International Approaches to Global Climate Change

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This article surveys the issues involved in slowing the climate change induced by global emissions of greenhouse gases, especially carbon dioxide. It addresses the possible social and economic impacts of global warming, the elements involved in evaluating the pros and cons of steps to reduce those impacts, and the issues involved in engaging most of the world's states in a cooperative endeavor to reduce greenhouse gas emissions. It expresses doubts about the efficacy of a global approach based on national emission targets, such as those set by the 1997 Kyoto Protocol, and favors instead mutually agreed actions focused on a common emission tax. It also discusses issues of compliance with an international agreement to reduce emissions, actions states can take in the absence of international agreement, and contingency actions that might be considered if the problem proves to be more serious than now seems to be the case.

Human activity since 1800 has resulted in the emission of great volumes of gaseous materials into the atmosphere. Some of these gases—notably carbon dioxide, methane, and chlorofluorocarbons (CFCs)—absorb Earth's radiation, leading potentially to a warming of Earth's surface, which in turn could alter the world's climate. At the molecular level, CFCs are the most potent "greenhouse gases," but carbon dioxide has been emitted in greatest volume, largely from clearing forests and from burning coal and oil, and has the longest life in the atmosphere, thus accumulating over time. Atmospheric concentration of carbon dioxide in recent years has reached 360 parts per million (ppm), compared with about 280 ppm around 1800, and on some current projections is headed to 700 ppm (two and a half times preindustrial concentrations) by 2100 (Council of Economic Advisers 1998).

Wide scientific consensus suggests that under these conditions Earth's surface will become warmer on average, with temperature increases being higher in the higher latitudes. Sea levels will also rise, partly from melting glaciers but mainly from thermal expansion. Average global precipitation will increase.

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Beyond these general effects, the consensus dissipates. Earth's atmospheric physics and chemistry are complicated and not well understood; neither is the relationship between the atmosphere and the oceans nor that between climate and the biosphere (all forms of life). As a result, few agree on the rate at which chemical or biological processes take carbon dioxide out of the atmosphere, on the influence of greater warming and evaporation on cloud formation (which affects the extent to which the sun's rays are reflected away from Earth's surface), on the rate at which the oceans absorb heat from the atmosphere, and on a host of other relevant issues. Thus there is little agreement on either the ultimate extent or the pace of warming for any given trajectory of greenhouse gas emissions.[1]

Neither is the future trajectory of emissions known with high confidence, although continued "business-as-usual" economic growth can be expected to result in ever greater consumption of fossil fuels for many decades. The Intergovernmental Panel on Climate Change (IPCC 1996b) assumes in its main "business-as-usual" case a global growth of 1.1 percent a year in emissions of carbon dioxide between 1990 and 2100. At this rate, and in the absence of actions to reduce the growth of greenhouse gas emissions, the generally accepted range of warming over the course of the next century is 1.0–3.5°C, with a best guess of perhaps 2.0°C, and an equivalently uncertain rise in sea level of about half a meter.[2]

Confronted with these possibilities, the international community agreed at Rio de Janeiro in 1992 on a Framework Convention on Climate Change and at Kyoto in 1997 on a protocol that committed the countries listed in annex I of the framework convention to reduce emissions by the year 2012 to estimated 1990 levels or up to 8 percent lower, with the targets varying from country to country.[3] The countries listed in the framework convention include the 24 members of the Organisation for Economic Co-operation and Development (OECD) in 1995 plus Central and Eastern Europe and some successor states to the Soviet Union. The Kyoto Protocol has not yet come into force, and indeed the Clinton administration indicated it would not submit the document for Senate ratification until "significant participation" by leading developing countries was assured, as requested by Senate resolution.

Social and Economic Impacts

Several key potential economic effects of global warming have been identified. Perhaps the most important is the effect on global food production. But concerns have also been expressed about health, rising sea levels, and the general amenity of life. In addition, climate changes will have significant effects on nonhuman ecological communities.

Agriculture

The impact of climate on agriculture depends on the detailed effects of climate change, particularly the regional and seasonal changes in precipitation. But the adverse effects (if any) that might occur under that heading must be assessed against the facts that plants rely on carbon dioxide as a major input to production; that increased atmospheric carbon dioxide, taken alone, would actually increase agricultural yields; and that agricultural producers around the world, but especially in temperate zones, have a demonstrated capacity for adapting to a variety of changes in their economic as well as physical environment. Comprehensive work on agricultural response to global climate change is still in an early stage, but several studies suggest that changes of the likely magnitude will not have a significant impact on global food output, although significant effects might be experienced at the regional level. For example, Schimmelpfennig and others (1996) show that 20–30 percent declines in output of grains at two locations in the United States under substantial increases in temperature (4–5°C) are greatly moderated, or even converted into increases, with plausible adaptations by farmers; the carbon dioxide fertilization effect would ensure increases for all three products—maize, soybeans, and winter wheat (Reilly 1998:246). Similarly, Darwin and others (1995) show that under four climate models, declines in global production of cereals caused by a doubling of atmospheric carbon dioxide become modest increases when farmer adaptation and market adjustments are allowed. As table 1 shows, small declines in nongrain food production are more than offset by increases in cereal and livestock (Meyer and others 1998).[4]

Although global food production does not seem to decline with global warming—on the contrary—the regional distribution is uneven. Production rises in the higher latitudes, partly because of an increase in arable land, and tends to fall in the

Table 1. *Percentage Changes in Global Production of Cereals by Climate Change Scenario*

World	*No adaptation*	*Land use fixed*	*No restrictions on use*
GFDL	–23.5	–0.6	0.3
GISS	–22.6	0.2	0.9
OSU	–18.6	–0.5	0.2
UKMO	–29.3	–0.2	1.2

Note: "No adaptation" represents the additional quantities firms would be willing to sell at 1990 prices under the alternative climate. The next two columns represent changes in equilibrium quantities, under new equilibrium prices, with land use fixed and with no restrictions on land use. The results are based on equilibrium scenarios in four climate models that assume a doubling of atmospheric carbon dioxide: those developed at the Geophysical Fluids Dynamics Laboratory (GFDL), the Goddard Institute of Space Studies (GISS), Oregon State University (OSU), and the United Kingdom Meteorological Office (UKMO).

Source: Adapted from Darwin and others (1995); Reilly (1998).

Tropics, primarily because of an assumed decline in the availability of water. But the uncertainties must again be emphasized, particularly regarding regional effects, where the global climate models vary substantially in their projections.

Disease

Global warming may increase the threat of contagious diseases, which tend to thrive in warm climates. In particular, the potential range of endemic malaria will be extended as the relevant insect vector is able to move farther from the equator. But again, humans are not simply going to accept the increased spread of disease without strong reaction. Much more medical and pharmacological research is now devoted to temperate diseases and health conditions than to tropical diseases, largely because today's rich countries are mainly in temperate latitudes and they understandably pay most attention to the health conditions that most concern their residents. If malaria or other tropical diseases were to extend into these latitudes, one can assume that more resources would be devoted both to stopping the spread of the diseases and to immunizing the population against them. Advances in genetic engineering give added confidence that most diseases can be overcome or at least kept under control.

