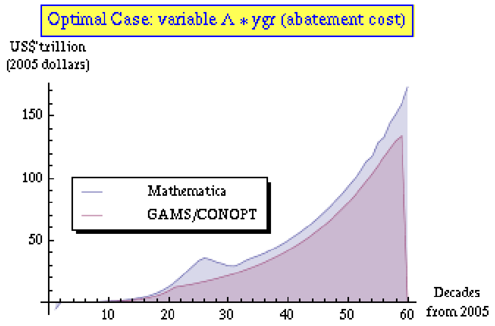




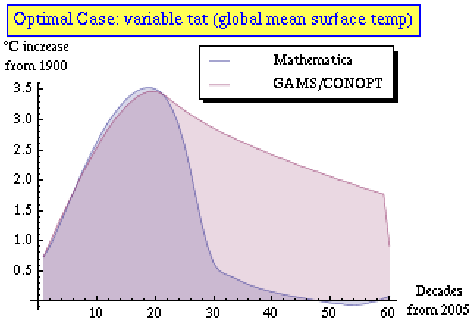




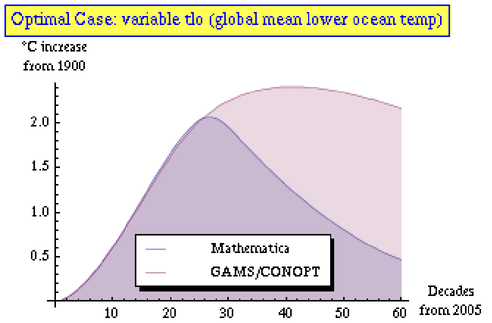
Mathematica radiative forcing drops quickly after 20 decades and reaches 1900 levels 30 decade. In contrast, GAMS/CONOPT forcing declines slowly.



Mathematica abatement costs are marginally higher than GAMS/CONOPT.



As with radiative forcing, the remodelled global mean temperature falls quickly after 20 decades. Both models show a maximum surface temperature rise of almost 3.5C.



Nordhaus' sustained radiative forcing and terrestrial temperatures drive lower ocean temperature to the significantly greater level of 2.4C compared to the remodelled 2.0C.

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i The topological model calculations were completed on UTS' Orion high performance cluster of 16 nodes running Red Hat Enterprise Linux 5 (64bit) with the following specifications: 2.93GHz 4MB Cache X6800 Core 2 Extreme (dual core) with 1066MHz FSB, 4GB 667MHz DDR2-RAM, 2x 80GB 7,200 RPM SATA II Hard Drives (raid 0). Calculation on other memory intensive models were completed on UTS' Titan cluster of 8 nodes running Red Hat Enterprise Linux 5 (64bit) with the following specifications: 2 x 3.16GHz 2x6MB Cache Xeon X5460 (quad core) with 1333MHz FSB, 16GB 667MHz DDR2-RAM, 2 x 300GB 15,000 RPM SAS Hard Drive (Raid 0)

ii http://reference.wolfram.com/mathematica/tutorial/UnconstrainedOptimizationIntroduction.html#509267359 © 2008 Wolfram Research, Inc.

iii http://reference.wolfram.com/mathematica/tutorial/UnconstrainedOptimizationLineSearchMethods.html © 2008 Wolfram Research, Inc.

iv http://reference.wolfram.com/mathematica/tutorial/UnconstrainedOptimizationPrincipalAxisMethod.html © 2008 Wolfram Research, Inc.

v http://reference.wolfram.com/mathematica/tutorial/ConstrainedOptimizationLocalNumerical.html#85183321 © 2008 Wolfram Research, Inc.

vi http://reference.wolfram.com/mathematica/tutorial/UnconstrainedOptimizationLineSearchMethods.html © 2008 Wolfram Research, Inc.

Appendix 6 Benchmarking with Linear Programming

A6.1 Data envelopment analysis

Joseph Farrell (1957) developed the method of data envelopment analysis (DEA) to rank the efficiency of production units in an unbiased way. His method uses linear programming to locate piecewise linear planes or facets of the production function that sit at the outer of the observations where the greatest efficiency occurs.

This technique assumes that at least some of the production units are successfully maximising efficiency, while others may not be doing so. Implicitly, the method creates a best virtual proxy on the efficient frontier for each real producer. By computing the distance of these latter units from their best virtual proxy frontier and partitioning inefficiency among the inputs, strategies are suggested to make the sub-optimally performing production units more efficient.

In contrast to PCA's statistical techniques, DEA's formulation of the production function does not rely on probability distributions. For this reason, it is called a non-parametric method.

DEA Advantages

The main advantages of DEA derive from its ability to reveal sensitivity data and returns to scale that are not evident in PCA. For example, an input minimising formulation provides additional information for each production unit in direct relation to its peers on theta (θ) and iota (ι). Theta is the proportion of inefficiency that could be eliminated by the proportional reduction in inputs in order to obtain the projected input values. Iota (ι) is the total amount of inefficiency, equal to the total weighted distance between observed and projected points standardised by inputs.

The DEA formulation to maximise efficiency of a production unit, which Farrell calls a “decision making unit” (DMU) is stated as:

Maximise: aggregate outputs divided by aggregate inputs for each production unit by finding output and input coefficients (u_r, v_i) that minimise the distance between each production unit and the efficient frontier:

$$\Theta_n = \frac{\sum u_r y_{rn}}{\sum v_i x_{in}}$$

where:

Θ_n = efficiency of production unit n

n = number of production unit, which ranges from 0 to $n+1$

by varying:

u_r = weight, shadow price or coefficient of output r that maximises Θ_n

v_i = weight, shadow price or coefficient of input i that maximises Θ_n

where u_r , $v_i \geq 1$

Constraint: subject to the same ratio for the other units not exceeding unity (which is the maximum efficiency):

$$\frac{\sum u_r y_{rn}}{\sum v_i x_{ij}} ' \leq ' 1$$

where:

y_{rn} = output r of production unit n

x_{in} = input i of production unit n

j = index of production units, ranges from 1 to n

r = index of outputs that ranges from 1 to m (the number of outputs)

i = index of inputs that ranges from 1 to s (the number of inputs)

Every DEA computation may be formulated as either a primal output maximising problem, as shown above, or the Lagrange multiplier solution which is input minimising. This input minimising approach is known as the “dual” solution.

Charnes, Cooper & Rhodes (1978) observed that Farrell's non-linear and computationally complex objective function could be converted to ordinary fractional linear programming problems. Their model assumed constant returns to scale such that production can be increased or decreased without affecting efficiency. This work led to the widespread uptake of DEA. The seminal textbook on DEA is now Cooper, Seiford & Tone (2007).

The key assumptions in DEA are: at least some of the production units are successfully maximising efficiency, while others may not be doing so; the best producers can be used as a virtual proxy for the efficient frontier for each real producer; inefficiency can be partitioned among the inputs based on the distances; strategies are suggested to make the production units more efficient; returns to scale are constant such that production can be increased or decreased without affecting efficiency.[i]

Charnes, Cooper & Rhodes (1978, p.429) suggest that the usefulness of DEA analysis is enhanced by virtue that inputs need only be ordinal amounts, for example, psychometric or management performance factors. This allows the inefficiency analysis to be examined with various partitions of inputs, which is highly fertile for new management strategies.

Leibenstein & Maital (1992) suggest other advantages accrue because there is no restriction on the form of the production function and it does not need to be fully specified for the analysis to be successful; it is unbiased in that there is *a priori* no priority given to any input or output over another; the technology can be analysed to see if the production function should be forced through the origin to model constant returns to scale (A. Charnes et al. 1978) or allowed to exhibit variable returns to scale by not passing through the origin (Banker et al. 1984); and organisations can be readily studied even if their inputs and outputs are not subject to the market.

DEA disadvantages

Various authors note that DEA is less suited to a small number of production units (William W. Cooper et al. 2007);[ii] DEA shows only *relative inefficiency* rather than the potential for all production units (including those with best practise) to perform much better; DEA uses extreme points of efficiency as benchmarks but it's peers may be unable to emulate this for various reasons; and a small change to one of the best practise units can lead to large changes in analysis (William W. Cooper et al. 2007; Ahn & L. M. Seiford 1992; Leibenstein & Maital 1992).

DEA returns to scale

The simplest assumption in using DEA is that returns to scale are constant, as formulated in the illustration below. This means that production can rise or fall with the same mix of inputs. Therefore all apparent inefficiencies are due to management practices.

$$\text{Minimise } E_n \quad w_{1,}\ldots,w_N, E_n$$

Subject to:

$$\sum_{j=1}^{N} w_j y_{ij} - y_{in} \geq 0 \quad i=1,\ldots, I$$

$$\sum_{j=1}^{N} w_j x_{kj} - E_n x_{kn} \leq 0 \quad k=1,\ldots, K$$

$$w_j \geq 0 \quad j=1,\ldots, N$$

where:

N = *number of organisations*

I = *number of different outputs* y_{in}

K = *number of different inputs* x_{kn}

w_j = *weights applied across N organisations*

E_n = *efficiency score of nth organisation*

Illustration 41: DEA Constant Returns to Scale Formulation (En)

Some production plants are constrained by being too small and therefore inefficient. In other cases a production plant can be far too large for its current throughput and so can increase production without adding capacity. In the business world, there is a remorseless endeavour to introduce flexibility into production functions. Mergers, takeovers and rationalisation tends to resolve situations where returns to scale are permanently mismatched and not tuned into a relatively constant band of operation. The marginal production function in DEA may be adjusted for variable rather than constant returns to scale. A constant returns to scale formulation is reformulated with an additional constraint that the weights w_j must sum to 1. This fits a tighter frontier to the data. The following linear program problem is used for variable returns to scale:

Minimise S_n

$$w_{1,}\dots,w_N,S_n$$

Subject to:

$$\sum_{j=1}^{N} w_j y_{ij} - y_{in} \geq 0 \quad i=1,\dots,I$$

$$\sum_{j=1}^{N} w_j x_{kj} - S_n x_{kn} \leq 0 \quad k=1,\dots,K$$

$$\sum_{j=1}^{N} w_j = 1$$

$$w_j \geq 0 \quad j=1,\dots,N$$

where:

N = *number of organisations*

I = *number of different outputs* y_{in}

K = *number of different inputs* x_{kn}

w_j = *organisation weights*

S_n = *efficiency of nth organisation*

Illustration 42: DEA variable returns to scale (S)

Minimise R_n

$$w_{1,}\dots,w_N,R_n$$

Subject to:

$$\sum_{j=1}^{N} w_j y_{ij} - y_{in} \geq 0 \quad i=1,\dots,I$$

$$\sum_{j=1}^{N} w_j x_{kj} - R_n x_{kn} \leq 0 \quad k=1,\dots,K$$

$$\sum_{j=1}^{N} w_j \leq 1$$

$$w_j \geq 0 \quad j=1,\dots,N$$

where:

N = *number of organisations*

I = *number of different outputs* y_{in}

K = *number of different inputs* x_{kn}

w_j = *organisation weights*

R_n = *efficiency of nth organisation*

Illustration 43: DEA non-increasing returns to scale (R)

Scale Efficiency (SE) is calculated as the ratio of efficiency with Constant Returns (CR) to efficiency with Variable Return (Illustration 3), i.e. $SE = E_n / S_n$. If the value of this ratio is 1, then the production unit is operating at optimal scale; if less than 1 it is not operating at optimum scale.

Where SE is less than 1, it is necessary to calculate another ratio to determine whether a production unit is above or below its optimum scale: the ratio of efficiency with Constant Returns to efficiency with Non-increasing Returns to Scale. If the ratio of E_n / R_n is equal to 1, then organisation n has increasing returns to scale and needs to increase its size to achieve optimum scale. Conversely, if E_n / R_n is less than 1, then organisation n is subject to decreasing returns to scale and is considered too large relative to its optimum size, therefore needing to reduce its size.

A6.2 Linear programming

Primal and dual formulations

Although the intertemporal model developed in this dissertation employs nonlinear programming, it is useful to understand how simple single period models can be built with linear programming.

Linear programming in benchmarking was discussed in *Chapter 4 Economic models for climate change policy analysis*. It was shown that *Theory of Complementary Slackness* is important in presenting an optimal solution to the dual formulation of a primal problem. The dual solution is the value of the Lagrange multipliers, which are the marginal productivities of the resources and equal to the shadow prices of the resources. In all cases where an optimal solution for the primal problem will be feasible then it will be possible to find an optimal solution to the dual formulation.

From first principles, it can be shown that the monetary output of the economy is the price vector $\underline{p}$ multiplied by the quantity y of commodities (ten Raa 2005). Therefore, an economy seeking to maximise welfare measured as consumption will maximise $\underline{p}\,y$. However, this maximisation will be subject to constraints of labour and capital, and perhaps energy and pollution.

The primal maximisation problem is therefore:

$$Max \quad \underline{p}\,y \quad : A\,x + y \le x,\; k\,x \le M,\; l\,x \le N,\; x \ge 0$$

Where the constraints represent:

Quantity	$A\;x + y \le x$	*where x is total output (units), y is demand (units)* and *A is Leontief's technical coefficient magtrix*
Capital	$k\;x \le M$	*where k is the capital required per unit of output, M is available capital stock*
Labour	$l\;x \le N$	*where l is the labour required per unit of output, N is available labour stock*

Mathematica implements this with DualLinearProgramming, returning a vector of x-values, shadow prices, lower bound and upper bound slacks:

$$\begin{array}{lll} \text{Primal} & Min\ \ c^T x & : A_1 x = b_{1,}\ A_2 x \geq b_{2,}\ l \leq x \leq u \\ \text{Dual} & Max\ \ b^T y + l^T z - u^T w & : A^T y + z - w = c\ ,\ y_2 \geq 0,\ z, w \geq 0 \end{array}$$

DualLinearProgramming returns the vector $\{x, y, z, w\}$

If both problems are feasible, the solution is the same and two equations apply:

$$\begin{array}{l} (A_2 x - b_2)^T y_2 \ = \ 0 \\ (l - \hat{x})^T \hat{z} \ = \ (u - \hat{x})^T \hat{w} \ = \ 0 \end{array}$$

Gross National Product

For the primal maximisation problem above, which in shorter form is:

$$Max\ \ \underline{p}\, y : A\, x + y \leq x\ ,\ k\, x \leq M\ ,\ l\, x \leq N\ ,\ x \geq 0$$

The constraints can be shown using matrix notation as:

$$\begin{bmatrix} A - I & I \\ k & 0 \\ l & 0 \\ -I & 0 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \leq \begin{bmatrix} 0 \\ M \\ N \\ 0 \end{bmatrix} \quad \text{or} \quad C \begin{bmatrix} x \\ y \end{bmatrix} \leq \begin{bmatrix} 0 \\ M \\ N \\ 0 \end{bmatrix}$$

With the objective function:

$$\begin{bmatrix} 0 & \underline{p} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad \text{or} \quad a \begin{bmatrix} x \\ y \end{bmatrix}$$

Using these conventions, the specification of the linear program becomes:

$$Max \quad a\begin{bmatrix} x \\ y \end{bmatrix} \; : \; C\begin{bmatrix} x \\ y \end{bmatrix} \leq \begin{bmatrix} 0 \\ M \\ N \\ 0 \end{bmatrix}$$

The Lagrangian shadow prices are:

$$\lambda = [p \quad r \quad \omega \quad \sigma]$$

Where:

p	*commodity price*
r	*rate for rental of capital*
ω	*wage rate*
σ	*the slack*

Following (Schrijver 1986, pp.90-6) the Lagrangian equation is given by:

$$[p \quad r \quad \omega \quad \sigma]\begin{bmatrix} A-I & I \\ k & 0 \\ l & 0 \\ -I & 0 \end{bmatrix} = [0 \quad \underline{p}]$$

which rearranges to two equations having the following meanings:

Equation	**Meaning**
$p = \underline{p}$	*shadow prices are the same as real world prices*
$p = pA + rk + \omega l - \sigma$	*shadow prices are the aggregate of factor input prices*

Now, the primal and the dual solutions are linked by the *Main Theorem of Linear Programming* $ax = \lambda b$ so:

$$[0 \quad p]\begin{bmatrix} x \\ y \end{bmatrix} = [p \quad r \quad \omega \quad \sigma]\begin{bmatrix} 0 \\ M \\ N \\ 0 \end{bmatrix}$$

Which provides the well-known macroeconomic value equation:

$$\underline{p}\, y = r\, M + \omega\, N$$
$$\text{or } National\ Income = National\ Product$$

Make and Use tables

The traditional approach to input output modelling is to use Wassily Leontief's technical coefficients (A) matrix where the feasibility of industrial production and bill of final goods is assessed with a “quantity system” and prices are determined by a separate “price system”.

However, Leontief's A matrix is derived from the basic national accounts of each country, standardised as Use and Make tables pursuant to UN System of National Accounts 1993 (SNA93). The Use or U matrix records the commodities demanded by industries for production. The V matrix records the production of commodities by industries.

A Make table V lists all the commodity outputs per production unit. It is called a “pure Make table” if there is just one commodity per production unit and every commodity is produced by a production unit." The Australian and GTAP input output tables are prepared on this basis.

The difference V-U provides the net output of each commodity. In commodity terms $V^T - U$ is the Gross Domestic Product of the economy. In money terms $V^T - U$ is the value-added by the economy, which is the Gross Domestic Income. These are the same as the final macroeconomic equation of value derived above:

$$\underline{p}\, y = r\, M + \omega\, N$$
$$\text{or } National\ Income = National\ Product$$

Since National Product is the sum of Consumer demand, Government demand and Net Export demand, then if s is the level of activity of the production units in the economy:

$$V^T \cdot s = U.s + Y + G + E - M$$
or
$$(V^T - U) \cdot s = Y + G + E - M$$

which is analogous to the Leontief formulation:

$$A.x + Y + G + E - M = x$$
or
$$(1 - A) \cdot x = Y + G + E - M$$

Equating the UV and Leontief formulations:

$$(V^T - U) \cdot s = (1 - A) \cdot x$$

and since $x = V^T \cdot s$ then the U, V and A matrices are related by the equations:

$$U = A \cdot V^T, \text{ or } U \cdot V = A$$

Under optimisation, competitive equilibrium occurs by maximising the objective function and determining shadow prices . Industry activities s vary, causing labour and capital resources to substitute between production sectors.

The substitution between production sectors depends upon the price of the inputs, which is the assumption of the Transcendental Production function. Also, the price of inputs responds to microeconomic supply & demand.

Primal and dual expressed as a UV formulation

ten Raa assumes that the criterion of economic policy is to maximise domestic absorption. Technological constraints are provided by the UV material balance. Resource constraints are provided by the usage of factor inputs of labour and capital compared to endowments.

The primal becomes:

$$\begin{aligned}&\textit{Maximise } Y\\&\text{subject to the constraints:}\\&\textit{Material balance}: \quad (U - V^T)\cdot s + Y + G + E - M \leq 0\\&\textit{Labour endowment}: \quad \omega\cdot s \leq N\\&\textit{Capital endowment}: \quad k\cdot s \leq K\end{aligned}$$

The dual of the linear program provides Lagrange multipliers and resource slacks. As we have seen in *Chapter 4 Economic models for climate change policy analysis*, the Lagrange multipliers represent the shadow prices associated with the constraints, which are also the factor productivities.

The sorts of questions ten Raa has addressed with the UV technique are:

- How much can the level of final demand be raised if the economy is made more efficient?
- What is the comparative advantage of the economy and best composition of imports and exports?
- Is structural/technical/efficiency change or business cycle change responsible for a rise in standard of living?
- Are competition and performance positively or negatively related?
- What is the increase in commodity prices with a new tax?
- What is the increase in employment if government expenditures increase?
- What are the engines of growth in an economy, when productivity spills-over to other industries?
- Can services increase productivity? Have increases in manufacturing productivity been due to eliminating (outsourcing) low productivity service activities?

Production function of the economy with trade

The net output of the economy is domestic demand plus net exports, so:

$$(V^T - U)\cdot e = a + \begin{bmatrix} d \\ 0 \end{bmatrix}$$

Where the value of net exports is the negative of the trade deficit $\underline{p}d' \geq' -D$ and domestic demand includes investment, which in competitive economies is the Net Present Value of future consumption (Weitzman 1976).

