FOIA Number: 2017-1095-F

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Subseries:

OA/ID Number: 13727

FolderID:

Folder Title:
T&T [Targets & Timetables] Current Draft--[Climate Change]

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Targets and Timetables : Executive Summary

How ambitious should we be in seeking to ameliorate global climate change? Is it more advisable to reduce emissions of greenhouse gases (GHG) early and rapidly, or more gradually? This paper examines policy options for GHG emissions targets and timetables and reviews the academic literature and other relevant information and analysis to compare them. We find that a given environmental goal, expressed in terms of the level at which atmospheric GHG concentrations are induced to level off, can be attained at far lower economic costs if emission reductions are phased in gradually rather than suddenly. More specifically, we conclude that a moderate path such as "eliminate emissions growth by 2010-2020, and return emissions to 1990 levels by 2040," seems to be preferable on economic grounds to the more aggressive alternative "return emissions to 1990 levels by 2010."

1. Tradeoffs between front-loading and back-loading emissions reductions

It is easy to state the basic forces at work in the trade-off between front-loaded (reducing emissions earlier) and back-loaded emissions reductions (allowing emissions reductions over longer periods).

Four factors work in favor of back-loading:

- need to ~~allowing~~ allow time for the capital stock to turn over. By way of stylized illustration, scrapping all coal-fired power plants by 2010 would mean writing off 88% of the capital stock in this sector; waiting until 2020 would necessitate scrapping only 49% of the plants before the end of their normal useful life.
- the time-value of money. Resources not spent on emission reductions early on can be invested at a positive return, so as to purchase more emission reductions later.
- allowing for uncertainty to be resolved.
- giving more lead time to develop and implement new technologies.

The most important argument in favor of front-loading:

- political credibility. An announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 years or more into the future -- will not be credible. Only early concrete measures will send the signal necessary to move patterns of research, investment, and consumption onto the new path.

2. The costs of "1990 levels by 2010"

The costs of reducing emissions to 1990 levels by 2010, as the cost of any path, depend heavily on the international regime and domestic implementation. "We can do it smart or we can do it dumb." But any effective program will have to raise the cost of GHG emissions, particularly the cost of using fossil fuels that put carbon dioxide into the air. A broad range of models place the carbon permit price required to achieve this target in the range of $70 - $200 per ton. This surcharge translates into an increase in the price of gasoline between 18 and 50 cents per gallon and an increase in the price of coal between 250 and 500 percent. Averaging over fuels, these price increases are nine times greater than the BTU tax that was proposed in 1993, and as great as the oil shocks of the 1970s. (The necessary increase in price could be cut if we are able to pay Russia, developing countries, or others to reduce emissions in our place. But the remaining price increase would nevertheless be substantial.)

These increases in the price of energy might or might not have the substantial negative effects on output of the 1970s oil shocks. Whether they do depends on many things, such as whether the policy is implemented efficiently (e.g., by auctioning emissions permits or a carbon tax) or inefficiently (e.g., by command-and-control style regulation), and whether any revenues that may be generated are redistributed by means of tax cuts that lower the cost of capital to firms. In any case, the policy will have substantial negative effects on consumption, in order to free up resources for investment in new low-carbon plant and equipment.

3. The effects of a moderate path, peaking in 2010-2020

One possible more moderate path is specified as follows:

(i) begin to reduce the rate of growth of emissions in the near-term (2000-2010),

(ii) eliminate emissions growth in the medium term (so that emissions at the end of the decade 2010-2020 were the same as at the beginning), and

(iii) return emissions to the 1990 level in the longer term (e.g., 2040).

The overall cost of this approach is much less than that of the more aggressive timetable, 1990 by 2010. Estimates suggest that the price of carbon would be between $5/ton and $12/ton in 2010. (It would have to continue to rise thereafter, as is also true under the first approach.) Gas prices would rise by an estimated 2 to 3 cents in 2010, and coal prices by 25%-35%. Effects on the economy are scaled down accordingly. Estimates of the loss in consumption are roughly 1/10-1/3 the size of the more aggressive approach.

4. Environmental effects of alternative dates for stabilizing emissions

What is the environmental loss that the planet must bear in exchange for economic gain from slowing emissions cuts? The answer depends entirely on emissions during the remainder of the 21st century (and thereafter). Differences in emissions in the early years of the century have virtually no effect on the cumulative concentration levels. But "even the longest journey begins with a single step." Differences in that first step are important to the extent that they begin the journey down different pathways.

Let us consider the environmental effects of four different emissions paths of increasing ambition in controlling GHG emissions. The first path represents emissions growth in the absence of any policy intervention, a.k.a. business as usual (BAU). The second is the moderate path described above, which peaks in 2010, and the third is achieving 1990 by 2010. The final path is even more aggressive and achieves emissions 10% below 1990 levels by 2010. We assume that each path eventually stabilizes annual emissions at the 1990 level (or 10% below, in the last case) through the remainder of the century. Note that this assumption, while it implies a growing gap with the BAU growth path over time, does not cut emissions enough to prevent concentrations in the atmosphere from increasing.

As one can see from the table below, under BAU, estimated temperatures rise 1.06 and 2.36 degrees centigrade in 2050 and 2100, respectively. The moderate path mitigates the warming by 0.06 degrees in 2050 and 0.19 in 2100. The 1990 by 2010 path reduces the warming relative to BAU by an estimated 0.08 and 0.21 degrees, in the respective years, a very small additional effect relative to the moderate path. The most aggressive path has virtually the same small effect. The three policy options postpone by 6 to 9 years the date at which total atmospheric CO2 concentrations reach a level that is double the pre-industrial level (about 550 ppmv).

Environmental effect (degrees centigrade)	Path of emissions of GHG			
	BAU	Moderate path	1990 levels by 2010	10% below 1990 levels by 2010
Temperature increase in 2050, **total**	1.06	.99	.98	.97

Temperature increase in 2100, **total**	2.36	2.17	2.15	2.11
Temperature increase in 2050, **relative to BAU**	0	-.07	-.08	-.09
Temperature increase in 2100, **relative to BAU**	0	-.19	-.21	-.25
Additional years until CO2 doubling, **relative to BAU**	0	6	7	9

5. A big difference in cost for two paths to the same ultimate goal

Perhaps the strongest case against an aggressive path like "1990 in 2010" is that *the same ultimate goal in terms of concentrations* can be achieved far more cheaply by imposing aggressive cuts in emissions later in the 21st century rather than earlier. Recall that estimated concentrations and temperatures continue to rise in subsequent centuries under any of the paths outlined above. In order to put a bound on the eventual climate disruption, one has to put a bound on concentrations, which in turn requires that we reduce emissions below 1990 levels. Modelers can compute the path that minimizes the total economic costs of attaining a given ultimate concentration target, and we can compare it to other paths leading to the same target.

The most important implication of the least cost mitigation path is that it costs the U.S. $0.124 trillion in terms of lost consumption (present discounted value), as compared to $0.303 trillion under the "1990 in 2010" path. Thus *the least cost mitigation path generates savings of 60 percent from the 1990 in 2010 path.* Assuming that environmental effects depend on concentrations, there is little or no environmental cost to be weighed against the large economic benefits of going more slowly.

The estimated least-cost path has several other interesting implications. It indicates that emissions rise gradually in the early years and that Annex I countries' emissions peak in the decade 2020-2030 at about 29 percent above 1990 levels. Annex I emissions do not return to their 1990 levels until after 2050. This least cost mitigation path generates quite low values for carbon emissions rights in the early years. The permit price is only $2/ton in 2010, and slowly rises thereafter. Only in the latter part of the century does it rise significantly, to $156/ton in

2100.

The experiment assumes that developing countries are successfully brought in to the agreement, with their participation phased in between 2030 and 2050. Emissions from developing countries peak in 2050. Without the participation of the developing countries, attaining the target of 550 ppmv concentrations is virtually impossible, since they are such a rapidly growing share of world emissions.

It is important to keep in mind that all these cost estimates are "best case" scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

6. Political credibility

A path under which emissions peak in the decade 2020-2030 is far more conservative than the paths that have been discussed in international negotiations. The strong argument for moving the timetable forward is the one mentioned above: political credibility. The year 2020 is more than two decades in the future. A path under which emissions peak in the decade 2010-2020 represents early commitment to a tangible target ("eliminate emissions growth"), while estimates suggest that it is almost as beneficial as the least-cost path. The political credibility of the path could be further boosted by commitments at earlier dates such as 2000-2010 ("reduce emissions growth"). Credibility would be particularly enhanced by a specific proposal to raise the price of energy, even if by only a small amount, if domestic political opposition was not overwhelming.

More aggressive paths are likely to arouse greater political opposition, in correspondence to their greater economic cost. Where domestic opposition is sufficiently great to kill a proposal politically, the set-back will be to international political credibility -- and to environmental progress. The last section of the paper, however, discusses one possible option that might have the effect of helping to limit the economic cost and corresponding domestic opposition, for any given target/timetable: an escape clause triggered by the price of carbon emissions.

Predecisional draft. Very preliminary. Close hold. Do not distribute

Targets and Timetables

A U.S proposal for "targets and timetables" for reducing countries' emissions of greenhouse gases (GHG) must be made soon. ~~The U.N. Framework Convention on Climate Change has called for~~ We need economically cost-effective remedies to the problem ~~[cite? From JY]~~. Tradeoffs have to be made -- both with respect to the ultimate target and with respect to the timetable under which it is achieved. The subject of this paper is how to do them. (The paper does not directly focus on two other key sets of policy decisions -- domestic implementation, and proposals for developing country participation and other sorts of "when-and-where flexibility".)

It is futile to search for a single comprehensive econometric model within which these questions can be appropriately raised and definitively answered. Even within a given model, answers depend critically on the precise nature of the question asked (e.g., the extent of global participation and international trading, whether and how any revenue is recycled, what is assumed about technological progress, etc.) Furthermore, each model has strengths and weaknesses; each has questions to which it is better or worse suited to answer. Some, for example, model the energy sector in detail. Some allow for the fact that a coal-fired power plant cannot costlessly be converted to one that runs on natural gas. Some have enough tax policy detail to distinguish alternative ways of redistributing tax revenues. Some are capable of showing short-term macroeconomic disequilibria. Some include a long-term "carbon cycle" model that can keep track of the accumulation of GHG concentrations in the atmosphere and their climatological effects. Some break down the rest of the world into regions and so can model international trade. But No one model does everything.

The existence of modeling difficulties does not mean that we can abandon rigorous economic analysis. Rather, we must employ a broad set of economic tools to analyze the policy options. The tools employed in this paper include results from models of the energy sector and economy over the next 25 years, including but not limited to the models that were used by the Interagency Analytical Team (IAT) earlier in this year. The survey also includes models that are designed to operate on the longer time frame that is relevant for thinking about climatological effects. Other tools include simple relevant statistics, "meta-analyses" of existing models, historical and sectoral examples, and basic economic reasoning. Drawing on this broad array of analytical tools allows an intelligent evaluation of the policy alternatives.

1. Why do economists estimate high costs to early reductions in emissions?

The large economic impact of aggressive action

The measures necessary to implement serious reductions in GHG emissions would inevitably have very major effects on the U.S. economy. One path that has been widely discussed in the U.S. is to return to 1990 levels in 2010. (Still more aggressive paths seek to cut emissions 10 percent or more below 1990 levels by 2010. Intermediate paths are to return to 1990 levels by 2020, or to 10 percent above 1990 levels by 2010.) Estimates suggest that to reduce 2010 emissions to the level of 1990, it would be necessary to increase the price of energy on the order of $100 per ton of carbon.