Moreover, the world economy will continue to grow; indeed, that is a key assumption underlying the projections of carbon dioxide emissions. Even a modest growth of 1 percent a year in global per capita income will result in a 170 percent increase in incomes over a century; a more likely growth rate of 1.5 percent would increase global per capita income by a factor of 4.4, with even more rapid growth in many regions that are now relatively poor. Increases in income enlarge the possible and likely human reactions to all aspects of the environment, including threats from disease. Malaria is virtually unknown in Singapore, near the equator, while it is common across the border in Malaysia. Greater wealth improves the capacity of both individuals and societies to control their environment.

Coastal Inundation

A rise in sea level will of course affect the habitability of coastal areas, where much of the world's population lives. A half-meter rise in sea level may not appear like much, but allowing for storm surges means that it could make currently inhabited areas uncomfortable, or even uninhabitable in extreme cases. Nicholls and others (1995) estimate that 5 percent of the world population would be affected, with 1 percent seriously at risk. But again, people will try to protect themselves by some combination of moving away and adjusting their structures and behavior. Nicholls and others estimate that a combination of such measures will reduce the population at risk by 88 percent, to 0.14 percent of the world population. Adaptation measures are estimated to cost 0.056 percent of gross world product annually, or little more than 1/20th of 1 percent, although of course costs vary by region.

Market Impacts and Amenities

Various attempts have been made to assess the overall costs of climate change, and controversy surrounds the process. Among the most controversial issues are objections by some noneconomists to the insistence of economists on valuing the expected changes at market prices or something approximating them and the disagreements among economists on how best to do this. This is not the place to review the extensive and somewhat confused literature, but I do note that human behavior guided by foresight, or even by expectations based on one or two unpleasant experiences, can do a great deal to mitigate the costs of global climate change. To assume that people remain both ignorant and passive in the face of change is absurd; the entire international process involving the IPCC, the framework convention, and the Kyoto Protocol demonstrates that people are capable of thinking ahead and acting in anticipation—although not always wisely!

The emerging literature suggests that the best-guess costs associated with global warming are likely to be low, not catastrophic, as popular treatment of the subject sometimes suggests (table 2). Moore (1998), who assesses both the measurable and the not-so-easily measurable gains and losses for the United States, concludes that the United States is likely to be a net beneficiary of climate change—a result that would be even clearer for more northerly countries such as Canada and Russia. He argues that health is likely to improve in a warmer climate, that daily life would be more pleasant, and that recreational possibilities, although changed, would be changed in ways that cater more to current revealed preferences for recreation. Mendelsohn and Neumann (1999) have reached a similar conclusion.

The possibility that some countries may actually gain from climate change potentially complicates the prospects of a global agreement to limit the factors that lead to

Table 2. *Market Impacts with a 2.5°C Warming*
(percentage of gross domestic product)

Region	*Fankhauser*[a]	*Mendelsohn*[a]	*Tol*[a]
OECD	0.77	–0.17	0.27
Non-OECD	0.67	0.03	0.76
World	0.72	–0.18	0.52

Note: A minus sign signifies a net gain.

a. Mendelsohn assumes a 2.5°C rise in global mean temperature in 2060, whereas Fankhauser and Tol assume that this rise occurs in 2050. Note that only in Tol does damage depend on the rate of climate change. In all three cases, vulnerability is assumed as in 1990.

Source: Tol (1998).

climate change, since it will be difficult to persuade people to undertake costly or painful actions for benefits that accrue mainly to others.

Nonhuman Ecological Systems

Although human beings have demonstrated a remarkable capacity for adaptation to a variety of conditions and new developments, the same cannot be said about other species. Rapid climate changes may find many species unable to adapt in the time required.

Rising sea levels will affect natural ecosystems, particularly wetlands, which are known for their high levels of biological activity. Moreover, some human adaptation may come at the further expense of wetlands. For example, Nicholls and others (1995) estimate that without countervailing measures, rising sea levels will adversely affect 56 percent of the world's wetlands, and this figure rises to 59 percent when allowance is made for measures to protect human settlement. Existing wetlands are in rapid decline, however, for reasons that have nothing to do with climate change. If wetlands are to be preserved, affirmative human action will have to be taken, whether or not climate change threatens them.

Warming of temperate and northern latitudes will alter the natural vegetation, which in turn will alter the natural fauna. But trees take a long time to grow, and species move in nature only as rapidly as seeds can be carried by wind or creatures into newly habitable territory. Humans can assist other species to adapt to the new conditions, however, provided the requisite knowledge is available and the issue is considered sufficiently important.

Speciation is much higher in the Tropics than in higher latitudes. Microecosystems flourish in that climate, where highly specialized plants and (especially) animals with limited ranges have developed. Fortunately, temperature increases are likely to be least in tropical zones, but changes in precipitation and carbon dioxide fertilization will permit some species to flourish at the expense of others, possibly driving some to extinction.

A Framework for Collective Decisionmaking

Concerns about global climate change have led to pleas and indeed to some national commitments to slow or reverse the growth of greenhouse gas emissions. It is useful to identify the structural characteristics involved in attempting to mitigate global warming through formal collective action. There are three key features.

First, climate change brought about through an increased atmospheric concentration of greenhouse gases is a global issue, since whatever their earthly origin, the gases are widely dispersed in the upper atmosphere. Effective restraint must therefore involve all (actual and prospective) major emitters of greenhouse gases. Rich industrial countries account for most of the emissions today, but the Soviet Union was a major contributor before its dissolution and economic collapse in 1991, and the area can be expected to become a major source with economic recovery. Rapidly growing developing countries will become major contributors within a time frame that is relevant for managing the issue. Thus while the same requirements need not be imposed on all countries from the beginning, the agreement needs to be structured so that all countries will eventually participate. By one estimate, for example, full implementation of the Kyoto Protocol and continuation at the prescribed lower emission levels by annex I countries would slow the increase in average global surface temperature in 2050 by only 0.05°C, from an increase of 1.4° to 1.35°.

Second, the rewards from restraints on greenhouse gas emissions will come in the (politically) distant future, while the costs will occur in the political present. Moreover, the rewards are highly uncertain. The residents of some of today's countries, such as Canada, Russia, and perhaps the United States, may even expect to benefit from moderate climate change. It will thus be difficult to persuade people that they should make sacrifices in their own living standards for the sake of uncertain gains to their grandchildren and great-grandchildren, and to the grandchildren of others, remote in distance. The wide distribution of expected but distant benefits in response to collective action today provides an incentive for every country to encourage all to act but then to avoid acting itself—the so-called free-rider problem.

Third, the pervasiveness of the sources of greenhouse gas emissions—notably fossil fuel use, rice cultivation, and cattle production—implies that restraint will involve changes in behavior by hundreds of millions—if not billions—of people, and not merely by 180 or fewer governments, as in the typical treaty. Thus the most important part of an effective regime to limit climate change involves not the relationships among states but the effective influence of governments on the behavior of their citizens.

No major legally binding regulatory treaty touches all of these characteristics to the same degree. Typically, treaties apply to the actions of either governments themselves or a relatively few firms in a relatively few countries, as in the cases of halting nuclear testing or limiting production of CFCs. The Convention on International Trade in Endangered Species perhaps comes closest in its comprehensiveness; it requires states to prohibit international trade in an agreed list of products. The Chemical Warfare Convention is extremely intrusive in its monitoring requirements but has not yet come into force. The various agreements for management of international fisheries require cooperation from hundreds of fishermen, but with a few exceptions, these pacts have not been notably successful.

