"ON ECONOMIC DISEQUILIBRIUM AND FREE LUNCH"

by

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Abstract

There is a sharp disagreement between mainstream economists and advocates of energy efficiency as regards the potential for "free lunches" or "no regrets" policies to cut greenhouse gas emissions. From an economics perspective, the critical question is whether the economic system is — or is not — close to a Pareto-optimum equilibrium state. If so, it follows that most technological systems now in place are optimum, or nearly so, from an economic perspective. If not, there may be many sub-optimal technologies in place, with corresponding opportunities for very high returns on appropriate investments. This paper presents some of the evidence supporting the latter thesis.

Background

The core idea of economics is an equilibrium between the "forces" of supply and demand. The notion of equilibrium is defined only for an hypothetical static situation. But a very large part of economic theory is concerned with the notion of exchange markets as equilibrating mechanisms. Adam Smith coined the term "invisible hand" to characterize the function of markets in matching supply with demand, not only in the aggregate sense, but individually for all goods and services being produced and exchanged.

Leon Walras reduced the idea of equilibrium in economics to mathematical form. He conjectured that in a free competitive market a unique set of non-negative prices must exist that will clear the market by balancing the supply and demand of any number of commodities simultaneously. Walras also postulated a detailed mechanism (*tâtonnement*) by means of which the market-clearing price set can be achieved [Walras 1874]. This proposition was not proved by him, but it fascinated generations of mathematically inclined economists, and even pure mathematicians. The first general proof that an exchange market will equilibrate, i.e. that a set of prices exists at which the market "clears", and that the market will eventually find these prices, was not published until 80 years later [Arrow & Debreu 1954]. A surprisingly large literature has grown up around various approaches to the proof of convergence of (static) exchange markets to states of Pareto-optimality.

Static equilibrium in the Walrasian sense is a Pareto-optimal state towards which all spontaneous economic processes tend. From the perspective of exchange markets, it is the state where all possible trades that would leave the parties better off have already taken place. No further trades can occur. Obviously there is no place in this static picture for production, consumption, depreciation, investment, or economic growth. These are essentially dynamic phenomena. Thus, when growth became a central topic of economic theory in the 1930's some explicit generalization of the static theory became necessary. The most natural generalization is to introduce an exogenous expansionary force that operates on the system as a whole without differentiating among its parts. At first it was thought that exogenous growth in the so-called factors of production (labor, capital) would suffice. Later, as a result of empirical work by Abramovitz and others, it was realized that some additional factor was needed. This new factor became known as 'factor productivity' or 'technical change'. The important feature of this modified picture, however, is the essential disconnection between factors of production, or factor productivity, and internal market processes.

John von Neumann first constructed (originally in 1932) a simple multi-sector "equilibrium growth" model with the convenient property that its behavior can be analyzed explicitly [von Neumann 1945]. The model assumes an economy consisting of a number of interdependent sectors, each of which grows at exactly the same rate as the economy as a whole, thus preserving the original structure. Productivity growth is assumed to be constant for all sectors and for all time. This mathematical property, known as *homotheticity*, permitted many of the theorems that could be proved for a static equilibrium to be extended to a (quasi) dynamic model. Homothetic growth models of the von Neumann type, assume that the economic system is always in a quasi-static Walrasian equilibrium. Von Neumann's model has been equally influential among theorists, despite its lack of realism. Numerous so-called "turnpike" theorems and "golden rules" pertain to the long-run behavior of von Neumann models.

However, all this mathematical theorizing has little to do with real economic growth. Homothetic models preserve sectoral structure, but real technological change does not. Moreover, technological change in the real world tends to be localized, lumpy, somewhat accidental, and "fast-slow", rather than gradual and steady. One of the most penetrating insights in the history of economics was Arnold Schumpeter's observation that technological change is a process of "creative destruction" [Schumpeter 1912, 1934]. New industries are created; others decline and some may disappear. Steam power displaced horsepower and sails; internal combustion engines displaced steam engines; oil replaced coal (which replaced wood, as a fuel), and new energy sources will eventually displace fossil fuels. But none of this could happen in a homothetic model-world.

Dynamic models took a great leap forward beyond simple homotheticity — at least toward practical use — with the advent of dynamic programming in the 1950's, optimal controls models in the 1960's and computable general equilibrium (CGE) models in the 1980's. It is worth recalling that the fundamental idea of 'optimal controls' or CGE models is quite simple. It is assumed that the future is exactly like the present except for *gradual, steady and predictable* changes in the factors of production (labor, capital) and factor productivity. A set of slowly-changing environmental or other constraints (such as the total amount of some exhaustible resource or the allowable level of some pollutant output) can also be introduced.

Thus, some structural changes can now be accommodated by the models. The optimal investment and consumption levels at each point in time can then be determined. It is a mere blink of the mind's eye to assert that the optimal path will be the actual path. This is where the modelers stand today.

While the assumption of homotheticity has been relaxed, economic growth models, from von Neumann to the present day, have invariably assumed that economic growth is a quasi-equilibrium process in which Pareto-optimality is preserved at all times. The assumption of equilibrium growth — or, more accurately, growth "in" equilibrium — is essentially equivalent to Candide's assertion that "*All is for the best in the best of all possible worlds*". This paper argues that the above prescription does not characterize the real world, and that the simplification involved is absolutely critical for some policy issues, most notably the long-range climate warming (CO_2 and other "greenhouse gas" emissions) issue that has been addressed recently through the use of CGE models. To borrow a vernacular expression: CGE models tend to "throw out the baby with the bathwater".

For some purposes, no doubt, the assumption of perpetual Pareto-optimality is not too important. It can be (and has been) argued that a model based on false assumptions may nevertheless be useful if it can make good predictions. Since no model can reflect all the complexities of the real world, this argument has some power. But the test, of course, is whether the predictions made by a simplified model are consistently good ones. Since economic forecasting models are notoriously poor, even in the very short run, there is no empirical evidence that CGE models make good predictions in the long run. On the contrary, CGE models seem to be used for the same reason mountains are climbed: "because they are there". This is not a good enough reason, if major policy choices are at stake, and if important underlying assumptions are unjustified. As it happens, however, the choice of model assumptions matters very much indeed in areas pertaining to environmental policy, such as global climate change, and environmental acidification and toxification.

Older models in the general equilibrium tradition (but only partially implemented) include the ETA-Macro model developed at Stanford University and the Electric Power Research Institute (EPRI) [Manne 1977; Manne & Richels 1989, 1991], the Brookhaven MARKAL model [Fishbone & Abilock 1981; Morris *et al* 1990], the Nordhaus-Yohe model [Nordhaus & Yohe 1983], the ERM model [Edmonds & Reilly 1985, 1991; Edmonds *et al* 1986], the DOE Fossil 2 model [Bradley *et al* 1991], and the Wharton/DRI/EPA model [Shackleton *et al* 1992]. The general scheme of these models is similar to that employed by ERM. The model calculates GNP directly from exogenous assumptions about labor force and labor productivity. The energy sector is treated explicitly, with energy demand derived from exogenous determinants including population, GNP, end-use efficiency, energy prices and energy taxes/subsidies/tariffs. Energy supply is typically determined by a linear programming model, which optimizes the choice of fuel and conversion technology, for given levels of aggregate energy demand. The energy-GNP interaction is taken into account through demand price elasticities. The ERM is regional (9 regions). ERM and similar models have been used to estimate both future emissions and the cost of reducing such emissions.