The constrained formulation for maximisation of final domestic demand is:

$$Max \;\; e^T ac \;:\; (V^T - U)\cdot s \geq a\, c + \begin{bmatrix} z \\ 0 \end{bmatrix},\; Ks \leq M,\; Ls \leq N,\; \underline{p}\; z \geq -D,\; s \geq 0$$

Where:

$$\begin{aligned} z \quad &= new\;\; export\;\; vector \\ c \quad &= a\;\; scalar\;\; expansion\;\; factor \\ 1/c \quad &= efficiency\;\; of\;\; the\;\; economy\;\; measured\;\; as\;\; \frac{actual\;\; output}{potential\;\; output} \end{aligned}$$

The usual prime and dual formulations are:

$$\begin{aligned} &Max \;\; ax \;:\; Cx \leq b \\ &Min \;\; \lambda b \;:\; \lambda C = a \end{aligned}$$

For which we have the primal schema:

$$Max \;\; \begin{bmatrix} 0 & e^T & 0 \end{bmatrix} \begin{bmatrix} s \\ c \\ z \end{bmatrix} \;:\; \begin{bmatrix} U - V^T & a & \begin{bmatrix} I \\ 0 \end{bmatrix} \\ K & 0 & 0 \\ L & 0 & 0 \\ 0 & 0 & -\underline{p} \\ I & 0 & 0 \end{bmatrix} \begin{bmatrix} s \\ c \\ z \end{bmatrix} \leq \begin{bmatrix} 0 \\ M \\ N \\ D \\ 0 \end{bmatrix}$$

and the dual schema:

$$Min \;\; \begin{bmatrix} p & r & \omega & \varepsilon & \sigma \end{bmatrix} \begin{bmatrix} 0 \\ M \\ N \\ D \\ 0 \end{bmatrix} \;:\; \begin{bmatrix} p & r & \omega & \varepsilon & \sigma \end{bmatrix} \begin{bmatrix} U - V^T & a & \begin{bmatrix} I \\ 0 \end{bmatrix} \\ K & 0 & 0 \\ L & 0 & 0 \\ 0 & 0 & -\underline{p} \\ I & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & e^T a & 0 \end{bmatrix}$$

The dual reduces to:

$$Min \;\; r \geq 0 \; M + \omega \; N + \varepsilon \; D \;\; : \;\; p(V^T - U) \leq r \; K + \omega \; L \, , \, pa = e^T \; a \, , \; p_T = \varepsilon \; \underline{p}$$

Where:

p_T = vector of tradeable commodity prices
$\underline{p}$ = terms of trade (world trade currency US $)
p = vector of prices (local currency)
and
ε = exchange rate
= shadow price of the deficit constraint
= increase of final demand per dollar of international debt

Where two countries trade, the material balances of the two economies need to be jointly balanced. There is only one level of imports and one international shadow price for each traded commodity that satisfies the pooled material balance, notwithstanding the direction of trade,:

$$(V^T - U) \cdot s \; + \; (\tilde{V}^T - \tilde{U}) \cdot \tilde{s} \; \geq \; a c \; + \; \tilde{a} \, \tilde{c}$$

Secondly, the net exports for each country needs to be controlled so that the pooled material balance does not runaway in favour of one country due to better terms of trade as exports increase. This would lead to final demand in one economy being maximised in the presence of massive production, while production sectors in the other economy are shut down (with demand satisfied by imports).

Therefore economies that experience a virtuous increase in terms of trade, for the same value of exports, achieve a much higher attainable domestic demand. The reverse occurs if the level of exports increases due to an expansion of volume and reduction in terms of trade.

Where two countries engage in trade, the final demand vector c is maximised with:

$$Max \quad c \quad : \begin{bmatrix} U-V^T & a & 0 & \begin{bmatrix} I_T \\ 0 \end{bmatrix} \\ K & 0 & 0 & 0 \\ L & 0 & 0 & 0 \\ -I & 0 & 0 & 0 \\ 0 & \tilde{a}\gamma & \tilde{U}-\tilde{V}^T & \begin{bmatrix} -I_T \\ 0 \end{bmatrix} \\ 0 & 0 & \tilde{K} & 0 \\ 0 & 0 & \tilde{L} & 0 \\ 0 & 0 & -I & 0 \end{bmatrix} \begin{bmatrix} s \\ c \\ \tilde{s} \\ z \end{bmatrix} \leq \begin{bmatrix} 0 \\ M \\ N \\ 0 \\ 0 \\ \tilde{M} \\ \tilde{N} \\ 0 \end{bmatrix}$$

and γ is optimised to the trade balance, subject to $p_T z = p_T d$. The dual is:

$$Min \begin{bmatrix} p & r & \omega & \sigma & \tilde{p} & \tilde{r} & \tilde{\omega} & \tilde{\sigma} \end{bmatrix} \begin{bmatrix} 0 \\ M \\ N \\ 0 \\ 0 \\ \tilde{M} \\ \tilde{N} \\ 0 \end{bmatrix} \quad :$$

$$\begin{bmatrix} p & r & \omega & \sigma & \tilde{p} & \tilde{r} & \tilde{\omega} & \tilde{\sigma} \end{bmatrix} \begin{bmatrix} U-V^T & a & 0 & \begin{bmatrix} I_T \\ 0 \end{bmatrix} \\ K & 0 & 0 & 0 \\ L & 0 & 0 & 0 \\ -I & 0 & 0 & 0 \\ 0 & \tilde{a}\gamma & \tilde{U}-\tilde{V}^T & \begin{bmatrix} -I_T \\ 0 \end{bmatrix} \\ 0 & 0 & \tilde{K} & 0 \\ 0 & 0 & \tilde{L} & 0 \\ 0 & 0 & -I & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \end{bmatrix}$$

In a perfect world, a γ would be sought that brings net exports to zero. However, this is unrealistic and so the observed commodity trade vector is used instead:

$$p_T \cdot z \;=\; p_T \cdot d$$

The location of comparative advantages in a system of more than two economies requires the vector scanner, γ , in a nonlinear maximisation to find the value such that the consequent vector of national surpluses for all economies but one is mapped into the observed surpluses. Walras' law takes care of the remaining economy.

MRIO formulation

For a two-country multiregional IO model, the LinearProgramming schema is:

$$Max \;\; a_1 c_1 + a_2 c_2 \;:$$

$$\begin{bmatrix} a_1 & 0 & U_1 - V_1^T & 0 & Rect1 \\ 0 & a_2 & 0 & U_2 - V_2^T & Rect1 \\ 0 & 0 & K_1 & 0 & 0 \\ 0 & 0 & 0 & K_2 & 0 \\ 0 & 0 & L_1 & 0 & 0 \\ 0 & 0 & 0 & L_2 & 0 \\ 0 & 0 & 0 & 0 & Rect2 \\ 0 & 0 & 0 & 0 & Square \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ s_1 \\ s_2 \\ z \end{bmatrix} \begin{bmatrix} \le VertVector[0] \\ \le VertVector[0] \\ \le M_1 \\ \le M_2 \\ \le N_1 \\ \le N_2 \\ \le VertVector[E] \\ = VertVector[0] \end{bmatrix}$$

Where $Rect1$ is a matrix with rows equal to the number of commodities and columns of $countries * countries * commodities$. The matrix expresses that each commodity can be exported to the same commodity line of another country (and indeed to itself, although this is constrained to zero in the trade equivalences matrix).

exporting->	$country\,1$	$country\,1$	$country\,2$	$country\,2$
importing->	$country\,1$	$country\,2$	$country\,1$	$country\,2$
	$commodities$	$commodities$	$commodities$	$commodities$
$commodities$	$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

$Rect2$ is a matrix of prices, with the number of rows equal to the number of countries, with each element being -1 and the right hand vector of Total Net Exports for each country equal to $VertVector[E]$ (as above).

$$\begin{array}{cccccc} \text{exporting->} & country\,1 & country\,1 & country\,2 & country\,2 & \\ \text{importing->} & country\,1 & country\,2 & country\,1 & country\,2 & \\ & commodities & commodities & commodities & commodities & \\ countries & \begin{pmatrix} -1 & -1 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} -1 & -1 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ -1 & -1 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ -1 & -1 \end{pmatrix} & \begin{matrix} continued \\ next\,line\,... \end{matrix} \end{array}$$

$$\cdot \begin{pmatrix} z_{cou1,cou1,commodities} \\ z_{cou1,cou2,commodities} \\ z_{cou2,cou1,commodities} \\ z_{cou2,cou2,commodities} \end{pmatrix} <= \begin{pmatrix} Total\ Net\ Exports_{cou1} \\ Total\ Net\ Exports_{cou2} \end{pmatrix}$$

$Square$ is a $countries * countries * commodities$ square matrix of trade equivalences such that the trade of a country with itself is constrained to zero and the trade of each commodity, between each pair of trading countries, is constrained to zero such that total world trade flows net to zero:

If $cou_2 = cou_1$ then $z_{cou_2, cou_1, comm} = 1$ (this is really an Identity matrix)
If $cou_2 \neq cou_1$ then $z_{cou_1, cou_2, comm} = -1$

Iterating through $\{cou, cou, commodities\}$ with the last dimensions changing the most frequently,creating a new line in the z-equivalence matrix with each iteration ...

$$\begin{array}{cccccc} & & & country\,1 & country\,1 & country\,2 & country\,2 \\ & & & country\,1 & country\,2 & country\,1 & country\,2 \\ & & & commodities & commodities & commodities & commodities \\ cou1 & cou1 & comm & \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \\ cou1 & cou2 & comm & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} & \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \\ cou2 & cou1 & comm & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} & \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \\ cou2 & cou2 & comm & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \\ & & & & & & continued\ \ldots \end{array}$$

$$\cdot \begin{pmatrix} z_{cou1,cou1,commodities} \\ z_{cou1,cou2,commodities} \\ z_{cou2,cou1,commodities} \\ z_{cou2,cou2,commodities} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

In addition to constraining trade variables with the above z-equivalence matrix, non-traded commodities need to be further constrained such that there is zero trade. This is achieved within the limits for each variable specified for the LinearProgramming function. Limits on variables in the vector of the objective function are:

$$\begin{array}{lll} c[cou] & \{0,\infty\} & \textit{for each country's domestic demand multiplier} \\ s[U\ columns] & \{0,\infty\} & \textit{for each sector activity level} \\ z[cou,cou,com] & \{-\infty,\infty\} & \textit{for a traded commodity} \\ z[cou,cou,com] & \{0,0\} & \textit{for a non-traded commodity} \end{array}$$

$$\begin{array}{ll} \textit{where}: & \\ cou & = \textit{number of countries} \\ com & = \textit{number of commodities} \end{array}$$

A6.3 Emission permits, amelioration and abatement

Greenhouse gas pollution can be modelled as a “good” or “bad” commodity. There are various ways of implementing each.

Modelling pollution as a “bad”

If a quantity constraint is placed on the emission of a “bad” then the constraint is treated in the same way as a labour or capital constraint. Alternatively, the “bad” can be modelled with an extra account in both the U and V matrices and treated in the same way as other commodities. The key difference is that “bads” are modelled with the inequality reversed to the normal situation of a “good” commodity.

However, this dissertation implements pollution as a “good” rather than a “bad”.

Modelling pollution as a “good”

A “bad” such as greenhouse gas pollution can be treated in the same way as a “good” by redefining emissions as a new commodity requirement for emissions permits. An extra account is added to both the U and V matrices and then emissions permits can be treated as a traded market in the same way as other commodities.

It may also be useful to create an additional account in each of the U and V matrices for abatement services.

A6.4 Intertemporal stocks and flows model

ten Raa (ten Raa 2005, pp.166-75) derives a dynamic intertemporal model from spatial distributions (convolutions) of stocks and flows. The primary purpose of this analysis was to demonstrate equivalence of a UV dynamic model with Leontief's dynamic model (A and B matrices). This was successfully achieved and confirmed Brody's condition for the Leontief dynamic model.

Assuming that the trade vector Z is part of the consumption vector Y, the “stocks” equation is production $V*s$ equals uses $U*s$ plus consumption Y, where each of production and uses are convoluted with level activity in each time period:

$$V*s = U*s + Y$$

which upon differentiating becomes the flows equation:

$$\partial(V*s) = \partial(U*s) + \partial Y$$

The differential of a convolution product may be applied to either of the operators, and this done variously for V and U:

$$\partial V * s = U * \partial s + \partial Y$$

The change in V is the depreciation $\partial V = -\delta \cdot V$

Adjusting for zero elements in the convolution the flow equation becomes:

$$s_t - \delta \cdot V * s = U * \partial s + \partial Y$$

Substituting the first equation for stock balance $V * s = U * s + Y$:

$$s_t - \delta \cdot (U * s + Y) = U * \partial s + \partial Y$$

Leontief's assumption of instantaneous production means:

$U * s = U_0 \cdot s_t$ and correspondingly $U * \partial s = U_0 (s_{t+1} - s_t)$ so

$$s_t + \delta \cdot (U_0 \cdot s_t + Y) = U_0 (s_{t+1} - s_t) + (Y_{t+1} - Y_t)$$

This leads to the important material balance:

$$[1 + (1 - \delta) \cdot U_0] \cdot s_t - U_0 \cdot s_{t+1} - Y_{t+1} + (1 - \delta) \cdot Y_t = 0$$

The static equation $U - V + Y + I = 0$ from above can be substituted into this equation:

$U_0 \cdot s_t - V_0 \cdot s_t + Y_t + I = 0$ and, upon rearranging,
$U_0 \cdot s_t + Y_t = V_0 \cdot s_t - I$.

Upon rearranging this provides the final material balance:

$U_0 \cdot s_{t+1} + Y_{t+1} = s_t + (1 - \delta) (U_0 \cdot s_t + Y_t)$ or
$U_0 \cdot s_{t+1} + Y_{t+1} = s_t + (1 - \delta) (V_0 \cdot s_t - I)$

After investigating this dispersion method and discussing its application with ten Raa, this dissertation research uses an alternative intertemporal formulation based on standard accounting principles for stocks and flows.

A6.5 Appendix references

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i Techniques for including decreasing returns to scale and expanding returns to scale have since been developed to relax the assumption of constant returns to scale

ii Since if the number of inputs and outputs is large compared to the number of production units then some production units may be wrongly rated as efficient

Appendix 7 Mining the GTAP Database

A7.1 Aggregating the GTAP7 database

Region and commodity aggregations

The GTAP 7 database (Hertel 1999; Hertel & Walmsley 2008) may be aggregated using GTAP utility functions in the GTAPAgg package.[i]

An aggregation scenario may be prepared using "aggedit.exe" to produce an "agg" specification file, say "sntest01.agg". In this research, the regions defined in this file are:

Region No.	Code	Regions comprising
1	NAFTA (North America)	Can (Canada), usa (United States of America), mex (Mexico)
2	EU25 (European Union 25 countries)	aut (Austria), bel (Belgium), cyp (Cyprus), cze (Czech Republic), dnk (Denmark), est (Estonia), fin (Finland), fra (France), deu (Germany), grc (Greece), hun (Hungary), irl (Ireland), ita (Italy), lva (Latvia), ltu (Lithuania), lux (Luxembourg), mlt (Malta), nld (Netherlands), pol (Poland), prt (Portugal), svk (Slovakia), svn (Slovenia), esp (Spain), swe (Sweden), gbr (United Kingdom)
3	ROW (Rest of the World)	aus (Australia), nzl (New Zealand), xoc (Rest of Oceania), chn (China), hkg (Hong Kong), jpn (Japan), kor (Korea), twn (Taiwan), xea (Rest of Asia), khm (Cambodia), idn (Indonesia), lao (Lao People's Democratic Republic), mmr (Myanmar), mys (Malaysia), phl (Philippines), sgp (Singapore), tha (Thailand), vnm (Vietnam), xse (Rest of South East Asia), bgd (Bangladesh), ind (India), pak (Pakistan), lka (Sri Lanka), xsa (Rest of South Asia), xna (Rest of North America), arg (Argentina), bol (Bolivia), bra (Brazil), chl (Chile), col (Colombia), ecu (Ecuador), pry (Paraguay), per (Peru), ury (Uruguay), ven (Venezuela), xsm (Rest of South America), cri (Costa Rica), gtm (Guatemala), nic (Nicaragua), pan (Panama), xca (Rest of Central America), xcb (Caribbean), che (Switzerland), nor

Region No.	Code	Regions comprising
		(Norway), xef (Rest of EFTA), alb (Albania), bgr (Bulgaria), blr (Belarus), hrv (Croatia), rou (Romania), rus (Russian Federation), ukr (Ukraine), xee (Rest of Eastern Europe), xer (Rest of Europe), kaz (Kazakhstan), kgz (Kyrgyzstan), xsu (Rest of former Soviet Union), arm (Armenia), aze (Azerbaijan), geo (Georgia), irn (Islamic Republic of Iran), tur (Turkey), xws (Rest of Western Asia), egy (Egypt), mar (Morocco), tun (Tunisia), xnf (Rest of North Africa), nga (Nigeria), sen (Senegal), xwf (Rest of Western Africa), xcf (Central Africa), xac (South Central Africa), eth (Ethiopia), mdg (Madagascar), mwi (Malawi), mus (Mauritius), moz (Mozambique), tza (Tanzania), uga (Uganda), zmb (Zambia), zwe (Zimbabwe), xec (Rest of Eastern Africa), bwa (Botswana), zaf (South Africa), xsc (Rest of South Africa Customs Union)

The commodity classifications are also aggregated, as follows:

Generic Description	Commodities Comprising
food (agriculture and food processing)	pdr (paddy rice), wht (wheat), gro (cereal grains nec), v_f (vegetables, fruit, nuts), osd (oil seeds), c_b (sugar cane, sugar beet), pfb (plant-based fibres), ocr (crops nec), ctl (bovine cattle, sheep and goats, horses), oap (animal products nec), rmk (raw milk), wol (wool, silk-worm cocoons),frs (forestry), fsh (fishing), cmt (bovine cattle, sheep and goat meat products), omt (meat products), vol (vegetable oils and fats), mil (dairy products), pcr (processed rice), sgr (sugar), ofd (food products nec), b_t (beverages and tobacco products)
mnfc (manufacturing)	coa (coal), oil (oil), gas (gas), omn (minerals nec), tex (textiles), wap (wearing apparel), lea (leather products), lum (wood products), ppp (paper products, publishing), p_c (petroleum, coal products), crp (chemical, rubber, plastic products), nmm (mineral products nec), i_s (ferrous metals), nfm (metals nec), fmp (metal products), mvh (motor vehicles and parts), otn (transport equipment nec), ele (electronic equipment), ome (machinery and equipment nec), omf (manufactures nec)

Generic Description	Commodities Comprising
serv (services)	ely (electricity), gdt (gas manufacture, distribution), wtr (water), cns (construction), trd (trade), otp (transport nec), wtp (water transport), atp (air transport), cmn (communication), ofi (financial services nec), isr (insurance), obs (business services nec), ros (recreational and other services), osg (public administration and defence, education, health), dwe (ownership of dwellings)

The factor aggregations are:

Generic Factor	Comprising factors
land	LAN (land), NTR (NatRes, natural resources)
labour	ULA (UnSkLab, unskilled labour), SLA (SkLab, skilled labour)
capital	Capital

The “agg” file needs to be copied to a “txt” file, for example “sntest01.txt”. The database is aggregated by running “data-agg.bat sntest01” where the specification file is “sntest01.txt”. The aggregation function produces six output files in a director of the same name “sntest01”. The files are in “har” format, which is a proprietary GEMPACK format but may be viewed with “viewhar.exe”:[ii]

- gdat.har (main economic data file)
- gpar.har (parameter file for GTAP CGE model)
- gset.har (definitions file)
- gtax.har (calculated tax rates)
- gview.har (additional data file)
- gvole.har (energy volumes Mtoe)

There are a number of methods of transforming the data in “har” files for use in other database systems. Perhaps the most convenient is to generate a standard “sql script” file from each “har” file using “seehar.exe” in the Flexagg7 package of files. When “seehar.exe” initially executes, the following sequence of commands achieves an sql-script file in the same directory “sntest01”:

- type “sql” as the option and Carriage Return (Enter)
- type Carriage Return (Enter) to leave the options menu
- type the complete file location of the “har” file to be processed and Carriage Return (Enter) to continue (it may help to put the full address in Notepad and copy/paste it as the required location – then only the har file name needs to be appended)
- Carriage Return (Enter) to accept the default output file press;
- Carriage Return (Enter) to continue
- type "r" as the option and then Carriage Return (Enter) to output the data as an sql script file

The “sql” file can then be executed from an HSQLDB Database Engine or within Mathematica to create a standalone HSQLDB database corresponding to the “har” file. It will be necessary to remove some inconvenient apostrophises from the sql using a text editor (i.e. change Firms' to Firms and Agents' to Agents) and changing the table names to avoid conflict (i.e. edit basedata.sql and change HEADLIST, SETLIST and RARRAY to, say, HEADLISTBD, SETLISTBD and RARRAYBD).