These three structural factors make collective decisions regarding actions to mitigate global climate change exceptionally difficult. Serious mitigation necessarily involves major reductions in the actual and prospective consumption of energy based on fossil fuels (especially coal-fired electricity generation and the use of oil products for heat and transport). Because such consumption is at the very heart of modern industrialized economies, the costs of mitigation are both the economic and the psychological adjustments that must be made to move away from current energy systems and from wet rice and cattle production, which, along with leaks from gas and oil refining and distribution systems, are the main sources of methane from human activities. Moreover, the likelihood that the distribution of costs and benefits will be highly uneven across nations further complicates the task of reaching international agreement.

It is natural for an economist to compare the overall benefits of any proposed change with the overall costs required to make the change. Many noneconomists reject cost-benefit analysis as an artifact of calculators who ignore or underrate basic human values. But this rejection is simply an intellectual mistake; everyone who urges a change in policy (or resists one) is at least implicitly comparing costs with benefits. The disagreement, rather, is about how best to measure the alleged benefits and costs of the proposed change. Thus when Krause, Bach, and Koomey (1992) argue that on no account should the average global temperature be allowed to rise more than 2.5°C (the upper limit of Earth's temperature in the past 2 million years), implying, according to their worst-plausible-case calculations, that no more than 300 billion tons of additional carbon can be emitted into the atmosphere, they are implicitly arguing that the benefits of severe mitigation action are infinitely great and warrant any finite cost to achieve them. The authors are expressing an extreme degree of aversion to environmental risk. Others may properly disagree with such extreme valuation.

Table 3 illustrates the range of marginal benefits per ton of carbon emissions avoided and the range of marginal costs of reducing emissions by a ton of carbon for two different targets: a return to 1990 emissions and a 20 percent reduction from 1990 emissions. All the estimates must be taken as illustrative, as the methodologies used are quite different and are incomplete. With this caveat, these estimates show that costs generally exceed benefits, especially for 20 percent reductions in emissions. The wide variation suggests that the methodology for estimating costs and benefits can stand considerable improvement. Not surprisingly, the costs of reducing emissions rise with the magnitude of the reductions. Kram (1998) and Stavins (1999) suggest that the increases can be very steep.

The Discount Rate

Cutting greenhouse gas emissions involves incurring costs long before the benefits are registered. A comparison of near-term costs with future benefits requires use of a discount rate (or stream of rates) to put both benefits and costs into present value. Much has been written about the appropriate choice of a discount rate and the prin-

Table 3. *Selected Estimates of Benefits and Costs for Global Marginal Abatement of Carbon Dioxide*
(U.S. dollars per ton of carbon)

Benefit study	*Marginal benefit*[a]	*Cost model*[b]	*Marginal cost* *Stabilization*	*Marginal cost* *20 percent reduction*
Ayres and Walter	30–35	Jorgenson-Wilcoxen	20	50
Nordhaus	7	Edmonds-Reilly	70	160
Cline	8–154	Manne-Richels	110	240
Peck and Teisberg	12–14	Martin-Burniaux	80	170
Fankhauser	23	Rutherford	150	260
Maddison	8	Cohan-Scheraga	120	330

a. For most studies the marginal benefit increases over time. The estimates presented here correspond to the period 2001–10.

b. Cost estimates are from a study by the Energy Model Forum of Stanford University, which ran 14 different cost models using common assumptions and standardizing for the emission reduction scenarios shown above.

Source: IPCC 1996a: (tables 6.11, 9.4).

ciples that should undergird the choice. Theoretical and some practical economists have been fascinated by the Ramsey model of savings, which suggests that the optimum social rate of time preference (r) can be expressed by the simple equation $r = \tilde{n} + \grave{e}g$, where $\tilde{n}$ is the pure rate of time preference, $\grave{e}$ is the elasticity of marginal utility with respect to additional consumption, and g is the growth rate of per capita consumption (see Nordhaus 1994 or IPCC 1996a, ch. 4, for an explanation). Plausible numbers for these variables lead to discount rates ranging from 0.5 to 3 percent (IPCC 1996a; Cline 1998).

The underlying rationale for avoiding or mitigating climate change is to benefit future generations. Yet to undertake investments in the near future that yield, say, 2 percent over the next century does a great disservice to future generations compared with other investments that we have strong reason to believe yield much higher returns many years into the future, if not for an entire century. Surely, in the interest of future generations, society should prefer high-return investments to low ones.

There is evidence that returns to education in developing countries exceed 20 percent (Psacharopoulos 1985, 1994). Returns to college education for a male in the United States reportedly equal 13 percent (Council of Economic Advisers 1996). A study of more than 1,000 projects completed by the World Bank in the 1970s and 1980s yielded an average (prospective) return of 16 percent (Pöhl and Mihaljek 1989). The World Bank and the U.S. government have stated threshold returns of 10 percent for evaluating prospective investments (recently reduced to 7 percent by the U.S. government). The corporate sector of the U.S. economy, one that is relatively rich in capital by global standards, yields an average pretax real return well above 10 percent. For all these reasons, 10 percent seems to be a reasonable rate of discount. A high discount rate, of course, gives less weight to benefits (and costs) in the distant future. But that implication alone is not sufficient reason to reject it.

Maurice Scott of Oxford University has suggested 4 percent (reported in Beckerman 1996), partly because that has been the real yield on low-risk government bonds in recent decades. But even if resources can be extracted from the public at 4 percent, they should be invested in those activities with high (social) return. Only after we exhaust 10 and 7 and 5 percent opportunities should we accept investments with prospective yields of only 4 percent. Otherwise we deprive either future generations or our own generation unnecessarily.[5]

Some observers object to citing data on observed rates of return on grounds that actual decisions made today and in the past were not made under ideal conditions but instead reflect a number of imperfections both in markets and in the processes for making collective decisions. It would take me too far afield to explore this contention in relevant detail. Let me just stipulate that the real world is messy and that actual decisions (and market outcomes) deviate from any given set of ideal standards. The same observation applies to actions to mitigate greenhouse gas emissions. A plausible argument must be made that allowance for the various imperfections will raise the after-the-fact returns to mitigation actions relative to the observed returns on other investments.

The debate over the choice of a discount rate can be interpreted as an effort to reduce or eliminate imperfections in collective decisionmaking on public expenditures in general. But if such imperfections are important, and if other public investments seem to leave future generations still better off, low discount rates should also apply to those higher-yield investments. Advocates who apply them only to climate change must do so either because they believe the political prospects are better for improving collective decisionmaking on global climate change than for other, higher-yield public investments or because they must prefer mitigation of greenhouse gas emissions on some unstated grounds, not captured in the usual reckoning of costs and benefits over time, and want to support such actions—or both. In any event, it would be useful and desirable to open these considerations explicitly to wider discussion.

This sounds like common sense. What can be the objection to it? One possibility is that while the return on investment A (education, say) exceeds that on investment B (mitigation) in the near term, the reverse is true in the long run because of a secular decline in returns to investment A. Normally one could switch to B investments as returns to A drop below those to B. Investing in B now would be preferable only if for some reason it would be too late to switch to B investments later, after returns to new A investments fell.