Important recent examples of "true" CGE models that have been applied to energy policy or environmental issues such as the climate warming question include a static CGE model by

Willett [Willett 1985; Shortle & Willett 1986] and dynamic models by Goulder [Goulder & Summers 1989; Goulder 1992] and Jorgenson and Wilcoxen [Jorgenson & Wilcoxen 1990, 1990a; Jorgenson *et al* 1992]. European literature includes studies by Conrad et al [Conrad & Henseler-Unger 1986; Conrad & Schroeder 1991], Stephan [Stephan 1989] and Bergman [Bergman 1991, 1993]. In principle, the CGE models are able to endogenize the energy-GNP feedback, taxes, and prices. However labor productivity, energy supply schedules and end-use efficiency assumptions continue to be exogenous. Abatement costs are also exogenous in most models. Willett's static model was used to evaluate the economic implications of wastewater treatment. Jorgenson & Wilcoxen cover the whole range of environmental regulations, but with exogenous costs. Stephan's model introduces water pollution abatement cost functions for wastewater treatment. Bergman's deals with the economic effects of air pollution on the same basis.

The need for exogenous assumptions is a major weakness of any model that is to be used for periods of a century or more, since it fails to reflect, or allow for, any possibility of "radical" Schumpeterian change in the energy area, no matter how urgent the societal need.[1] It was, fundamentally, for its failure to allow for technological progress in response to societal needs that the Club of Rome's "limits to growth" model was severely criticized by many economists (including Nordhaus). Thus, it is rather inconsistent for economists to use models with the same limitations.

Implications of 'Dynamic Equilibrium'

Since the notion of 'dynamic equilibrium' is virtually an oxymoron, its precise definition need not worry us unduly. However the key characteristic of any equilibrium (or quasi-equilibrium) state is Pareto-optimality. The notion of Pareto-optimality was originally defined only for the static case, but it was adapted to accommodate homothetic growth and, more recently, dynamic programming. Thus, it is implicitly assumed in modern growth models that investment opportunities and producer goods are also freely exchanged in competitive markets. Thus investors acquire an optimal investment portfolio, and producers (firms) make optimal choices of product, production technology, location, etc.[2] The result is a monotonically increasing supply function of the classic form. With such a supply function, programming models yield unique and well-behaved solutions.

[1] For instance, none of the models consider the possibility of a satellite-based (or lunar based) photovoltaic system, even though the solar satellite program was evaluated extensively by the Department of Energy during the Carter administration. A lunar PV farm (with continuous replacement of radiation damaged cells) could very well be worth considering in the future. Current energy-economic models do not seriously consider lunar PV farms, systematic cultivation of biomass, PV hydrogen, fuel cells, fusion, or several other possibilities that are regarded as potentially feasible by a number of energy experts today [e.g. Johansson *et al* 1993].

[2] The implicit assumption that all firms have a choice among all possible production technologies is much stronger than the explicit assumption usually made in the theory of the firm, where each firm is assumed to have a unique set of production possibilities (differentiating it from other firms) within which it makes an optimal choice.

But is the classic increasing supply function realistic? It follows from Pareto-optimality (in the extended sense) that an 'dynamic equilibrium' economy would necessarily be characterized by more or less equal investment opportunity (or lack of it) in every sector at every moment in time. By the same token, risk would be spread uniformly over all sectors. All investments would yield essentially the same return, give or take small random deviations. There would be no investment in industries offering a rate of return less than the average, nor would there be any significant opportunities for obtaining returns on investment significantly greater than the average. In short, the seemingly harmless assumption that technical choices already made were invariably optimal precludes the possibility of "free lunches" or "no regret" solutions, no matter how often such solutions are tentatively identified and suggested by non-economists. The Pareto-optimality assumption rules out the possibility of major unexploited technological opportunities.

In the CGE model world, any exogenously introduced technological change, whether for safety, environmental or other reasons, can only be introduced as a new and tighter constraint. (recall that technological change is always exogenous in these models). If the new technology does not explicitly increase productivity, it necessarily becomes a drag on 'potential' economic growth. It is but a short step to equate "lost" economic growth, however hypothetical, with the "cost" of the proposed environmental constraint. The interpretation of 'lost gross output' as 'cost of change' is justified, for most economists, by the notion that GNP is a measure of aggregate social welfare.

Is this methodology plausible? More important, is it a reasonable basis on which to take enormously important policy decisions affecting the kind of world our descendants will inherit from us in the distant future? The question arises in an especially acute form in the area of energy conservation. A number of large-scale CGE-type model calculations have been carried out in the U.S. by various parties, using various models (including those described above, to explore the potential impact of a carbon tax to discourage CO_2 emissions. For instance, a recent study based on the ERM model concluded that to stabilize global CO_2 emissions, as compared to the "business as usual" case, would cost about $1 trillion (1985 $ per year by 2025 if the whole world shared the costs [Edmonds & Barns 1990]. It would cost about $2 trillion per year if the OECD countries carried the entire burden. The "cost", once again, is an estimate of potential growth not realized. This result is typical of CGE-type models.