In addition to the standard GTAP7 database files, GTAP also provides consistent data for greenhouse gas emissions from fossil fuel combustion in Gg CO_2 (Giga Grams of CO_2) in a supplementary file “gtap_co2_v7.har”, which corresponds to the energy volumes data “gsdvole.har” (Lee 2008).

Social Accounting Matrix

Once the stand alone database has been created then data may be selected from various tables. These tables have been arranged for GTAP's CGE model and require considerable interpretation. The best guide to interpreting these tables is with GTAP's own reconciliation to a Social Accounting Matrix (SAM), which is shown in the diagram below (McDonald & Patterson 2004, p.6):

Table 4. Mapping Transactions: Social Accounting Matrix for a Representative Country

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Imported Commod	Domestic Commod	Activities	Factors	Regional Household	Private Household	Trade Taxes	Import Sales Taxes	Domestic Sales Tax	Factor Taxes	Production Taxes	Direct Taxes	Govt	Capital	Import Margins	Export Margins	Rest of World	Totals
1	Imported Commodities			VIAM			VIPM							VIGM	VIIM				1:18
2	Domestic Commodities			VDAM			VDPM							VDGM	VDIM		VST	VXWD	2:18
3	Activities		VOM																3:18
4	Factors			VFM															4:18
5	Regional Household				EVOA-VDEP			TMTAX + TETAX	ISTAX	DSTAX	FTAX	PTAX	DTAX						5:18
6	Private Household					YH													6:18
7	Trade Taxes	VIMS-VIWS	VXWD - VXMD																TMTAX TETAX
8	Import Sales Taxes			VIAA-VIAM			VIPA-VIPM							VIGM-VIGA	VIIA-VIIM				ISTAX
9	Domestic Sales Tax			VDAA-VDAM			VDPA-VDPM							VDGM-VDGA	VDIA-VDIM				DSTAX
10	Factor Taxes			EVFA-VFM															FTAX
11	Production Taxes			PRODTAX											*PTAXINV*				PTAX
12	Direct Taxes				PTAXFACT														DTAX
13	Government					YG													13:18
14	Capital				VDEP	SAVE											VTWR-VST	VIWS-VTWR-VXWD	14:18
15	Import Margins	VTWR																	15:18
16	Export Margins															VTWR			16:18
17	Rest of World	VIWS-VTWR																	17:18
18	Totals	18:1	18:2	18:3	18:4	18:5	18:6	18:7	18:8	18:9	18:10	18:11	18:12	18:13	18:14	18:15	18:16	18:17	

Illustration 44: Social Accounting Matrix (Source: McDonald & Patterson 2004)

The SAM equations can be rationalised with the GTAP database tables as set out below.

Deriving commodity relationships from the SAM

Equations for the rows and columns:

$$
\begin{array}{ll}
\mathit{Sales}\ (\mathit{rows}\ 1\ \&\ 2) & = \mathit{Purchases}\ (\mathit{columns}\ 1\ \&\ 2) \\
\left\{ \begin{array}{l} (VIAM + VDAM) + (VIPM + VDPM) \\ + (VIGM + VDGM) + (VIIM + VDIM) \\ + VST + VXWD \end{array} \right\} & = \left\{ \begin{array}{l} VOM + VIMS - VIWS \\ + VXWD - VXMD + VTWR \\ + VIWS - VTWR \end{array} \right\}
\end{array}
$$

Using:

$$
\begin{array}{ll}
U & = VIAM + VDAM \\
C & = VIPM + VDPM \\
G & = VIGM + VDGM \\
I & = VIIM + VDIM
\end{array}
$$

and simplifying, the above equation becomes:

$$
\begin{array}{l}
U + C + G + I + VST = VOM + VIMS - VXMD \\
U + C + I + G + VST - VOM - VIMS + VXMD = 0
\end{array}
$$

However, $V = VOM$ and since $VOM = VOA + OUTTAX$ we need to include taxes. Therefore $VXWD = VXMD + XTAX$ and since we need to use world prices rather than market prices:

$VXMD = VXWD - XTAX$ and $VIMS = VIWS + MTAX$.

Therefore:

$$U + C + I + G + VST - V - (VIWS + MTAX) + (VXWD - XTAX) = 0$$

and rearranging to the material balance of the economy:

$$(U - V) + (C + I + G) + (VXWD - VIWS) - (MTAX + XTAX) + VST = 0$$

Also, the net output of the economy is $(V - U)$ so:

$$(V - U) = (C + I + G) + (VXWD - VIWS) - (MTAX + XTAX) + VST$$

where $(VXWD - VIWS) = Net\ Exports\ at\ World\ Prices$.

Therefore:

$$\begin{aligned} GNP &= (V - U) \\ &= (C + I + G) + \left\{ \begin{matrix} Net\ Exports\ at \\ World\ Prices \end{matrix} \right\} - (MTAX + XTAX) + VST \end{aligned}$$

where:

$$\begin{aligned} VST &= Export\ transport\ margins\ at\ Market\ Prices \\ VXMD &= Bilateral\ Exports\ at\ Market\ Prices \\ VXWD &= Bilateral\ Exports\ at\ World\ Prices \\ VIMS &= Bilateral\ Imports\ at\ Market\ Prices \\ VIWS &= Bilateral\ Imports\ at\ World\ Prices \end{aligned}$$

Material Balance

The material balance equation is:

$$(U-V)+(C+I+G)+ \ Net \ \ Exports \ \ at \ \ World \ \ Prices-(MTAX+XTAX)+VST \leq 0$$
$$(U-V)+(C+I+G)+ \ Net \ \ Exports \ \ at \ \ World \ \ Prices-Bias \leq 0$$
$$(U-V)+(C+I+G)+ \ Net \ \ Exports \ \ at \ \ World \ \ Prices \leq Bias$$

where $Bias = (MTAX + XTAX) + VST$.

Therefore,

$$Bias = (U-V)+(C+I+G)+Net \ Exports \ at \ World \ Prices$$

where $Bias$ is the difference in the rows of $U-V+C+I+G+X-M$ from zero due to taxes $(MTAX-XTAX)$ and export transport margins (VST) .

It might be noted that there is no column balance between the net exports of various countries unless taxes are included. Therefore, the column balance needs to be performed manually.

A7.2 Creation of GTAP economic databases within Mathematica

File: gtap_make_mathematica_db_03.nb

```
(* Open Connection *)
<< DatabaseLink`
conn = OpenSQLConnection[]

Clear[as, varray, vselect, vsumdomimp];
as[a_] := If[a == {}, {0}, a];
varray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name];
(*vdpm=varray["VDPM"][[All,{1,3,4}]];*)

vsource = varray["GVIEWRA", "CM04"];
vrows = Union[varray["GVIEWRA", "CM04"][[All, 3]]];
vselect[array_, region_, component_] := Select[array, #[[4]] == region &&
#[[5]] == component &][[All, {1, 3}]];
vsumdomimp[region_] := vselect[vsource, region, "prodrev"];
vsumdomimp["NAFTA"] // MatrixForm;
vregion[region_] := DiagonalMatrix[vsumdomimp[region][[All, 1]]];
vNAFTA = vregion["NAFTA"];
```

```
Print["vNAFTA                          : ", TableForm[vNAFTA,
TableHeadings →  {vrows, vrows}]];

Clear[uarray, uselect, usumdomimp, fsumdomimp];
uarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] →  "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
usource = uarray["GVIEWRA", "SF01"];
uselect[array_, region_, source_, component_, urows_, ucols_] :=
Select[array,     MemberQ[urows, #[[3]]] && MemberQ[ucols, #[[4]]] &&
#[[5]] == region && #[[6]] ==        source && #[[7]] == component &]
[[All, {1, 3, 4}]];
usumdomimp[region_] := Transpose[{ uselect[usource, region, "domestic",
"mktexp", vrows, vrows][[All, 1]] /. x_ /; x -> as[x] + uselect[usource,
region, "imported", "mktexp", vrows, vrows][[All, 1]] /. x_ /; x ->
as[x], uselect[usource, region, "domestic", "mktexp", vrows, vrows][[All,
2]], uselect[usource, region, "domestic", "mktexp", vrows, vrows][[All,
3]]}];
usumdomimp["NAFTA"] // MatrixForm;
uregion[region_] := Transpose[Partition[usumdomimp[region][[All, 1]],
Length[vrows]]];
uNAFTA = uregion["NAFTA"];
Print["uNAFTA                          : ", TableForm[uNAFTA,
TableHeadings →  {vrows, vrows}]];

frows = Complement[Union[varray["GVIEWRA", "SF01"][[All, 3]]], vrows];
fsumdomimp[region_] := Transpose[{ uselect[usource, region, "domestic",
"mktexp", frows, vrows][[All, 1]] /. x_ /; x -> as[x] + uselect[usource,
region, "imported", "mktexp", frows, vrows][[All, 1]] /. x_ /; x ->
as[x], uselect[usource, region, "domestic", "mktexp", frows, vrows][[All,
2]], uselect[usource, region, "domestic", "mktexp", frows, vrows][[All,
3]]}];
fsumdomimp["NAFTA"] // MatrixForm;
fregion[region_] := Transpose[Partition[fsumdomimp[region][[All, 1]],
Length[frows]]];
fNAFTA = fregion["NAFTA"];
Print["fNAFTA factor inputs            : ", TableForm[fNAFTA,
TableHeadings -> {frows, vrows}]]

gnpregion[region_] := uregion[region] - Transpose[vregion[region]];
gnpNAFTA = gnpregion["NAFTA"];
Print["uNAFTA - Inv_vNAFTA_Transpose   : ", TableForm[gnpNAFTA,
TableHeadings -> {vrows, vrows}]]

aregion[region_] := uregion[region].Inverse[Transpose[vregion[region]]];
aNAFTA = aregion["NAFTA"];
Print["aNAFTA technical matrix         : ", TableForm[aNAFTA,
TableHeadings -> {vrows, vrows}]]

Clear[yarray, yselect, ysumdomimp];
yarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT2"] -> "Ascending",
SQLColumn["ELEMENT1"] -> "Ascending"}];
ysource = yarray["GVIEWRA", "SF02"];
yselect[array_, region_, source_, component_, yrows_] := Select[array,
MemberQ[yrows, #[[3]]] && #[[4]] == region && #[[5]] == source && #[[6]]
== component &][[All, {1, 3}]];
ysumdomimp[region_] := Transpose[{ yselect[ysource, region, "domestic",
"mktexp", vrows][[All, 1]] /. x_ /; x -> as[x] + yselect[ysource, region,
"imported", "mktexp", vrows][[All, 1]] /. x_ /; x -> as[x],
yselect[ysource, region, "domestic", "mktexp", vrows][[All, 2]]}];
ysumdomimp["NAFTA"] // MatrixForm;
```

```
yregion[region_] := ysumdomimp[region][[All, 1]];
yNAFTA = yregion["NAFTA"];
Print["yNAFTA                          : ", TableForm[yNAFTA,
TableHeadings -> {vrows}]];

Clear[garray, gselect, gsumdomimp];
garray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT2"] -> "Ascending",
SQLColumn["ELEMENT1"] -> "Ascending"}];
gsource = garray["GVIEWRA", "SF03"];
gselect[array_, region_, source_, component_, yrows_] := Select[array,
MemberQ[yrows, #[[3]]] && #[[4]] == region && #[[5]] == source && #[[6]]
== component &][[All, {1, 3}]];
gsumdomimp[region_] := Transpose[{ gselect[gsource, region, "domestic",
"mktexp", vrows][[All, 1]] /. x_ /; x -> as[x] + gselect[gsource, region,
"imported", "mktexp", vrows][[All, 1]] /. x_ /; x -> as[x],
gselect[gsource, region, "domestic", "mktexp", vrows][[All, 2]]}];
gsumdomimp["NAFTA"] // MatrixForm;
gregion[region_] := gsumdomimp["NAFTA"][[All, 1]];
gNAFTA = gregion["NAFTA"];
Print["gNAFTA                          : ", TableForm[gNAFTA,
TableHeadings -> {vrows}]];

Clear[exarray, exselect, exsumdomimp, exsumdomimp];
exarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT2"] -> "Ascending",
SQLColumn["ELEMENT1"] -> "Ascending"}];
exsource = exarray["GVIEWRA", "BI01"];
tocous = Union[exsource[[All, 5]]];
exselect[array_, region_, urows_, toreg_] := Select[array, MemberQ[urows,
#[[3]]] && #[[4]] == region && #[[5]] == toreg && #[[6]] == "exprev" &]
[[All, {1, 3}]];
exsumdomimp[region_] := Transpose[{ Apply[Plus, Map[exselect[exsource,
region, vrows, #][[All, 1]] /. x_ /; x -> as[x] &, tocous]],
exselect[exsource, region, vrows, region][[All, 2]]}];
exregion[region_] := {Transpose[ Partition[exsumdomimp["NAFTA"][[All,
1]], Length[vrows]]]}
exsumdomimp["NAFTA"] // MatrixForm;
exNAFTA = exregion["NAFTA"];
Print["exNAFTA                          : ", TableForm[exNAFTA,
TableHeadings -> {{"    "}, vrows}]]

Clear[imarray, imselect, imsumdomimp, imsumdomimp];
imarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT2"] -> "Ascending",
SQLColumn["ELEMENT1"] -> "Ascending"}];
imsource = imarray["GVIEWRA", "BI02"];
fromcous = Union[imsource[[All, 5]]];
imselect[array_, region_, urows_, toreg_] := Select[array, MemberQ[urows,
#[[3]]] && #[[4]] == region && #[[5]] == toreg && #[[6]] == "impcost" &]
[[All, {1, 3}]];
imsumdomimp[region_] := Transpose[{ Apply[Plus, Map[imselect[imsource,
region, vrows, #][[All, 1]] /. x_ /; x -> as[x] &, fromcous]],
imselect[imsource, region, vrows, region][[All, 2]]}];
imregion[region_] := {Transpose[ Partition[imsumdomimp["NAFTA"][[All,
1]], Length[vrows]]]}
imsumdomimp["NAFTA"] // MatrixForm;
imNAFTA = imregion["NAFTA"];
Print["imNAFTA                          : ", TableForm[imNAFTA,
TableHeadings -> {{"    "}, vrows}]]

Clear[ygsum];
```

```
ygsum[region_] := Transpose[{ysumdomimp[region][[All, 1]] +
gsumdomimp[region][[All, 1]], vrows}];
ygsum["NAFTA"] // MatrixForm;
ygregion[region_] := ygsum[region][[All, 1]];
ygNAFTA = ygregion["NAFTA"];
Print["ygNAFTA                        : ", TableForm[ygNAFTA,
TableHeadings -> {vrows}]];

Clear[csarray, csselect, cssumdomimp];
csarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT1"] -> "Ascending"}];
cssource = csarray["GVIEWRA", "AG06"];
csselect[array_, region_] := Select[array, #[[3]] == region &][[All, {1,
3}]];
cssumdomimp[region_] := Transpose[{ csselect[cssource, region][[All,
1]] /. x_ /; x -> as[x], csselect[cssource, region][[All, 2]]}];
cssumdomimp["NAFTA"] // MatrixForm;
csregion[region_] := cssumdomimp[region][[All, 1]];
csNAFTA = csregion["NAFTA"];
Print["csNAFTA                        : ", TableForm[csNAFTA,
TableHeadings -> {{"cap "}, {""}}]];

Clear[parray, pselect, psumdomimp];
parray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,  SortingColumns -> {SQLColumn["ELEMENT1"] -> "Ascending"}];
psource = csarray["GDATRA", "POP"];
pselect[array_, region_] := Select[array, #[[3]] == region &][[All, {1,
3}]];
psumdomimp[region_] := Transpose[{ pselect[psource, region][[All, 1]] /.
x_ /; x -> as[x], pselect[psource, region][[All, 2]]}];
psumdomimp["NAFTA"] // MatrixForm;
pregion[region_] := psumdomimp["NAFTA"][[All, 1]];
pNAFTA = pregion["NAFTA"];
Print["pNAFTA                         : ", TableForm[pNAFTA,
TableHeadings -> {{"pop "}, {""}}]];
```