This is a rough midpoint, around which there is a great range of uncertainty. The range of estimates in the IAT exercise was $80-$140, for the case without international trading. Some agencies believe that the necessary increase in price would be less than this, others that it would be more. It is anticipated that prices would have to continue to increase after 2010, even if emissions were not brought down any further, because of the widening gap vis-a-vis the business-as-usual case. (Energy modelers often make the assumption that, once the price of carbon goes high enough, some sort of unidentified "back-stop technology" will eventually be developed, thereby putting a limit on how high the price ultimately goes. But there is no way of knowing when or at what price such technology would come in.)

These estimates are representative of the broad economic literature. In a similar exercise, the Energy Modeling Forum, based in Stanford, has assessed a set of targets and timetables with 10 models (EMF-12, 1994; Gaskins and Weyant, 1993; Weyant, 1994; Richels, Edmonds, Gruenspecht, and Wigley, 1996). These models, employing the same benchmark assumptions, assessed the economic effects of achieving carbon emissions stabilization relative to 1990 in the year 2000 (with implementation beginning in 1990). The modeling results all clearly indicate that the tighter the emissions constraint, the higher the price of carbon.

[insert chart on average carbon taxes required to achieve C emission reductions in the U.S., 2000-2020]

The rough estimate of $100/ton in 2010 represents an increase in the price of oil of $11/barrel (52%), an increase in the price of gasoline of 26 cents/gallon, and an increase in the price of coal of 273%. One standard of comparison is the BTU tax that the Administration proposed in 1993. The increase contemplated here is 9 times larger. (This is for a weighted average of fuels. The multiple for coal is greater than this, and for oil is less.) 5 - 7

These large price changes signal major changes in the allocation of resources across activities and sectors. Need they require a reduction in the rate of growth of aggregate income and output? This depends, in particular, on two things. First, adjustment costs can impose a

negative effect on GDP and employment, especially in the short term. Model estimates of GDP losses from "1990 by 2010" reached __ in the IAT exercise under some pessimistic assumptions, and are higher in some other estimates. ___. The EMF-12 exercise also demonstrated that higher permit prices associated with tighter carbon emissions constraints resulted in larger GDP losses in 2010.

[insert chart on GDP losses from EMF-12]

Second, if measures to raise the price of energy result in the generation of revenues for the government, and they are used to reduce the cost of capital to firms (e.g., by means of an investment tax credit), despite the regressive implications for the distribution of income, then negative effects on economic growth can in the long run be moderated, eliminated, or possibly even reversed.[1] The meta-analysis of 162 simulations derived from 16 leading models by Repetto and Austin (1997, p.13) concludes that the negative effect on national income from stabilization in 2020 can be offset or reversed *if*:

(i) tax revenues are recycled so as to reduce the cost of capital to corporations,
(ii) developing countries participate in the agreement, *and*
(iii) optimistic assumptions are made regarding the availability of non-carbon backstop technologies, efficient economic responses, and increased energy and product substitution. If any of these optimistic assumptions fail, the GDP effect turns negative.

However, the best single measure of aggregate economic costs is the appropriate summation over time -- the present discounted value -- of foregone consumption. Even in a case so optimistic that there might be no effect on output, early action to address climate change would require a diversion of resources from consumption to investment. Thus the present discounted value of consumption is likely to fall. By way of analogy, defense build-ups have appreciable economic costs, in terms of foregone consumption, even though there is often little or no negative effect on aggregate GDP.

Analogy with the oil shocks of the 1970s

A standard of comparison for judging the magnitude of the price increases entailed in climate change policy is the oil shocks of the 1970s. The energy price increase now contemplated [an estimated 88 percent] for stabilization by 2010 is on the same order of magnitude as either the 1973-74 or 1979-80 oil price increases. Again, this is for a weighted average of primary fuels. Fossil fuel prices net of inflation doubled between 1972 and 1975, and doubled again by 1981.

[1] E.g, Jorgenson (1996).

Gasoline prices rose by 30 percent between 1972 and 1974 and by nearly another 50 percent from 1974 to 1981. Coal, as a substitute for oil, also experienced a price increase in the earlier episode, but by much less.

One can check independently how the price increase necessary in the present context compares to those of the oil shock decade . Carbon emissions in the year 2000 will be about 15% percent above 1990 levels (EIA ___). Between 1973 and 1984, U.S. energy use ~~departed~~

a departure from its usual growth trend, ~~and~~ was essentially unchanged in absolute terms. U.S. emissions fell by only 6.2%. This comparison suggests that to return emissions to 1990 levels between 2000 and 2010, a decline of 15%, would require much greater increases in energy prices than took place over the decade of the oil shocks. (Admittedly, a carbon tax would be better-targeted at coal vs oil vs other substitutes than the 1970s oil shocks.)

Those price increases, which are designated "supply shocks," are widely believed to have led to high levels of inflation that were eventually reversed only by means of high interest rates and very large losses in output over time. More specifically, they are believed to have led directly to the recessions of 1974 and 1980. (Indeed, the contraction in output, as much as the fall in the energy/output ratio, was a prime force reducing energy use below its long-run trend.) Some economists also believe that the oil shocks may have played a role in the abrupt slowdown in the long-term trend of productivity growth evidenced in the U.S. and other industrialized countries after 1973, ~~but~~ though that is much less certain.

The large models that have been used to examine climate change policy tend to exclude supply-shock effects. [Only the DRI model is a macro model capable of addressing these effects; and it shows a loss of only 150,000 to 400,000 jobs in 2010.] The idea is that a path of gradual increases in energy prices will be fully built into the expectations of firms and workers, because of clear commitments to future policies. Thus they will be able to plan ahead and avoid serious microeconomic dislocation and macroeconomic disturbance. Furthermore, the 70s oil shocks entailed large transfers from the U.S. and other oil-importing countries to OPEC, thus depressing real income and spending in the former; a self-imposed energy price increase to address global climate change need not entail such a transfer of purchasing power. Still, if it is contemplated to introduce large increases in energy prices over a period as short as a single decade, it is worth remembering the experience of 1972-81.

The role of turnover of the capital stock

Why do economic models consistently find that the cost of major reductions in emissions is much higher if they are implemented by 2010 than if they are stretched out for another decade or more? There are several arguments against early reductions and in favor of waiting. (There are also a number of reasons for wanting to go fast, listed in bullet form in the Section on cost-benefit analysis below.) They include:

(1) the time-value of money (resources not spent on emission reductions early on can be invested at a positive return, so as to purchase more emission reductions later[2]),
(2) allowing for uncertainty to be resolved, and
(3) giving more lead time to develop and implement new technologies. But the most important reason for waiting is :
(4) to allow time for the capital stock to turn over.

The basic point is that it would be very expensive to scrap the entire capital stock, to replace it with more carbon-free plant and equipment, while it is still in the prime of its useful life. But 20 to 40 years out into the future, much of our existing plant and equipment will be ready for replacement anyway, whether because the plant and equipment have depreciated gradually or because they have more suddenly come to the end of their useful life.

[FIGURE 1 GOES HERE]

The effect of the turnover of the capital stock is built into some of the models used to address climate change [e.g., Markal Macro; though not into most "bottom-up" engineering studies, like the Department of Energy's Five-Labs study]. But it may be useful to look at a simple illustration of the point, for the case of the capital stock in power generation.

Figure 1 shows the effects of an accelerated replacement schedule for all of the 7.900 electric power plants built during the last 40 years. [One could skip directly to coal-fired plants (next paragraph), to save space.] Imagine, to take an extreme case, that all power plants had to be shut down within ten years (by 2007), and replaced with less-polluting technology. This would imply replacing 6,330 plants before the end of their normal lifespan, or 80 per cent of the total. Now imagine a policy that required replacement of all power plants in 20 years. This would constitute an accelerated replacement of 4,600 plants, or 58 per cent of the total. If one could wait 30 years, the complete replacement would mean an accelerated replacement of 2,000 plants, 26 per cent of the total. If one waited forty years, under the stylized assumption of a 40-year life there would be no additional cost to replacing them. [We have truncated the distribution at 40 years, the average lifespan of existing electric power plants. There are other plants that are still in use 50, 60, or even 90 years after they were built. But their numbers are small, and by the end of 40 years the cost of shutting them down would in any case be much-reduced, particularly as technology will have advanced in the meantime.]

Figure 2a does the same exercise for the set of power plants that are coal-fired. This is the

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[2] Meanwhile, a higher fraction of carbon emissions will have been naturally removed from the atmosphere by a fixed date, e.g., into the oceans, the earlier those emissions occur. (Manne and Richels (1995, 1997).

class of generators that produce the most carbon and that would thus have to be replaced even under a moderate plan to address climate change. If a complete change-over of coal plants were to be accomplished in 10 years, 799 of the 1,122 coal-fired plants (71 per cent) would have to be replaced before the end of their expected lifespan. If replacement occurs over 20 years, 488 plants would be affected, or 43 percent of the total. If one could wait 30 years, 227 plants would be closed prematurely, or 20 per cent of the total.

Perhaps a comparison between 2010 and 2020 would be most relevant, as these two years figure prominently in the targets-and-timetables debate. In our stylized hypothetical experiment, imagine that all power plants had to be shut down by 2010 (i.e., within 13 years). This would imply replacing 88 percent of the plants before the end of their normal lifespan. Now imagine that all power plants had to be replaced by 2020 (23 years). This would constitute an accelerated replacement of only half the plants.

[FIGURES 2a AND 2b GO HERE]

Figure 2b repeats the exercise on the basis of coal plant *capacity*. Since newer plants tend to have larger capacity, the effects of a rapid replacement schedule are magnified. Closing all plants within 10 years implies that 289 million KW of capacity would be prematurely shut down, or 90 per cent of the total. If one could wait 20 years, 235 million KW of capacity would be affected, or 73 per cent. For 30 years, the capacity that would have to be replaced falls to 116 million KW, or 36 per cent of the total.

This exercise is not intended to be an estimate of the costs of different time-tables, even within this one sector. Rather, the point has been to illustrate concretely the importance of allowing time for the capital stock to turn over, and to illustrate it in a transparent framework that is independent of modeling assumptions over which analysts might differ.

Evaluation of alternative paths

One can pose the question regarding effects of alternative paths in three ways. (i) How do the economic and environmental effects of "1990 by 2010" compare to those of more moderate paths, e.g., in which that level is attained at some later date? (ii) What are the economic effects of alternative paths toward the same ultimate environmental objective, e.g., eventual stabilization of concentrations at twice pre-industrial levels? (iii) What is the optimal unconstrained path to balance estimates of economic costs and environmental benefits? The remainder of the paper considers ~~each question, though in reverse order.~~

[or would it be better to do it in order (i) (ii) (iii): 1990-LEVEL RESULTS, THEN 550PPM CONSTRAINT, THEN IA MODELS?]

2. Cost-benefit analysis in the Integrated Assessment models

It is difficult to put economic costs and climate benefits into the same unified analytical framework. This is in part because the effects are so uncertain, especially with regard to climate, and in part because the climate effects take place on a very long time scale. So-called Integrated Assessment models attempt to put everything into one framework. They attempt to quantify the benefits of averted climate change in the distant future, as well as the economic costs of programs to address emissions, and to compare the two.

Integrated Assessment models began with Nordhaus (1989, 1994). By now many of these models exist. An Appendix I to this paper elaborates, and the literature is surveyed by Manne (1996). Those models that can be used for cost-benefit analysis tend to give a similar result: a plan that optimally balances costs and benefits calls for relatively small actions at the beginning, with the result that GHG emissions continue to rise, although at a reduced pace, for at least a century. Concentrations reach ___ ppmv by 21__.