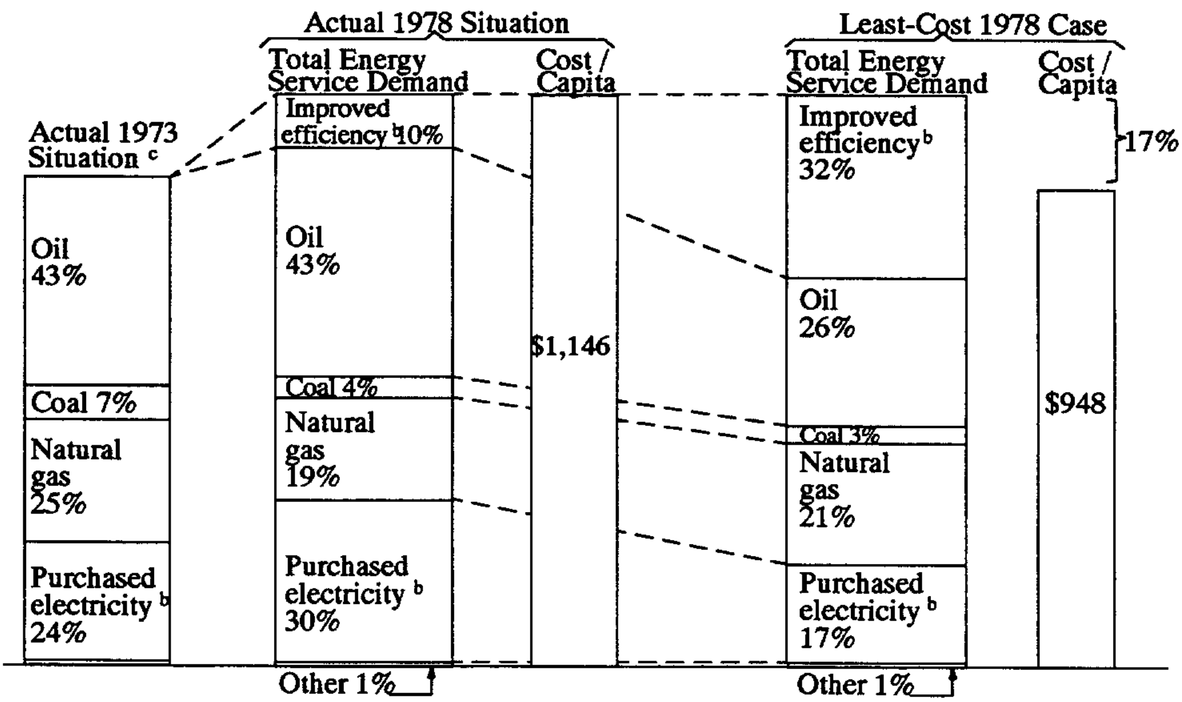
In the CGE and similar models there is no allowance for the possibility of energy savings at no cost, or even at a profit (the "free lunch"). According to standard theory, such a situation should not arise in a competitive market. When an engineer suggests that such possibilities exist in reality, the stock rejoinder is "if such an opportunity did exist, some entrepreneur would find and exploit it". If an apparent opportunity is not exploited the standard explanation is "hidden costs". This satisfies most economists but few engineers or scientists [e.g. Johansson *et al* 1993].

A recent study sponsored by four major organizations (Union of Concerned Scientists, Natural Resources Defense Council, Greenpeace and the World Resources Institute) entitled *America's Energy Choices: Investing in a Strong Economy and a Clean Environment* reached conclusions almost diametrically opposed to those obtained by the equilibrium models. It concluded that a 70% reduction in CO_2 emissions could be achieved in 40 years, at an annual "cost" of $2.7 trillion but with annual savings worth $5 trillion, for a net annual gain of $2.3 trillion. Obviously, this result is inconsistent with the GCE assumption of Pareto-optimality and growth-in-equilibrium.

Who is right?

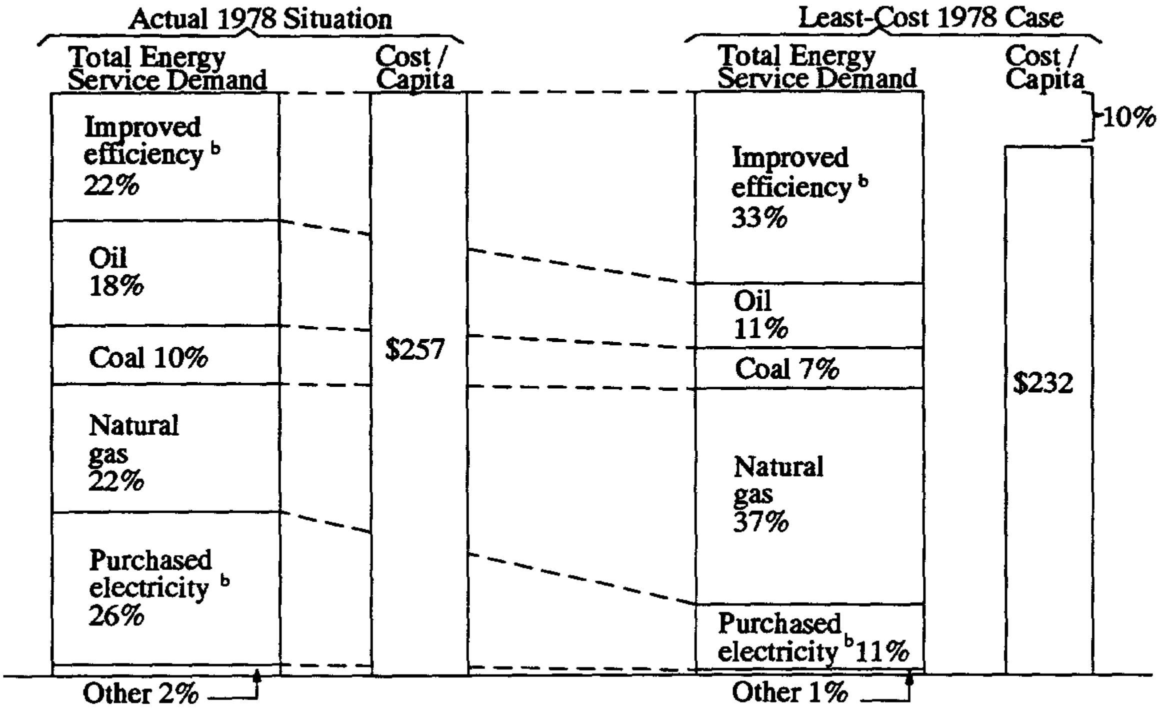
Evidence Pointing to Disequilibrium

As noted earlier, investment opportunities offering rates of return far above the average constitute direct evidence of economic disequilibrium. (In an equilibrium economy such opportunities should not exist). There is a growing body of evidence supported by numerous examples that many investments — for instance in energy or resource conservation — can pay for themselves in reduced operating costs in a few months to a few years, even at present (lower) energy prices. A "free lunch" is an investment opportunity that requires little or no new investment, and which results in a net saving, rather than a net cost. It is like money lying on the street, waiting to be picked up. If opportunities do exist the economy cannot be in equilibrium.



(a) The primary fuel equivalent of service demand in 1978 was 79.0 quads, plus 9.2 quads of improved efficiency (calculated against a base of stock & equipment in place in 1973) or a total of 88.2 quads. Actual service depends on the conversion efficiency of fuels & equipment utilized.
1 quad = a quadrillion = 10**15 BTU. Another means of visualizing a quad is 1 million barrels/day of oil equivalent = 10**15 BTU (quads)/year.
(b) In terms of primary fuel (c) Primary fuels demand in 1973 was 74.6 quads.