Comparison of U & V matrices with SAM for Mathematica

File: gtap_comparison_uv_amatrix.nb

```
(* Open Connection *)
<< DatabaseLink`
conn = OpenSQLConnection[]
Clear[as, varray, vselect, vsumdomimp];
as[a_] := If[a == {}, {0}, a];
varray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name];
(*vdpm=varray["VDPM"][[All,{1,3,4}]];*)
vsource = varray["GVIEWRA", "CM04"];
vrows = Union[varray["GVIEWRA", "CM04"][[All, 3]]];
vselect[array_, region_, component_] := Select[array, #[[4]] == region &&
#[[5]] == component &][[All, {1, 3}]];
vsumdomimp[region_] := vselect[vsource, region, "prodrev"];
vsumdomimp["NAFTA"] // MatrixForm;
vNAFTA = DiagonalMatrix[vsumdomimp["NAFTA"][[All, 1]]];
Print["vNAFTA                         : ", TableForm[vNAFTA,
TableHeadings -> {vrows, vrows}]];
Clear[uarray, uselect, usumdomimp, fsumdomimp];
```

```
uarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,
   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
usource = uarray["GVIEWRA", "SF01"];
uselect[array_, region_, source_, component_, urows_, ucols_] :=
Select[array,   MemberQ[urows, #[[3]]] && MemberQ[ucols, #[[4]]] &&
#[[5]] == region && #[[6]] ==        source && #[[7]] == component &]
[[All, {1, 3, 4}]];
usumdomimp[region_] := Transpose[{ uselect[usource, region, "domestic",
"mktexp", vrows, vrows][[All, 1]] /. x_ /; x -> as[x] + uselect[usource,
region, "imported", "mktexp", vrows, vrows][[All, 1]] /. x_ /; x ->
as[x], uselect[usource, region, "domestic", "mktexp", vrows, vrows][[All,
2]], uselect[usource, region, "domestic", "mktexp", vrows, vrows][[All,
3]]}];
usumdomimp["NAFTA"] // MatrixForm;
uNAFTA = Transpose[Partition[usumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["uNAFTA                          : ", TableForm[uNAFTA,
TableHeadings -> {vrows, vrows}]];

frows = Complement[Union[varray["GVIEWRA", "SF01"][[All, 3]]], vrows];
fsumdomimp[region_] := Transpose[{ uselect[usource, region, "domestic",
"mktexp", frows, vrows][[All, 1]] /. x_ /; x -> as[x] + uselect[usource,
region, "imported", "mktexp", frows, vrows][[All, 1]] /. x_ /; x ->
as[x], uselect[usource, region, "domestic", "mktexp", frows, vrows][[All,
2]], uselect[usource, region, "domestic", "mktexp", frows, vrows][[All,
3]]}];
fsumdomimp["NAFTA"] // MatrixForm;
fNAFTA = Transpose[ Partition[fsumdomimp["NAFTA"][[All, 1]],
Length[frows]]];
Print["fNAFTA factor inputs            : ", TableForm[fNAFTA,
TableHeadings -> {frows, vrows}]]

gnpNAFTA = uNAFTA - Transpose[vNAFTA];
Print["uNAFTA - Inv_vNAFTA_Transpose   : ", TableForm[gnpNAFTA,
TableHeadings -> {vrows, vrows}]]

aNAFTA = uNAFTA.Inverse[Transpose[vNAFTA]];
Print["aNAFTA technical matrix         : ", TableForm[aNAFTA,
TableHeadings -> {vrows, vrows}]]

Clear[yarray, yselect, ysumdomimp];
yarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT2"] -> "Ascending",
SQLColumn["ELEMENT1"] -> "Ascending"}];
ysource = yarray["GVIEWRA", "SF02"];
yselect[array_, region_, source_, component_, yrows_] := Select[array,
MemberQ[yrows, #[[3]]] && #[[4]] == region && #[[5]] == source && #[[6]]
== component &][[All, {1, 3}]];
ysumdomimp[region_] := Transpose[{ yselect[ysource, region, "domestic",
"mktexp", vrows][[All, 1]] /. x_ /; x -> as[x] + yselect[ysource, region,
"imported", "mktexp", vrows][[All, 1]] /. x_ /; x -> as[x],
yselect[ysource, region, "domestic", "mktexp", vrows][[All, 2]]}];
ysumdomimp["NAFTA"] // MatrixForm;
yNAFTA = ysumdomimp["NAFTA"][[All, 1]];
Print["yNAFTA                          : ", TableForm[yNAFTA,
TableHeadings -> {vrows}]];

Clear[garray, gselect, gsumdomimp];
```

```
garray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,   SortingColumns -> {SQLColumn["ELEMENT2"] -> "Ascending",
SQLColumn["ELEMENT1"] -> "Ascending"}];
gsource = garray["GVIEWRA", "SF03"];
gselect[array_, region_, source_, component_, yrows_] := Select[array,
MemberQ[yrows, #[[3]]] && #[[4]] == region && #[[5]] == source && #[[6]]
== component &][[All, {1, 3}]];
gsumdomimp[region_] := Transpose[{ gselect[gsource, region, "domestic",
"mktexp", vrows][[All, 1]] /. x_ /; x -> as[x] + gselect[gsource, region,
"imported", "mktexp", vrows][[All, 1]] /. x_ /; x -> as[x],
gselect[gsource, region, "domestic", "mktexp", vrows][[All, 2]]}];
gsumdomimp["NAFTA"] // MatrixForm;
gNAFTA = gsumdomimp["NAFTA"][[All, 1]];
Print["gNAFTA                          : ", TableForm[gNAFTA,
TableHeadings -> {vrows}]];

Clear[ygsum];
ygsum[region_] := Transpose[{ysumdomimp[region][[All, 1]] +
gsumdomimp[region][[All, 1]], vrows}];
ygsum["NAFTA"] // MatrixForm;
ygNAFTA = ygsum["NAFTA"][[All, 1]];
Print["ygNAFTA                         : ", TableForm[ygNAFTA,
TableHeadings -> {vrows}]];

Clear[csarray, csselect, cssumdomimp];
csarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT1"] -> "Ascending"}];
cssource = csarray["GVIEWRA", "AG06"];
csselect[array_, region_] := Select[array, #[[3]] == region &][[All, {1,
3}]];
cssumdomimp[region_] := Transpose[{ csselect[cssource, region][[All,
1]] /. x_ /; x -> as[x], csselect[cssource, region][[All, 2]]}];
cssumdomimp["NAFTA"] // MatrixForm;
csNAFTA = cssumdomimp["NAFTA"][[All, 1]];
Print["csNAFTA                         : ", TableForm[csNAFTA,
TableHeadings -> {{"cap "}, {""}}]];

Clear[parray, pselect, psumdomimp];
parray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT1"] -> "Ascending"}];
psource = csarray["GDATRA", "POP"];
pselect[array_, region_] := Select[array, #[[3]] == region &][[All, {1,
3}]];
psumdomimp[region_] := Transpose[{ pselect[psource, region][[All, 1]] /.
x_ /; x -> as[x], pselect[psource, region][[All, 2]]}];
psumdomimp["NAFTA"] // MatrixForm;
pNAFTA = psumdomimp["NAFTA"][[All, 1]];
Print["pNAFTA                          : ", TableForm[pNAFTA,
TableHeadings -> {{"pop "}, {""}}]];

(* CHECK ON A MATRIX *)

Clear[vdarray, vdselect, vdsumdomimp, vdsumdomimp];
vdarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
vdsource = vdarray["GDATRA", "VDFM"];
vdselect[array_, region_, urows_, ucols_] := Select[array, MemberQ[urows,
#[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &][[All, {1, 3,
4}]];
vdsumdomimp[region_] := Transpose[{ vdselect[vdsource, region, vrows,
vrows][[All, 1]] /. x_ /; x -> as[x], vdselect[vdsource, region, vrows,
```

```
vrows][[All, 2]],    vdselect[vdsource, region, vrows, vrows][[All,
3]]}];
vdsumdomimp["NAFTA"] // MatrixForm;
vdNAFTA = Transpose[ Partition[vdsumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["vdNAFTA                          : ", TableForm[vdNAFTA,
TableHeadings -> {vrows, vrows}]]

Clear[viarray, viselect, visumdomimp, visumdomimp];
viarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
visource = viarray["GDATRA", "VIFM"];
viselect[array_, region_, urows_, ucols_] := Select[array, MemberQ[urows,
#[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &][[All, {1, 3,
4}]];
visumdomimp[region_] := Transpose[{viselect[visource, region, vrows,
vrows][[All, 1]] /. x_ /; x -> as[x], viselect[visource, region, vrows,
vrows][[All, 2]],    viselect[visource, region, vrows, vrows][[All,
3]]}];
visumdomimp["NAFTA"] // MatrixForm;
viNAFTA = Transpose[ Partition[visumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["viNAFTA                          : ", TableForm[viNAFTA,
TableHeadings -> {vrows, vrows}]]

Clear[vdvisum];
vdvisum[region_] := Transpose[{vdsumdomimp[region][[All, 1]] +
visumdomimp[region][[All, 1]], vdsumdomimp[region][[All, 2]],
vdsumdomimp[region][[All, 3]]}];
vdvisum["NAFTA"] // MatrixForm;
vdviNAFTA = Transpose[Partition[vdvisum["NAFTA"][[All, 1]],
Length[vrows]]];
Print["vdviNAFTA                        : ", TableForm[vdviNAFTA,
TableHeadings -> {vrows, vrows}]];

Clear[enarray, enselect, ensumdomimp, ensumdomimp];
enarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
ensource = enarray["GDATRA", "VFM"];
enselect[array_, region_, urows_, ucols_] := Select[array, MemberQ[urows,
#[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &][[All, {1, 3,
4}]];
ensumdomimp[region_] := Transpose[{ enselect[ensource, region, frows,
vrows][[All, 1]] /. x_ /; x -> as[x], enselect[ensource, region, frows,
vrows][[All, 2]],  enselect[ensource, region, frows, vrows][[All, 3]]}];
ensumdomimp["NAFTA"] // MatrixForm;
enNAFTA = Transpose[ Partition[ensumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["enNAFTA                          : ", TableForm[enNAFTA,
TableHeadings -> {frows, vrows}]]

Clear[fbarray, fbselect, fbsumdomimp, fbsumdomimp];
fbarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,    SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
fbsource = fbarray["GDATRA", "FBEP"];
```

```
fbselect[array_, region_, urows_, ucols_] := Select[array, MemberQ[urows,
#[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &][[All, {1, 3,
4}]];
fbsumdomimp[region_] := Transpose[{fbselect[fbsource, region, frows,
vrows][[All, 1]] /. x_ /; x -> as[x], fbselect[fbsource, region, frows,
vrows][[All, 2]],   fbselect[fbsource, region, frows, vrows][[All, 3]]}];
fbsumdomimp["NAFTA"] // MatrixForm;
fbNAFTA = Transpose[ Partition[fbsumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["fbNAFTA                          : ", TableForm[fbNAFTA,
TableHeadings -> {frows, vrows}]]

Clear[ftarray, ftselect, ftsumdomimp, ftsumdomimp];
ftarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
ftsource = ftarray["GDATRA", "FTRV"];
ftselect[array_, region_, urows_, ucols_] := Select[array, MemberQ[urows,
#[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &][[ All, {1, 3,
4}]];
ftsumdomimp[region_] := Transpose[{ftselect[ftsource, region, frows,
vrows][[All, 1]] /. x_ /; x -> as[x], ftselect[ftsource, region, frows,
vrows][[All, 2]],   ftselect[ftsource, region, frows, vrows][[All, 3]]}];
ftsumdomimp["NAFTA"] // MatrixForm;
ftNAFTA = Transpose[ Partition[ftsumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["ftNAFTA                          : ", TableForm[ftNAFTA,
TableHeadings -> {frows, vrows}]]

Clear[isarray, isselect, issumdomimp, issumdomimp];
isarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
issource = ftarray["GDATRA", "ISEP"];
isselect[array_, region_, urows_, ucols_, source_] := Select[array,
MemberQ[urows, #[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &&
#[[6]] ==        source &][[All, {1, 3, 4, 6}]];
issumdomimp[region_] := Transpose[{ isselect[issource, region, vrows,
vrows, "domestic"][[All, 1]] /. x_ /; x -> as[x] + isselect[issource,
region, vrows, vrows, "imported"][[All, 1]] /. x_ /; x -> as[x],
isselect[issource, region, vrows, vrows, "domestic"][[All, 2]],
isselect[issource, region, vrows, vrows, "domestic"][[All, 3]]}];
issumdomimp["NAFTA"] // MatrixForm;
isNAFTA = Transpose[ Partition[issumdomimp["NAFTA"][[All, 1]],
Length[vrows]]];
Print["isNAFTA                          : ", TableForm[isNAFTA,
TableHeadings -> {vrows, vrows}]]

(*Clear[osarray,osselect,ossumdomimp,ossumdomimp];
osarray[array_,name_]:=SQLSelect[conn,array,SQLColumn["HEADNAME"]==
name,SortingColumns->{SQLColumn["ELEMENT2"]-
>"Ascending",SQLColumn[ "ELEMENT1"]->"Ascending"}];
ossource=ftarray["GDATRA","OSEP"];
osselect[array_,region_,urows_]:=Select[array,MemberQ[urows,#[[3]]]&&#[[4
]]==region&][[All,{1,3}]];
ossumdomimp[region_]:=Transpose[{osselect[ossource,region,vrows]
[[All,1]]/.x_/;x->as[x],osselect[ossource,region,vrows][[All,2]]}];
ossumdomimp["NAFTA"]//MatrixForm;
osNAFTA={Transpose[Partition[ossumdomimp["NAFTA"]
[[All,1]],Length[vrows]]]};
```

```
Print["osNAFTA                          :
",TableForm[osNAFTA,TableHeadings->{{"    "},vrows}]]*)

Clear[tfarray, tfselect, tfsumdomimp, tfsumdomimp];
tfarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,
   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
tfsource = tfarray["GDATRA", "TFRV"];
fromcous = Union[tfsource[[All, 5]]];
tfselect[array_, region_, urows_, fromreg_] := Select[array,
MemberQ[urows, #[[3]]] && #[[4]] == region && #[[5]] == fromreg &][[All,
{1, 3}]];
tfsumdomimp[region_] := Transpose[{ Apply[Plus, Map[tfselect[tfsource,
region, vrows, #][[All, 1]] /. x_ /; x -> as[x] &, fromcous]],
tfselect[tfsource, region, vrows, region][[All, 2]]}];
tfsumdomimp["NAFTA"] // MatrixForm;
tfNAFTA = {Transpose[ Partition[tfsumdomimp["NAFTA"][[All, 1]],
Length[vrows]]]};
Print["tfNAFTA                          : ", TableForm[tfNAFTA,
TableHeadings -> {{"    "}, vrows}]]

Clear[vsarray, vsselect, vssumdomimp, vssumdomimp];
vsarray[array_, name_] := SQLSelect[conn, array, SQLColumn["HEADNAME"] ==
name,
   SortingColumns -> {SQLColumn["ELEMENT3"] -> "Ascending",
SQLColumn["ELEMENT2"] -> "Ascending", SQLColumn["ELEMENT1"] ->
"Ascending"}];
vssource = vsarray["GDATRA", "VTWR"];
fromcous = Union[vssource[[All, 6]]];
vsselect[array_, region_, urows_, ucols_, fromreg_] := Select[array,
MemberQ[urows, #[[3]]] && MemberQ[ucols, #[[4]]] && #[[5]] == region &&
#[[6]] ==        fromreg &][[All, {1, 3}]];
vssumdomimp[region_] := Transpose[{ Apply[Plus, Map[vsselect[vssource,
region, vrows, vrows, #][[All, 1]] /. x_ /; x -> as[x] &, fromcous]],
vsselect[vssource, region, vrows, vrows, region][[All, 2]]}];
vssumdomimp["NAFTA"] // MatrixForm;
vsNAFTA = {Transpose[ Partition[vssumdomimp["NAFTA"][[All, 1]],
Length[vrows]]]};
Print["vsNAFTA                          : ", TableForm[vsNAFTA,
TableHeadings -> {{"serv"}, vrows}]]

Clear[totasum];
dim = {Max[Length[vrows]*Length[vrows], Length[frows]*Length[vrows]], 1};
totasum[region_] := Transpose[{Flatten[ SparseArray[Band[{1, 1}] ->
Thread[{vdvisum[region][[All, 1]]}], dim] + SparseArray[ Band[{1, 1}] ->
Thread[{ensumdomimp[region][[All, 1]]}], dim] + SparseArray[ Band[{1, 1}]
-> Thread[{fbsumdomimp[region][[All, 1]]}], dim] + SparseArray[ Band[{1,
1}] -> Thread[{ftsumdomimp[region][[All, 1]]}], dim] +
SparseArray[ Band[{1, 1}] -> Thread[{issumdomimp[region][[All, 1]]}],
dim] + (*SparseArray[Band[{1,1}]->Thread[{ossumdomimp[region][[All,
1]]}],dim]+*) SparseArray[ Band[{1, 1}] -> Thread[{tfsumdomimp[region]
[[All, 1]]}], dim] + SparseArray[ Band[{1, 1}] ->
Thread[{vssumdomimp[region][[All, 1]]}], dim]], ensumdomimp[region][[All,
2]], ensumdomimp[region][[All, 3]]}];
totasum["NAFTA"] // MatrixForm;
totaNAFTA = {Total[ Transpose[ Partition[totasum["NAFTA"][[All, 1]],
Length[vrows]]]]};

Print["totaNAFTA                        : ", TableForm[totaNAFTA,
TableHeadings -> {{"    "}, vrows}]];
```

```
dataaNAFTA = vdviNAFTA.Inverse[DiagonalMatrix[Flatten[totaNAFTA]]];
Print["calc NAFTA technical matrix      : ", TableForm[dataaNAFTA,
TableHeadings -> {vrows, vrows}]];

Print["compare aNAFTA technical matrix  : ", TableForm[aNAFTA,
TableHeadings -> {vrows, vrows}]]
```

Greenhouse gas aggregation and creation of database within Mathematica

File: eghg_aggregate.nb

```
<< DatabaseLink`
conn1 = OpenSQLConnection["gtap3eghg"]
conn2 = OpenSQLConnection["gtap3res"]
Clear[mapping, positiona, positionb, from, to, map, mapuc];
istream = OpenRead["/home/stuart/Documents/gtap/GTPAg7/sntest01.agg"];
records = Select[ReadList[istream, Record, RecordSeparators -> "= "],
   StringFreeQ[#, "!"] &];
mapping[n_] := Rest[StringSplit[records[[n]]]];
positiona[n_] := Flatten[Position[mapping[n], "&"]];
positionb[n_] := Rest[RotateRight[Join[{-1}, positiona[n]]]];
to[n_] := mapping[n][[positiona[n] + 1]];
from[n_] := mapping[n][[positionb[n] + 2]];
map[n_] := Thread[from[n] -> to[n]];
mapuc[n_] := Thread[ToUpperCase[from[n]] -> to[n]];
produnitmap = map[2];
regionmap = mapuc[4];
factormap = map[6];
othermap = {"HH" -> "demand", "Govt" -> "demand", "CGDS" -> "invest"};
remap = Join[produnitmap, regionmap, factormap, othermap];
mappedarray = SQLSelect[conn1, "RARRAY"] /. remap
ghg = Union[mappedarray[[All, 3]]];
commodities = Union[mappedarray[[All, 4]]];
produnits = Union[mappedarray[[All, 5]]];
regions = Union[mappedarray[[All, 6]]];
(*Total[Select[mappedarray,
#[[3]]=="CO2"&&#[[4]]=="ecoa"&&#[[5]]=="food"&&#[[6]]=="EU25"&]
[[All,1]]];*)

SQLDropTable[conn2, "EGHG"];
SQLCreateTable[conn2, SQLTable["EGHG"], {SQLColumn["RVALUE", DataTypeName
-> "FLOAT"], SQLColumn["HEADNAME", DataTypeName -> "VARCHAR", DataLength
-> 10], SQLColumn["ELEMENT1", DataTypeName -> "VARCHAR", DataLength ->
10], SQLColumn["ELEMENT2", DataTypeName -> "VARCHAR", DataLength -> 10],
SQLColumn["ELEMENT3", DataTypeName -> "VARCHAR", DataLength -> 10]
}];

SQLDelete[conn2, "EGHG"];
For[l = 1, l <= Length[regions], l++,
  For[k = 1, k <= Length[produnits], k++,
    For[j = 1, j <= Length[commodities], j++,
      For[i = 1, i <= Length[ghg], i++,
        SQLInsert[conn2, "EGHG", SQLColumnNames[conn2, SQLTable["EGHG"]]
[[All, 2]],        {Total[Select[mappedarray, #[[3]] == ghg[[i]] &&
#[[4]] == commodities[[j]] && #[[5]] == produnits[[k]] && #[[6]] ==
regions[[l]] &][[All,  1]]], ghg[[i]], commodities[[j]], produnits[[k]],
regions[[l]]}]
];];];];
```