This type of configuration is theoretically possible, but a plausible case must be made for both parts before one can conclude that A should be rejected in favor of B at the outset. In the standard neoclassical economic model, the returns to capital are assumed to fall steadily as the ratio of capital to labor (and other factors) rises. But in historical—as distinguished from analytical—time, technical change has constantly increased the returns to (new) capital, and there is no reason to believe that the process will stop during the next century. Thus if returns to class A are high now relative to B, they are likely to remain so.

Distributional Considerations

The IPCC (1996a, ch. 4) authors seem to reject the efficiency argument that is emphasized here, not on the foregoing grounds but on the basis of equity. In essence, they argue that one cannot ethically say that investment A is superior to investment B even if it yields higher total future benefits if those who experience losses as a result of the investment are not actually compensated (in the absence of a social welfare function that indicates the relative weights that should attach to winners and losers).

This is a valid theoretical point. But if taken literally and applied seriously, it is a prescription for total inaction, especially when time frames as long as 100 years are under consideration. First, there is no collectively agreed social welfare function, and no prospect of one at a global level, so we cannot generally weigh winners against losers, especially over so long a time. Second, we cannot possibly know distant future winners and losers from our actions today. Try, for example, to identify the winners and losers from completion of the U.S. transcontinental railroad in 1869, or to forecast the winners and losers 100 years hence from construction of the Three Gorges Dam in China. And third, even if we had the requisite knowledge about future winners and losers and our preferences among them, we cannot bind future generations to adhere to those preferred outcomes. If we make rules, future generations can unmake them. If we plant trees, they can cut them down. If we consume less coal, they can consume more—and may actually do so because it is more readily available to them. The one legacy that cannot be reversed (short of a collapse of civilization) is enhanced knowledge—both a deeper understanding of nature and improved technology.

We should be concerned above all with passing more knowledge and higher incomes to the next generation than we received from our parents and should allow its members to decide how to distribute them. They will do so in any case, regardless of what we think. This is not to suggest that we should be completely indifferent to distributional effects. Our actions will affect the initial distribution of the next generation, and collectively we may want to avoid certain actions on grounds that we do not like their distributional effects. But here I mean the direct consequences of our actions, on which it may be possible to get collective agreement to avoid imposing extreme losses on certain classes of people. We cannot carry this logic into the more distant future, however, for the reasons already mentioned: we cannot possibly know the future impact on people (for one thing, we do not even know where they will be), and we cannot commit future generations to our preferences even if we did.

In any case, it is rather odd to urge costly action now for the sake of poor people in the distant future when we are not willing to take very costly action now for the sake of reducing poverty today. We have actual evidence on the amounts we are willing to spend, individually and collectively, in the name of economic development of today's poor countries: about 0.3 percent of the gross domestic product (GDP) of the rich countries, and only a portion of that is devoted to reducing poverty as such. If we are really concerned about the impact of possible future climate change on poor people, we should take more active steps to reduce their current poverty. That would improve their capacity to adapt to such climate changes as may take place and to take mitigation actions themselves.

If there is a general disposition within the rich countries to help people in poor countries, the best way to do it is probably through education. Education has at least three advantages with respect to mitigation of climate change. First, the rate of return seems to be substantially higher, at least on the estimates that have been made so far. Second, it is harder for future generations to undo the redistribution favored by this generation, since educated parents are likely to want to see their children educated. Third, education increases the capacity of any society, and of individuals, to adapt to changing circumstances, including but not limited to changes in climate.

Risk Aversion

It is widely taken for granted, at least on big issues, that people dislike uncertainty; they have an aversion to risk and are willing to pay something to reduce risk. This is the attitude that underlies the willingness of individuals to take out fire or liability insurance, to mitigate the possible costs of uncertain and perhaps even improbable unfavorable events.

The uncertainties associated with mitigating global climate change and its attendant costs are at least as great—and probably greater—than the uncertainties associated with other investments that could be made today; given risk aversion, one might thus conclude that costly mitigation actions should not be undertaken. However, the payoff from mitigation actions now will be greatest if the magnitude of global climate change and the associated costs turn out to be high, even if that is judged to be a low probability. Of course, if the costs associated with global climate change are low, any investment in mitigation actions will have a low or negligible return. But such investment may still be worthwhile as insurance against an uncertain but possibly costly contingency.

How do these considerations influence the discount rate? The precise answer is not at all straightforward, unless the uncertainty itself is related in a particular way to the passage of time. Roughly speaking, however, where an uncertain outcome (the future payoff from mitigation actions) is negatively correlated with the overall economic prospects and where the uncertainty grows exponentially with time, some deduction from the discount rate used to evaluate mitigation actions is warranted. How much? That depends in detail on the nature of the uncertainty, an issue that needs much greater discussion, and on the degree of aversion to risk. But presumably it was this sort of consideration that led U.S. policymakers in 1980 to stipulate a discount rate of only 7 percent for publicly financed energy-related projects, 3 percentage points lower than the general standard for government investments. Serious disturbances in the field of energy, unlike other areas, can lower gross national product by a multiple, so some component of the energy investment can be regarded as an insurance premium designed to attenuate the economic impact of large disturbances in the world oil market.

Nordhaus (1994) models the determinants of climate change and the effects on emissions, temperature increase, warming damage, world output, and so on, focusing on optimal mitigation policies. He recalculates the optimal mitigation policy, taking into account uncertainties in those factors that influence climate change. Not surprisingly, the optimal reduction in greenhouse gas emissions, and the carbon tax required to achieve it, are higher in the presence of these uncertainties than they would be with confident best-guess projections. Concretely, the optimal carbon tax during the 1990s under the uncertain conditions postulated by Nordhaus is $12 a ton, compared with less than $5 a ton on the best-guess projection. Of course, the optimal policy is likely to change in response to new knowledge.

What about the possibility of truly disastrous outcomes as a result of global warming? Although the scientific community does not put a high probability on any of them, three are sometimes mentioned: first, warming sufficient to release the extensive methane contained in the Arctic permafrost, leading to a strong and possibly rapid reinforcement of warming; second, warming sufficient to break up the Antarctic ice dam and raise the oceans several meters, rather than half a meter, higher; and third, glacial melting in Greenland of a volume and character sufficient to deflect southward the warm North Atlantic currents, paradoxically making Europe a much *colder* place.

These possibilities, however remote, raise the question of risk aversion and how much insurance societies are willing to buy against improbable but highly costly contingencies. There is no doubt that individuals vary greatly in their degree of risk aversion and that commercial insurance policies do only a modest job of bringing these diverse preferences into harmony at the margin. The market for differences in preference regarding risk is much less well developed than the market to take advantage of differences in time preference. Each society has its own mechanism, through the political process, for deciding and acting on the degree of collective risk aversion. But the mechanism for the world as a whole is much less well developed, being mediated through diplomatic conferences such as those at Rio in 1992 and Kyoto in 1997, followed by public debate and ratification.

The political process, while essential for making decisions on collective risk, contains some serious weaknesses. Most notably, the discussion is not conducive to honesty and straightforwardness. Some risk-averse parties will exaggerate the risks to persuade those who are less risk-averse than themselves. Others will attempt to minimize the estimated costs of early action or suggest that they can be borne by nonvoters (for instance, corporations). And some will cite legitimate concerns about greenhouse warming to encourage society as a whole to adopt a certain "lifestyle," such as relying less on the automobile, a technology that has been liberating for many people. By the same token, those who expect to bear the costs of political decisions in response to concerns about climate change will tend to minimize the risks and exaggerate the costs of mitigation—or even deny that a problem exists. In short, we should be on guard against strong but misleading or exaggerated arguments by all sides.