Figure 1: Energy Sector Market Shares[(a)] of Various Technologies
Source: [Sant 1979]



(a) The primary fuel equivalent of service demand in 1978 was 28.2 quads, plus 7.9 quads of improved efficiency & 0.8 quads of biomass (calculated against a base of stock & equipment in place in 1973) or a total of 88.2 quads.
(b) In terms of primary fuel

Figure 2: Industry Energy Sector Market Shares[(a)] of Various Technologies
Source: [Sant 1979]

Engineers and businessmen think of costs, not as economic growth foregone, but in a more traditional way. A businessman would try to compute cost as the annualized net *additional* capital and operating costs of investing in and using a new technology. For a business or a householder, a "net saving" translates into a profit, or a return on investment. The usual standard of comparison is money invested in high quality government bonds or, simply "money in the bank". In other words, if a given investment produces a greater return (assuming equal risk) than money invested at the current rate of interest, it is "profitable" in the above sense. The usual target rate of return-on-investment (ROI) for business investments — which tend to be fairly risky, and which must allow for taxes on the profits — is typically around 25% to 30% per annum. If the best return that can be realistically expected is only 15%, a prudent businessman will not make the investment.[3]

Given that capital is scarce, a rational investor will choose the most profitable ventures first. Thus, a large firm will typically try to rank order the various proposals for capital spending (in order of expected ROI) and go down the list until either the available money for investment runs out or the threshold is reached. In principle, government would do the same. In a quasi-equilibrium economy, there should be enough capital to fund all of the promising

[3] On the other hand, for a government (which does not have to pay taxes and can borrow money at lower rates than a private business), an 8% or 10% expected rate of return is probably adequate justification. (This is often equated roughly with the social discount rate).

projects, i.e. all the projects with expected ROI above the appropriate threshold level. It follows that the really "good" (i.e. profitable) projects should be funded as soon as they appear on the horizon. In an economy very close to equilibrium there should be no (certainly very few) investment opportunities capable of yielding annual returns of 50% or more.

Many authors have argued for the existence of such opportunities. If this is true, it constitutes a major challenge to the economists' standard assumption that existing technical choices were "optimal" to begin with. Case study after study has shown that changes in the energy production/consumption system can be identified that would pay for themselves in just a few months or a few years at most [e.g. Hirst & Hannon 1979; Lovins *et al* 1981; Williams *et al* 1983; ACEEE 1984; Berman 1985; Geller 1985, 1988; Goldemberg *et al* 1987, 1987a; Akbari *et al* 1988; Lovins 1988; Rosenfeld & Hafemeister 1985; Nelson 1989; Williams 1990, 1990a; Ayres 1991; Mills *et al* 1991]. A study carried out by the Italian energy research institute ENEA is typical of the results of engineering surveys [e.g. d'Errico *et al* 1984]. It found technological "fixes" with payback times of 1-3 years — well below the typical threshold for most firms and several times faster than investments in new supplies . Appendix A, taken from the ENEA study, lists numerous examples of commercially available equipment, together with typical applications and pay-back times.

A typical example is the compact fluorescent light bulb, touted by Amory Lovins of the Rocky Mountain Institute. According to him a 15 watt compact bulb can replace a 75 watt conventional incandescent light, last 13 times longer and cut energy consumption (and electricity costs) by 80% to 90%. Lovins has characterized this as "No free lunch. It's a lunch they pay you to eat" [Cherfas 1991]. People are skeptical of advertising claims, for good reason. The new bulbs may not be quite as good as Lovins has claimed, and they do have some drawbacks (for example, a tendency to flicker). But the slow rate of public acceptance may be attributable in large part to the fact that there are large fixed investments in highly automated incandescent light bulb factories. This makes the dominant producers like GE, Philips, Siemens *et al* less than wildly enthusiastic about pushing the newer technology.

A study by the Mellon Institute for the Department of Energy [Mellon Institute 1983] argued strongly for a "least cost energy policy" that would generate substantial savings [Sant 1979; see also Carhart 1979; Sant & Carhart 1981]. The results are worth a brief recapitulation. In economic terms, the least-cost strategy would have saved $800 per family (17%) or $43 billion in that year alone [ibid]. Taking the year 1973 as a standard for comparison, such a strategy would have involved a sharp reduction in the use of centrally generated electricity (from 30% to 17%) and a reduction in petroleum use from 36% to 26%. The only primary fuel to increase its share would have been natural gas (from 17% to 19%). Interestingly, the Mellon study suggested that "conservation services" would have increased their share from 10% to 32% in the optimal case. See *Figures 1* and *2*.

The Mellon study concluded that energy conservation would *not* have been a net cost, as any equilibrium growth model would necessarily have predicted. Rather, it would have produced net savings translatable into increased growth. Between 1973 and 1978 "conservation services" reduced actual energy consumption in the U.S. by 10% compared to the 1973 baseline pattern; but a 32% reduction would have been both possible and cheaper! The differential between actual and potential is 22%.[4] The greatest potential savings were to be found in the so called "buildings" sector (23%). However, non-trivial savings (10%) were also available in the industrial sector. Significant opportunities also existed in industry, notably by avoiding (or in other words, using) waste heat by means of heat-cascading, heat pumps and co-generation (of electricity and process heat).

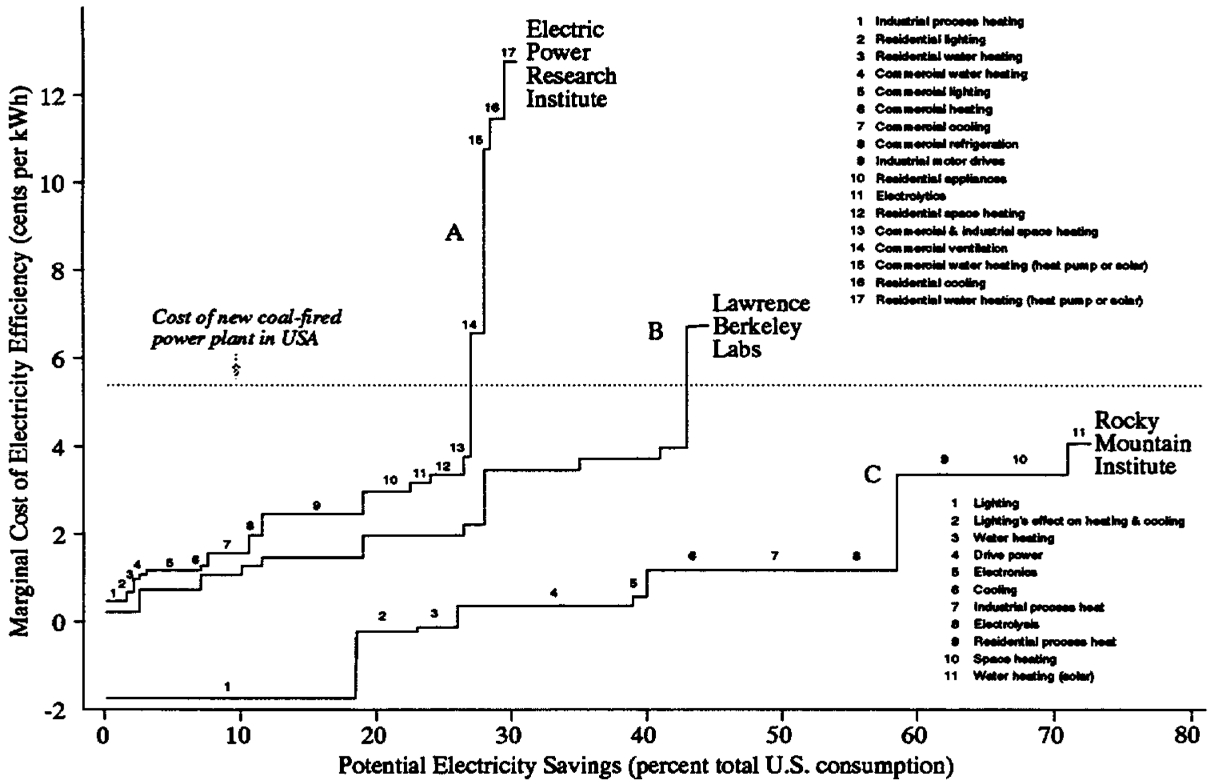


Figure 3: Alternative Estimated Supply Curves for Electricity in the U.S.
Source: [adapted from Fickett et al 1990]