In the simplest case, damage from warming is assumed to rise linearly with temperature. But it is plausible that the costs in fact begin to rise more sharply, e.g., when concentrations and temperature go above a threshold level. Findings by Peck-Tiesberg (1992), using the CETA model and the case of a non-linear damage function (allowing the damage to rise increasingly sharply with the temperature), call for emissions peaking in 2080-2090.

Some of the authors have characterized in a striking way the gap between the optimal paths that their models produce and the frequently heard proposal to return emissions to 1990 levels by 2010: In their models, the economic costs of such a strong early response are so great that, if that were the only alternative, we would be better off doing nothing at all [~~Jorgenson testimony? Can't find it in there. It's ____ of Stanford?~~]. In other words, the economic costs of "1990 levels by 2010" outweigh the benefits.

Arguments for earlier action

This conclusion, and the methodology that produced it, have been criticized on a number of grounds.

- Some claim that it gives insufficient weight to the (small, but nonetheless alarming) probability of a discontinuously-large and essentially irreversible catastrophe, such as the melting of the West Antarctic ice sheet [which might raise ocean levels by 5 to 6 meters], a runaway "positive-feedback" greenhouse effect (e.g., from methane release), or structural changes in ocean currents such as the Gulf Stream. [references: Cline (1992, p.34-35, Revelle, 1983, p.442, IPCC 1996a; Schelling ~~AER~~ 1995?]
- Some claim that it gives insufficient weight to the welfare of future generations that will

bear the costs of climate change (that is, the discount rate is too high). [references: Cline (1992) and Howarth (1996).]

- Some claim that it neglects basic uncertainty about all parameters -- the economic effects, the climate effects, and the discount rate necessary to compare the two. [reference: Pizer (1996)]
- Some claim that it omits a basic point about political credibility: an announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 years or more into the future -- will not be credible, and understandably so (Austin, 1997). The arguments for postponing sharp cuts in emissions ten years only work if people use the intervening period to begin adjusting. If they are skeptical of the need to adjust, then ten years later nothing will have been accomplished, and the economy at that point will face the same high costs to early reductions as before. Only early concrete measures will send the signal necessary to move people's patterns of research, investment, and consumption onto the new path. [3]

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3. Estimates of least-cost paths to stabilize concentration levels

For the reasons just enumerated, much of the debate about GHG stabilization takes as given that simply allowing emissions to continue to grow for a long period, even at a reduced rate, as contemplated by the authors referenced in the preceding section, puts the biosphere at too much risk and is not credible politically. An alternative strategy is to reason that the probability of catastrophe may rise to unacceptable levels unless GHG concentrations are capped at some particular level. Such an approach has the disadvantage that the choice of any specific concentration cap is arbitrary, and is inconsistent with the spirit of cost-benefit analysis. But it has the advantage of being analytically tractable, and offers a meaningful focal point for negotiation.

Stabilization of concentrations at 550 ppmv

We will consider the question of the optimal path subject to the constraint that concentrations be stabilized at 550 ppmv (approximately double the pre-industrial level of 275

[3] An opposing credibility point is also made: A proposed agreement that demonstrably imposes much higher costs than an alternative more measured approach, and thereby invites prohibitively great domestic political opposition, will also suffer from credibility problems both here and abroad.

ppmv[4]). One might ask why we need accept a level of concentrations, and corresponding probability of catastrophe, as high as this. Indeed, why accept any probability of catastrophe? It is important to recognize that it is already too late to keep this probability at zero (even if one were to accept that it would have been worth the cost to do so, had we known at the beginning of the Industrial Revolution what we know now). Atmospheric concentrations are already at 365 ppmv, and it is impossible to prevent them rising further in the short run; one would have to reduce emissions almost to zero to do so.

[It would be useful to quantify the implicit gap between this strategy and the strategies resulting from the unconstrained optimization by the Integrated Assessment models. The difference represents the role being accorded to the four bullet points above. In addition, some sensitivity analysis with respect to the level of the concentration constraint would be desirable.]

Results for a less aggressive path

The Energy Modeling Forum evaluated two forms of emissions paths to achieve specified carbon dioxide concentrations (EMF-14). A suite of six models, employing the same set of benchmark assumptions, assessed an aggressive path, the IPCC Working Group I path (WGI), and a more moderate path, based on work by Wigley, Richels, and Edmonds (WRE). Both sets of paths can achieve concentration stabilization at 550 ppmv or other targets levels. WRE argue that a less aggressive path can achieve the same stabilization goal at much lower economic costs.

The aggressive WGI path entails Annex I fossil fuel emissions peaking in 1990, and falling 24 percent worldwide below 1990 levels by 2010.[5] (Of course, it is too late for this scenario to be realized. Seven years have passed during which emissions manifestly have not in fact begun to fall in the overwhelming majority of OECD countries. Below, we will also consider other alternative proposals that, while sufficiently ambitious as to be expensive to achieve, at least have the virtue of not having been already ruled out by history.)

For the WRE path, emissions from OECD countries as well as from other Annex I countries (Russia and most of Eastern Europe) peak in the decade 2010-2020. (Annex I emissions do not return to their 1990 levels until sometime early in the decade 2030-2040. The

[4] The concentration figure refers only to CO2. Emission of other greenhouse gases will raise the carbon-equivalent, or warming potential, above this level.

[5] *Worldwide* emissions rise 8 percent by 2010 [from 5.885 to 6.351]. These numbers come from 8/28 personal communication with Richels. (Earlier information had worldwide emissions rising 13.64% by 2010 under the IPCC path [to 7.798 PgC]. Evidently the former statistic refers only to fossil fuel emissions and the latter to all carbon emissions.)

price of crude oil peaks in 2040.) The peak in worldwide emissions lags two decades behind the peak in Annex I emissions because the developing countries' emissions do not peak until 2050. Both paths stabilize global carbon dioxide concentrations under the same timeframe.

[insert chart with WRE and WGI emissions paths]

To estimate the economic effects of these pathways, the modelers must employ a burden-sharing rule. Carbon dioxide concentrations cannot be stabilized without developing country participation. Consistent with the U.S. negotiating position, these model runs assume that developing countries agree to binding targets in the future. The modelers assumed that developing countries will continue to increase their emissions along the business as usual path until 2030. During this period, Annex I will undertake emissions reductions. In 2030, developing countries will begin to reduce their emissions growth. By 2050, emissions rights will be allocated to countries on a per capita basis.[6]

As noted earlier, the best single measure of aggregate economic costs is the present discounted value, i.e, the appropriate summation over time, of foregone consumption. The following two tables illustrate the conclusions -- robust across various models -- from the comparison of the aggressive and moderate paths to the same environmental goal. The first table indicates that, on average, the moderate path achieves the same environmental goal at only 30% of the cost of the aggressive path. Indeed, with international permit trading, the cost of the moderate path is approximately 20% of the cost of the aggressive path. The second chart, a permutation of the first, clearly demonstrates the value of international permit trading. With one exception, the ratios of the costs of an emissions path with trading, to the same path without trading, are considerably less than one. International permit trading, on average, results in less than half the costs of the same emissions path without trading.

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[6] Based on 1990 populations. This formula could imply large transfers from OECD countries to developing countries. We consider an alternative scenario in the next section -- that the developing countries do not participate at all. It would also be desirable to look at the implications of a plan under which a small number of middle-income countries (particularly Korea and Mexico) begin to limit emissions by 2010. Without China and India, however, the emissions of the middle-income countries are a small fraction of the world total, so that their involvement would be important only in order to point the way for other emerging economies, rather than to reduce emissions perceptibly in their own right. A plan where developing countries ultimately were assigned targets determined by a formula putting equal weight on population, GDP, and past emissions would probably be more realistic (even though more complicated) than simplified extremes such as population alone or past emissions alone. Formulas based on population are probably too generous to poor countries for rich countries to agree, while formulas based on 1990 emissions alone are far too generous to rich countries for the poor countries to agree.

The Effects of Emissions Pathway on Consumption Losses by OECD Countries, 550 ppmv Stabilization Goal, EMF-14

Model	Trading	WRE	WG1	WRE/WG1
CETA	no	1.83	5.94	0.31
CPBRIVM	no	0.64	3.25	0.20
FUND	no	9.82	11.71	0.84
MERGE	no	0.85	6.12	0.14
MiniCAM	no	1.58	6.51	0.24
SGM	no	1.84	6.17	0.30
CETA	yes	1.86	4.03	0.46
CPBRIVM	yes	0.17	0.99	0.17
FUND	yes	1.47	4.97	0.30
MERGE	yes	0.60	3.24	0.19
MiniCAM	yes	0.54	3.44	0.16
SGM	yes	0.13	1.48	0.086
			Average:	0.28

source: Weyant, 1997

The Effects of Trading on Consumption Losses by OECD Countries, 550 ppmv Stabilization Goal, EMF-14

Model	Pathway	Trading	No Trading	Trading/No Trading
CETA	WRE	1.86	1.83	1.02
CPBRIVM	WRE	0.17	0.64	0.27
FUND	WRE	1.47	9.82	0.15
MERGE	WRE	0.60	0.85	0.71
MiniCAM	WRE	0.54	1.58	0.34
SGM	WRE	0.13	1.84	0.07

CETA	WGI	4.03	5.94	0.68
CPBRIVM	WGI	0.99	3.25	0.30
FUND	WGI	4.97	11.71	0.42
MERGE	WGI	3.24	6.12	0.53
MiniCAM	WGI	3.44	6.51	0.53
SGM	WGI	1.48	6.17	0.24
			Average:	0.44

source: Weyant, 1997

The modelers in the EMF-14 exercise did not attempt to calculate the least-cost path for achieving concentration stabilization goals.

The least-cost mitigation path, compared to 2010 constraints

Manne and Richels (1997a,1997b) are believed to be the first researchers to have computed the path that minimizes costs (using the MERGE model), subject to the constraint of stabilizing concentrations at a level such as 550 ppmv.[7] As the EMF-14 results illustrate, the MERGE model generates results on the costs of concentration stabilization that fall among the middle of the economic models. In their papers, they employ the same international burden-sharing rule as EMF-14.

Their model implies that the least cost mitigation path has emissions from Annex I countries peaking in the decade 2020-2030, a bit behind the WRE path. The peak of Annex I emissions is 29 percent above 1990 levels. [Source: personal communication from Richels, 8/21 and 8/28/97.] Emissions do not return to their 1990 levels until after 2050. Emissions from developing countries peak in 2050. The sum of the two, total worldwide emissions, also peaks in 2050. (By mid-century, developing countries are such an important source of emissions that they dominate the global peaking date and the date of return to 1990 levels.) Worldwide emissions return to their 1990 levels shortly before the end of the 21st century.

This least cost mitigation path generates quite low values for carbon emissions rights after implementation in 2000. The permit price is only $2/ton in 2010, and rises slowly to $3/ton in 2020. Only in the latter part of the century does it rise significantly, to $156/ton in 2100.

[7] Also Manne and Richels (1995). Kosobud, et al (1994) examine alternative paths to achieve a given temperature target in 2100. All three papers find that a return to 1990 emission levels early in the 21st century is a needlessly costly way to attain the 2100 goals for concentration and climate.

The following table, from Manne and Richels (1997b), demonstrates the effect of constraining Annex I emissions relative to 1990 levels in 2010, in contrast to the least cost path. This constraint is imposed over the period 2010-2030. After 2030, further reductions in Annex I emissions occur in order to meet the constraint of concentrations at 550 ppmv.[8] Manne and Richels (1997b) constrained the year 2000 emission levels to the BAU level, under the assumption that treaty implementation could not occur before that date. Developing countries again participate, consistent with the burden sharing formula described above. Thus the permit price estimates presuppose full global participation and trading ("where flexibility") but not intertemporal trading ("when flexibility").