One way to deal with a potentially important problem that is subject to profound uncertainties is to establish a framework for action with broad participation and institutional procedures for integrating new information into decisions, as Schmalensee (1998) has urged, but to avoid costly actions that may turn out to be mistaken.

International Burden-Sharing

Suppose that the international community decides that steps should be taken to reduce greenhouse gas emissions and that many or all nations should be involved. What might be included in such a treaty? One approach, reflected in the Kyoto Protocol, is to impose national targets on emissions, possibly permitting some of the allowed emissions to be transferred from one nation to another. A second approach, which has received less attention, would call for a set of actions that states would agree to undertake. In my view, mutually agreed actions have better prospects of mitigating emissions than national targets.

Setting National Targets

When quantitative targets are imposed within countries, they almost universally respect recent history, being set at levels roughly in proportion to recent use (for instance, oil refinery throughput or emissions of sulfur or harvests of halibut). Targets based on emissions in a fixed base year such as 1990, as at Kyoto, have a similar character. They in effect allocate property rights to the existing tenants, accepting the right of ownership by virtue of possession or use. Targets allocated on this basis will be completely unacceptable, however, to countries that are or expect to be industrializing rapidly and that anticipate a disproportionately rapid growth in demand for fossil fuels. They will argue that most of the existing stock of greenhouse gases was emitted by rich countries and that those countries should therefore bear a disproportionate responsibility for cutting back. Thus developing countries did not commit themselves to reduce emissions at Rio or Kyoto; within Europe, Greece and Spain expressed similar reservations.

Some observers have suggested that simple distributive justice would require that emission rights be based on population. Such an allocation would favor heavily populated poor countries such as Bangladesh, China, India, Indonesia, and Nigeria. To be meaningful in limiting climate change, such allocations would require drastic cutbacks in emissions by rich countries, implying radical reductions in living conditions there if implemented quickly. Targets based on population would be insensitive to varying resource endowments (such as hydroelectric power) and to the fact that countries depend on vastly different fuel mixes and have different levels of fuel consumption.

Reductions in living standards could be mitigated, but not avoided, by the sale of unused emission rights from poor to rich countries (discussed further below). But the financial transfers involved if emission rights were based on population would be immense relative to foreign assistance today—far greater than is likely to be politically tolerable. If carbon emissions were to take a plausible value of $100 a ton, for instance, the typical American family of four would have to pay $2,200 a year to sustain its current (direct and indirect) average level of emissions of about 26 tons a year, 22 tons over its per capita allocation (roughly 6 billion tons of carbon emissions a year divided by a world population of roughly 6 billion people). Total U.S. transfers to the rest of the world would amount to $130 billion a year, more than 10 times current U.S. foreign aid expenditures. Moreover, the transfers in practice would be made to governments, despite the underlying moral rationale for basing targets on population, and many people would question the desirability of transferring large sums to governments whose responsiveness to the needs of their own citizens has been indifferent or worse.

A natural compromise has been suggested: base the national targets on GDP (or recent past emissions) initially and gradually convert them to population-based targets over, say, 25 years. Here, however, we encounter some unpleasant arithmetic with respect to population-based emission rights. In 1995 India's per capita income (on a purchasing power basis) was about 5.2 percent that in the United States. Suppose that per capita income in India grows at 5 percent a year over the next 25 years and per capita income in the United States grows at 1 percent a year (this is a plausible scenario, although in reality the gap in growth rates is not likely to be so wide). Under those assumptions, Indian per capita income 25 years from 1995 (in 2020) would still equal only 14 percent of per capita income in the United States, and per capita consumption of energy would be many times higher in the United States than in India. Thus, after 25 years, one of three possible scenarios would emerge: India would not be effectively constrained; the United States would be very tightly constrained; or (under tradable emission permits) there would be huge transfers from the United States to India. The sense of global community is not likely to be great enough by 2020 to sustain such large transfers—it is not that great *within* the United States today—and in any case such large transfers, either to governments or directly to citizens, would probably not be desirable, as some of the highly oil-dependent countries have discovered.

Perhaps the most reasonable way to allocate emission rights and the obligation to reduce emissions would be to calculate a "business-as-usual" trajectory of emissions for each country on the basis of recent history, development prospects, and past experience with the evolution of greenhouse gas emissions in relation to economic development. Then each country could be charged with reducing emissions by a uniform percentage, chosen in relation to global reduction requirements, relative to the assigned trajectory. Of course, even if this principle of allocation of rights and responsibilities were accepted as reasonable, the debate would simply shift to the choice of trajectories for each country. Developing economies aspire to grow rapidly. The Republic of Korea and Taiwan, China, have demonstrated that growth of more than 8 percent a year for three decades is possible. Most developing countries will set their aims similarly high and insist on energy-consumption growth to support them. They will be reluctant to accept lower emission targets without assurance that the technology will be available to achieve their growth targets with the lower emissions. Who is to say they are wrong?

Implementing the Agreement

Once national targets have been established, they must be translated into conditions that induce firms and households to change their consumption patterns to avoid certain activities. For large firms—generators of electricity, say—that could perhaps be done by fiat simply by setting quantitative limits for each generating plant. But for most economic agents the only practical way to alter behavior is to create price disincentives; that is, to tax the activities that generate the emissions.

Every international agreement must address the question of compliance and the associated question of monitoring behavior to discover if it deviates from the treaty requirements. In principle, given the objective, all significant greenhouse gases should be covered. In practice, given the many actors involved and the many sources of emissions, such broad coverage would be impossible to monitor and police. For practical reasons, therefore, attention is usually focused on fossil fuel consumption (plus a few other concentrated emitting activities, such as cement production). Monitoring such consumption is more or less manageable, since most of it must pass through some relatively narrow choke points (gas pipelines, oil refineries, electricity generating stations). Most coal production can be monitored at the mine-head or on the barges and railroads that transport the coal.

But this still leaves out a lot of emissions. Only about half of the greenhouse gas emissions (measured by radiative forcing, which is what is relevant for climate change) since 1850 have come from the burning of fossil fuels (IPCC 1996b). The rest have resulted from the burning of tropical forests, cultivation of livestock and rice, dumping of garbage, and losses from gas pipelines. Omitting these sources would misrepresent total emissions. The Kyoto Protocol covers 24 gases, including methane and nitrous oxide, in addition to carbon dioxide (Council of Economic Advisers 1998). Monitoring emissions of all these gases will be difficult—and probably impossible—if developing countries are covered by the requirement.

If the fossil fuel carbon emission targets for rich countries are so demanding, how are they to be met? Conceptually, there are four ways: more efficient conversion of fossil fuels to usable energy in existing plants; switching away from fuels that are high in carbon per unit of energy produced (basically, shifting from coal to natural gas); building new plants that use less carbon per unit of usable energy (for example, nuclear power plants); and reducing end-user demand for energy. Unfortunately, the scope is limited for further change at the easiest monitoring points. Obsolete generating plants can be replaced with more efficient or less carbon dependent ones, but replacement demand in the OECD countries will be modest during the next 20 years, and replacing generating plants before they become obsolete is extremely expensive. In developing countries the demand for electric power is rising rapidly, so most of the generating capacity that will be available in those countries in 2010 could in principle be designed to use technology with reduced carbon dependence.