Other optimization studies yield similar results. For example, *Figure 3* shows three different supply curves for electric power, estimated by three different U.S. groups. The most conservative curve (A) was provided by A.P. Fickett and C.W. Gellings of the Electric Power Research Institute (EPRI), which is funded by the electric utilities. Nevertheless, it indicates that demand side savings would be cheaper than adding new capacity up to nearly 30% of current consumption levels. The most optimistic curve (C), prepared by Lovins and the staff of the Rocky Mountain Institute, suggest that demand reduction of over 70% could be achieved at a net savings. Lawrence Berkeley Laboratories (DOE) obtained intermediate results, with electricity use reduction of 40% at net savings.

[4] On the basis of the Mellon Institute's figures, the 22% unachieved but possible energy savings in 1978 would have reduced carbon dioxide production by at least 25% as compared to actual emissions. This amounted to around 275 million tons. The monetary savings to energy consumers would have been $43 billion, as noted, or about $65 per ton of CO_2 saved.

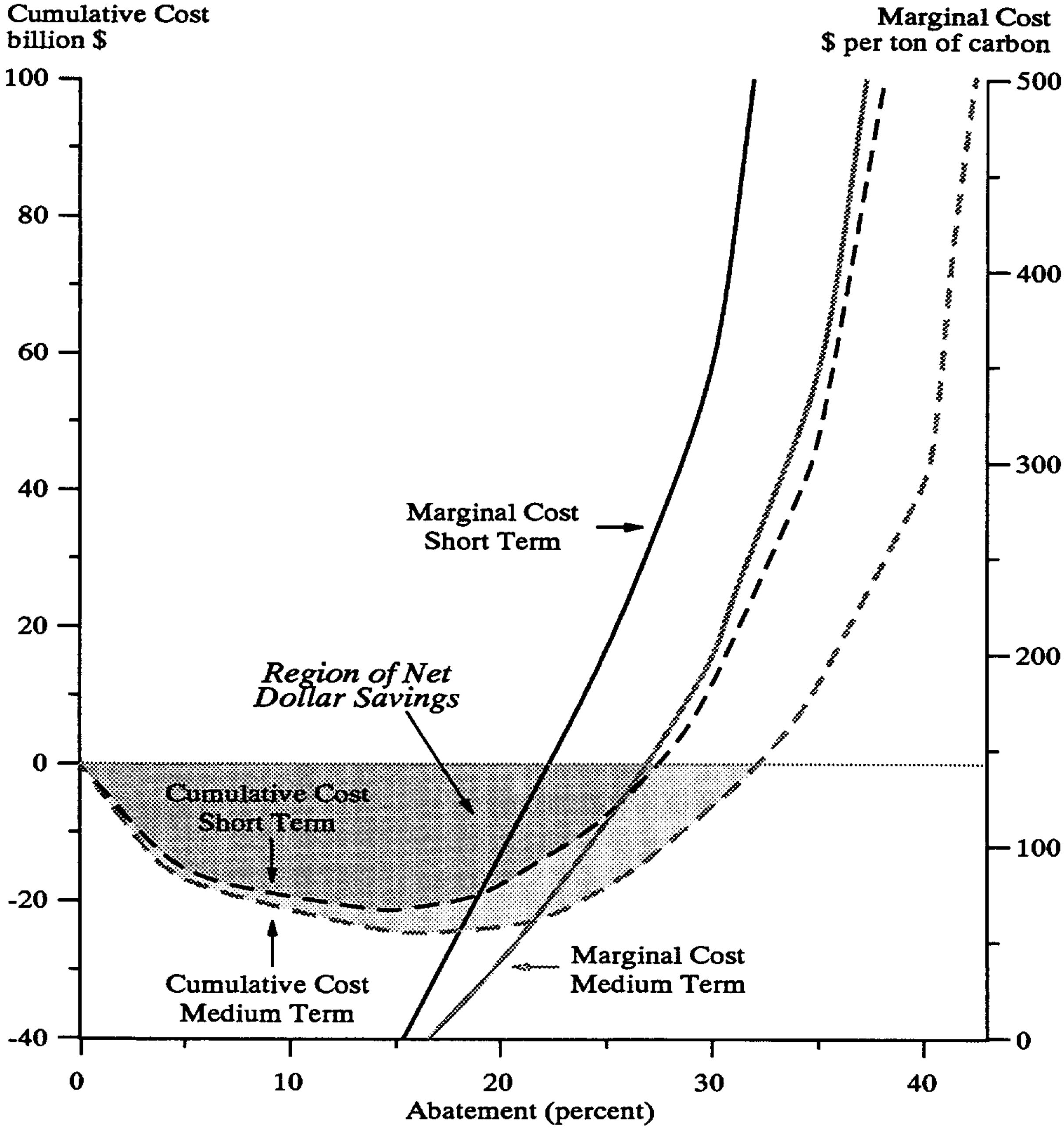
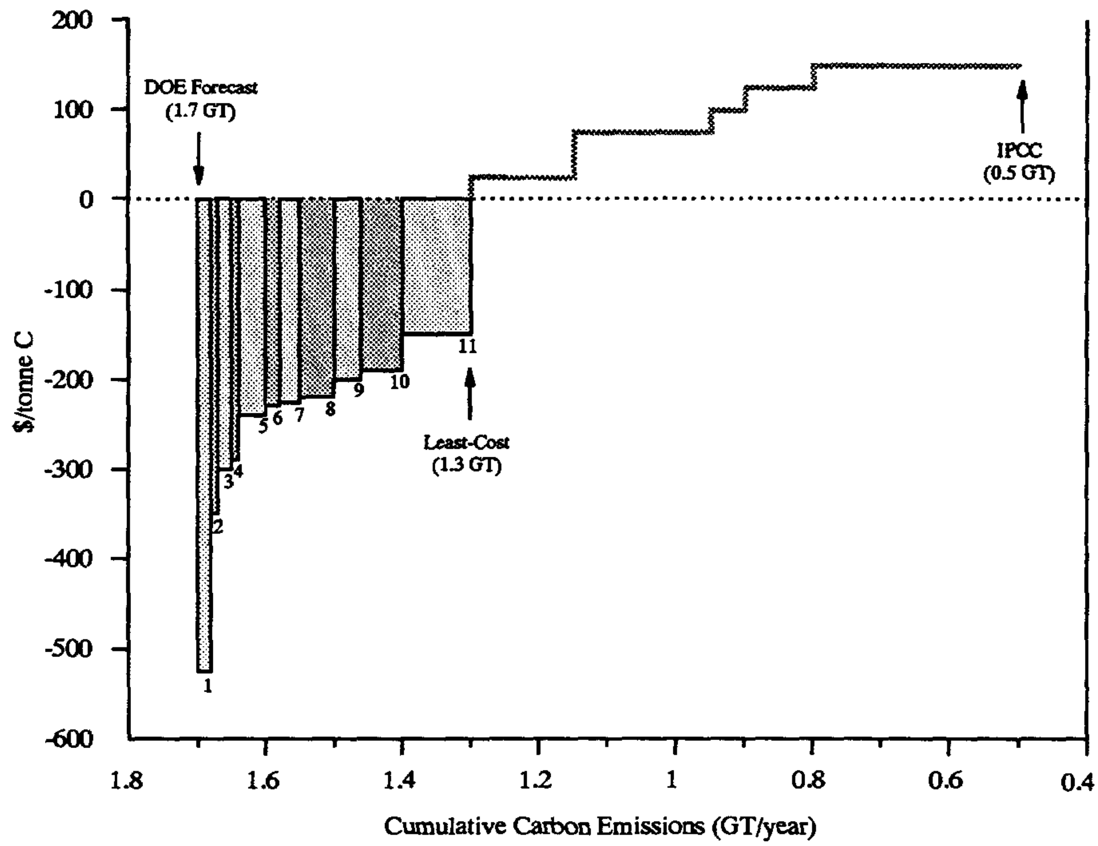