A7.3 Data mining the GTAP database in Mathematica

File: Gtapfunctions.m

```
BeginPackage["Gtapfunctions`",{"DatabaseLink`"}]
vrows::usage="vrows gives the commodity rows of the matrix."
frows::usage="frows gives the factor rows of the matrix."
regions::usage="regions gives the regions in the dataset."
vregion::usage="vregion[n] gives the V matrix."
uregion::usage="uregion[n] gives the V matrix."
iregion::usage="iregion[n] gives the Investment matrix."
fregion::usage="fregion[n] gives the Factor matrix."
gnpregion::usage="gnpregion[n] gives the U-Transpose[V] matrix."
aregion::usage="aregion[n] gives the A matrix."
imregion::usage="imregion[n] gives the Import matrix."
exregion::usage="exregion[n] gives the Export matrix."
txregion::usage="txregion[n] gives the export transport margins."
yregion::usage="yrgion[n] gives the Household demand matrix."
gregion::usage="gregion[n] gives the Government demand matrix."
ygregion::usage="ygregion[n] gives the combined Household & Government
demand matrix."
biregion::usage"biregion[n] gives the bias of U-V+C+I+G+X-M"
csregion::usage="csregion[n] gives the Capital Stock."
pregion::usage="pregion[n] gives the Population."
eyregion::usage="yeregion[n] gives the combined Household energy demand
matrix."
eexregion::usage="eexregion[n] gives the Energy bilateral trade matrix."
euregion::usage="euregion[n] gives the firms' purchases of Energy."
gfgregion::usage="gfgregion[n] gives the firms production of greenhouse
gases."
gygregion::usage="gygregion[n] gives the combined Household & Government
production of greenhouse gases."
gigregion::usage="gigregion[n] gives the investment production of
greenhouse gases."

Begin["`Private`"]
conn=OpenSQLConnection["gtap3res"];
Clear[varray,vselect,vsumdomimp];
(*as[a_]:=If[a=={},{0},a];*)
(* the varray is different to others because V needs to be at market
prices, including output taxes *)
varray[array_,name_]:=SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name];
(*vdpm=varray["VDPM"][[All,{1,3,4}]];*)
vsource=varray["GVIEWRA","CM04"];
regions=Union[varray["GVIEWRA","CM04"][[All,4]]];
vrows=Union[varray["GVIEWRA","CM04"][[All,3]]];
vselect[array_,region_,component_]:= Select[array,#[[4]]==region &&
#[[5]] == component&][[All,{1,3}]];
vsumdomimp[region_]:= Transpose[{ vselect[vsource,region,"prodrev"]
[[All,1]] +  vselect[vsource,region,"outtax"][[All,1]],
vselect[vsource,region,"prodrev"][[All,2]]}];
vregion[region_]:= DiagonalMatrix[vsumdomimp[region][[All,1]]];
(*vsumdomimp["NAFTA"]//MatrixForm
vNAFTA=vregion["NAFTA"];
Print["vNAFTA                          : ",TableForm[vNAFTA,TableHeadings
→ {vrows,vrows}]]; *)

Clear[uarray,uselect,usumdomimp];
uarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name,SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
```

```
SQLColumn["ELEMENT2"] → "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
usource=uarray["GVIEWRA","SF01"];
uselect[array_,region_,source_,component_,urows_,ucols_]:=
Select[array,MemberQ[urows,#[[3]]] && MemberQ[ucols,#[[4]]]&&#[[5]] ==
region&&#[[6]] == source&&#[[7]] == component&][[All,{1,3,4}]];
usumdomimp[region_]:=
Transpose[{ uselect[usource,region,"domestic","mktexp",vrows,vrows]
[[All,1]] + uselect[usource,region,"imported","mktexp",vrows,vrows]
[[All,1]], uselect[usource,region,"domestic","mktexp",vrows,vrows]
[[All,2]], uselect[usource,region,"domestic","mktexp",vrows,vrows]
[[All,3]]}];
uregion[region_]:= Transpose[Partition[usumdomimp[region]
[[All,1]],Length[vrows]]];
(* usumdomimp["NAFTA"]//MatrixForm;
uNAFTA= uregion["NAFTA"];
Print["uNAFTA                          : ",TableForm[uNAFTA,TableHeadings
→ {vrows,vrows}]]; *)

Clear[fssumdomimp];
frows = Complement[Union[varray["GVIEWRA","SF01"][[All,3]]],vrows];
fsumdomimp[region_]:=Transpose[{ uselect[usource,region,"domestic","mktex
p",frows,vrows][[All,1]] +
uselect[usource,region,"imported","mktexp",frows,vrows][[All,1]],
uselect[usource,region,"domestic","mktexp",frows,vrows][[All,2]],
uselect[usource,region,"domestic","mktexp",frows,vrows][[All,3]]}];
fregion[region_]:= Transpose[Partition[fsumdomimp[region]
[[All,1]],Length[frows]]];
(* fsumdomimp["NAFTA"]//MatrixForm;
fNAFTA=fregion["NAFTA"];
Print["fNAFTA factor inputs            : ",TableForm[fNAFTA,TableHeadings
→ {frows,vrows}]] *)

gnpregion[region_]:=uregion[region]-Transpose[vregion[region]];
(* gnpNAFTA=gnpregion["NAFTA"];
Print["uNAFTA - Inv_vNAFTA_Transpose   :
",TableForm[gnpNAFTA,TableHeadings → {vrows,vrows}]] *)

aregion[region_]:=uregion[region].Inverse[Transpose[vregion[region]]];
(* aNAFTA=aregion["NAFTA"];
Print["aNAFTA technical matrix         : ",TableForm[aNAFTA,TableHeadings
→ {vrows,vrows}]] *)

Clear[txarray,txselect,txsumdomimp];
txarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] →
"Ascending",SQLColumn["ELEMENT2"] → "Ascending",SQLColumn["ELEMENT1"]-
>"Ascending"}];
txsource=txarray["GVIEWRA","CM01"];
txselect[array_,region_,urows_]:= Select[array,MemberQ[urows,
#[[3]]]&&#[[5]] == region&&#[[4]] == "trans"&][[All,{1,3}]];
txsumdomimp[region_]:=Transpose[{ txselect[txsource,region,vrows]
[[All,1]], txselect[txsource,region,vrows][[All,2]]}];
txregion[region_]:=txsumdomimp[region][[All,1]];

Clear[exarray,exselect,exsumdomimp];
(* the exarray is different to others because it needs to be at world
prices, including export taxes & transport so use the CIF disposition *)
exarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name,SortingColumns → {SQLColumn["ELEMENT3"] →
"Ascending",SQLColumn["ELEMENT2"] → "Ascending",SQLColumn["ELEMENT1"] →
"Ascending"}];
exsource=exarray["GVIEWRA","BI03"];
```

```
tocous=Union[exsource[[All,5]]];
exselect[array_,region_,urows_,toreg_,component_]:=
Select[array,MemberQ[urows,#[[3]]]&&#[[4]] == region&&#[[5]] ==
toreg&&#[[6]] == component&][[All,{1,3}]];
exsumdomimp[region_]:=Transpose[{ Apply[Plus,Map[exselect[exsource,region
,vrows,#,"fob"][[All,1]]&,tocous]] +
Apply[Plus,Map[exselect[exsource,region,vrows,#,"trans"]
[[All,1]]&,tocous]], exselect[exsource,region,vrows,region,"fob"]
[[All,2]]}];
exregion[region_]:= Flatten[Transpose[Partition[exsumdomimp[region]
[[All,1]],Length[vrows]]]];
(*exsumdomimp["NAFTA"]//MatrixForm;
exNAFTA=exregion["NAFTA"];
Print["exNAFTA                          :
",TableForm[exNAFTA,TableHeadings → {{"    "},vrows}]]*)

Clear[imarray,imselect,imsumdomimp];
imarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name,SortingColumns → {SQLColumn["ELEMENT3"] →
"Ascending",SQLColumn["ELEMENT2"] → "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
imsource=imarray["GVIEWRA","BI02"];
fromcous=Union[imsource[[All,4]]];
imselect[array_,region_,urows_,toreg_]:=
Select[array,MemberQ[urows,#[[3]]]&&#[[5]] == region&&#[[4]] ==
toreg&&#[[6]] == "impcost"&][[All,{1,3}]];
imsumdomimp[region_]:=
Transpose[{ Apply[Plus,Map[imselect[imsource,region,vrows,#]
[[All,1]]&,fromcous]], imselect[imsource,region,vrows,region][[All,2]]}];
imregion[region_]:= Flatten[Transpose[Partition[imsumdomimp[region]
[[All,1]],Length[vrows]]]];
(*imsumdomimp["NAFTA"]//MatrixForm;
imNAFTA=imregion["NAFTA"];
Print["imNAFTA                          :
",TableForm[imNAFTA,TableHeadings → {{"    "},vrows}]]*)

Clear[yarray,yselect,ysumdomimp];
yarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name,SortingColumns → {SQLColumn["ELEMENT2"] →
"Ascending",SQLColumn["ELEMENT1"] → "Ascending"}];
ysource = yarray["GVIEWRA","SF02"];
yselect[array_,region_,source_,component_,yrows_]:=
Select[array,MemberQ[yrows, #[[3]]] && #[[4]] == region&&#[[5]] ==
source&&#[[6]] == component&][[All,{1,3}]];
ysumdomimp[region_]:=Transpose[{ yselect[ysource,region,"domestic","mktex
p",vrows][[All,1]] + yselect[ysource,region,"imported","mktexp",vrows]
[[All,1]], yselect[ysource,region,"domestic","mktexp",vrows][[All,2]]}];
yregion[region_]:=ysumdomimp[region][[All,1]];
(* ysumdomimp["NAFTA"]//MatrixForm;
yNAFTA=yregion["NAFTA"];
Print["yNAFTA                          : ",TableForm[yNAFTA,TableHeadings
→ {vrows}]]; *)

Clear[garray,gselect,gsumdomimp];
garray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name,SortingColumns → {SQLColumn["ELEMENT2"] →
"Ascending",SQLColumn["ELEMENT1"] → "Ascending"}];
gsource=garray["GVIEWRA","SF03"];
gselect[array_,region_,source_,component_,yrows_]:=
Select[array,MemberQ[yrows, #[[3]]]&&#[[4]] == region&&#[[5]] ==
source&&#[[6]]==component&][[All,{1,3}]];
```

```
gsumdomimp[region_]:=Transpose[{ gselect[gsource,region,"domestic","mktex
p",vrows][[All,1]] + gselect[gsource,region,"imported","mktexp",vrows]
[[All,1]], gselect[gsource,region,"domestic","mktexp",vrows][[All,2]]}];
gregion[region_]:=gsumdomimp["NAFTA"][[All,1]];
(* gsumdomimp["NAFTA"]//MatrixForm;
gNAFTA=gregion["NAFTA"];
Print["gNAFTA                          : ",TableForm[gNAFTA,
TableHeadings → {vrows}]]; *)

Clear[ygsum];
ygsum[region_]:= Transpose[{ysumdomimp[region][[All,1]] +
gsumdomimp[region][[All,1]],vrows}];
ygregion[region_]:= ygsum[region][[All,1]];
(* ygsum["NAFTA"]//MatrixForm;
ygNAFTA=ygregion["NAFTA"];
Print["ygNAFTA                         : ",TableForm[ygNAFTA,
TableHeadings → {vrows}]]; *)

Clear[csarray,csselect,cssumdomimp];
csarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT1"] → "Ascending"}];
cssource=csarray["GVIEWRA","AG06"];
csselect[array_,region_]:= Select[array,#[[3]] == region&][[All,{1,3}]];
cssumdomimp[region_]:= Transpose[{ csselect[cssource,region][[All,1]],
csselect[cssource,region][[All,2]]}];
csregion[region_]:= cssumdomimp[region][[All,1]];
(* cssumdomimp["NAFTA"]//MatrixForm;
csNAFTA=csregion["NAFTA"];
Print["csNAFTA                         :
",TableForm[csNAFTA,TableHeadings → {{"cap "},{""}}]]; *)

Clear[parray,pselect,psumdomimp];
parray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT1"] → "Ascending"}];
psource=csarray["GDATRA","POP"];
pselect[array_,region_]:= Select[array,#[[3]] == region&][[All,{1,3}]];
psumdomimp[region_]:= Transpose[{ pselect[psource,region][[All,1]],
pselect[psource,region][[All,2]]}];
pregion[region_]:= psumdomimp[region][[All,1]];
(*psumdomimp["NAFTA"]//MatrixForm;
pNAFTA=pregion["NAFTA"];
Print["pNAFTA                          : ",TableForm[pNAFTA,TableHeadings
→ {{"pop "},{""}}]];*)

Clear[iarray,iselect,isumdomimp];
iarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending",SQLColumn["ELEMENT1"] →
"Ascending"}];
isource= iarray["GVIEWRA","SF01"];
iselect[array_,region_,source_,component_,urows_,ucols_]:=
Select[array,MemberQ[urows,#[[3]]] && MemberQ[ucols,#[[4]]] && #[[5]] ==
region && #[[6]] == source && #[[7]] == component&][[All,{1,3,4}]];
isumdomimp[region_]:=Transpose[{ iselect[isource,region,"domestic","mktex
p",vrows,{"CGDS"}][[All,1]] +
iselect[isource,region,"imported","mktexp",vrows,{"CGDS"}][[All,1]],
iselect[isource,region,"domestic","mktexp",vrows,{"CGDS"}][[All,2]],
iselect[isource,region,"domestic","mktexp",vrows,{"CGDS"}][[All,3]]}];
(*iregion[region_]:= Transpose[Partition[isumdomimp[region][[All,1]],
Length[vrows]]];*)
iregion[region_]:= isumdomimp[region][[All,1]];
(*iNAFTA=iregion["NAFTA"]
isumdomimp["NAFTA"]//MatrixForm
```

```
Print["iNAFTA                          : ",TableForm[iNAFTA,TableHeadings
→ {vrows,"CGDS"}]];*)

Clear[biregion];
biregion[region_]:= Total[uregion[region]-Transpose[vregion[region]],{2}]
+ ygregion[region] + iregion[region] + exregion[region] -
imregion[region];
(*biregion["NAFTA"]*)

Clear[eyarray,eyselect,eysumdomimp];
eyarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT2"] →
"Ascending",SQLColumn["ELEMENT1"] → "Ascending"}];
eysource = eyarray["GVOLERA","EVH"];
erows = Union[eyarray["GVOLERA","EVH"][[All,3]]];
eyselect[array_,region_,yrows_]:= Select[array,MemberQ[yrows,#[[3]]] &&
#[[4]] == region&][[All,{1,3}]];
eysumdomimp[region_]:= eyselect[eysource,region,erows];
(*the following form is required to cope with null values *)
eyregion[region_]:= Table[Apply[Plus,Select[eysumdomimp[region],#[[2]] ==
i&][[All,1]]],{i,erows}];
(*eyregion["NAFTA"]//MatrixForm
eyNAFTA=eyregion["NAFTA"];
Print["eyNAFTA                          :
",TableForm[eyNAFTA,TableHeadings → {erows}]];*)

Clear[eexarray,eexselect,eexsumdomimp];
(* the eexarray *)
eexarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
eexsource=eexarray["GVOLERA","EVT"];
tocous=Union[eexsource[[All,5]]];
eexselect[array_,region_,yrows_,tocous_]:=
Select[array,MemberQ[yrows,#[[3]]] && #[[4]] == region && #[[5]] ==
tocous&][[All,{1,3}]];
eexsumdomimp[region_]:=Transpose[{ Apply[Plus,Map[eexselect[eexsource,reg
ion,erows,#][[All,1]]&,tocous]], eexselect[eexsource,region,erows,region]
[[All,2]]}];
(*the following form is required to cope with null values *)
eexregion[region_]:= Table[Apply[Plus,Select[eexsumdomimp[region], #[[2]]
== i&][[All,1]]], {i,erows}];
(*eexsumdomimp["NAFTA"]//MatrixForm
eexNAFTA=eexregion["NAFTA"];
Print["eexNAFTA                          :
",TableForm[eexNAFTA,TableHeadings → {erows,{"   "}}]]*)

Clear[eimarray,eimselect,eimsumdomimp];
(* the eimarray *)
eimarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending",SQLColumn["ELEMENT1"] →
"Ascending"}];
eimsource = eimarray["GVOLERA","EVT"];
fromcous= Union[eimsource[[All,4]]];
eimselect[array_,region_,yrows_,fromcous_]:=
Select[array,MemberQ[yrows,#[[3]]] && #[[5]] == region && #[[4]] ==
fromcous&][[All,{1,3}]];
eimsumdomimp[region_]:=
Transpose[{Apply[Plus,Map[eimselect[eimsource,region, erows,#]
[[All,1]]&,fromcous]], eimselect[eimsource,region,erows,region]
[[All,2]]}];
```

```
(*the following form is required to cope with null values *)
eimregion[region_]:= Table[Apply[Plus,Select[eimsumdomimp[region],
#[[2]]==i&][[All,1]]],{i,erows}];
(*eimsumdomimp["NAFTA"]//MatrixForm
eimNAFTA=eimregion["NAFTA"];
Print["eimNAFTA                          :
",TableForm[eimNAFTA,TableHeadings → {erows,{"   "}}]]*)

Clear[euarray,euselect,eusumdomimp];
euarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
eusource=euarray["GVOLERA","EVF"];
euselect[array_,region_,erows_,ucols_]:=
Select[array,MemberQ[erows,#[[3]]] && MemberQ[ucols,#[[4]]] && #[[5]] ==
region&][[All,{1,3,4}]];
eusumdomimp[region_]:= euselect[eusource,region,erows,vrows];
(*the following form is required to cope with null values *)
euregion[region_]:=
Transpose[Table[Apply[Plus,Select[eusumdomimp[region], #[[2]] == j &&
#[[3]] == i&][[All,1]]],{i,vrows},{j,erows}]];
(*eusumdomimp["NAFTA"]//MatrixForm
euNAFTA=euregion["NAFTA"];
Print["euNAFTA                          :
",TableForm[euNAFTA,TableHeadings → {erows,vrows}]];*)

Clear[gfgarray,gfgselect,gfgsumdomimp];
gfgarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
gfgsource = gfgarray["EGHG","CO2"];
ghgrows = Union[gfgarray["EGHG","CO2"][[All,3]]];
gfgselect[array_,region_,ghgrows_,ucols_]:=
Select[array,MemberQ[ghgrows,#[[3]]] && MemberQ[ucols,#[[4]]] && #[[5]]
== region&][[All,{1,3,4}]];
gfgsumdomimp[region_]:= gfgselect[gfgsource,region,ghgrows,vrows];
(*the following form is required to cope with null values *)
gfgregion[region_]:=
Transpose[Table[Apply[Plus,Select[gfgsumdomimp[region],#[[2]] == j &&
#[[3]] == i&][[All,1]]],{i,vrows},{j,ghgrows}]];
(*gfgsumdomimp["NAFTA"]//MatrixForm
gfgNAFTA=gfgregion["NAFTA"];
Print["gfgNAFTA                          :
",TableForm[gfgNAFTA,TableHeadings → {ghgrows,vrows}]];*)

Clear[gygarray,gygselect,gygsumdomimp];
gygarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending", SQLColumn["ELEMENT1"] →
"Ascending"}];
gygsource = gygarray["EGHG","CO2"];
gygcols = {"demand"};
gygselect[array_,region_,ghgrows_,ucols_]:=
Select[array,MemberQ[ghgrows,#[[3]]] && MemberQ[ucols,#[[4]]] && #[[5]]
== region&][[All,{1,3,4}]];
gygsumdomimp[region_]:= gygselect[gygsource,region,ghgrows,gygcols];
(*the following form is required to cope with null values *)
gygregion[region_]:=
Flatten[Table[Apply[Plus,Select[gygsumdomimp[region],#[[2]] == j &&
#[[3]] == i&][[All,1]]],{i,gygcols},{j,ghgrows}]];
(*gygsumdomimp["NAFTA"]//MatrixForm
```

```
gygNAFTA=gygregion["NAFTA"];
Print["gygNAFTA                          :
",TableForm[gygNAFTA,TableHeadings → {ghgrows,gygcols}]];*)

Clear[gigarray,gigselect,gigsumdomimp];
gigarray[array_,name_]:= SQLSelect[conn,array,SQLColumn["HEADNAME"] ==
name, SortingColumns → {SQLColumn["ELEMENT3"] → "Ascending",
SQLColumn["ELEMENT2"] → "Ascending",SQLColumn["ELEMENT1"] →
"Ascending"}];
gigsource=gigarray["EGHG","CO2"];
gigcols={"invest"};
gigselect[array_,region_,ghgrows_,ucols_]:=
Select[array,MemberQ[ghgrows,#[[3]]] && MemberQ[ucols,#[[4]]] &&
#[[5]]==region&][[All,{1,3,4}]];
gigsumdomimp[region_]:= gigselect[gigsource,region,ghgrows,gigcols];
(*the following form is required to cope with null values *)
gigregion[region_]:=
Flatten[Table[Apply[Plus,Select[gigsumdomimp[region],#[[2]] == j &&
#[[3]] == i&][[All,1]]],{i,gigcols},{j,ghgrows}]];
(*gigsumdomimp["NAFTA"]//MatrixForm
gigNAFTA=gigregion["NAFTA"];
Print["gigNAFTA                          :
",TableForm[gigNAFTA,TableHeadings → {ghgrows,gigcols}]];*)

End[]
EndPackage[]
```

A7.4 Data mining Mathematica's country database for the population growth using GTAP aggregations

File: Gtapaggregation.m

```
BeginPackage["Gtapaggregation`"]
aggregions::usage="aggregions gives the input and output regions."
wgtpopgrowth::usage="wgtpopgrowth gives weighted population growth of
regions in the aggregation file."
Begin["`Private`"]
Clear[mapping,positiona,positionb,from,to,map,mapuc,mapuc2,regionmap,popu
lation,popgrowth,wgtpopgrowth];
istream=OpenRead["/home/stuart/Documents/gtap/GTPAg7/sntest01.agg"];
records=Select[ReadList[istream,Record,RecordSeparators->" = "],
StringFreeQ[#,"!"]&];
mapping[n_]:=Rest[StringSplit[records[[n]]]];
positiona[n_]:=Flatten[Position[mapping[n],"&"]];
positionb[n_]:=Rest[RotateRight[Join[{-1},positiona[n]]]];
to[n_]:=mapping[n][[positiona[n]+1]];
from[n_]:=mapping[n][[positionb[n]+2]];
(*map[n_]:=Thread[from[n]->to[n]];
mapuc[n_]:=Thread[ToUpperCase[from[n]]->to[n]];
produnitmap=map[2];regionmap=mapuc[4];factormap=map[6];*)
mapuc2[n_]:=Thread[{ToUpperCase[from[n]],to[n]}];
regionmap[n_]:=Select[mapuc2[4],#[[2]]==n&][[All,1]];
aggregions=Map[{#,regionmap[#]}&,Union[to[4]]];
population[r_,n_]:=CountryData[aggregions[[r,2,n]],"Population"];
popgrowth[r_,n_]:=CountryData[aggregions[[r,2,n]],"PopulationGrowth"];
```

```
wgtpopgrowth[m_]:= Sum[population[m,n]*popgrowth[m,n],
{n,Length[aggregions[[m,2]]]}] / Sum[population[m,n],
{n,Length[aggregions[[m,2]]]}];
nonrowcou=Quiet[Thread[CountryData[Flatten[Map[regionmap[#]&,Rest[RotateR
ight[Union[to[4]]]]]]]]];
rowcou1=Complement[CountryData["Countries"],nonrowcou];
rowcou2=Map[{#,CountryData[#,"PopulationGrowth"]}&,rowcou1];
rowcou3=Select[rowcou2,NumericQ[#[[2]]]&][[All,1]];
rowpop=Total[Map[CountryData[#,"Population"]&,rowcou3]];
rowwgt=Total[Map[CountryData[#,"Population"]*CountryData[#,"PopulationGro
wth"]&,rowcou3]];
wgtpopgrowth[Length[aggregions]]:=rowwgt/rowpop;
End[]
EndPackage[]
```

A7.5 Appendix references

Hertel, T. & Walmsley, T.L., 2008. *GTAP: Chapter 1: Introduction*, Center for Trade Analysis, Purdue University. Available at: https://www.gtap.agecon.purdue.edu/databases/v7/v7_doco.asp [Accessed November 14, 2008].