The consequence is that most of the reduction in the rich countries must come from downstream, at or near the points of final demand, where the number of consumers is greatest. Quantitative rationing is neither desirable nor feasible in market economies, so the reductions must be achieved by some combination of price (dis)incentives, exhortation through publicity, and education on best practice. Many consumers are not aware of the ways they can conserve energy without making radical changes in lifestyle. But in any case the key to success is not at the intergovernmental treaty level but rather in the incentives each government can provide to its own citizens. A treaty merely provides a vehicle for rough "burden-sharing" across countries and some international discipline in pursuit of the targets.

Opportunities for reducing emissions in new electric generating plants and other new industrial facilities will be greater, and the marginal cost lower, in developing countries than in mature economies. That realization has led to an emphasis on "joint implementation," a procedure whereby agents in rich countries can obtain credit against national targets in their own countries for making emission-reducing investments in developing countries. The idea is attractive. But under the Kyoto Protocol, the developing countries do not have national targets. Therefore, avoiding reductions in emissions in rich countries by investing in poor countries by itself will not reduce global emissions, since much investment must and will be undertaken in developing countries anyway. Reducing global emissions can be accomplished only by establishing detailed criteria for "additionality" in emission-reducing new investments—that is, by establishing norms by country and by project for least-cost power generating or energy-using investments and then counting reductions in emissions relative to such norms. The norms themselves would be changed as technology advanced. Establishing such norms would be both complicated and controversial because it would necessarily involve both judgment and approximation.

Imposing a Carbon Tax

There is an important alternative to setting national emission targets: an international agreement on a set of actions calibrated to achieve the desired emissions. Because to accomplish their quantitative objectives governments must in any case create the appropriate behavior-altering incentives for their citizens, and because setting a national allocation of global emission rights for both rich and poor countries is likely to prove so contentious as to be impossible, it may be easier simply to agree on a common use of instruments. For problems such as reducing emissions, the favorite instrument of economists is to tax the offending activity. All countries would agree to impose a common carbon tax, which would increase the price of fossil fuels in proportion to their carbon content. Such a tax would have at least two major advantages. First, it would encourage reduction of emissions where that can be done at least cost. All emitters would have the same incentive to act, but only those who saved more in tax payments than it cost to reduce emissions would undertake reductions; others would simply pay the tax. A carbon tax would encourage users everywhere to switch to natural gas (which would benefit Iran, Russia, and other countries with large gas reserves) and, more important, would prompt consumers generally to conserve fossil fuels. Second, a carbon tax would generate funds for governments that have trouble finding sources of revenue that do not have negative effects on economic incentives to work, save, or undertake commercial risks.

A common carbon tax would be easy to monitor. Enforcement would be more difficult, but all large countries except Cuba and the Democratic Republic of Korea hold annual consultations with the International Monetary Fund (IMF) on their macroeconomic policies, including the overall level and composition of their tax revenues, and the IMF could provide reports to the agency that monitors the treaty governing greenhouse gas emissions. Such reports could, if necessary, be supplemented by international inspection of the major taxpayers (for instance electric utilities) and of the tax agencies of participating countries.

Such a regime would present a major problem to democratic countries, however, because taxation goes to the heart of parliamentary prerogative, and most democracies will not welcome taxation by international agreement. Moreover, even modest energy taxes are politically unpopular.

Two additional problems need to be mentioned, neither insuperable. The first is that countries tax energy (especially oil) differently, and some countries continue to price both coal and oil well below world levels. Should a uniform tax be levied on an uneven initial condition? If existing pricing practices are taken to reflect national preferences for allocating resources, a case can be made that the new carbon tax should be uniform, regardless of the initial tax burden. Of course, national policies would have to be monitored to ensure that the effect of the new tax was not undermined by other changes in tax or subsidy policy. Alternatively, the treaty could simply require a minimum national tax on emissions from fossil fuels, allowing existing taxes to drop toward that minimum, as advocated by Nordhaus.

The second problem concerns the disposition of revenue. Available estimates suggest that to have a significant impact on emissions, the tax might have to be substantial and thus would generate a great deal of revenue. To whom should this revenue accrue? Oil-producing states will suggest that if oil is to be taxed, they should levy it and get the revenue—indeed, that is what the attempts by the Organization of Petroleum Exporting Counties to control oil prices amount to. Oil-consuming countries, however, would feel doubly aggrieved if they charged more for oil to discourage its consumption and yet did not get the tax revenue; they would insist that the tax be levied on consumption and that the revenues accrue to them, not least so that they could reduce other taxes to ensure their continued prosperity and growth. In practice, the latter view is likely to prevail.

There is, however, a third possible claimant for the revenue: the international community. The international community has accepted a number of collective obligations that are cumulatively expensive. The most apparent are caring for refugees and peacekeeping operations, each of which cost the United Nations about $1.3 billion in 1995. Special assessments are now made for these activities, and several countries, including Russia and the United States, are in arrears. The regular UN budget runs $1.2 billion a year. In addition, donor countries finance the United Nations Development Programme and the International Development Association (at about $5 billion a year) to provide economic assistance to the poorest developing countries. Under the Rio framework convention, cooperation by developing countries in reducing emissions is conditioned on new financial support from the rich countries. Some or all of these activities could be financed in part by the tax revenues levied in pursuit of reduced emissions; obviously the major emitters, currently the rich countries, would pay most of the tax. But as poor countries develop, their contribution would increase automatically.

Estimates from several global energy-environment models suggest that a uniform reduction in carbon emissions from a "business-as-usual" baseline for each country or region would require very different carbon tax rates if that were the policy instrument used to reduce emissions. A uniform tax rate across the regions studied would result in quite different reductions from the baseline—as one would expect from the observation that countries around the world use energy with very different degrees of efficiency. Table 4 reports the per-ton carbon tax (in 1990 U.S. dollars) that would

Table 4. *Per-Ton Carbon Tax Required by 2050 to Achieve a 2 Percent Annual Reduction in Carbon Emissions from Baseline*
(1990 U.S. dollars)

Region	*Edmonds/ Reilly*	*Manne/ Richels*	*Green*	*Carbon rights trade model*
United States	1,096	208	340	754
Other OECD members	734	208	299	365
Former Soviet Union	325	990	180	2,245
China	341	240	67	1,109
Rest of world	1,012	727	329	763

Source: Dean and Hoeller (1993:153).

be required in five regions in the year 2050 to reduce carbon emissions by 2 percent a year from the baseline trajectory. Since the baseline trajectories project an increase in energy-related carbon emissions from roughly 6 billion tons a year in 1990 to 11 billion–19 billion tons in 2050, the 2 percent a year reduction would leave emissions that ranged between 3.3 billion and 5.7 billion tons in 2050, less than the 1990 levels.