Figure 4: Cumulative & Marginal Cost of CO_2 Abatement; Short & Medium Term
Source: [Adapted from Cifuentes 1991]



Notes:
The x-axis shows total national carbon emissions reduction achievable through the adoption of the 11 cost-ranked measures listed below. The upper limit (1.7 GT) represents the current US DOE forecast for the year 2000. The "IPCC label indicates the level of reductions necessary to stabilize atmospheric concentrations of greenhouse gases according to the Intergovernmental Panel on Climate Change. The y-axis indicates the net cost of implementing each measure. Negative costs reflect a net economic benefit compared to the DOE forecast. The average net economic benefit of avoided emissions for Steps 1-11 is $231 per tonne.

Legend:
1. Raise the federal gasoline tax by 12 cents per liter within 5 years and spend part of the revenue on mass transit and energy-efficiency programs.
2. Use white surfaces and plant urban trees to reduce air conditioning loads associated with the summer "heat island" effect in cities.
3. Increase the efficiency of electricity supply through development, demonstration, and promotion of advanced generating technologies.
4. Raise car and light truck fuel-efficiency standards, expand the gas-guzzler tax, and establish gas-sipper rebates: new cars average 5.2*l*/100km and new light trucks average 6.71*l*/100km by 2000.
5. Reduce federal energy use through life-cycle cost-based purchasing.
6. Strengthen existing federal appliance efficiency standards.
7. Promote the adoption of building standards and retrofit programs to reduce energy use in residential and commercial buildings.
8. Reduce industrial energy use through research and demonstration programs, promotion of cogeneration and further data collection.
9. Adopt new federal efficiency stands on lamps and plumbing fixtures.
10. Adopt acid rain legislation that encourages energy efficiency as a means for lowering emissions and reducing emissions control costs.
11. Reform federal utility regulation to foster investment in end-use energy efficiency and cogeneration.

Figure 5: Net Costs of Avoiding Emissions: USA in 2000
Source: [Mills et al 1991; Figure 2]

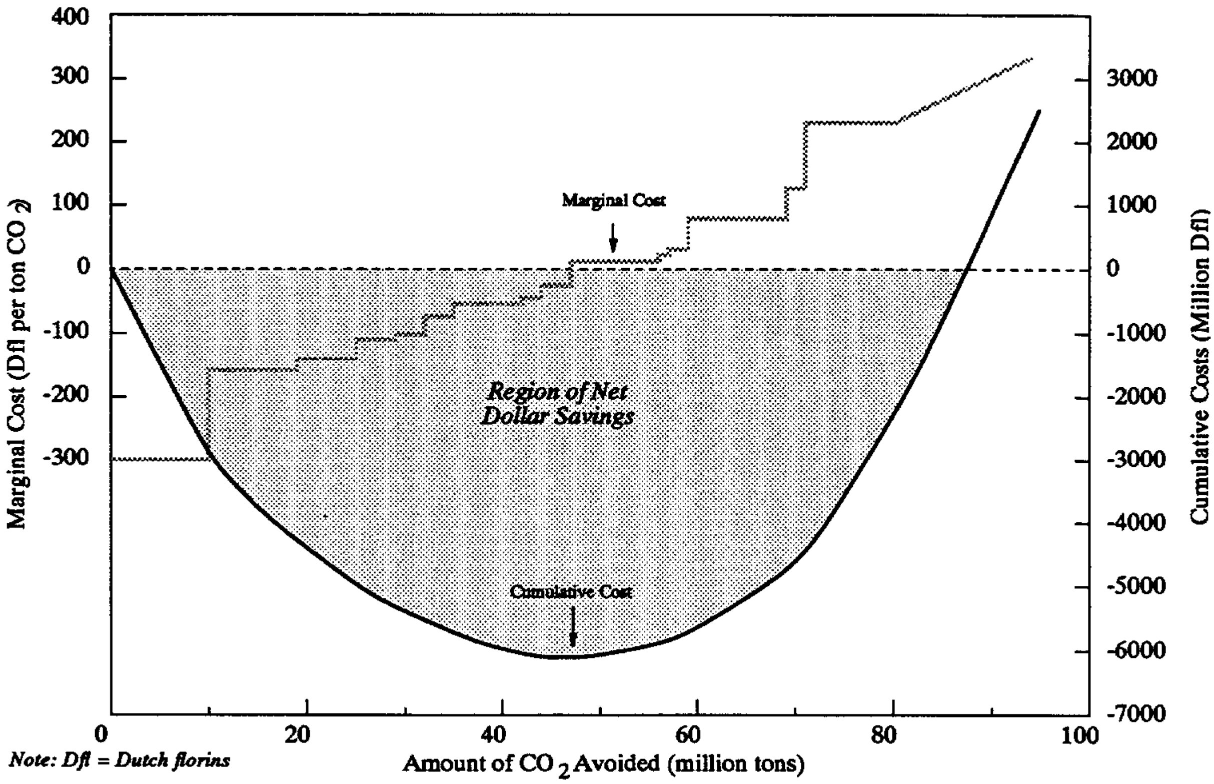


Figure 6: Cumulative & Marginal Cost of CO_2 Abatement
Source: [Adapted from Blok 1989]