Change in emissions relative to 1990 in 2010	Permit Price in 2010 ($/ton)	Permit Price in 2020 ($/ton)	Consumption Losses (trillions of dollars)[9]		
			U.S.	Annex I	World
+10%	4	65	0.293	0.564	0.782
0%	67	88	0.303	0.619	0.939
-10%	120	112	0.429	1.054	1.276

According to Manne and Richels (1997b), their least cost mitigation path costs the U.S. $0.124 trillion in terms of lost consumption (present discounted value), as compared to $1.28 trillion under the IPCC Working Group path and as compared to $0.303 trillion under the "1990 in 2010" path. Thus the least cost mitigation path generates savings of 90 percent from WG1 and 60 percent from the 1990 in 2010 path.[10]

It is important to keep in mind that all these cost estimates are "best case" (almost utopian) scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if

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[8] The proponents of "1990 by 2010" do not always specify what they would like emissions to do for the remainder of the century. In this section, we assume further reductions in order to meet the 550 ppmv constraint. In the next section of the paper, we instead "straightline" the rest of the century.

[9] The present discounted value of consumption assumes a 5% discount rate and a time horizon of 1990-2100.

[10] Most of this gain is also reflected in the WRE path, which peaks in 2010-2020, as described above.

less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

What if the developing countries do not agree to go along?

It is difficult to imagine that taxpayers in the U.S. and other industrialized countries will agree to transfers to developing countries on the scale implied by the EMF/Manne-Richels burden-sharing schedule. According to one model, transfers under the "1990 by 2010" path would be $8 ½ billion in 2010, and rise to $24 billion by 2050. According to another set of estimates (from Battelle), the U.S. would have to pay $32 billion to other countries in 2035 under the WRE path, and $181 billion under the WG-1 path. The transfers would then continue to rise, to an estimated $85 billion or $170 billion, under the two respective paths, in 2050.

What if rich and poor countries are unable to come to an agreement? How would the absence of the developing countries from an agreement affect the targets-and-timetables decision of industrialized countries? On the one hand, as a matter of arithmetic, meeting the 550ppmv concentration constraint would require more aggressive targets and timetables on the part of the Annex I countries, if indeed it would be possible at all. On the other hand, as a matter of politics, the absence of the developing countries would probably lead the peoples of the Annex I countries to choose a less aggressive path, even though it would produce a higher terminal concentration level. (An analytical balancing of costs and benefits would give the same answer -- a less ambitious target -- once the concentration constraint is relaxed.) [11]

To consider the possibility that developing countries might decline to participate, we ask what would be the effects, both economic and environmental, if the Annex I countries are constrained to the WRE path, but developing countries"free-ride" (i.e., developing countries remain on their BAU path). The welfare losses (in terms of present discounted value) will depend upon whether there is trading in emission rights among Annex I countries. If Annex I trading occurs, then Annex I countries' losses increase from $0.62 trillion to $0.91 trillion, or 47%. If emission trading among Annex I countries does not occur, then losses rise to $1.00 trillion, or 61%. For the U.S., in the absence of developing country participation, welfare losses rise from $0.28 to $0.36 trillion, or 29%, assuming Annex I trading. Without Annex I trading, U.S. losses rise to $0.41 trillion or 46%.[12]

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[11] Conversely, the developing countries are less likely to agree to participate if the Annex I countries have not already taken serious action.

[12] For purposes of this comparison, we assume that if developing countries do participate, there will be full global trading.

Meanwhile, the non-participation of the developing countries means a clear failure to meet the goal of capping global emissions at 550 ppmv. Even if the Annex I countries choose an aggressive path of reducing emissions 10% below 1990 levels by 2010 (and stay at that level thereafter), the effect is to reduce global concentrations only 7 % below BAU levels in the year 2100. This is less than a third of the reductions achieved when the developing countries participate [22%; conversation 8/28] This result illustrates the problem of free riding. Moreover, the estimate does not include an allowance for "leakage" of carbon savings from participating to non-participating countries (e.g., reduced oil demand in the former, via a lower world price of oil, raises oil consumption in the latter). Once leakage effects are added to the free-riding problem, the difficulty of accomplishing meaningful reductions without the help of developing countries are even greater. The savings is only 5 percent in this case. In other words, of the 22 percent reductions achieved when the developing countries participate, 15 percentage points are lost to free-riding, and another 2 points to carbon leakage. [conversation 8/29.] This estimate captures only one of the possible leakage channels, via the world oil and gas market. It omits, for example, the relocation of production in polluting industries to non-participating countries. Indeed, models do not even attempt to measure this effect, because it is so difficult to do.

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What if there is no international trading?

It is important to keep in mind that the permit price estimates cited earlier assume perfect global trading. Under this assumption, emission reductions occur where it is cheapest to do so regardless of geographic location. What if there is no opportunity to buy emission reductions from lower-cost countries? The following table shows permit prices in 2010 when Annex I emissions are constrained to 1990 levels under alternative assumptions about where flexibility. If the U.S. must attain its target entirely by domestic emission cuts, because developing countries do not participate and there is not trading even among Annex I countries, then the cost rises steeply. These conditions triple the price of the "1990 by 2010" target, in terms of the marginal cost of abatement, from $67/ton to $204.

U.S. Permit Prices in 2010, 1990 Level in 2010 Scenario

Where Flexibility	Global Trading	Annex I Only Trading	Domestic Only Trading
Permit Price in 2010 ($/ton)	67	132	204

It is important also to note that the gains from international trading are highly uncertain. In the case where developing countries do not participate, the extent to which Russia and Eastern Europe are a source of low-cost emission reductions depends heavily on the extent to which they fail in the future to recover from their recent contractions in output. Discussion usually presupposes that the United States will be a net buyer of permits, and several models confirm this. (The SGM shows "1990 by 2010" leading to $8 ½ billion in U.S. permit purchases in 2010, rising to $54 billion in 2050. This is why Annex I trading reduces the permit price in the table.) The U.S., however, is the next lowest-cost major emitter among Annex I countries, after the former Communist bloc. (Europe and Japan already conserve on energy, largely via already-high energy taxes on petroleum products, so they have less scope for further reductions.) If Russia and Eastern Europe begin to grow strongly, the U..S. could become a net *seller* of permits before long. If so, international trading will result in a higher price, not a lower price. McKibbin and Wilcoxen ( ) have built the G-cubed model to explore the international dimensions of climate change policy. They find that the U.S. turns into a net seller of permits by 2020 (to the tune of $38 billion, as opposed to purchases of $2-3 billion in 2010). If this result is right, then the high prediction for the carbon price is the right one, regardless whether there is trading among Annex I countries or not (though trade in permits is still beneficial).

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4. What is the trade-off between the paths currently under discussion?

As we have seen, the Manne-Richels results suggest that the optimal path has Annex I emissions peaking in the decade 2020-2030 and returning to 1990 levels after 2050. The WRE path has Annex I emissions peaking in 2010-2020, and is almost as cost-effective as the least-cost path. Yet the paths for emission reductions that have been discussed in the international negotiations are far more aggressive than these.

What are the additional economic costs, and climatological benefits, of moving from the least-cost path to "1990 levels by 2010"? Table 4, "Climate and Economic Variables under Alternative Emissions Paths," is designed to answer this question. It reports results from the SGM model (on economic variables) and the MAGICC model (on climatic variables), under the assumption that once emissions are returned to their 1990 levels, they are held there for the remainder of the century. The economic costs of the more aggressive path can be measured in several ways. The price of gasoline in 2010 would rise by 26 cents a gallon and coal prices by 273 percent, as compared to only 3 cents per gallon on the less ambitious path, and an increase in coal prices of only 53 per cent. The total economic loss, in the present discounted value of foregone consumption, $206 billion, as compared to only $95 billion on the less ambitious path.

[These figures cumulate lost consumption out only to 2050, and thus are not comparable with the figures cited in the preceding section.] What is accomplished by the more aggressive strategy? The date at which concentrations are doubled is postponed by a mere 3 years (beyond the nine-year postponement achieved by the less aggressive path). The estimated warming in 2100 (2.45 degrees under the business as usual case) is reduced by a mere .03 degrees.. While different observers will weigh the economic costs and climate benefits in different ways, the percentage increase in costs from early action seems large compared to the percentage reduction in concentrations and warming.

This conclusion omits that concentrations continue to rise in subsequent centuries. The way to address such concerns is by means of models (such as Integrated Assessment models) that keep track of economic and environmental effects on a longer time frame. The preceding section of the paper ("Least-cost Paths to Stabilize Concentration Levels") explains how more moderate paths can attain the identical objective, in terms of terminal concentration levels, with lower economic costs than "1990 in 2010." But all these results leave out the major argument for early action mentioned elsewhere: the need for political credibility of an announced long-term plan. This argument suggests that a moderate path should be accompanied by early and specific announcement of serious domestic measures of implementation.

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Table 4: **Climate and Economic Variables under Alternative Emissions Paths ***

		Concentration Level (ppmv)		Year at Which Concentration Reaches 2x Pre-Industrial Level **	Change in Temperature from 1990 Level (Celsius)	
	Year	2050	2100		2050	2100
	Business As Usual (BAU)	502	711	2065	1.06	2.36
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	-21	-66	+9	-0.09	-0.25
	1990 beginning in 2010	-18	-55	+8	-0.08	-0.21
	peak in 2015, 1990 in 2040	-13	-53	+6	-0.06	-0.19
	1990 +10% beginning in 2010	-13	-49	+6	-0.07	-0.18

		Carbon Permit Price ($ per ton): Domestic Trading		Carbon Permit Price ($ per ton): Annex I Trading		Consumption *** (billions of $)
		2010	2050	2010	2050	
	Business As Usual (BAU)	0.00		0.00		121,650
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	+175	+924	+91	+238	-980
	1990 beginning in 2010	+108	+582	+41	+149	-740
	peak in 2015, 1990 in 2040	+12	+563	+11	+153	-270
	1990 +10% beginning in 2010	+60	+310	+17	+113	-460

Summary description

A plan to return carbon emissions to their 1990 levels by 2010 postpones by 9 years the date at which CO_2 concentrations reach twice pre-industrial levels. Global warming would be reduced by 0.21 degrees by the year 2100 versus an estimated 2.36 degrees under BAU. Under this emissions path the value of the estimated foregone consumption is $740 billion.

A less ambitious path -- "eliminate emissions growth by 2010-2020" -- would postpone the doubling date by 2 years less, and would lead to another 0.02 degrees of warming. But, the economics would become much easier: The value of foregone consumption would be only $270 billion.

* Preliminary CEA projections. The origin of these preliminary numbers is described on the accompanying page.

** Pre-industrial concentrations of CO2 were approximately 275 ppmv.

*** Assumes domestic trading only. Annex I or worldwide trading may substantially reduce these costs. Deviations are foregone consumption assuming a 5% discount rate for the time horizon 2000-2050.

September 10, 1997

Sources and Explanations

Sources

Business As Usual (BAU) emissions projections are based on the assumptions employed in the IAT process. These projections incorporate the Annual Energy Outlook and International Energy Outlook projections, and closely mirror the IPCC IS92a emissions profiles with modifications made for the economic decline in the Former Soviet Union and Eastern Europe. BAU concentration and temperature projections are from the MAGICC model. Carbon permit price estimates and foregone consumption figures are from the SGM model. All these results were provided by Jae Edmonds, Marshall Wise, and Chris MacCracken at Battelle, Washington, DC.