By 2050 the world price (in 1990 dollars) of oil, 56 percent carbon by weight, is assumed to be $50 a barrel, two and half times its price in 1997. More recent projections suggest lower oil prices in the future, resulting from substantial improvements in the technology for discovering and extracting oil. Lower oil prices would lead to greater carbon emissions and thus to the need for greater taxes to bring them down to a target level. The price of coal, 75 percent carbon by weight, is assumed to be $60 a ton, about twice the recent price at points of exportation. Thus a tax in 2050 of $208 per ton of carbon would represent a 31 percent tax on oil and a 260 percent tax on coal. The loss in GDP engendered by this emission reduction program ranges (across the studies) from 1.3 to 4.9 percent in 2050 for the United States, from 2.3 to 6.4 percent for the countries of the former Soviet Union, and from 2.1 to 5.1 percent for the rest of the world—today's developing countries, minus China (Dean and Hoeller 1993). These results must be regarded as merely exploratory rather than definitive, but even the low estimates suggest a substantial cost to bringing energy-related carbon dioxide emissions below 1990 levels. The revenue these taxes would raise is also substantial. For instance, a carbon tax of $208 a ton in the United States would raise nearly $300 billion in revenue, 1.8 percent of estimated GDP in 2050. A carbon tax of $329 a ton in the rest of the world would raise $610 billion in 2050, nearly 3.2 percent of rest-of-world GDP in that year.

Trading Emission Rights

A gain in efficiency of emission reduction similar to that which would be achieved by a uniform world carbon tax can be achieved by allocating national targets to the major emitters of carbon dioxide and allowing them to purchase or sell emission permits. A world market would quickly develop in such tradable emission permits, with a uniform world price. An emitter that could reduce emissions at a cost lower than the permit price would have an incentive to do so and would then sell its unneeded permits into the world market. An emitter that could reduce emissions only at a cost above the permit price could save money by buying enough permits to cover its excess emissions. Table 4 suggests that there would be much scope and mutual gain from a global market in permits, since the estimated costs of reducing emissions vary greatly from region to region in all the models.

The U.S. government, which has estimated the gains from trading emission rights, projects that the marginal cost for meeting the Kyoto target of 93 percent of 1990 emissions by 2012 would be about $200 a ton of carbon (calculated from Council of Economic Advisers 1998). If emission permits were allocated and traded, this cost would be reduced by 72 percent, to $56 a ton. Americans would not meet the 7 percent reduction themselves but rather would buy permits, mainly from Russia, which would have an easier time meeting its Kyoto target of no change from 1990 because of the collapse of heavy industry after 1990 and because of the considerable scope that country has for improving energy efficiency. Adding some key developing countries such as China and India to the trading regime would reduce the price to an estimated $23 a ton, allowing Americans to buy more permits more cheaply. The developing countries, by the same token, would receive substantial payments for their surplus emission rights.

An effective market in emission rights requires that the trading parties have well-defined property rights. These parties could in principle be governments, but in most countries permits would have to be allocated to the relevant firms. The allocation of emission rights would be a nontrivial political issue because of the distributional implications. As noted above, the historical tendency is to allocate quotas on the basis of historical performance. But the emission rights would have substantial value, and there would be little social merit in allowing the grandchildren of today's emitters to continue to own the rights 50 years from now. The distortions over time from "grandfathering" the emission rights could be avoided by auctioning the rights to the emitters from the start, with the revenues accruing to governments. Some of the revenues could temporarily subsidize today's emitters, which would have the major burden of adjustment in the new regime.

Because of the need to establish clear property rights to emissions, such a regime could include only annex I countries under the Kyoto Protocol; other countries have no emission targets. The inclusion of key developing countries would require them to agree to (necessarily growing) national targets and to a mechanism for allocating national targets to the emitting firms. Such allocation would of course be a strong temptation to graft and corruption because the rights would have substantial value under current estimates.

A permit trading regime would, moreover, require careful monitoring and enforcement to ensure that parties that had sold emission rights in fact cut their emissions to the levels stipulated. Another issue would be the potentially large transfers of wealth from permit-buying countries to permit-selling countries, with the magnitude of the transfer depending not only on the price of the permits but also on the initial allocation of emission targets, a matter touched on earlier.

Of course, implementation of the Kyoto targets without extension or global trading would also have distributional implications across countries, brought about both through the relocation of high-energy-using activities (and the associated investment) to countries without targets and through changes in the terms of trade that would result from implementing the Kyoto regime and making the secondary adjustments to that implementation.

The Kyoto Protocol, if taken seriously, will be costly to implement, will have a sharp impact, and will be of little benefit to the climate. Signatory governments have not leveled with their citizens on the full implications of implementing the agreement. When those implications are known, the public is likely to balk; it is plausible that most annex I countries will not meet the ambitious targets of the Kyoto Protocol by 2012. A cynic might argue that politicians understand this fully and have undertaken a classic straddle to have their cake and eat it too: cater to the single-minded constituents demanding immediate action on climate change, while committing themselves to an international framework that is likely to prove unworkable—not exactly a tragedy, since it may be neither necessary nor desirable.

Of course, any regime that taxes fossil fuels (directly or indirectly), that excludes some countries from the control regime, and that permits (or prohibits) trades in emission permits will have substantial redistributive effects among countries. Energy-intensive industries will move to countries that are not covered by the regime, hence influencing trade and investment flows. Countries' terms of trade will shift, especially away from exporters of fossil fuels. And, if trading is permitted, sales of emission permits will redistribute income from one country to another.

Compliance

Inevitably, the question of international coordination brings up the issue of free riders or noncompliers. Since the signatories are sovereign states and there is no overarching disciplinarian, as there is (in principle) within countries, fines or economic sanctions are the possible means of forcing compliance.

It would be difficult to prohibit trade related to the emission of greenhouse gases without in effect prohibiting trade with the offending country, since carbon dioxide–producing energy is required for virtually all production. But prohibiting trade could impose costs not only on the offending countries but also on their trading partners that might well exceed the likely costs of global climate change. The advantages of one international regime would be sacrificed for another. Even if the threat worked, in the sense that countries were induced to comply with the emission objectives and the threat therefore did not have to be exercised, its existence might induce some important countries—China comes to mind—to reduce their dependence on trade as a matter of policy to avoid the possible cost of sanctions in the future, and that too would represent a cost of compliance.

Chayes and Chayes (1995) have argued that treaty law need not rely predominantly on sanctions, either in theory or in fact, and that indeed in many cases sanctions are counterproductive. They conclude that most actual or apparent deviations from treaty provisions arise from ambiguity and indeterminacy of treaty language, from limitations on the capacity of governments to carry out their undertakings, or from major changes in circumstances from those prevailing at the time the treaty was ratified. Deliberate violation of treaties is rare, and when it occurs on important issues, major participants exert extreme pressure outside the treaty for resumption of compliance, as happened with the violation of the Non-Proliferation Treaty by Iraq and the threatened withdrawal from that pact by the Democratic Republic of Korea.

The key factors in ensuring compliance are a commitment to the treaty objectives plus a high degree of transparency in governmental actions. Many regulatory agreements have a potential free-rider problem; countries are more likely to adhere to the provisions if other governments are seen to be adhering to the provisions, so a regular system for monitoring and reporting on the activities and actions covered by the treaty is important.

These days, the very legitimacy of many governments arises from their responsibility for international relations and their integration into the community of nations. External and, increasingly, domestic pressure will usually keep governments from deliberately flouting internationally agreed behavior. The need to engage publics in the reduction of greenhouse gas emissions, however, raises the issue of whether governments have the capacity to carry out their international commitments. Taxes are easier to monitor than quantitative emission targets.