Hertel, T.W., 1999. *Global Trade Analysis: Modeling and Applications*, Cambridge University Press.

Lee, H., 2008. *An Emissions Data Base for Integrated Assessment of Climate Change Policy Using GTAP*, Center for Global Trade Analysis. Available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1143 [Accessed June 26, 2009].

McDonald, G.W. & Patterson, M.G., 2004. Ecological footprints and interdependencies of New Zealand regions. *Ecological Economics*, 50(1-2), 49-67.

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i GTAPAgg contributed to GTAP by Mark Horridge, Centre of Policy Studies, Monash University, Melbourne, Australia

ii GEMPACK is a General equilibrium modelling software developed at Centre for Policy Studies, Monash University, Melbourne, Australia

Appendix 8 The Sceptre Model

Sceptre is an acronym for Spatial Climate-Economic Policy Tool for Regional Equilibria.

A8.1 Sceptre Model Flowchart

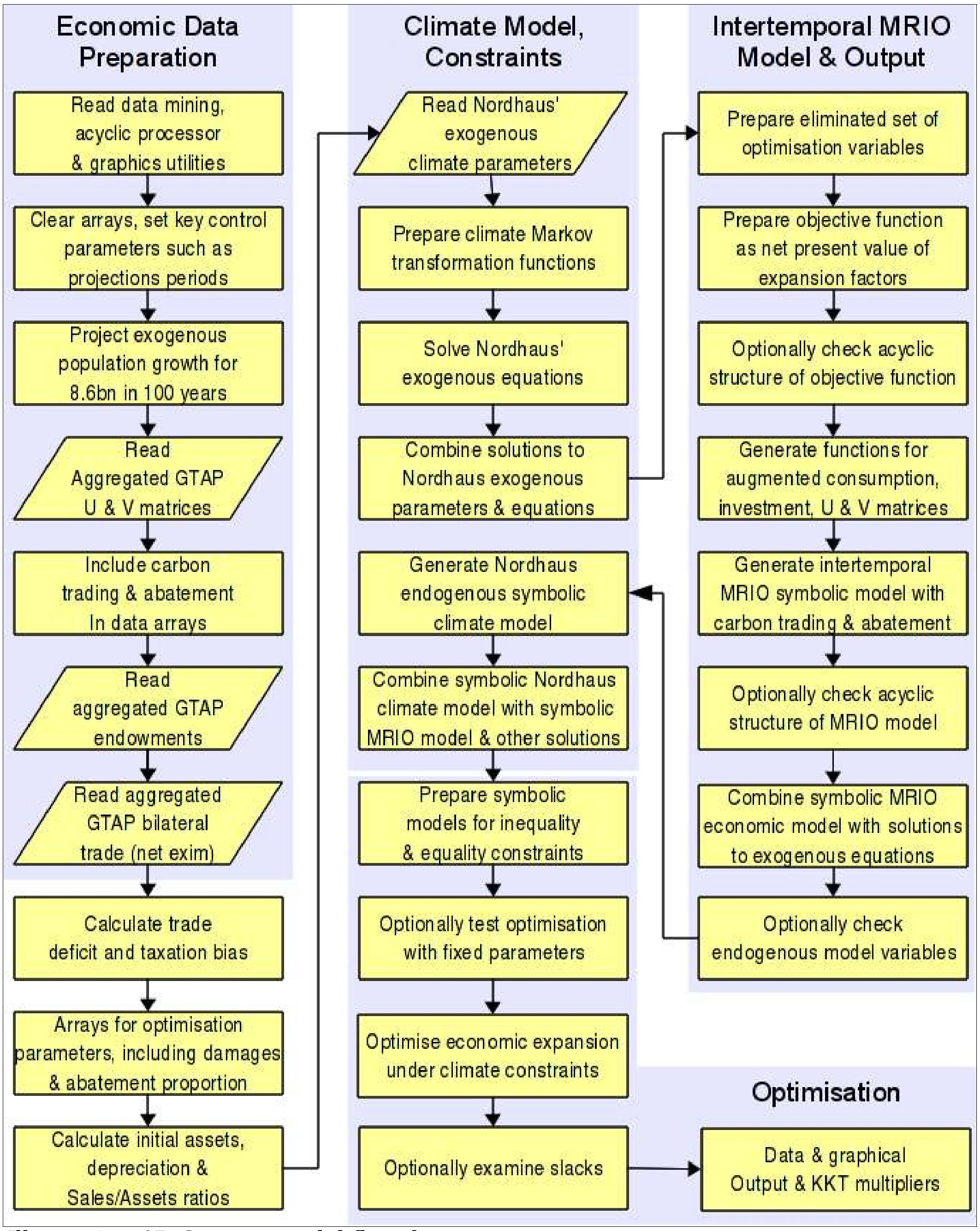

Illustration 45: Sceptre model flowchart

A8.2 Sceptre Mathematica Code

File: m12_13p_2C_100.nb

Read data mining, acyclic processor and graphical utilities

```
<< Topofunctions.m
<< Gtapfunctions.m
<< Gtapaggregation.m
<< PlotLegends`
(*DECADE MODEL*)
(*greenhouse gas emissions are included as an additional production
sector with amelioration cost based on backstop technology assumption*)
(*this version includes mitigated ghg as well as pure permit trading*)
(*This model returned to full non linear optimisation in one step using
the ability to quickly solve the Model with defined parameters. A
nonlinear constraint is also used for the damages feedback loop.*)
```

Clear arrays & set key control parameters

```
Clear[pop, popg, pops, u, v, inv, a, kap, lab, exim, deficit, ivector,
bias, kendowment, labempl, lendowment, γvector, svector, zvector,
dvector, μvector, invest, investv, ninvvec, δ1yr, δ, s2a1yr, s2avect,
mvector, tatvec, alvect, utilfn, pre1, pre2, pre3, obj1, obj2, obj3,
model1, model2, model3, post1, post2, post3, ineqcons1, ineqcons2,
ineqcons3, eqcons1, eqcons2, eqcons3];
periods = 13; ρ = (1 + 0.04)^10 - 1; δ1yrav = 0.04; unemp = 0.065;
(*conversion of Gg (=1,000 tonnes of CO2 equivalent) to Gigatonnes
carbon-equivalent divide by gg2gtc*)
gg2gtc = (44/12)*(10^9/10^3);
```

Project exogenous population growth

```
(*initial population*)
pop[0, n_] := pop[0, n] = pregion[regions[[n]]];
(*initial population growth per decade*)
popg[0, n_] := popg[0, n] = (1 + wgtpopgrowth[n])^10 - 1;
popg[m_, n_] := popg[0, n]*Exp[-0.341 m];
(*calibrated to reduce growth rates for asymptotic population of 8.6
billion in 10 decades*)
(*pop[m_,n_]:=pop[m-1,n]*(1+popg[m,n]);popt[m_]:=popt[m]=Sum[pop[m,n],
{n,cou}];popt[10]*)
pops[m_, n_] := pops[m, n] = pops[m - 1, n]*(1 + popg[m, n]);
pops[0, n_] := pops[0, n] = 1;
```

Read aggregated GTAP U and V matrices

```
(*include "gaml" for greenhouse gas amelioration and "gtra" for ghg
carbon permit trading*)
vrows2 =  Flatten[Append[vrows, {"gaml", "gtra"}]]; ucols =
Length[vrows2]; urows = Length[vrows2]; vcols = urows; cou =
Length[regions];
```

Include carbon trading & abatement in data arrays

```
mnfccom = Flatten[Position[vrows2, "mnfc"]];
nontradcom = Flatten[Position[vrows2, "serv"]];
gamlcom = Flatten[Position[vrows2, "gaml"]];
gtracom = Flatten[Position[vrows2, "gtra"]];
a[0, n_] := a[0, n] = PadRight[ygregion[regions[[n]]], ucols]*10;
inv[0, n_] := inv[0, n] = PadRight[iregion[regions[[n]]], ucols]*10;
u[0, n_] := u[0, n] = PadRight[uregion[regions[[n]]], {urows, ucols}]*10;
v[0, n_] := v[0, n] = PadRight[vregion[regions[[n]]], {Length[vrows2],
vcols}]*10;
```

Read aggregated GTAP endowments

```
kap[0, n_] := kap[0, n] = PadRight[fregion[regions[[n]]][[1]], ucols]*10;
lab[m_, n_] := lab[m, n] = PadRight[fregion[regions[[n]]][[2]],
ucols]*10;
```

Read aggregated GTAP bilateral trade (net exim)

```
exim[0, n_] := exim[0, n] = PadRight[MapAt[0 &, exregion[regions[[n]]] -
imregion[regions[[n]]], nontradcom], {ucols}]*10;
exim[m_, n_] := exim[m, n] = ReplacePart[exim[0, n], {gamlcom -> If[n ==
1, cou - 1, -1], gtracom -> If[n == 1, cou - 1, -1]}];
ivector[m_, n_] := Table[1, {p, urows}];
```

Calculate trade deficit and taxation bias

```
deficit[m_, n_] := deficit[m, n] = Min[Total[exim[m, n]]*pops[m, n], 0];
bias[m_, n_] := bias[m, n] = (u[0, n] - Transpose[v[0, n]]).ivector[0, n]
+ a[0, n] + inv[0, n] + exim[0, n];
(*note that a bias is required for financial balance and represents
import less export taxes*)
kendowment[0, n_] := kendowment[0, n] = Total[kap[0, n]];
labempl[m_, n_] := labempl[m, n] = Total[lab[m, n]] ;
lendowment[m_, n_] := lendowment[m, n] = labempl[m, n] pops[m, n]/(1 –
unemp);
```

Arrays for optimisation parameters including damages & abatement proportion

```
γvector[m_, n_] := Table[γ[m, n], {urows}];
svector[m_, n_] := Table[s[m, n, p], {p, urows}];
zvector[m_, n_] := Table[z[m, n, p], {p, urows}];
(*MapAt[0&,Table[z[m,n,p],{p,urows}],nontradcom]*)
dvector[m_, n_] := ReplacePart[ivector[m, n]*dam[m], {gamlcom -> 1,
gtracom -> 1}];
μvector[m_, n_] := ReplacePart[Table[μ[m, n, p], {p, urows}], {gamlcom ->
0, gtracom -> 0}];
investv[m_, n_] := ReplacePart[Table[invest[m, n, p], {p, urows}],
{gamlcom -> 0,   gtracom -> 0}];(*set investv=0 for greenhousegases*)
```

Calculate initial assets, depreciation & Sales/Assets ratios

```
investv[0, n_] := investv[0, n] = ReplacePart[ivector[0, n], {gamlcom ->
0, gtracom -> 0}];
ninvvec[m_, n_] := ReplacePart[Table[ninv[m, n, p], {p, urows}], {gamlcom
-> 0, gtracom -> 0}];(*set ninvect=0 for greenhousegases*)
ninvvec[0, n_] := ninvvec[0, n] = Total[csregion[regions[[n]]]] * kap[0,
n]/ kendowment[0, n];(*single year figure*)
(*the following is required because sometimes depreciation is more than
investment.
ninvec[0]=ninvec[-1](1-δ)+10*inv[0](1-(δ)/2) where ninvec[0]=ninvec[-1]
and ninvec[-1] is eliminated*)
δ1yr[0, n_] := δ1yr[0, n] = Map[Min[#, δ1yrav] &, inv[0, n]/
(10*ninvvec[0, n] + inv[0, n]/2 + 10^-6)];
δ[m_, n_] := δ[m, n] = (1 + δ1yr[0, n])^10 – 1 (*10 δ1yr[0,n]*);
(*s2avect[m_,n_]:=(Transpose[v[0,n]].ivector[0,n])*(ivector[m,n]-δ[m,n])/
(ninvvec[0,n]-inv[0,n]*(ivector[m,n]-δ[m,n]/2));*)

(*PRE PROCESSING: exogenous variables*)
s2a1yr[0, n_] := s2a1yr[0, n] = Transpose[v[0, n]].ivector[0, n]*
(ivector[0, n] - δ1yr[0, n])/(10*ninvvec[0, n] - inv[0, n]*(ivector[0, n]
- δ1yr[0, n]/2) + 10^-6);
s2avect[m_, n_] := s2avect[m, n] = s2a1yr[0, n]*Sum[(1 + ((1 + popg[0,
n])^0.1 - 1))^i, {i, 1, 10}];(**)
```

Read Nordhaus' exogenous climate parameters

```
initialvals = {
...(*conversion of GtC carbon content of the atmosphere to co2 ppm divide
by*) convppm -> 2.123,
   (*initial growth rate of technology per decade*)ga0 -> 0.092,
   (*initial growth rate of technology per decade*)ga[0] -> 0.092,
   (*initial level of total factor productivity*)al[0] -> 1,
   (*decline rate of technological change per decade*)dela -> 0.001,
   (*estimated radiative forcing of non-carbon gases in 2000 & 2001*)
   fex0 -> -0.06, fex1 -> 0.30,
   (*emissions in control regime parameters for 2005, 2015, 2205*)
   (*carbon emissions from land deforestation 2005 in GtC per decade*)
   eland0 -> 11,
   (*equivalent carbon growth parameter per year*) gσ0 -> -0.0730,
   (*decarbonisation per decade linear parameter*) dσ1 -> 0.003,
   (*decarbonisation per decade quadratic parameter*) dσ2 -> 0.00,
   (*fraction of emissions in control regime in 2005, 2015 & 2205*)  κ1
-> 1, κ2 -> 1, κ21 -> 1,
   (*decline rate of participation in control regime*)dκ -> 0,
   (*abatement cost control exponent*) θ -> 2.8,
   (*backstop technology cost $'000 per tonne of carbon 2005*) pback ->
1.17,
   (*backstop technology, final to inital cost ratio*) backrat -> 2,
   (*backstop technology, initial rate of decline in cost per decade*)
gback -> 0.05,
   (*CO2-equivalent emissions to GNP ratio 2005*) σ[0] -> 0.13418,
   (*damage intercept calibrated for quadratic at 2.5 °C in 2105*) ψ1 ->
0,
   (*damage quadratic calibrated for quadratic at 2.5 °C in 2105*) ψ2 ->
0.0028388,
   (*damage exponent calibrated for quadratic at 2.5 °C in 2105*) ψ3 ->
2,
```

```
   (*pre-industrial (1750) radiative forcing in watts per m2*) mat1750 ->
596.4,
   (*estimated forcings as result of equilibrium CO2 doubling*) η -> 3.8,
   (*CO2 concentration in atmosphere 2005 in GtC*) mat[0] -> 808.9,
   (*CO2 concentration in upper strata of oceans 2005 in GtC*) mup[0] ->
1255,
   (*CO2 concentration in lower strata of oceans 2005 in GtC*) mlo[0] ->
18365,
   (*atmospheric temp change in °C from 1900 to 2000*) tat[0] -> 0.7307,
   (*ocean lower strata temperature change in °C from 1900 to 2000*)
tlo[0] -> 0.0068,
   (*climate-equation coefficient for upper level*) ξ1 -> 0.22,
   (*transfer coefficient upper to lower ocean stratum*) ξ3 ->
    0.3,
   (*transfer coefficient for lower level of ocean*) ξ4 -> 0.05,
   (*equilibrium temperature impact of double CO2 °C*) t2xco2 -> 3,
   (*damages at base year*) Ω0 -> 0.99849,
   μ0 -> 0.005 (*,Λ[0]->0.66203,dam[1]->1*)};
```

Prepare climate Markov transformation functions

```
mvector[m_] := {mat[m], mup[m], mlo[m]};
mtransform = {{1, ϕ11, ϕ21, 0}, {0, ϕ12, ϕ22, ϕ32}, {0, 0, ϕ23,
ϕ33}} /. Flatten[Solve[{ϕ12 == 0.189288, ϕ23 == 0.05, ϕ11 == 1 - ϕ12,
ϕ21 == 587.473*ϕ12/1143.894, ϕ22 == 1 - ϕ21 - ϕ23, ϕ32 ==
1143.894*ϕ23/18340, ϕ33 == 1 - ϕ32}]];

(*note that the above matrix rows & columns are the reverse of the \
indices, for consistency with DICE*)
tatvec[m_] := {tat[m], tlo[m]};
tatransform = {{1 - ξ1 (η/ t2xco2 + ξ3), ξ1 ξ3}, {ξ4, 1 - ξ4}}
/.initialvals;
taforcing = {ξ1, 0} /. initialvals;
alvect[m_, n_] := alvect[m, n] = ReplacePart[ivector[m, n]*al[m],
{gamlcom -> 1, gtracom -> 1}] /. initialvals;
```

Solve Nordhaus' exogenous equations

```
(*POST PROCESSING*)
pre1[m_, n_] := {};(**)
pre2[m_] := {
   (*exogenous radiative forcing per year for other ghg*)
   fex[m] == fex0 + If[m < 12, 0.1*(fex1 - fex0)*(m - 1), 0.36],
   (*emissions from deforestation land changes*)
   eland[m] == eland0*(1 - 0.1)^m,
   (*cumulative improvement in energy efficiency*)
   gσ[m] == gσ0*Exp[-dσ1*10*(m - 1) - dσ2*10*(m - 1)^2],
   (*partfract, fraction of emissions in control regime, suspect WN
condition for stability κ[1]=0.25372*)
   κ[m] == If[m == 1, κ1, If[m < 25, κ21 + (κ2 - κ21) * Exp[-dκ*(m - 2)],
κ21]],
   (*growth rate of productivity from start to period*)
   ga[m] == ga0*Exp[-dela*10*(m - 1)],
   (*total factor productivity*)
   al[m] == al[m - 1]/(1 - ga[m]),
   (*ratio of abatement cost with incomplete participation to that with
complete participation*)
   Π[m] == κ[m]^(1 - θ),
   (*adjusted cost of backstop technology $'000/tC*)
   Θ[m] == (pback(*/θ*))*(backrat - 1 + Exp[-gback*(m – 1)])/ backrat
   (*CO2 equivalent emissions output ratio*)
```

```
   (*σ[m]==σ[m-1]/(1-gσ[m])*)
   (*Λ[m]==Π[m]*Θ[m]μ[m]^θ*)
   };
pre3 = {};
preext = Simplify[Flatten[{
      Array[pre1, {periods, cou}],
      Array[pre2, periods],
      pre3}] /. initialvals];
If[Length[preext] == 0, Print["*** error in PARAMETER PRE PROCESSING
***"]];
prelhs = preext /. {a_ == b_ -> a}; prerhs = preext /. {a_ == b_ -> b};
prerhsresult = prerhs //. Thread[prelhs -> prerhs];
```

Combine solutions to Nordhaus exogenous parameters & equations

```
initialvals = Join[initialvals, Thread[prelhs -> prerhsresult]];
NotebookDelete[printtemp];
printtemp = If[Length[initialvals] == 0, PrintTemporary["**Error in
Parameter Pre Processing **"], PrintTemporary["Pre Processing
completed....commencing Objective solve...."]];
```

Prepare eliminated set of optimisation variables

```
(* MACROECONOMIC MODEL*)

modelinpvars = Complement[Union[Cases[Flatten[{
       Array[svector, {periods, cou}],
       Array[γvector, {periods, cou}],
       Array[zvector, {periods, cou}],
       Array[μvector, {periods, cou}],
       Array[μa, {periods, cou}],
       Array[μi, {periods, cou}],
       Array[dvector, {periods, cou}]
       }], x_Symbol[_Integer ..], Infinity]],
   Flatten[Map[Table[s[m, 1, #], {m, periods}] &, Flatten[{1,
gamlcom}]]],
   Flatten[Table[z[m, 1, p], {m, periods}, {p, urows}]],
   Flatten[Map[Table[z[m, n, #], {m, periods}, {n, 2, cou}] &,
Flatten[{nontradcom, gamlcom, gtracom}]]]]];
(*remove μi in the optimisation variables because the values are zero*)
optimvars = Complement[modelinpvars, Flatten[Array[μi, {periods, cou}]]];
```