Participation Cases

Annex I Participation Only: Assumes full compliance of stated targets and timetables by countries in Annex I; rest of the world behaves as in BAU.

Targets and Timetables

1990 (+/-10%) in 2010: Emissions follow BAU through 2000, reduce to 1990 (+/-10%) levels by 2010, and remain at 1990 (+/-10%) levels thereafter.

Peak in 2015, 1990 in 2040: Emissions follow BAU through 2005, peak at 2010 BAU levels in 2015, and stabilize at 1990 levels in 2040 and into the future. Because of linear interpolation in emissions profile between 2015 and 2040, this scenario may slightly overestimate the deviation of concentration from BAU.

Trading Scenarios

Domestic Trading: Trading only within each country.

Annex I Trading: Permits are grandfathered to Annex I nations based on 1990 emissions levels. All Annex I countries participate in the trading of permits.

Price Assumptions

Carbon: U.S. permit prices for the four policy options are from SGM, which assumes that all revenues are returned to the economy through a lump-sum redistribution.

Consumption: Deviations are present discounted value of foregone consumption differences for United States in billions of dollars between BAU and scenarios. The present discounted value assumes a discount rate of 5% and a time horizon of 2000-2050.
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5. Escape clauses and other flexibility provisions

In addition to the question of the stringency of targets and timetables, there are a number of other important determinants of the economic costs of a program encompassed in the term "flexibility". The U.S. has proposed both "when flexibility" and "where flexibility."

Examples of "when flexibility" are our proposals for targets that are multi-year averages, for multiple target periods, and for banking and borrowing. An example of "where flexibility" is international trading, especially with the participation of developing countries. All of these proposals could substantially reduce the cost of a given level of emissions, and are crucial elements of our ability to attain moderate targets, let alone more ambitious targets. Costs would be far higher without them.

Another possibility that has recently received attention in the inter-agency process is to add one or more escape clauses. The main idea is to safeguard against unexpectedly large economic costs of emissions reductions. These are costs that could turn out to be unexpectedly large if the economic growth rate turned out higher than expected, or if unrealistic estimates regarding the ease of reducing emissions were built into treaty targets. One possible escape clause would focus on the price of energy per ton of carbon.

Nordhaus (1997) and McKibbin and Wilcoxen (1997) have proposed plans under which there is a cap on how much the price of carbon can rise. The proposal is that above a certain level, governments (or perhaps a supranational authority) could make available an indefinite quantity of emission permits at the predetermined price. The system would operate as a "tariff-rate quota," in which countries were allowed to emit up to their assigned share for free, but then bore a penalty for any emissions in excess of that share. Pizer (1997) estimates that, in the presence of uncertainty, the optimal price rule generates gains that are five times greater than the optimal permit (quantity) rule. While the academic proposals tend to call for common policies and measures to be negotiated worldwide, the idea could usefully be integrated into the U.S. proposal for targets and timetables regarding emission quantities, in the form of a conditional

escape clause. The effect would be to convert the quantity limit into a price instrument under circumstances when the burden would otherwise be too burdensome.

Escape clauses could also serve other purposes as well. Possibilities include:

- An escape clause that would be triggered in the future if continued **scientific research** determined that the dangers from GHG concentrations and climate change were much less than previously feared. Presumably the treaty would be renegotiated in such a case anyway. But the arguments for putting this language in now are three: (1) to facilitate the change, should this come to pass, (2) so that we don't look foolish in the eyes of history if this should come to pass, and most importantly, (3) to help allay the fears of today's skeptics.

- An escape clause that would be triggered in the future if **developing country accession** turned out to be less than we expect after Kyoto.

- An escape clause that would be triggered by other Annex I countries' **failure to abide** by their commitments.

Each of these proposals, might be useful in avoiding economic costs that otherwise might be incurred needlessly.

6. Conclusions and Summary

[SEE EXECUTIVE SUMMARY AT THE BEGINNING]

Appendix I: Integrated Assessment Models (M. Toman)

*******2. Cost-benefit analysis in "Integrated Assessment" models

Integrated Assessment (IA) analyses try to bring together assessments of the physical, ecological, economic, and social impacts of climate change with assessments of policies for responding to climate change and their socioeconomic consequences.

Generally speaking, the models can be described schematically as linking economic decisions in the energy (and agriculture) sectors that give rise to GHG emissions (and changes in carbbon sequestration), models of atmospheric composition, climatic change, and changes in oceans, and models that describe the potential impacts of climate change on health, natural resources, coaatal areas, and other factors of socioeconomic interest. Different components of various IA frameworks are represented in differing degrees of detail and sophistication. A few models contain the capacity to be used for a benefit-cost analysis, in which it is possible to evaluate changes in the long-term path of GHG emissions that maximizes the net benefits of GHG control (these benefits are the avoided damages of climate change less the costs of control). A larger number of IA models can evaluate the benefits and costs of specified policies but are unable to indicate what emissions reductions maximize net benefits. IA frameworks are inherently more "top-down" in their characterization of economic decisionmaking, though some models contain a fair amount of energy sector detail.

A very striking feature of IA models is that they tend to indicate the desirability -- from the perspective of maximizing net benefits over time -- of emissions continuing to rise well into the next century, if not beyond. (For a recent comparison of IA model results, see Manne 1996. By 2010, the models indicate only small deviations downward from a business as usual (BAU) path (see also IPCC 1996b, Chapter 10). In some cases the emissions do stabilize toward the middle of the next century, but in other cases they continue rising (though more slowly than with business as usual) even beyond 2100. These emissions paths clearly imply increases in atmospheric concentrations of GHGs well beyond the kinds of targets that have been considered in current policy debates (e.g., 550 ppm). One important consequence is that the models indicate costs of near-term emissions stabilization well in excess of the avoided damage costs.

Criticisms of the results in the Integrated Assessment models

As noted in the text, number of criticisms have been levelled at these IA results. These criticisms include:

Failure to consider the possibility of unlikely but catastrophic events that could result from climate change (e.g., catastrophic sea level rise from melting of the Antarctic ice sheet, runaway global warming from frozen methane releases, or relocation of the Gulf Stream).

Failure to give adequate consideration to the scale of potential damages, even in the absence of catastrophe. Cline (1992), for example, argues that damages are much higher than is incorporated in most IA models (see also IPCC 1996a, Chapter 6 for various estimates). One specific concern that has been raised is that the IA models do not account adequately for the costs of a less stable climatic and ecological systems in the face of GHG accumulations.

Failure to consider the adverse consequences of less aggressive abatement policies for future generations + in the context of IA models themselves, the criticism is that discounting of future generations' well-being is excessive. Cline (1992) also raises this concern, as does Howarth (1996).

Failure to consider how uncertainty about all these effects affects the "optimal" decision (Pizer 1996).

Failure to consider how lack of early action will jeopardize the achievement of any longer-term mitigation by signalling a lack of political will, or how lack of early action will retard induced technical progress that is needed to make mitigation affordable (Grubb *et al* 1995).

Sensitivity analyses carried out with IA models suggest that at least some of these criticisms are not major concerns; others may be serious concerns, but empirical judgments are not possible given the current state of knowledge. The Manne (1996) survey referred to above considered scenarios in which the climate's sensitivity to accumulating GHGs was greater than is typically assumed, or the the damages are larger (by a factor of almost 8) for a given change in the atmosphere. In either case emissions should (from the perspective of maximizing net benefits) be lower, but the extra degree of emissions reductions required by 2010 is significant (on the order of 25 percent or more) only if climate damages are much higher than expected (the sensitivity of the atmosphere to GHG emissions seems much less important in these analyses). And even in this case, emissions still will be higher than 1990 levels unless the atmosphere and the ecological-economic systems both are quite sensitive. (Broadly similar conclusions follow if, instead of looking at higher damages, one looked at damages that grew proportionately faster as atmospheric GHG concentrations grew (Peck and Teisberg 1993). Thus, the IA models give little support for a policy of near-term emissions stabilization unless damages turn out to be much higher than at least some experts expect.

As noted, one of the criticisms of many integrated assessments (IAs) is that they do not incorporate the possibility of catastrophe. Recent extensions of the IA literature include the possibility of a major, discontinuous jump inh the damages caused by climate change. For example, a European paper by Gjerde et al (1997) incorporates the risk that climate change will sudenly cause damages equal to a significant share of global GDP. The risk is assumed to rise with an increase in temperatre from global warming; following Nordhaus (1994b), the benchmark risk scenario assumes a 12% chance of a loss equal to 25% of GDP (the scale of the great depression) in 2090 if climate has warmed by 3 degrees C. Incorporating this risk into the IA framework causes the optimal path for global emissions to be reduced, but not by that much in the early years. By 2060, optimal emissions are only somewhat over half what they would have been without the risk of catastrophe, but the reduction by 2020 is on the order of 15% below the no-catastrophe case and still above emissions in 1990.[13] Even sharper emissions reductions are implied if the catastrophe is truly shattering (on the order of the entire GDP), or if the discount rate is extremely low (high intergenerational egalitarianism.)

It is also true that the results of IA models are sensitive to the choice of discount rate used to compare consumption today and in the future. A very low discount rate will imply greater weight on damages accruing over time to future generations, and thus the need for a more aggressive abatement strategy. This tradeoff is influenced by the rate of economic growth, since growth will make future generations better off and thus better able to afford and respond to the damages of climate change (Schelling 1995). However, there are numerous economic and ethical controversies surrounding the appropriate way to discount future damages in IA models, and no clear consensus has emerged. One important point that is often ignored in this debate is how much *today's* generation is willing to sacrifice to provide for the increased protection of future generations through GHG abatement; this is a critical unknown since it is today's generation that must necessarily must decide to pay the bill. All that can be said analytically, therefore, is that intergenerational equity *might* be an argument for more aggressive abatement.

Uncertainty about future damages or other influences on the costs and benefits of abatement can make a difference. However, Pizer's (1996) analysis suggests that the most important source of uncertainty concerns the nature of our preferences for consumption

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[13] The no-catastrophe optimal path is substantially below BAU in this analysis, an artifact of the assumptions of low abatement cost and high damage cost.

and environmental protection. (Unlike the Manne (1996) analysis, Pizer considers the possibility that damages may be lower as well as larger.) A recent paper by Gjerde *et al* (1997) considers the risk of a sudden loss of economic output and well-being on the scale of the Great Depression from climate change. While their analysis indicates more aggressive abatement than other IA analyses without this risk, the introduction o the risk has little relative effect on the desirable level of emissions reduction by 2010, and little effect for a number of years thereafter (unless the loss is much larger even than the Depression).

This leaves the issues of political credibility and induced technical change. As for the latter, it is true that sending a less strong signal to energy markets will slow up technical progress. However, there is great uncertainty about how much of a loss this would be in practice, and the loss would have to be greater than most models seem to indicate before the substantial costs of near-term stabilization could be justified. This does *not* mean, however, that *no* actions are justified on cost-benefit grounds to reduce emissions or stimulate technical progress. Aside from initial steps to curb emissions growth, which signal the need for technical change, longer-term measures to promote the development of new technology are warranted. Political credibility is a more complicated issue.
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First Steps Toward a Credible and Effective Long-Term Strategy

As noted, the intertemporally flexible alternative approach to achieving a long-term emissions reductions target has been criticized in some quarters as being akin to a license for indefinite postponement of emissions reductions, making the proposal noncredible in terms of the long-term enforceability of domestic emissions reductions (Won't those who want to delay now just want more delay later? Why would anyone be motivated to pursue emissions reductions early with this expectation?) and in terms of the signal sent to the international community. There also has been criticism that these policies will not stimulate enough near-term innovation to lower the cost of long-term emissions reductions. These are important concerns that need to be addressed in a complete analysis of intertemporally flexible policy options.