A group at Brookhaven National Laboratories has recently undertaken what it calls a "least cost energy study" using its MARKAL linear programming model [Fishbone & Abilock 1981; Morris *et al* 1990; Morris *et al* 1991]. However the BNL group contented itself with a forecast without determining the least cost means of supplying current U.S. energy needs. However, the MARKAL data base yields the marginal energy cost curves shown in *Figure 4*. Both short and medium term supply curves dip well below zero before beginning to rise. Incremental cost does not become positive until savings (i.e. CO_2 abatement) exceed 25% of current energy costs. This result is quite consistent with the earlier Mellon results. This is evidence of unexploited opportunities to save both energy and money i.e "free lunch". Several other published energy supply curves, all with the same basic shape, are found in [Lovins & Lovins 1991]. Similar curves have been published by other authors, such as [Mills *et al* 1991] and the Netherlands [Blok 1989]. The latter two are shown in *Figures 5 and 6*.

Even more compelling evidence of unexploited opportunities for high returns, indicating disequilibrium, comes from the experience of the Louisiana Division of Dow Chemical Co. in the U.S. In 1981 an "energy contest" was initiated, with a simple objective: to identify capital projects costing less than $200,000 with payback times of less than 1 year [Nelson 1989]. In its first full year (1982), 38 projects were submitted, of which 27 were selected for funding. Total investment was $1.7 million and the 27 projects yielded an average ROI of 173%. (That is, the payback time was only about 7 months). Since 1982, the contest has continued, with an increased number of projects funded each year. The ROI cutoff was reduced year-by year to 30% in 1987, and the maximum capital investment was gradually increased. For 1993 140 projects were funded for $9.1 million. *Table I* below summarizes the results of the Dow experience.

Table I: Summary of Louisiana Division Contest Results - All Projects

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Winning Projects	27	32	38	59	60	90	94	64	115	108	109	140
Capital, $MM	1.7	2.2	4.0	7.1	7.1	10.6	9.3	7.5	13.1	8.6	6.4	9.1
Average ROI (%)	173	340	208	124	106	97	182	470	122	309	305	298
ROI Cut-Off (%)	100	100	100	50	40	30	30	30	30	30	50	50
Savings, $M/yr												
Fuel Gas[a]	2970	7650	6903	7533	7136	5530	4171	3050	5113	2109	5167	4586
Capacity	83	-63	1506	2498	798	3747	13368	32735	8656	17909	11645	20311
Maintenance	10	45	-59	187	357	2206	583	1121	1675	2358	2947	2756
Miscellaneous	—	—	—	—	—	19	-98	154	2130	5270	518	788
Total Savings	3063	7632	8350	10218	8291	11502	18024	37060	17575	27647	20277	28440

Source: [Nelson 1993: Tables 4 and 6]

It is important to note that, although the number of funded projects increased each year, there was (through 1993) no evidence of saturation. Numerous profitable opportunities for saving energy, with payback times well below one year, still exist even after the program has been in existence for 12 years. More recent data became available in the spring of 1993. Almost unbelievably, the average ROI increased. For the years 1991 and 1992 the ROI's were 309% and 305%, with a slight decline to 298% in 1993. Over the 12 years since the contest began, the average post-audit ROI on 575 audited projects was 204% and total audited savings are over $100 million per year.

On the average, al contest projects have paid for themselves in 6 months, with a drop to 4 months in the last 3 years! One would have to suspect that the program could still be expanded many-fold before reaching the 30% ROI threshold. Furthermore, it is important to emphasize that these opportunities exist even in a sophisticated and cost conscious firm at relatively low U.S. energy prices. Should taxes or a new energy crisis force U.S. prices higher (i.e. toward world levels), the number of such opportunities would be multiplied further.

If the studies cited above are correct, there exist major opportunities to save both energy and money at the same time. If these opportunities are not chimerical, the economy *cannot* be in the assumed state of equilibrium. Evidence of economic disequilibrium, in terms of an enormous disparity between modest (10%-15%) rates of return on "conventional" energy supply investments and extraordinarily high (100% up) financial returns available from energy conservation investments, tends to confirm the heterodox position [Ayres 1991; Ayres & Walter 1991].

The evidence of profitable opportunities for materials conservation is less well documented, but nevertheless impressive. The 3-M Company has been a leader. In 1975 it introduced a company-wide program called "Pollution Prevention Pays", or PPP. Project proposals at 3M were judged by the following four criteria: (1) reduce or eliminate a problem pollutant (2) use energy and raw materials more efficiently, (3) introduce a technical innovation of some sort and (4) offer a financial incentive to the company. Since 1975 some 2500 projects have been funded which cut air pollution produced by the firms plants by 50%, while also saving $500 million. (An additional $600 million was also saved by energy conservation projects). Dow Chemical Co. has a similar program called Waste Reduction Always Pays, or WRAP. For the Louisiana Division, WRAP projects (as distinguished from energy contest projects, typically achieve ROI's over 100%, although there is no formal ROI cutoff requirement [Nelson 1993].

Other companies have followed 3M's lead. Of course PPP and WRAP are slogans to catch the attention of employees and the public. Clearly waste reduction does not always save money. But, if the standard neo-classical assumption were valid such profitable "no regrets" opportunities would not exist at all. The fact that progressive firms have found many opportunities to reduce wastes, and save significant sums of money at the same time, is significant. The key seems to be remarkably simple: to question the comfortable assumption that every process and every procedure is already optimal, and to look actively for better alternatives.

Most economists are unaware of the extent of the evidence for disequilibrium. The standard explanation for why such opportunities are not exploited, citing unspecified "hidden costs" hardly seems convincing. Institutional barriers and market failures are much more plausible. It should be said, incidently, that to admit the existence of significant and persistent departures from Pareto optimality is not to deny the existence of equilibrating tendencies or "forces". Both can exist (and apparently do exist) at the same time. A water skier follows the motor boat, in a macro sense, but he makes wide excursions from the boat's actual path.

In this regard, it is worthwhile pointing out that theoretical work by Brian Arthur [Arthur 1988], has clarified the existence of straightforward economic mechanisms — notably returns to scale and returns to adoption — that can "lock in" inferior technologies and "freeze out" superior ones. It is also obvious that socio-political mechanisms (lobbying by special interests) can and often do assist in distorting the outcomes of technological competitions. Such mechanisms tend to create and preserve economic disequilibria.