Prepare objective function as net present value of expansion factors

```
(*OBJECTIVE: endogenous variables, written as equations that equal zero.
Note that vector form is used*)
utilfn[x_] := x; utilpars = {};
(*utilfn[x_]:=1-Chop[ua Exp[-uk x],10^-5];utilpars=FindFit[{{0.85,0.5},
{1.5,0.85}},utilfn[x],{ua,uk},x];*)
(*utilfn[x_]:=ua-ub/(uc+x);utilpars=FindFit[{{0.5,-10},{1,1},{2,
1.15}},utilfn[ux],{ua,ub,uc},ux];*)
(*utilfn[x_]:=ua (1-ub/x);utilpars=FindFit[{{0.5,-1000},
{1,1}},utilfn[ux],{ua,ub},ux];*)
obj1[m_, n_] :=(*utility normalised by population growth, use for all
periods*){
   utility[m, n] - (utilfn[γ[m, n]/pops[m, n]] /. {utilpars})};
```

```
obj2[m_] :=(*net present value of utility*){
   npvutility[m] - (npvutility[m + 1] + Sum[utility[m, n], {n, cou}])/(1
+ ρ)};
obj3 = {npvutility[periods + 1] - Sum[utility[periods, n], {n, cou}]/ρ};
objext = Select[Simplify[Flatten[{
       Array[obj1, {periods, cou}],
       Array[obj2, {periods}],
       obj3} /. initialvals]], ! NumericQ[#] &];
```

Optionally check acyclic structure of objective function

```
(*USE THE FOLLOWING THREE LINES TO CHECK THE TOPOLOGICAL STRUCTURE OF THE
OBJECTIVE FUNCTION*)
(*objtopo=toponodes[objext/.Equal->Subtract/.Thread[modelinpvars->1]]; *)
(*Print["residual input variables: ",objtopo[[3]]];*)
(*If[Length[objinpvars]>0,printemp=PrintTemporary["Objective directed
acyclic graphs completed...."]];*)

objoutvars = Union[Cases[objext, x_Symbol[_Integer ..], Infinity]];
objvar = npvutility[1];
objcalcvars = Complement[objoutvars, modelinpvars];
objsolns = Flatten[Solve[Thread[objext == 0], objcalcvars]];
objfn = -objvar /. objsolns;
NotebookDelete[printtemp];
printtemp = If[Length[objsolns] == 0, PrintTemporary["**Error in
Objective Solve **"], PrintTemporary["Objective solve
completed....solving macroeconomic model...."]];
```

Generate functions for augmented consumption, investment, U & V matrices

```
(*PREPARE MACROECONOMIC MODEL MATRICES*)
a[m_, n_] := a[m, n] = ReplacePart[a[0, n], Flatten[{
       gamlcom -> (Total[gygregion[regions[[n]]], 2]*10/ gg2gtc)*μa[m,
n],
       gtracom -> (Total[gygregion[regions[[n]]], 2]*10/ gg2gtc)*(1 -
μa[m, n])
       }]] /. initialvals;
inv[m_, n_] := inv[m, n] = ReplacePart[inv[0, n], Flatten[{
        gamlcom -> (Total[gigregion[regions[[n]]], 2]*10/ gg2gtc)*μi[m,
n],
        gtracom -> (Total[gigregion[regions[[n]]], 2]*10/ gg2gtc)*(1 -
μi[m, n])
        }]] /. Thread[Flatten[Array[μi, {periods, cou}]] -> 0] /.
initialvals;(*remove μi since there is no data for investment ghg*)
u[m_, n_] := u[m, n] =
(*this replacement sets up the cost of ameliorating greenhouse gases by
industry. It assumes that the same output v is available but with
increased u due to climate damage v-ku=(v-u)dam/Ω0 so ku=v-(v-u)dam/Ω0
This assumption implies constant returns to scale. Note also that labour
is not subject to environmental damages*)
      ReplacePart[
     Transpose[v[0, n]] - (Transpose[v[0, n]] - u[0, n])*alvect[m, n]*
dvector[m, n]/Ω0, Flatten[{
Map[{ Flatten[{#, gamlcom}] -> Total[(Π[m]*Θ[m]*μ[m, n, #]^(θ -
1))*(10^3 10^9/10^6)*(Total[gfgregion[regions[[n]]]*10/gg2gtc][[#]]*μ[m,
n, #] + a[m, n][[gamlcom]]*a[0, n][[#]]/Total[a[0, n], 2] + inv[m, n]
[[gamlcom]]* inv[0, n][[#]]/Total[inv[0, n], 2]), 2],
```

```
Flatten[{gamlcom, #}] -> (Total[gfgregion[regions[[n]]]]
[[#]]*10/gg2gtc)*μ[m, n, #],
Flatten[{gtracom, #}] -> (Total[gfgregion[regions[[n]]]]
[[#]]*10/gg2gtc)*(1 - μ[m, n, #])
       } &, Complement[Range[urows], gamlcom, gtracom]]}]] /.
initialvals;

v[m_, n_] := v[m, n] = ReplacePart[v[0, n], Flatten[{
Flatten[{gamlcom, gamlcom}] -> Total[u[m, n][[gamlcom, All]], 2] +
Total[a[m, n][[gamlcom]], 2] + Total[inv[m, n][[gamlcom]], 2] +
Total[exim[m, n][[gamlcom]], 2],
Flatten[{gtracom, gtracom}] -> Total[u[m, n][[gtracom, All]], 2] +
Total[a[m, n][[gtracom]], 2] + Total[inv[m, n][[gtracom]], 2] +
Total[exim[m, n][[gtracom]], 2]
       }]] /. initialvals;
```

Generate intertemporal MRIO symbolic model with carbon trading & abatement

```
(*MACROECONOMIC MODEL*)

model1[m_, n_] :=(*flows balance, use for all periods*){
   (u[m, n] - Transpose[v[m, n]]).svector[m, n] + a[m, n]*γvector[m, n] +
inv[m, n]*investv[m, n] + exim[m, n]*zvector[m, n] - bias[m, n],
   ninvvec[m, n] - ninvvec[m - 1, n]*(ivector[m, n] - δ[m, n]) - inv[m,
n]*investv[m, n]*(ivector[m, n] - δ[m, n]/2),
   Map[zvector[m, n][[#]] &, nontradcom](*nontraded commodities: forces
the trade to zero*)
   (*Map[investv[m,n][[#]]&, Flatten[{gamlcom,gtracom}]]*)(*greenhouse
gases: forces investment to zero*)
   };(**)
model2[m_] :=(*net zero trade between countries*){Sum[
    exim[m, n]*zvector[m, n], {n, cou}]};
model3 = {};
modelext = Select[Simplify[Flatten[{
       Array[model1, {periods, cou}],
       Array[model2, periods],
       model3} /. initialvals]], ! NumericQ[#] &];
modeloutvars = Select[Union[Cases[modelext, x_Symbol[_Integer ..],
Infinity]],
       !NumericQ[#] &];
```

Optionally check acyclic structure of MRIO model

```
(*USE THE FOLLOWING FOUR LINES TO LOOK AT THE MODEL'S TOPOLOGICAL
STRUCTURE OF THE MACROECONOMIC MODEL*)
(*modeltopo=toponodes[modelext/.Equal->Subtract];*)
(*modelinpvars=modeltopo[[3]]*)
(*If[Length[modelinpvars]>0,printtemp=PrintTemporary["Model directed
acyclic graphs completed...."]];*)
```

Combine symbolic MRIO model with solutions to exogenous equations

```
modelcalcvars = Complement[modeloutvars, modelinpvars];
modelsolns = Flatten[Solve[Thread[modelext == 0], modelcalcvars]];
```

Optionally check endogenous model variables

```
(*USE THE FOLLOWING EIGHT LINES TO CHECK THE ENDOGENOUS MODEL VARIABLES*)
(*Expect the first Solve to return an svars error. The second Solve
should be error free.*)
(*modeltest=Select[modelext/.Thread[Cases[Array[μvector,
{periods,cou}],x_Symbol[_Integer..],Infinity]-
>0.005]/.Thread[Flatten[Array[μa,{periods,cou}]]-
>0.005]/.Thread[Flatten[Array[dam,periods]]->1],!NumericQ[#]&];
modelsolnstest=Flatten[Solve[Thread[modeltest==0]]];
modelsolnstestallvars=Union[Flatten[Map[Cases[modelsolnstest[[#]],x_Symbo
l[_Integer..],Infinity]&,Range[Length[modelsolnstest]]]]]];
modelsolnstestoutvars=Sort[Map[First[Cases[modelsolnstest[[#]],x_Symbol[_
Integer..],Infinity]]&,Range[Length[modelsolnstest]]]];
modelsolntestinpvars=Complement[modelsolnstestallvars,modelsolnstestoutva
rs]
optimvarsadjusted=Select[optimvars/.Thread[Cases[Array[μvector,
{periods,cou}],x_Symbol[_Integer..],Infinity]-
>0.005]/.Thread[Flatten[Array[μa,{periods,cou}]]-
>0.005]/.Thread[Flatten[Array[dam,periods]]->1],!NumericQ[#]&]
modeltestchecksolve=Solve[Thread[modeltest==0],optimvarsadjusted];
modeltestexcessvars=Complement[modelsolntestinpvars,modelinpvars]
modeltestcheckvars=Complement[optimvarsadjusted,modelsolntestinpvars]*)

NotebookDelete[printtemp];
printtemp = If[Length[modelsolns] == 0, PrintTemporary["** error in Model
Solve **"], PrintTemporary["Macroeconomic model solve completed....post
processing...."]];
```

Generate Nordhaus endogenous symbolic climate model

```
(*POST PROCESSING DICE CLIMATE EQUATIONS*)
post1[m_, n_] := {};(**)

post2[m_] := {
   (*eind is CO2-equivalent emissions GtC*)
   eind[m] == Total[Sum[((Transpose[v[m, n]].svector[m, n]))[[gtracom]],
{n, cou}], 2],
   (*etot is the sun of industrial and deforestation emissions*)
   etot[m] == eland[m] + eind[m],
   (*mat, mup & mlo are the Gt of carbon in the atmosphere*)
   Thread[mvector[m] == mtransform.Prepend[mvector[m - 1], etot[m]]],
   (*rforcing is radiative forcing in watts per m2*)
   rforcing[m] == fex[m] + η Log[2, (mat[m - 1] + mat[m])/(2*mat1750)],
   (*tat and tlo are °C temperature changes in the atmosphere & lower
ocean*)
   Thread[tatvec[m] == tatransform.tatvec[m - 1] +
taforcing*rforcing[m]],
   (*Ω is damages multiplier of GNP*)
   Ω[m] == 1/(1 + ψ1*tat[m] + ψ2*tat[m]^ψ3)
   };
post3 = {};
postext = Select[Flatten[{
      Array[post1, {periods, cou}],
      Array[post2, periods],
      post3} /. initialvals], FreeQ[#, True | False] &];
postlhs = postext /. {a_ == b_ -> a};
postrhs = postext /. {a_ == b_ -> b};
postrhsresult = postrhs //. Thread[postlhs -> postrhs];
```

```
postrhsresult = postrhsresult //. modelsolns;
If[Length[postrhsresult] == 0, Print["*** error in POST PROCESSING
***"]];
```

Combine Nordhaus symbolic climate model with symbolic MRIO model & other solutions

```
modelsolns = Join[modelsolns, Thread[postlhs -> postrhsresult]];
NotebookDelete[printtemp]; printtemp = PrintTemporary["Post processing
completed....preparing constraints"];
```

Prepare symbolic models for inequality & equality constraints

```
(*INEQUALITY CONSTRAINTS: note that the functions need to be threaded if
they are vectors*)
(*IMPORTANT NOTE: write all inequality constraints as m.x>=0 and omit
>=0*)
(*balance of payments, labour & sales2assets constraint*)
(*the first constraint places a price on carbon and the "-ve" sign is to
make ">=0" *)
(*note that the sales to assets constraint with s2avect is not applied to
the greenhouse gas equation where there is no stock of greenhouse
permits*)

ineqcons1[m_, n_] := {
   Map[(ninvvec[m - 1, n]* s2avect[m, n] - (Transpose[v[m, n]].svector[m,
n]))[[#]] &, Complement[Range[urows], gamlcom, gtracom]],
   exim[m, n].zvector[m, n] - deficit[m, n],
   lendowment[m, n] - lab[m, n].svector[m, n],
   lab[m, n].svector[m, n] - labempl[m, n]*γ[m, n],
   Map[investv[m, n][[#]] &, Complement[Range[urows], gamlcom, gtracom]],
   svector[m, n],
   μvector[m, n], 1 - μvector[m, n],
   μa[m, n], 1 - μa[m, n],
   γvector[m, n]
   };
(*Map[-(((u[m,n]-Transpose[v[m,n]]).svector[m,n])*dvector[m,n]*al[m]+
a[m,n]*γvector[m,n]+inv[m,n]*investv[m,n]+exim[m,n]*zvector[m,n]-
bias[m,n])[[#]]&,Flatten[{gamlcom,gtracom}]],*)
(*the first constraint following is to manage the ending inventories of
commodities except carbon*)
ineqcons2[n_] := {
   Map[(investv[periods, n]*inv[periods, n] - investv[periods - 1,
n]*inv[periods - 1, n])[[#]] &, Complement[Range[urows], gamlcom,
gtracom]]
   };
ineqcons3[m_] := If[m > 10, {tat[m - 1] - tat[m], eind[m - 1] - eind[m]},
{}];
(*After 100 years, temperature and emissions must continue to decline*)
ineqcons4 = {2.0 – tat[10]}; (*At 100 years, temperature rise must be
2C*)
ineqconsext = Union[Flatten[{
     Array[ineqcons1, {periods, cou}],
     Array[ineqcons2, cou],
     Array[ineqcons3, periods],
     ineqcons4
     }]];
NotebookDelete[printtemp]; printtemp =
```

```
 PrintTemporary["Inequality constraints completed...."];
(*EQUALITY CONSTRAINTS*)
(*IMPORTANT NOTE: write all equality constraints as m.x==0 and omit ==0*)
eqcons1[m_, n_] := {};(**)
eqcons2[n_] := {};(**)
eqcons3[m_] = {Ω[m] – dam[m]}; (*calculated damage multiplier must equal
assumed parameter. Note that both Ω and dam are internal endogenous
variables and not optimisation variables*)
eqconsext = Union[Flatten[{
     Array[eqcons1, {periods, cou}],
     Array[eqcons2, cou],
     Array[eqcons3, periods]}]];
NotebookDelete[printtemp];
printtemp = PrintTemporary["Equality constraints completed...."];
constraintsorig = Select[Join[Thread[ineqconsext >= 0], Thread[eqconsext
== 0]] /.initialvals, FreeQ[#, True | False] &];
constraints = Select[constraintsorig //. modelsolns /. initialvals,
FreeQ[#, True | False] &];
(*Print["Ready for optimisation..."];*)
```

Optionally test optimisation with fixed parameters

```
(*OPTIMISATION*)
NotebookDelete[printtemp]; printtemp =
 PrintTemporary["Optimising...."];
(*TEST OPTIMISATION WITH FIXED μ AND μa*)
If[False, initvars2 = Join[
     Thread[{Cases[optimvars, x_s | x_γ | x_z], 1}],
     Thread[{Cases[optimvars, x_dam], Ω0}]] /.initialvals;
  constraints2 = Select[constraints /.Thread[Flatten[Array[μ, {periods,
cou, urows}]] -> μ0]/.Thread[Flatten[Array[μa, {periods, cou}]] ->
μ0]/.initialvals, FreeQ[#, True | False] &];
  optim = FindMinimum[{objfn, constraints2 //. modelsolns}, initvars2 (*,
MaxIterations->1000*)] // Timing;
Print[optim]
];
```

Optimise economic expansion under climate constraints

```
(*ITERATION VARIABLES*)
(*initvars=Thread[{optimvars,optimvars/.optimfinal}],*)
initvars = Join[
    Thread[{Cases[optimvars, x_s], 1}],
    Thread[{Cases[optimvars, x_γ | x_z], 1}],
    Thread[{Cases[optimvars, x_dam], Ω0}],
    Thread[{Cases[optimvars, x_μ | x_μa], μ0}]] /.initialvals;

(*USE THE FOLLOWING THREE LINES FOR INITIAL CONSTRAINT CHECKING*)
If[False,
  initrepl = Thread[initvars[[All, 1]] -> initvars[[All, 2]]];
  NotebookDelete[printtemp];
  printtemp = Print["initial unsatisfied constraints: ",
Length[Cases[constraints /. initrepl, False]], " out of ",
Length[constraints]];
  If[False, Print["initial constraints: ", constraints]]];

(*MAIN NON LINEAR OPTIMISATION*)
If[True,
  itercount = 0;
```

```
  objfncurr = 0;
  optimaccuracygoal = 4;
  optimmaxiterations = 2000;
  NotebookDelete[printtemp];
  printtemp = PrintTemporary["iter ... " <> ToString[Length[constraints]]
<> " constraints with accuracy goal of " <> ToString[10^-
optimaccuracygoal // N] <> " & max iterations " <>
ToString[optimmaxiterations]];
(*optim=Monitor[FindMinimum[{objfn,constraints},initvars, AccuracyGoal-
>optimaccuracygoal, MaxIterations-
>optimmaxiterations,StepMonitor:>(itercount++;
objfnprev=objfncurr;objfncurr=objfn;)],
{itercount,ScientificForm[objfncurr ],ScientificForm[objfncurr-
objfnprev], Count[constraints, False]}]//Timing;*)

optim = Monitor[
     FindMinimum[{objfn, constraints}, initvars, (*AccuracyGoal →
      optimaccuracygoal,*) MaxIterations -> optimmaxiterations,
      StepMonitor :> itercount++],
      itercount] // Timing;
  resultvars = optim[[2, 2]];
  (*update initvars for manual repeat calculations if required*)
  initrepl = Thread[initvars[[All, 1]] -> initvars[[All, 2]]];
  initvars = Thread[{optimvars, optimvars /. resultvars}];
  (*NOTIFY OUTPUT OF OPTIMISATION*)
  NotebookDelete[printtemp];
  Print["Nonlinear optimisation in ", Round[optim[[1]], 1], " seconds in
", Round[MaxMemoryUsed[]*10^-6], "mb memory with objective function
result of ", objfn /. resultvars // Short];
  Print["Maximum iterations set to ", optimmaxiterations, " with ",
itercount, " used. Optimisation accuracy set to ", 10^-
optimaccuracygoal // N  , "."];
  Print["There are ", Length[resultvars] + Length[modelsolns], "
variables in total (or ", Length[resultvars] + Length[modelsolns] +
Length[initialvals], " with parameters)."];
  Print["The ", Length[resultvars], " optimisation variables are: ",
If[False, resultvars, resultvars // Short]]
];
```

Optionally examine slacks

```
(*USE THE FOLLOWING LINES FOR FINAL CONSTRAINT CHECKING*)
If[True,
 consvaluepre = constraints /. initrepl;
 consvaluepost = constraints /. resultvars;
 unsatcons = Flatten[Position[consvaluepost, False]];
 slacks = constraints[[unsatcons]] /. {a_ >= b_ -> (a - b), a_ <= b_ ->
(b - a), a_ == b_ -> (a - b)} /. resultvars;
 slackcutoff = 10^-4;
 slackszero = Flatten[Position[Chop[slacks, slackcutoff], 0]];
 slacksnz = Complement[Range[Length[slacks]], slackszero];
 slackskey = unsatcons[[slacksnz]];
 slackskeyvals = constraints[[slackskey]] /. {a_ >= b_ -> (a - b), a_ <=
b_ -> (b - a), a_ == b_ -> (a - b)} /. resultvars;
 Print["There are ", Length[constraints], " constraints. Following
optimisation ",
 Length[Cases[consvaluepost, False]], " remain unsatisfied compared to ",
 Length[Cases[consvaluepre, False]], " prior to optimisation."];
 If[False,
  Print["The slacks of the ", Length[Cases[consvaluepost, False]], "
unsatisfied constraints are ", slacks]];
 If[Length[constraints] == Length[constraintsorig],
```

```
  If[Length[slackskey] > 0,
   If[Length[slackskey] == 1,
    Print["The only key unsatisfied constraint with slack > ",
slackcutoff // N, " is ", Flatten[Thread[{constraintsorig[[slackskey]],
slackskeyvals}]]],
    Print["The ", Length[slackskey], " key unsatisfied constraints with
slacks > ", slackcutoff // N, " are ",
Thread[{constraintsorig[[slackskey]], slackskeyvals}]]],
   Print["All ", Length[Cases[consvaluepost, False]] " of the unsatisfied
constraints have slacks < ", slackcutoff // N]
   ],
  Print["Cannot identify constraints with slacks because constraint
lengths vary ", Length[constraintsorig], " ", Length[constraints]]];
 Table[Beep[]; Pause[0.5], {i, 5}];
 Speak["Stuart, I now have the results you asked for, so come over here
and give me a hug!"]]
FrontEndExecute[FrontEndToken["Save"]]
```