As for reduced innovation incentives, there may indeed be some negative effect, but the size of this effect is unknown and may be minor and/or transient if emitters do see the long-term policy goal as credible. It can also be lessened by appropriate policy commitments to the funding of GHG-reducing R&D programs.

The credibility issue is more complicated, but even here there are several sides to the issue. A policy of significantly larger and more expensive near-term emissions reductions is by no means automatically more credible, from either an economic or political perspective. Moreover, intertemporal flexibility is not the same as doing nothing for a period of many years. Some near-term reductions can still be implemented, to build confidence in the commitment to longer-term reductions and to gain experience with the process of and opportunities for emissions reductions. We would thus advocate that a policy of cost-effective intertemporal flexibility in the timing of emissions reductions be coupled with a mandate for some modest but concrete initial emissions reductions, relative to business as usual, that grow over time as the economy makes the transition toward leveling off and reducing its emissions. Again, this can be coupled with a policy of support for R&D that lowers the cost of future GHG emissions reductions.

"Safe corridors"

Several recent studies have used the "safe corridors" concept for specifying desirable paths of emissions reductions over time. This concept seeks to indicate which time paths of emissions satisfy not only a limit on long-term concentrations of GHGs, but also other constraints. Common additional constraints are that the rate of temperature rise should not exceed a certain amount per decade, ostensibly as a proxy for avoiding environmental damages that might be produced by more rapid temperature rises; and that emissions reductions should not be larger than a certain percentage per year, ostensibly as a proxy for not imposing too large a cost burden on the economy.

These studies generally call for relatively significant near-term emissions reductions, largely as a result of the constraint on the decadal rate of temperature increase. However, this approach to damage avoidance is entirely ad hoc. While some scientists have expressed concerns about environmental stress from rapid temperature change, the IPCC does not provide a strong scientific basis for concluding that certain decadal rates of temperature increase are unacceptably risky (indeed, even specifying a more continuous relationship between the rate of temperature change and damages, like the relationships in IA models between the long-term change in temperature and damages, can only be done on the basis of analyst judgments). In addition, the arbitrary constraints on the rate of emissions reduction do not in any way capture the links between the shape of the emissions path and the costs to the economy, as discussed in Section 3 ("Estimates of least-cost paths to stabilize concentration levels"). Accordingly, we do not believe the safe corridors approach offers a sound basis for public policy evaluation of emission control strategies.

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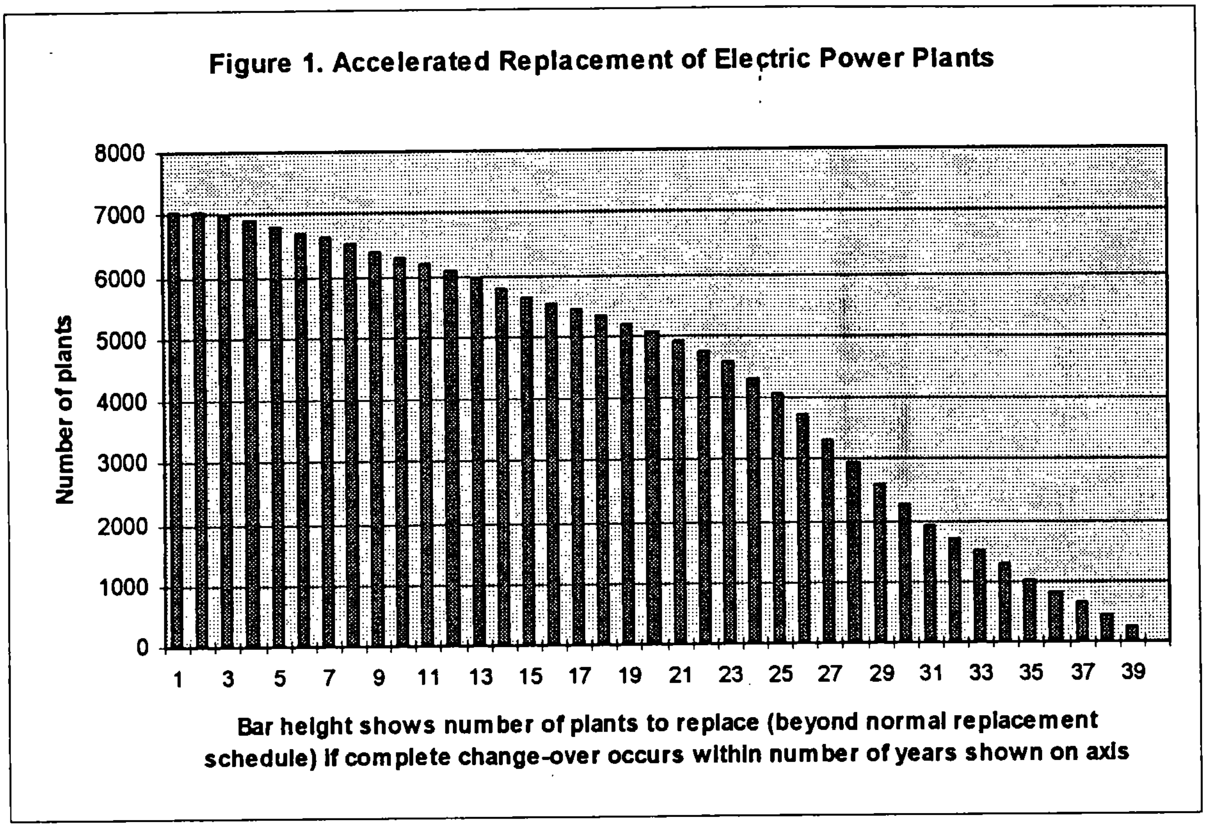
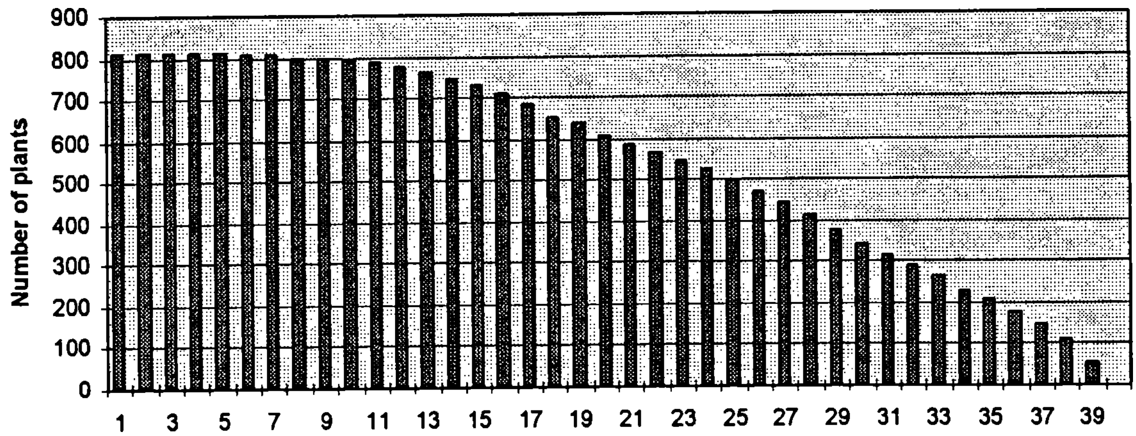


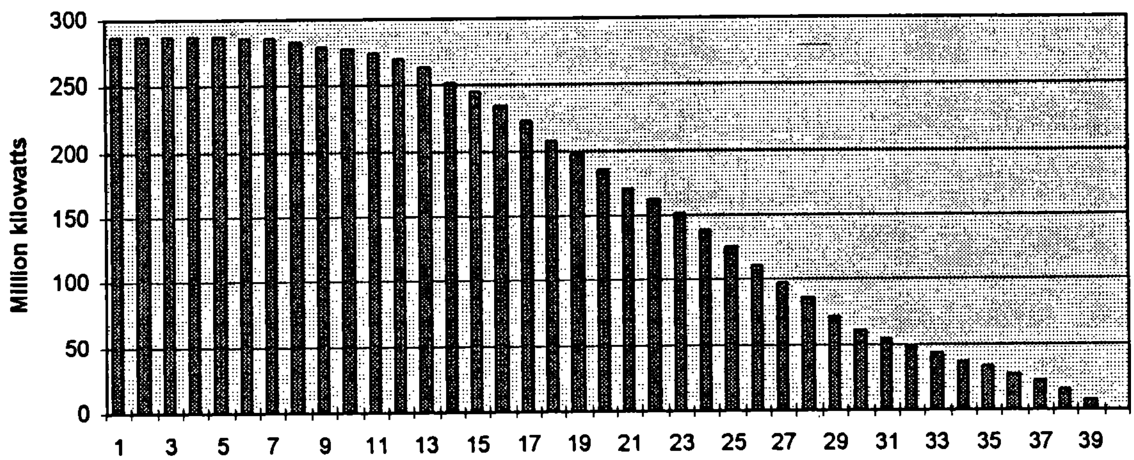
Figure 1. Accelerated Replacement of Electric Power Plants
Number of plants
8000
7000
6000
5000
4000
3000
2000
1000
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
Bar height shows number of plants to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

Figure 2a: Accelerated Replacement of Coal Plants



Bar height shows number of plants to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

Figure 2b: Accelerated Replacement of Coal Plant Capacity



Bar height shows coal capacity to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

p2 end ¶1 Pay Russia, LDCs. "but the remaining Δ? nevertheless substantial"

p9 ¶1 suggests require much greater increases in e prices than in decade of oil shocks

p18-19 "almost utopian scenarios"

p21 T/P gains from trade highly uncertain. If Russia gains strongly, trade might not lower p at all.