Concluding Comments

There is no theoretical reason, nor any empirical evidence, to justify the assumption that the real economic system is ever actually in, or even very close to Pareto-optimal equilibrium condition. Indeed, on reflection, this can hardly be surprising. After all, an equilibrium state is one in which "nothing happens or can happen"[5] because all exchange transactions that could improve anyone's welfare have already occurred! All the interesting economic actions and reactions, in short, occur not *at* equilibrium, but *en route* to equilibrium. Growth-in-

[5] To paraphrase a famous characterization of thermodynamic equilibrium.

equilibrium is a convenient analytic fiction. But as a basis for forecasting the future it is perverse nonsense because neither the causes nor the consequences of the assumed growth can be taken into account within such a model.

A much more comprehensive economic theory is needed, to explain the mechanisms (or "forces") that move economic systems *toward* equilibrium, and thereby drive them to evolve. Once these mechanisms are identified and understood, it should be possible to predict the *rates* of approach to equilibrium under various conditions, especially concerning information transfer. The needed theory would also explain how and why the economic system is forced away from its hypothetical (i.e. 'shadow') equilibrium condition by radical Schumpeterian technological changes, or socio-political upheavals. The needed theory would also endogenize technological change, within a given framework of technological possibilities determined by the laws of nature and the properties of real materials. However, such a theory is for the future.

Meanwhile, national policymakers tend to favor the orthodox neo-classical position, because it is favored by the majority of academic economists and built into virtually all of their models. This is so despite the fact that the equilibrium postulate is purely theoretical, and is contradicted by considerable empirical evidence. The reason for this bias is three-fold. First, among academics the equilibrium assumption permits fairly complex models to be constructed and solved, whereas to discard the equilibrium assumption would be to discard the use of models. Second, there is honest but widespread misunderstanding among economists and policymakers alike, of the limitations of large computerized CGE models. And, third, among model-users in and out of government there is an element of self-interest. Equilibrium models essentially justify the *status quo*. Academics need research funding, and established interests are the best source. Politicians, who determine the priorities of government agencies, themselves depend on campaign contributions by established interests that oppose radical change.

This tendency to justify the *status quo* is unfortunate, to say the least, in a world where many current trends are unsustainable and radical change may be a necessary prerequisite to long-run human survival itself.

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Appendix A

N	Area of Application	Type	Input	Output	Cost K US$	Saving K US$	Payback years
1	boilers	recuperator	gas waste LE 400° C	hot water GT 70° C	5.7	4.8	1–3
2	boilers	recuperator	gas waste LE 400° C	diathermic oil heating	28.4	20.5	1–3
3	incinerators	recuperator	gas waste LE 1200° C	steam 1–5 ATE	19.3	8.2	1–3
4	boilers	recuperator	gas waste	process water heat	9.2	5.1	2–3
5	boilers	recuperator	gas waste LE 400° C	process water heat LE 80° C	62.5	62.5	1–2
6	boilers	radiation recuperator	gas waste 900–1350° C	process water heat LE 600° C	44.3	42	1–2
7	air condit.	rotary exchanger	air LE 50° C	air cooling GE 15° C	12.5	5.7	2–3
8	boilers	rotary exchanger	gas waste LE 150° C	process air heat LE 120° C	15.9	26.1	0–1
9	boilers	rotary exchanger	gas waste LE 500° C	process air heat LE 400° C	45.5	64.2	0–1
10	air condit.	rotary recuperator	gas waste LE 200° C	external air heat/cooling	9.1	2.7	2–4
11	boilers	gravity recuperator	gas waste LE 170° C	process water heat	41.5	22.7	1–2
12	boilers	tubular recuperator	gas waste LE 440° C	process water heat	28.4	9.1	2–4
13	boilers	inclined tubes recup.	gas waste LE 170° C	process water heat	27.3	11.8	1–3
14	boilers	heating cube recup.	gas waste LE 250° C	process water heat	19.9	18.8	1–2
15	ovens	recuperator	gas waste LE 250° C	process water heat LE 150° C	6	1.7	2–4
16	boilers	recuperator	gas waste	room air heating	1	0.6	1–2
17	boilers	modular recuperator	gas waste LE 140° C	process air heat	4.5	8.5	0–2
18	boilers	recuperator notes	gas waste	process	14.2	6.1	2–3
19	boilers	plate exchanger	liquid waste LE 250° C	process water heat	54.5	33	1–2
20	boilers	rotary recuperator	liquid waste 40–95° C	process water heat	9.7	35.8	1–2
21	boilers	automatic recuperator	liquid waste LE 95° C	process water heat	55.7	37.8	1–2
22	boilers	re-evaporator	steam power	low pressure steam	7.4	13.9	0–1

N	Area of Application	Type	Input	Output	Cost K US$	Saving K US$	Payback years
23	tunnel exchanger	room air ovens	gas waste	room air heating	11.4	4.9	2–3
24	steel press	room air exchanger	gas waste	room air heating	22.7	15.9	1–2
25	refriger. groups	heat pump	gas waste	water heat LE 55° C	18.2	6.4	2–3
26	refriger. groups	heat pump	gas waste	water heat LE 75° C	198.9	94.3	2–3
27	refriger. groups	refr. heat recuperator	gas waste	water heat LE 55° C	244.3	142	1–2
28	refriger. groups	refr. heat recuperator	gas waste	water heat LE 55° C	8	8.4	0–2
29	refriger. groups	heat pump	gas waste	water heat LE 60° C	28.4	13.8	2–3
30	compressors transform.	heat pump	gas waste 25–35° C	water heat	0.9	0.4	2–3
31	refriger. groups		gas waste 25–35° C	water cooling	1.7	1.9	0–1
32	dryer	refrigerator	gas waste	water heat	1.7	1.9	0–1
33	air compressors	heating recuperat.	liquid waste	room air heating	15.3	11.1	1–2
34	air compressors	energy recuperat.	gas waste	water heat LE 80° C	2.6	1.6	1–3
35	computer center	air condition.	gas waste	water heat LE 70° C	4	21	0–2
36	refriger. groups	heating pump	gas waste	water heat LE 75° C	409.1	154.5	2–3
37	refriger. groups	plate exchanger	gas waste	water heat	25	50.6	0–1
38	refriger. groups	cool accumulat.	gas waste	cooling		14.2	
39	boilers	pyrolitic system	solid waste	fuel substitut.	113.6	49.4	2–3
40	boilers	grape boilers	solid waste	fuel substitut.			0–1
41	wood	chip boilers	solid waste	fuel substitut.	11.9	47.2	0–1
42	boilers	underwater combustion	liquid waste LE 60° C	process heating	23.9	7.8	2–4
43	boilers	radiant tubes	gas waste GT 300° C	room air heating	28.4	10.2	2–3
44	boilers	recuperator	gas waste	process heating			1–4
45	gas boilers	modular condenser	gas waste	process heating	11.4	5.4	2–3
46	room air exchange	air purifier	air waste	fuel substitut.	5	2.7	1–2
47	Industr. building		air waste	fuel substitut.	1.8	1.5	1–2
48	Industr. building		air waste	room air heating (floor)	48.3	22.7	1–3