Data and graphical output

```
(*PLOT GRAPHS*)
modelsolns1 = modelsolns /. resultvars;
lhside = Map[
   First[Cases[modelsolns1[[#]], x_Symbol[_Integer ..], Infinity]] &,
   Range[Length[modelsolns1]]];
rhside = lhside /. modelsolns1;
modelsolns2 = Thread[lhside -> rhside];
optimfinal = Sort[Join[resultvars, modelsolns2]];

thiscase = "Max 2C @100yrs: ";
ListLinePlot[Transpose[Array[\[Gamma], {periods, cou}]] /. resultvars,
  Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Expansion", "multiplier"]},
 PlotLabel ->
  Style[Framed[thiscase <> "expansion \[Gamma]"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[\[Mu][m, n, 2], {m, periods}, {n, cou}]] /.
  resultvars, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Proportion", "Abated"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Mfg abate \[Mu]"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[Transpose[Array[\[Mu]a, {periods, cou}]] /. resultvars,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Proportion", "Abated"]},
 PlotLabel ->
  Style[Framed[thiscase <> "amelioration \[Mu]a"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[{Array[eind, periods], Array[eland, periods]} //.
   modelsolns2 /. initialvals, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Emissions", ""]},
```

```
 PlotLabel ->
  Style[Framed[thiscase <> ": emissions eind,eland"], Blue,
   Background -> LightYellow], PlotLegend -> {"eind", "eland"},
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
Print[Round[Sum[eind[i], {i, 1, 5}]*3.67 /. optimfinal,
  1], " Gt C02 2000-2050 "]
Print[Round[Sum[eind[i], {i, 1, periods}]*3.67 /. optimfinal,
  1], " Gt C02 ", periods, " periods"]
ListLinePlot[{Array[tat, periods], Array[tlo, periods]} //.
  modelsolns2, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Temperature", "rise \[Degree]C"]},
 PlotLabel ->
  Style[Framed[thiscase <> "temperature rise"], Blue,
   Background -> LightYellow], PlotLegend -> {"tat", "tlo"},
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[{Array[mat, periods]/convppm} //. modelsolns2 /.
  initialvals, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"], "ppm"},
 PlotLabel ->
  Style[Framed[thiscase <> "carbon in atmosphere (mat) ppm"], Blue,
   Background ->
    LightYellow](*,PlotLegend->{"mat"},LegendSize->{0.4,0.2},\
LegendShadow->{.02,-.02},LegendPosition->{-.7,-.1}*)]
ListLinePlot[{Array[rforcing, periods] //. modelsolns2},
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Watts/sqm", "from 1900"]},
 PlotLabel ->
  Style[Framed[thiscase <> ": radiative forcing"], Blue,
   Background -> LightYellow]]
ListLinePlot[Array[\[CapitalOmega], {periods}] //. modelsolns2,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Damages", "multiplier"]},
 PlotLabel ->
  Style[Framed[thiscase <> "damages \[CapitalOmega]"], Blue,
   Background -> LightYellow]]
optimfinal
FrontEndExecute[FrontEndToken["Save"]]

(*Spatial Plots*)
output=optimfinal;
ListLinePlot[
 Transpose[Table[\[Mu][m, n, 1], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Proportion", "Abated"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Food abate \[Mu]"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[
 Transpose[Table[\[Mu][m, n, 3], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Proportion", "Abated"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Services abate \[Mu]"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
```

```
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]

ListLinePlot[
 Table[Total[Table[investv[m, n]*inv[0, n], {n, cou}], 2]/1000000, {m,
     periods}] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Investment", "$trillion/decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Investment"], Blue,
   Background -> LightYellow]]
ListLinePlot[
 Table[Total[Table[ninv[m, n, p], {p, urows - 2}, {n, cou}], 2]/
    1000000, {m, periods}] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Capital", "$trillion"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Capital"], Blue,
   Background -> LightYellow]]

ListLinePlot[
 Transpose[
    Table[(\[CapitalPi][m]*\[CapitalTheta][
         m]*\[Mu][m, n, 1]^(\[Theta] - 1))*10^3, {m, periods}, {n,
      cou}]] /. output /. initialvals, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$ per", "tonne"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Food amel/abate price"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[
 Transpose[
    Table[(\[CapitalPi][m]*\[CapitalTheta][
         m]*\[Mu][m, n, 2]^(\[Theta] - 1))*10^3, {m, periods}, {n,
      cou}]] /. output /. initialvals, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$ per", "tonne"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Mfg amel/abate price"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[
 Transpose[
    Table[(\[CapitalPi][m]*\[CapitalTheta][
         m]*\[Mu][m, n, 3]^(\[Theta] - 1))*10^3, {m, periods}, {n,
      cou}]] /. output /. initialvals, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$ per", "tonne"]},
 PlotLabel ->
  Style[Framed[thiscase <> "Services amel/abate price"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]
ListLinePlot[
 Transpose[
    Table[(\[CapitalPi][m]*\[CapitalTheta][
         m]*\[Mu]a[m, n]^(\[Theta] - 1))*10^3, {m, periods}, {n,
      cou}]] /. output /. initialvals, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$ per", "tonne"]},
```

```
 PlotLabel ->
  Style[Framed[thiscase <> "Consumpt. amel/abate price"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.1}]

ListLinePlot[
 Transpose[Table[s[m, n, 1], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "s " <> vrows2[[1]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[s[m, n, 2], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "s " <> vrows2[[2]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[s[m, n, 3], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "s " <> vrows2[[3]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]

ListLinePlot[
 Transpose[
  Table[v[m, n][[4, 4]]*s[m, n, 4] /. output, {m, periods}, {n,
    cou}]], Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["GtC", "per decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "amelioration & abatement"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[
  Table[v[m, n][[5, 5]]*s[m, n, 5] /. output, {m, periods}, {n,
    cou}]], Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["GtC", "per decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "emission permits traded"], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]

ListLinePlot[
 Transpose[Table[s[m, 1, p], {m, periods}, {p, urows - 2}]] /. output,
  Filling -> Axis,
```

```
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "s " <> aggregions[[All, 1]][[1]]], Blue,
   Background -> LightYellow], PlotLegend -> vrows2,
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[s[m, 2, p], {m, periods}, {p, urows - 2}]] /. output,
  Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "s " <> aggregions[[All, 1]][[2]]], Blue,
   Background -> LightYellow], PlotLegend -> vrows2,
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[s[m, 3, p], {m, periods}, {p, urows - 2}]] /. output,
  Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "s " <> aggregions[[All, 1]][[3]]], Blue,
   Background -> LightYellow], PlotLegend -> vrows2,
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]

ListLinePlot[
 Transpose[
   Table[(z[m, n, 1]*exim[m, n][[1]]/1000) /.
     z[m, 1, 1] -> -Sum[
        z[m, i, 1]*exim[m, i][[1]]/exim[m, 1][[1]], {i, 2, cou}], {m,
     periods}, {n, cou}]] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$billion", "per decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "z " <> vrows2[[1]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[
   Table[(z[m, n, 2]*exim[m, n][[2]]/1000) /.
     z[m, 1, 2] -> -Sum[
        z[m, i, 2]*exim[m, i][[2]]/exim[m, 1][[2]], {i, 2, cou}], {m,
     periods}, {n, cou}]] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$billion", "per decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "z " <> vrows2[[2]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[
   Table[(z[m, n, 3]*exim[m, n][[3]]/1000) /.
     z[m, 1, 3] -> -Sum[
        z[m, i, 3]*exim[m, i][[3]]/exim[m, 1][[3]], {i, 2, cou}], {m,
     periods}, {n, cou}]] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$billion", "per decade"]},
 PlotLabel ->
```

```
 Style[Framed[thiscase <> "z " <> vrows2[[3]]], Blue,
  Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]

ListLinePlot[
 Transpose[
   Table[(z[m, n, 4]*exim[m, n][[4]]) /.
     z[m, 1, 4] -> -Sum[
        z[m, i, 4]*exim[m, i][[4]]/exim[m, 1][[4]], {i, 2, cou}], {m,
     periods}, {n, cou}]] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["GtC amel", "per decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "z " <> vrows2[[4]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[
   Table[(z[m, n, 5]*exim[m, n][[5]]) /.
     z[m, 1, 5] -> -Sum[
        z[m, i, 5]*exim[m, i][[5]]/exim[m, 1][[5]], {i, 2, cou}], {m,
     periods}, {n, cou}]] /. output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["GtC permits", "per decade"]},
 PlotLabel ->
  Style[Framed[thiscase <> "z " <> vrows2[[5]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]

ListLinePlot[
 Transpose[Table[invest[m, 1, p], {m, periods}, {p, urows - 2}]] /.
  output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "invest " <> aggregions[[All, 1]][[1]]],
   Blue, Background -> LightYellow], PlotLegend -> Take[vrows2, 3],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[invest[m, 2, p], {m, periods}, {p, urows - 2}]] /.
  output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "invest " <> aggregions[[All, 1]][[2]]],
   Blue, Background -> LightYellow], PlotLegend -> Take[vrows2, 3],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[invest[m, 3, p], {m, periods}, {p, urows - 2}]] /.
  output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Activity", "Industry"]},
 PlotLabel ->
  Style[Framed[thiscase <> "invest " <> aggregions[[All, 1]][[3]]],
   Blue, Background -> LightYellow], PlotLegend -> Take[vrows2, 3],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
```

```
ListLinePlot[
 Transpose[Table[invest[m, n, 1], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Investment", "Activity"]},
 PlotLabel ->
  Style[Framed[thiscase <> "investment " <> vrows2[[1]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[invest[m, n, 2], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Investment", "Activity"]},
 PlotLabel ->
  Style[Framed[thiscase <> "investment " <> vrows2[[2]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[Table[invest[m, n, 3], {m, periods}, {n, cou}]] /. output,
 Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["Investment", "Activity"]},
 PlotLabel ->
  Style[Framed[thiscase <> "investment " <> vrows2[[3]]], Blue,
   Background -> LightYellow], PlotLegend -> aggregions[[All, 1]],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]

ListLinePlot[
 Transpose[
   Table[ninv[m, 1, p]/1000000, {m, periods}, {p, urows - 2}]] /.
  output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$trillion", "Capital"]},
 PlotLabel ->
  Style[Framed[thiscase <> "ninv " <> aggregions[[All, 1]][[1]]],
   Blue, Background -> LightYellow], PlotLegend -> Take[vrows2, 3],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[
   Table[ninv[m, 2, p]/1000000, {m, periods}, {p, urows - 2}]] /.
  output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$trillion", "Capital"]},
 PlotLabel ->
  Style[Framed[thiscase <> "ninv " <> aggregions[[All, 1]][[2]]],
   Blue, Background -> LightYellow], PlotLegend -> Take[vrows2, 3],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
 LegendPosition -> {-.7, -.3}]
ListLinePlot[
 Transpose[
   Table[ninv[m, 3, p]/1000000, {m, periods}, {p, urows - 2}]] /.
  output, Filling -> Axis,
 AxesLabel -> {Labeled["Decades", "from 2004"],
   Labeled["US$trillion", "Capital"]},
 PlotLabel ->
  Style[Framed[thiscase <> "ninv " <> aggregions[[All, 1]][[3]]],
   Blue, Background -> LightYellow], PlotLegend -> Take[vrows2, 3],
 LegendSize -> {0.4, 0.2}, LegendShadow -> {.02, -.02},
```

```
 LegendPosition -> {-.7, -.3}]
FrontEndExecute[FrontEndToken["Save"]]

(*USE THE FOLLOWING LINES FOR BINDING CONSTRAINT CHECKING*)
consvaluepost = constraints /. resultvars;
satcons = Flatten[Position[consvaluepost, True]];
slacks = constraints[[satcons]] /. {a_ >= b_ -> (a - b),
     a_ <= b_ -> (b - a), a_ == b_ -> (a - b)} /. resultvars;
slackcutoff = 10^-4;
slackszero = Flatten[Position[Chop[slacks, slackcutoff], 0]];
slackskey = satcons[[slackszero]];
slackskeyvals =
  constraints[[slackskey]] /. {a_ >= b_ -> (a - b),
     a_ <= b_ -> (b - a), a_ == b_ -> (a - b)} /. resultvars;
If[Length[constraints] == Length[constraintsorig],
  Print["The binding constraints with slack below +/- ", slackcutoff,
   " and slacks are: ",
   Flatten[Thread[{constraintsorig[[slackskey]], slackskeyvals}]]
   ],
  Print["Cannot identify constraints with slacks because constraint \
lengths vary ", Length[constraintsorig], " ", Length[constraints]]
  ];
FrontEndExecute[FrontEndToken["Save"]]
```

KKT multipliers

```
(*DUAL SOLUTION: using Kuhn Karush Tucker (KKT) conditions (Taha, 1982,
pp769-773)*)
(*This code is designed to cope with large scale optimisation results*)
Clear[λ, limitfn, limit2, gradg2, h];
gradf = SparseArray[D[objfn, {optimvars}] /. output];
outputres = Thread[optimvars -> (optimvars /. output)];
outputnonres = Complement[output, outputres];
limit0 = Simplify[
   constraints /. {a_ >= b_ -> (a - b), a_ <= b_ -> (b - a),
      a_ == b_ -> (a - b)} /. outputnonres];
limit1 = Simplify[limit0 /. outputres];
limit2[z_] := Module[{},
   Options[limitfn] = outputres;
   SetOptions[limitfn,
    optimvars[[z]] -> OptionValue[limitfn, optimvars[[z]]] + h];
   Return[limit0 /. Options[limitfn]]
   ];
(*Since integrals may be non-analytic use the general definition of an
integral*)
gradg2[z_] :=
  SparseArray[
   Limit[Chop[limit2[z] - limit1]/h,
     h -> 0] /. {∞ -> 0, -∞ -> 0}];
(*Solving 500,000 derivative equations take about 20 hours on 4 cores \
so use parallel processing*)
DistributeDefinitions[optimvars, \
outputres, limit0, limit1, limit2, gradg2]
gradg = Parallelize[Table[gradg2[z], {z, Length[optimvars]}]];
If[False, Print["gradg"]; Print[Normal[gradg]]];
(*The UnitStep is inserted because some constraints have small negative
slacks and are therefore set as binding*)
(*kktλ=Chop[Flatten[FindInstance[Flatten[{
Thread[gradf-Array[λ,Length[constraints]].Transpose[\
SparseArray[gradg]]==0],
Thread[Pick[Array[λ,Length[constraints]],constraints/.{a_>=b_-\
>True,a_==b_->False}]>=0],
```

```
Thread[Chop[limit1]*UnitStep[Chop[limit1]]*Array[λ,Length[\
constraints]]==0]
}],Array[λ,Length[constraints]],Reals]]]*)
kktzerosub =
  Flatten[Solve[
    Thread[Chop[limit1, 10^-5] UnitStep[Chop[limit1, 10^-5]]*
       Array[λ, Length[constraints]] == 0]]];
kktnonzeros =
  Cases[Array[λ, Length[constraints]] /. kktzerosub,
   x_Symbol[_Integer], Infinity];
kktλnonzero = FindInstance[Select[Flatten[{
      Thread[
       gradf - Array[λ, Length[constraints]].Transpose[
           SparseArray[gradg]] == 0],
      Thread[
       Pick[(Array[λ, Length[constraints]]),
         constraints /. {a_ >= b_ -> True, a_ == b_ -> False}] >= 0]
      }] /. kktzerosub, FreeQ[#, True]], kktnonzeros, Reals, 20]
kktλ = Union[kktzerosub, kktλnonzero[[1]]];
(*Print KKT multipliers*)

If[True, Print["KKT multipliers: ", kktλ]];
(*Print constraints with non-zero KKT multipliers*)
If[True,
  If[Length[constraintsorig] == Length[constraints],
   If[Length[kktλ] > 0,
    Print["Constraints with non-zero KKT multipliers: ",
     Cases[
      Table[{constraintsorig[[i]], (λ[i] /. kktλ),
        limit1[[i]]}, {i, Length[constraintsorig]}], {a_, b_, c_} /;
       b != 0]
     ],
    Print[
     "Have not printed Constraints with non-zero KKT multipliers \
because the length of constraints vector is not equal to length of \
original constraints vector."
     ]]]];
(*Print Amelioration & Abatement KKT multipliers*)
If[True,
  If[Length[constraintsorig] == Length[constraints],
   If[Length[kktλ] > 0,
    Print["Amelioration & Abatement constraints & KKT multipliers: ",
     Cases[
      Table[{constraintsorig[[
         i]], (λ[i] /. kktλ)}, {i,
        Length[constraintsorig]}], {a_, b_} /;

       Length[Select[Cases[a, x_Symbol[_Integer ..], Infinity],

          MemberQ[Complement[Flatten[Array[s, {periods, cou, 4}]],
             Flatten[Array[s, {periods, cou, 3}]]], #] &]
         ] > 0]],
    Print[
     "Have not printed Amelioration & Abatement constraints & KKT \
multipliers because the length of constraints vector is not equal to \
length of original constraints vector."]
    ]]];
(*Print Emissions Permits KKT multipliers*)
If[True,
  If[Length[constraintsorig] == Length[constraints],
   If[Length[kktλ] > 0,
    Print["Emissions Permits constraints & KKT multipliers: ",
     Cases[
```

```
      Table[{constraintsorig[[
         i]], (λ[i] /. kktλ)}, {i,
        Length[constraintsorig]}], {a_, b_} /;

       Length[Select[Cases[a, x_Symbol[_Integer ..], Infinity],

          MemberQ[Complement[Flatten[Array[s, {periods, cou, 5}]],
             Flatten[Array[s, {periods, cou, 4}]]], #] &]
         ] > 0]],
    Print[
     "Have not printed Emissions Permits constraints KKT multipliers \
because the length of constraints vector is not equal to length of \
original constraints vector."]
    ]]];
FrontEndExecute[FrontEndToken["Save"]]
```

A8.3 Appendix references:

Taha, H.A., 1987. *Operations Research: An Introduction* 4th ed., Macmillan Publishing Company.

Colophon

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CD-ROM Attachment

The paper version of this thesis contains a CD-ROM with the following files.

stuart_nettleton_dissertation_files

gtap_specification_files

sntest01.agg	Aggregation specification
sntest01.txt	Output of aggregation

mathematica_utility_files

gtap_make_mathematica_db_03.nb	Make Mathematica database from GTAP
gtap_comparison_uv_amatrix.nb	Due diligence functions
eghg_aggregate.nb	Emissions aggregation functions
Gtapfunctions.m	Database mining functions
Gtapaggregation.m	Database aggregation functions
Topofunctions.m	Acyclic processor functions
gtap3res.script & gtap3res.m	GTAP aggregated database
gtap3eghg.script & gtap3eghg.m	GTAP emissions database
readme_utility_files.txt	Notes for placing database resources

mathematica_model_files

m12_13p_2C_100.nb	Base Case of 2°C rise at 100 years
m12_13p_2C_100_no_gaml_no_gtra.nb	Base Case with no emission permits or amelioration/abatement trading
m12_13p_2C_100_s2a.nb	Base Case with impaired Sales/Asset
m12_13p_2C_100_tcx2.nb	Base Case with 2xtechnology cost
m12_13p_2C_100_tcx10.nb	Base Case with 10x increase in technology cost
m12_13p_2C_100_tcx20.nb	Base Case with 20x increase in technology cost
m12_13p_350_100.nb	Hansen/Gore/Tällberg 350 ppm Case
m12_13p_450_100.nb	Previous world target of 450 ppm
m12_13p_550_100.nb	Expected 550 ppm case
m12_13p_full_amel.nb	Radical perspective case
m12_13p_full_amel_no_cost.nb	*Laissez faire* case
m12_13p_full_amel_no_cost_no_dam.nb	Sceptic Case
m12_13p_normal.nb	Normal or "business as usual" case for comparison with Nordhaus' DICE
topo_test12_comp_sceptre.nb	Nordhaus' DICE business as usual case
readme_model_files.txt	Notes for running model files

Stuart Nettleton

Benchmarking
Climate Change Strategies
Under Constrained Resource Usage

University of Technology, Sydney

Dissertation Model Files v. m12
26 October 2009

Notes