9/18/97

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corre-sponding Reductions	AEEI	Ramp-up	Time Path	Outputs PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
SGM1	BAU	SGM, MAGICC	Battelle	n/a	n/a	n/a	n/a	n/a	n/a	IAT	n/a	1.0	n/a	-->2050, -->2100 (climate)	$121,650 billion (BAU consumption)	$9,185 billion (BAU GDP)
SGM9	-10% of 1990 in 2010	SGM, MAGICC	Battelle	-10% 1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$485 billion	$9,155 billion (-$30 billion)
SGM8	-10% of 1990 in 2010	SGM, MAGICC	Battelle	-10% 1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$980 billion	$9,149 billion (-$36 billion)
SGM10	-10% of 1990 in 2010	SGM, MAGICC	Battelle	-10% 1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$50 billion	$9,171 billion (-$14 billion)
SGM18	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$255 billion	$9,172 billion (-$13 billion)
SGM21	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$260 billion	$9,172 billion (-$13 billion)
SGM3	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$225 billion	$9,172 billion (-$13 billion)
SGM20	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$740 billion	$9,164 billion (-$21 billion)
SGM17	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$740 billion	$9,164 billion (-$21 billion)
SGM2	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$665 billion	$9,165 billion (-$20 billion)
SGM22	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$25 billion	$9,180 billion (-$5 billion)
SGM19	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$20 billion	$9,180 billion (-$5 billion)
SGM4	1990 in 2010	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$5 billion	$9,180 billion (-$5 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), ($)	Intl. Trade of Permits, U.S., 2050 (MMTCE), ($)	Date Received Run	File (h:\jaldy\)
SGM1	$0	$0	$0	502	711	2065	1.06	2.36	no peak: 2245 (2050)	n/a	n/a	n/a	08/21/97	cea90_~1.xls
SGM9	$91	$137	$238	481 (-21)	645 (-66)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	never returns	-180, (-$16.4 billion)	-332, (-$79.0 billion)	08/21/97	cea90m_~1.xls
SGM8	$175	$304	$924	481 (-21)	645 (-66)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	2010	n/a	n/a	08/21/97	cea90m_~1.xls
SGM10	$33	$37	$45	481 (-21)	645 (-66)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	no peak: 2060 (2050)	never returns	-332, (-$11.0 billion)	-845, (-$38.0 billion)	08/21/97	cea90m_~1.xls
SGM18	$39	$83	$150	478 (-24)	565 (-146)	2091 (+26)	0.96 (-0.10)	1.82 (-0.54)	no peak: 1712 (2050)	never returns	-209, (-$8.2 billion)	-362, (-$54.3 billion)	08/27/97	case2.xls, 9/4/97 fax
SGM21	$39	$83	$150	n/a	n/a	n/a	n/a	n/a	no peak: 1712 (2050)	never returns	-209, (-$8.2 billion)	-362, (-$54.3 billion)	08/27/97	case3.xls
SGM3	$42	$84	$149	486 (-16)	655 (-56)	2072 (+7)	0.99 (-0.07)	2.15 (-0.21)	no peak: 1714 (2050)	never returns	-202, (-$8.5 billion)	-364, (-$54.2 billion)	08/21/97	cea90_~2.xls
SGM20	$108	$188	$582	n/a	n/a	n/a	n/a	n/a	1550 (2000)	2010	n/a	n/a	08/27/97	case3.xls
SGM17	$108	$188	$582	476 (-26)	564 (-147)	2092 (+27)	0.95 (-0.11)	1.82 (-0.54)	1550 (2000)	2010	n/a	n/a	08/27/97	case2.xls, 9/4/97 fax
SGM2	$110	$191	$582	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	1637 (2005)	2010	n/a	n/a	08/21/97	cea90_~2.xls
SGM22	$15	$23	$0	n/a	n/a	n/a	n/a	n/a	no peak: 2239 (2050)	never returns	n/a	n/a	08/27/97	case3.xls
SGM19	$15	$23	$110	478 (-24)	565 (-146)	2091 (+26)	0.96 (-0.10)	1.82 (-0.54)	1883 (2040)	never returns	-316, (-$4.7 billion)	-500, (-$55.0 billion)	08/27/97	case2.xls, 9/4/97 fax
SGM4	$16	$23	$32	486 (-16)	655 (-56)	2072 (+7)	0.99 (-0.07)	2.15 (-0.21)	no peak: 2102 (2050)	never returns	-313, (-$5.0 billion)	-752, (-$24.1 billion)	08/21/97	cea90_~2.xls

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corre-sponding Reductions	AEEI	Ramp-up	Time Path	PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
SGM36	1990 in 2020	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2020	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	yes	-->2050, -->2100 (climate)	$195 billion	$9,179 billion (-$6 billion)
SGM35	1990 in 2020	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	yes	-->2050, -->2100 (climate)	$660 billion	$9,172 billion (-$13 billion)
SGM37	1990 in 2020	SGM, MAGICC	Battelle	1990 emissions level	stabilize in 2020	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	yes	-->2050, -->2100 (climate)	-$1 billion	$9,183 billion (-$2 billion)
SGM6	1995 in 2010	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	CR	1.0	no	-->2050, -->2100 (climate)	$380 billion	$9,175 billion (-$10 billion)
SGM5	1995 in 2010	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	CR	1.0	no	-->2050, -->2100 (climate)	$425 billion	$9,174 billion (-$11 billion)
SGM7	1995 in 2010	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	CR	1.0	no	-->2050, -->2100 (climate)	$30 billion	$9,179 billion (-$6 billion)
SGM33	1995 in 2020	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2020	Annex I	auction	lump-sum	no LDC part.	IAT	CR	1.0	yes	-->2050, -->2100 (climate)	$410 billion	$9,176 billion (-$9 billion)
SGM32	1995 in 2020	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	CR	1.0	yes	-->2050, -->2100 (climate)	$445 billion	$9,176 billion (-$9 billion)
SGM34	1995 in 2020	SGM, MAGICC	Battelle	1995 emissions level	stabilize in 2020	worldwide	auction	lump-sum	no LDC part.	IAT	CR	1.0	yes	-->2050, -->2100 (climate)	-$40 billion	$9,180 billion (-$5 billion)
SGM27	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$75 billion	$9,185 billion (0 billion)
SGM24	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$75 billion	$9,185 billion (0 billion)
SGM12	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$55 billion	$9,185 billion ($0 billion)
SGM30	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$75 billion	$9,185 billion (0 billion)
SGM11	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	$235 billion	$9,185 billion ($0 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), ($)	Intl. Trade of Permits, U.S., 2050 (MMTCE), ($)	Date Received Run	File (h:\jaldy\)
SGM36	$23	$86	$150	486 (-16)	656 (-55)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 1714 (2050)	n/a	-180 (-$4.14 billion)	-364 (-$54.6 billion)	09/10/97	case20~1.xls
SGM35	$71	$192	$582	484 (-18)	656 (-55)	2073 (+8)	0.98 (-0.08)	2.15 (-0.21)	1550 (2000)	2020	n/a	n/a	09/10/97	case20~1.xls
SGM37	$9	$24	$33	486 (-16)	656 (-55)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 2101 (2050)	n/a	-246 (-$2.21 billion)	-751 (-$24.78 billion)	09/10/97	case20~1.xls
SGM6	$74	$119	$202	483 (-19)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (2005)	never returns	36, (+$2.7 billion)	-122, (-$24.6 billion)	08/21/97	cea95_~1.xls
SGM5	$62	$131	$317	483 (-19)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (2005)	never returns	n/a	n/a	08/21/97	cea95_~1.xls
SGM7	$27	$32	$41	483 (-19)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	no peak: 2073 (2050)	never returns	-131, (-$3.5 billion)	-593, (-$24.3 billion)	08/21/97	cea95_~1.xls
SGM33	$57	$120	$203	482 (-20)	648 (-63)	2074 (+9)	0.97 (-0.09)	2.12 (-0.24)	no peak: 1599 (2050)	n/a	20 ($1.14 billion)	-119, (-$24.16 billion)	09/10/97	case20~2.xls
SGM32	$51	$131	$318	482 (-20)	648 (-63)	2074 (+9)	0.97 (-0.09)	2.12 (-0.24)	1550 (2000)	n/a	n/a	n/a	09/10/97	case20~2.xls
SGM34	$21	$33	$41	482 (-20)	648 (-63)	2074 (+9)	0.97 (-0.09)	2.12 (-0.24)	no peak: 2072 (2050)	n/a	-122 (-$2.56 billion)	-592 (-$24.27 billion)	09/10/97	case20~2.xls
SGM27	$11	$56	$153	n/a	n/a	n/a	n/a	n/a	1755 (2015)	never returns	-5, (-$0.06 billion)	-367, (-$56.2 billion)	08/27/97	case5.xls
SGM24	$11	$56	$153	481 (-21)	568 (-143)	2089 (+24)	0.98 (-0.08)	1.84 (-0.52)	1755 (2015)	never returns	-5, (-$0.06 billion)	-367, (-$56.2 billion)	08/27/97	case4.xls, 9/4/97 fax
SGM12	$0	$47	$155	491 (-11)	n/a	n/a	1.02 (-0.04)	n/a	1807 (2015)	never returns	0, (n/a)	-367, (-$56.9 billion)	08/21/97	cea90_~1.xls
SGM30	$11	$56	$153	489 (-13)	658 (-53)	2071 (+6)	1.00 (-0.06)	2.17 (-0.19)	1755 (2015)	never returns	-5, (-$0.06 billion)	-367, (-$56.2 billion)	08/27/97	case6.xls, 9/4/97 fax
SGM11	$0	$84	$559	489 (-13)	n/a	n/a	1.01 (-0.05)	n/a	1807 (2015)	2040	n/a	n/a	08/21/97	cea90_~1.xls

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corre-sponding Reductions	AEEI	Ramp-up	Time Path	PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
SGM26	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$270 billion	$9,184 billion (-$1 billion)
SGM23	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$270 billion	$9,184 billion (-$1 billion)
SGM29	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$270 billion	$9,184 billion (-$1 billion)
SGM25	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	worldwide	auction	lump-sum	LDC stabilizes at 2030 in 2030	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	-$3 billion	$9,185 billion (0 billion)
SGM31	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	-$5 billion	$9,185 billion (0 billion)
SGM28	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	worldwide	auction	lump-sum	LDC BAU to 2030, equal per capita in 2050	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$1 billion	$9,185 billion (0 billion)
SGM13	Peak in 2015	SGM, MAGICC	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	no	-->2050, -->2100 (climate)	-$8 billion	$9,185 billion ($0 billion)
SGM15	+10% of 1990 in 2010	SGM, MAGICC	Battelle	+10% 1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$95 billion	$9,181 billion (-$4 billion)
SGM14	+10% of 1990 in 2010	SGM, MAGICC	Battelle	+10% 1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$460 billion	$9,174 billion (-$11 billion)
SGM16	+10% of 1990 in 2010	SGM, MAGICC	Battelle	+10% 1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	PT	1.0	in 2005	-->2050, -->2100 (climate)	$1 billion	$9,184 billion (-$1 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), ($)	Intl. Trade of Permits, U.S., 2050 (MMTCE), ($)	Date Received Run	File (h:\jaldy\)
SGM26	$12	$99	$563	n/a	n/a	n/a	n/a	n/a	1729 (2015)	2040	n/a	n/a	08/27/97	case5.xls
SGM23	$12	$99	$563	481 (-21)	568 (-143)	2089 (+24)	0.98 (-0.08)	1.84 (-0.52)	1729 (2015)	2040	n/a	n/a	08/27/97	case4.xls, 9/4/97 fax
SGM29	$12	$99	$563	489 (-13)	658 (-53)	2071 (+6)	1.00 (-0.06)	2.17 (-0.19)	1729 (2015)	2040	n/a	n/a	08/27/97	case6.xls, 9/4/97 fax
SGM25	$4	$16	$111	481 (-21)	568 (-143)	2089 (+24)	0.98 (-0.08)	1.84 (-0.52)	1893 (2030)	never returns	-30, (-$0.1 billion)	-500, (-$55.5 billion)	08/27/97	case4.xls, 9/4/97 fax
SGM31	$4	$16	$33	489 (-13)	658 (-53)	2071 (+6)	1.00 (-0.06)	2.17 (-0.19)	no peak: 2101 (2050)	never returns	-30, (-$0.12 billion)	-751, (-$24.8 billion)	08/27/97	case6.xls, 9/4/97 fax
SGM28	$4	$16	$0	n/a	n/a	n/a	n/a	n/a	no peak: 2241 (2050)	never returns	n/a	n/a	08/27/97	case5.xls
SGM13	$0	$14	$33	491 (-11)	n/a	n/a	1.02 (-0.04)	n/a	no peak: 2102 (2050)	never returns	0, (n/a)	-752, (-$24.8 billion)	08/21/97	cea90_~1.xls
SGM15	$17	$56	$113	489 (-13)	662 (-49)	2071 (+6)	1.00 (-0.06)	2.18 (-0.18)	no peak: 1824 (2050)	never returns	-172, (-$2.9 billion)	-339, (-$38.3 billion)	08/27/97	case1.xls
SGM14	$60	$128	$310	488 (-14)	664 (-47)	2071 (+6)	0.99 (-0.07)	2.18 (-0.18)	1550 (2000)	never returns	n/a	n/a	08/27/97	case1.xls
SGM16	$7	$16	$25	489 (-13)	662 (-49)	2071 (+6)	1.00 (-0.06)	2.18 (-0.18)	no peak: 2128 (2050)	never returns	-219, (-$1.5 billion)	-643, (-$16.1 billion)	08/27/97	case1.xls