Incomplete Steps toward Mitigation

Understanding the processes of climate change and their social and economic impacts is a daunting task; the world's knowledge of ways to reduce emissions with minimal social disruption and to disseminate best practices remains highly imperfect. But knowledge can be advanced along a variety of fronts through the actions of individual countries, as well as through internationally sponsored research. Much of this activity is under way, especially research on improved energy efficiency and alternatives to fossil fuels, but governments should ensure that no promising idea is languishing for lack of funding. Knowledge will not resolve some issues, however, especially those concerning intergenerational distributional decisions and collective aversion to risk. These inevitably must be resolved through public discussion and political negotiations.

Even in the absence of an effective international agreement, countries may sensibly take steps to reduce greenhouse gas emissions. Subsidies and tax advantages that encourage the consumption of fossil fuels, especially—but not only—in developing countries, can be removed. Countries can encourage more rapid diffusion of available best practice in energy use through schools and public awareness programs. Sometimes outdated regulations need to be changed; for example, allowable rates in public utility regulation are often based on investment in new generating capacity but not on investment in conservation of electricity. Governments can provide funding for research in socially desirable new technologies and can, on their own, impose higher taxes on fossil fuels, devoting the revenues to reduction of other behavior-distorting taxes. There are many reasons other than inhibiting global climate change for adopting some or all of these measures: reduction of air pollution, reduction of urban congestion, and enhancement of energy security (especially with respect to imported oil). Reduction of greenhouse gas emissions would be a bonus, although a conscious one.

Further, international lending institutions such as the World Bank and the regional development banks are in the business of financing infrastructure projects in developing countries. Such infrastructure includes electric power generation and distribution, transport systems, and other major power-using activities. Once infrastructure is built, society adjusts to its long-lasting effects. Thus careful attention should be paid now to the longer-run social and economic implications of these investments. The extent and character of waste emissions, including greenhouse gases, should inform these investments, with special attention given to available best practice even when it is not considered by the principal contract-bidding firms. It is important to seek viable alternatives to coal-fired electricity generating plants, including a reexamination of the suitability of modern nuclear power technology with respect to safety, cost, and waste disposal.

A sensitive issue arises when investments in low-emission or nonemitting technologies cost *more* than the least-cost technologies (taking into account initial investment, maintenance, and lifetime input and waste disposal requirements). Should the lending institutions nonetheless insist on the investment that is more friendly to the environment? If so, who should pay for the incremental cost? It seems reasonable to decline to finance infrastructure investments that are unnecessarily damaging to the environment and acceptable to ask the borrowing country to pay fully for the incremental cost of any environmental benefits that accrue directly to it, but it is reasonable to expect the international community to pay most or all of the incremental cost (depending on the income level of the borrowing country) associated with greenhouse gas emissions in cases in which the benefits will accrue to the world as a whole.

Contingency Planning

Many adverse developments *could* occur as a result of global climate change. It is much more difficult—if not impossible—to forecast with confidence what *will* actually happen. Sòme analysts have projected benign effects from global warming and easy adaptation to the adverse effects—especially for those whose income gives them room to maneuver. Thus developing countries understandably give higher priority to economic development than to averting climate change if the latter in any way inhibits development.

The great uncertainty about impacts, the prospect of serious gainers as well as losers, the high apparent cost of near-term actions to reduce emissions, and the need for eventual participation by countries with substantially different initial circumstances and hence greatly different priorities—all these factors make early action to stop the growth of greenhouse gas emissions, much less to lower them, highly problematic. Suppose the best guesses about climate change turn out to be too optimistic; or suppose that the forecasts are accurate but the international community is unable to reach agreement on costly, effective mitigation actions; or suppose that agreement is reached but countries prove unable to implement it. What will the community of nations do if experience reveals that climate change is severe and adverse? This possibility suggests the need for contingency planning to supplement research to develop cheap, low-emitting sources of energy and to satisfy human wants with lower requirements for energy. Such contingency planning can take two broad paths.

The first concerns how best to adapt to more serious climate change. It means not only pushing ahead with both the basic science and applied research for genetic engineering in many areas, especially agriculture, but also finding potential substitutes for possible useful species that may be lost. That search could be supplemented by a systematic program for collecting, cataloguing, and storing genetic material, mainly but not exclusively from plants, in the form of seed banks and DNA.

The second concerns slowing global warming as rapidly as possible. One route involves sequestration and even withdrawal of greenhouse gases, mainly carbon dioxide, from the atmosphere on a scale at least equal to continuing emissions. That approach will involve good stack absorbers and storage depositories of carbon dioxide. But it also might involve mobilizing the biosphere. Rapidly growing trees could be planted on a massive scale (by using planes to drop seeds, for example), especially as climate change extends the areas that can support them. More unconventionally, barren portions of the oceans could be fertilized with the requisite minerals (thought mainly to be iron) so that microscopic carbon-loving plants can thrive.

A different approach would involve reducing the incidence of sunlight on Earth's surface, for example by placing reflecting surfaces in space or by increasing the albedo by altering cloud formation or by placing particulates in the atmosphere (through jet engine exhaust or by using cannons or rockets). Other possibilities will no doubt emerge over time. It is premature to commit to any particular method for rapid mitigation. Some suggestions will be impossibly expensive, and others will have unacceptable side effects, but it is important to encourage imaginative work on possible emergency actions.

Notes

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1. The principal tool of analysis for global climate change is a large computer model (General Circulation Model, or GCM), of which several are in use, that attempts to model Earth's past and future climate as a function of received radiation, the characteristics of the atmosphere (such as concentration of carbon dioxide), and the dynamics of climate formation.

2. Excellent summaries of the scientific consensus and uncertainties about global climate change can be found in IPCC (1996b) and in Wuebbles and Rosenberg (1998). More recent work suggests that increased ice in Antarctica induced by a warmer climate (due to higher precipitation there) would withdraw water from the oceans and thus reduce this projected rise in sea level, possibly by as much as 50 percent (Thompson and Pollard 1997).

3. The European Union is treated as a single unit, with the maximum target reduction of 8 percent below emission levels of 1990. The United States agreed to a reduction of 7 percent and Japan to 6 percent, and Russia agreed not to exceed its 1990 level.

4. Fischer and Rosenzweig (1996) also find that global warming will increase global food production by 2050, with carbon dioxide fertilization playing an especially important role.

5. The comment by Kenneth Arrow misses my point. Suppose, for the sake of argument, that *all* resources for additional investment are taken from consumption and none from investment, as Arrow suggests. The future is still best served if new investment is undertaken that has the highest rate of return; an allocational mistake is made otherwise. Hence, the appropriate discount rate for evaluating potential projects is the rate of return on existing (marginal) investments.

I am concerned with incremental decisions. Arrow's approach would lead to a much higher rate of *total* investment. Indeed, with enough potential projects yielding more than his preferred consumption discount rate, it could lead logically to *all* output being used for investment—an absurd outcome. Before it was reached, the consumption rate of discount would rise sharply, at least enough to keep consumption well above subsistence levels. That would imply higher consumption rates of discount than Arrow either calculates or observes. Another factor is relevant: public investments must be covered, directly or indirectly, by taxation. Taxation in rich countries is already around 40 percent of GDP (higher in Europe, lower in Japan and the United States). In pursuit of rational preferences, the voting public is not likely to support proposals that require much higher levels of public investment with relatively low rates of return, which ultimately will require higher levels of taxation out of only modestly higher income. This argument is weakened if the "investment" itself produces revenue, which would be the case with a tax on carbon emissions.

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