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	Paper Tons or Corresponding Reductions	AEEI	Ramp-up	Time Path	PDV (5%; 2000-2050) Foregone Consumption	GDP in 2010 (deviation from BAU)
MM1	BAU	Markal	DOE	n/a	n/a	n/a	n/a	n/a	n/a	IAT	n/a	~1.0	n/a	-->2025	n/a	$9,205 billion (BAU GDP)
MM2	1990 in 2010	Markal	DOE	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	$9,137 billion (-$68 billion)
MM3	1995 in 2010	Markal	DOE	1995 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	$9,152 billion (-$53 billion)
MM4	1990 in 2020	Markal	DOE	1990 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	$9,197 billion (-$8 billion)
MM5	Peak in 2015	Markal	DOE	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	n/a	~1.0	n/a	-->2025	n/a	$9,201 billion (-$4 billion)

ID	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, U.S., 2010 (MMTCE), ($)	Intl. Trade of Permits, U.S., 2050 (MMTCE), ($)	Date Received Run	File
MM1	$0	$0	n/a	n/a	n/a	n/a	n/a	n/a	no peak: 2066 (2025)	n/a	n/a	n/a	08/26/97	8_26run1.wk4
MM2	$148	$192	n/a	n/a	n/a	n/a	n/a	n/a	1586 (2005)	2010	n/a	n/a	08/26/97	8_26run1.wk4
MM3	$136	$146	n/a	n/a	n/a	n/a	n/a	n/a	1600 (2005)	n/a	n/a	n/a	08/26/97	8_26run1.wk4
MM4	$0	$198	n/a	n/a	n/a	n/a	n/a	n/a	1749 (2010)	2020	n/a	n/a	08/26/97	8_26run1.wk4
MM5	$0	$99	n/a	n/a	n/a	n/a	n/a	n/a	1767 (2015)	2040*	n/a	n/a	08/26/97	8_26run1.wk4

1. 1990 by 2010

2. 1990 by 2020

3 Peak in 2015, 1990 by 2040

4. 1995 by 2010

ID	Scenario	Model	Modelers	Target	Timetable	Trading	Permit Allocation	Revenue Recycling	Burden Sharing	BAU Emissions Path Assumption	AEEI	Ramp-up	Time Path	Outputs PDV (3%; 2000-2050) Foregone Consumption	Permit Prices: 2010	Permit Prices: 2025	Permit Prices: 2050	Electricity Prices: 2010, 2025, 2050
SGM1	BAU	SGM	Battelle	n/a	n/a	n/a	n/a	n/a	n/a	IAT	1.0	n/a	-->2050, -->2100 (climate)	$183,155 billion (BAU consumption)	$0	$0	$0	
SGM2	1990 in 2010	SGM	Battelle	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$1126 billion	$110	$191	$582	
SGM3	1990 in 2010	SGM	Battelle	1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	384 billion	$42	$84	$149	
SGM4	1990 in 2010	SGM	Battelle	1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$5 billion	$16	$23	$32	
SGM5	1995 in 2010	SGM	Battelle	1995 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$737 billion	$62	$131	$317	
SGM6	1995 in 2010	SGM	Battelle	1995 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$645 billion	$74	$119	$201	
SGM7	1995 in 2010	SGM	Battelle	1995 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$38 billion	$27	$32	$41	
SGM8	-10% if 1990 in 2010	SGM	Battelle	-10% 1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$1630 billion	$175	$304	$924	
SGM9	-10% if 1990 in 2010	SGM	Battelle	-10% 1990 emissions level	stabilize in 2010	Annex I	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$808billion	$91	$137	$238	
SGM10	-10% if 1990 in 2010	SGM	Battelle	-10% 1990 emissions level	stabilize in 2010	worldwide	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$63 billion	$33	$37	$45	
SGM11	Peak in 2015	SGM	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$498 billion	$0	$84	$559	
SGM12	Peak in 2015	SGM	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	Annex I	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	$125 billion	$0	$47	$155	
SGM13	Peak in 2015	SGM	Battelle	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	worldwide	auction	lump-sum	no LDC part.	IAT	1.0	no	-->2050, -->2100 (climate)	-$16 billion	$0	$14	$33	
MM1	BAU	Markal	DOE	n/a	n/a	n/a	n/a	n/a	n/a	IAT	~1.0	n/a	-->2025	n/a	$0	$0	n/a	
MM2	1990 in 2010	Markal	DOE	1990 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	~1.0	n/a	-->2025		$148	$192	n/a	
MM3	1995 in 2010	Markal	DOE	1995 emissions level	stabilize in 2010	domestic only	auction	lump-sum	no LDC part.	IAT	~1.0	n/a	-->2025		$136	$146	n/a	
MM4	1990 in 2020	Markal	DOE	1990 emissions level	stabilize in 2020	domestic only	auction	lump-sum	no LDC part.	IAT	~1.0	n/a	-->2025		$0	$198	n/a	
MM5	Peak in 2015	Markal	DOE	2010 BAU emissions in 2015; 1990 level in 2040	stabilize in 2040	domestic only	auction	lump-sum	no LDC part.	IAT	~1.0	n/a	-->2025		$0	$99	n/a	
	550ppm Least-Cost	MERGE	Richels	550ppm concentration														

Oil Prices: 2010, 2025, 2050	Conc. (ppmv) in 2050 (Deviation from BAU)	Conc. (ppmv) in 2100 (Deviation from BAU)	Year Conc. (550 ppmv) Reaches 2x Pre-Ind. Level (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2050 (Deviation from BAU)	Change in Temp. (deg. C) from 1990 in 2100 (Deviation from BAU)	Emissions Peak, mmtce (year)	Year Returns to 1990	Intl. Trade of Permits, 2010, 2050 (mmtce)	Date Received Run	File	
	502	711	2065	1.06	2.36	no peak: 2245 (2050)	n/a	n/a	08/21/97	aldy/sgmruns/cea90_~1.xls	
	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	1637 (2005)	2010	n/a	08/21/97	aldy/sgmruns/cea90_~2.xls	
	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 1714 (2050)	never returns	-202, -364	08/21/97	aldy/sgmruns/cea90_~2.xls	
	485 (-17)	658 (-53)	2072 (+7)	0.99 (-0.07)	2.16 (-0.20)	no peak: 2102 (2050)	never returns	-313, -752	08/21/97	aldy/sgmruns/cea90_~2.xls	
	481 (-21)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (2005)	never returns	n/a	08/21/97	aldy/sgmruns/cea95_~1.xls	
	481 (-21)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	1637 (200	never returns	36, -122	08/21/97	aldy/sgmruns/cea95_~1.xls	
	481 (-21)	648 (-63)	2074 (+9)	0.98 (-0.08)	2.12 (-0.24)	no peak: 2073 (2050)	never returns	-131, -593	08/21/97	aldy/sgmruns/cea95_~1.xls	
	481 (-21)	653 (-58)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	2010	n/a	08/21/97	aldy/sgmruns/cea90m_~1.xls	
	481 (-21)	653 (-58)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	1637 (2005)	never returns	-180, -332	08/21/97	aldy/sgmruns/cea90m_~1.xls	
	481 (-21)	653 (-58)	2074 (+9)	0.97 (-0.09)	2.11 (-0.25)	no peak: 2060 (2050)	never returns	-332, -845	08/21/97	aldy/sgmruns/cea90m_~1.xls	
	489 (-13)	653 (-58)	2072 (+7)	1.01 (-0.05)	2.15 (-0.21)	1807 (2015)	2040	n/a	08/21/97	aldy/sgmruns/cea90_~1.xls	
	489 (-13)	653 (-58)	2072 (+7)	1.01 (-0.05)	2.15 (-0.21)	1807 (2015)	never returns	0, -367	08/21/97	aldy/sgmruns/cea90_~1.xls	
	489 (-13)	653 (-58)	2072 (+7)	1.01 (-0.05)	2.15 (-0.21)	no peak: 2102 (2050)	never returns	0, -752	08/21/97	aldy/sgmruns/cea90_~1.xls	
	n/a	n/a	n/a	n/a	n/a	no peak: 2066 (2025)	n/a	n/a	08/26/97	aldy/markal~1/8_26run1.wk4	
	n/a	n/a	n/a	n/a	n/a	1586 (2005)	2010	n/a	08/26/97	aldy/markal~1/8_26run1.wk4	
	n/a	n/a	n/a	n/a	n/a	1600 (2005)	n/a	n/a	08/26/97	aldy/markal~1/8_26run1.wk4	
	n/a	n/a	n/a	n/a	n/a	1749 (2010)	2020	n/a	08/26/97	aldy/markal~1/8_26run1.wk4	
	n/a	n/a	n/a	n/a	n/a	1767 (2015)	2040*			aldy/markal~1/8_26run1.wk4	

p3 end
The gain seems small relative to the ~~rest~~ economic cost.

p5 bottom

p10 (a) macro shock
(b)

Zachary M. Candelario

09/26/97 05:33:01 PM

Record Type: Record

To: Jeffrey A. Frankel/CEA/EOP, Adele C. Morris/CEA/EOP

cc:
Subject: T+T Fact checking

All numbers in Targets and Timetables that referred to Manne and Richels 9-21 paper have been checked.

1. In the table on page 20 of T+T, the permit price for Annex I only trading is 132 in T + T, but Manne and Richels list it as 131. This may be due to rounding differences.

2. On page 3 of T+T, second paragraph: the moderate path peaks in 2010-2020, not in 2010, as cited.

Predecisional draft. Preliminary. Close hold. Do not distribute. 8/29; rev. 9/16/97,am19,jf25

Targets and Timetables : Executive Summary

How ambitious should we be in seeking to ameliorate global climate change? Is it more advisable to reduce emissions of greenhouse gases (GHG) early and rapidly, or more gradually? This paper examines policy options for GHG emissions targets and timetables and reviews the academic literature and other relevant information and analysis to compare them. We find that a given environmental goal, expressed in terms of the level at which atmospheric GHG concentrations are induced to level off, can be attained at far lower economic costs if emission reductions are phased in gradually rather than suddenly. More specifically, we conclude that a moderate path such as "eliminate emissions growth by 2010-2020, and return emissions to 1990 levels by 2040," seems to be preferable on economic grounds to the more aggressive alternative "return emissions to 1990 levels by 2010."

1. Tradeoffs between front-loading and back-loading emissions reductions

It is easy to state the basic forces at work in the trade-off between front-loaded (reducing emissions earlier) and back-loaded emissions reductions (allowing emissions reductions over longer periods).

Four factors work in favor of back-loading:

- allowing time for the capital stock to turn over. By way of stylized illustration, scrapping all coal-fired power plants by 2010 would mean writing off 88% of the capital stock in this sector; waiting until 2020 would necessitate scrapping only 49% of the plants before the end of their normal useful life.
- the time-value of money. Resources not spent on emission reductions early on can be invested at a positive return, so as to purchase more emission reductions later.
- allowing for uncertainty to be resolved.
- giving more lead time to develop and implement new technologies.

The most important argument in favor of front-loading:

- political credibility. An announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 years or more into the future -- will not be credible. Only early concrete measures will send the signal necessary to move patterns of research, investment, and consumption onto the new path.

2. The costs of "1990 levels by 2010"

The costs of reducing emissions to 1990 levels by 2010, as the cost of any path, depend heavily on the international regime and domestic implementation. "We can do it smart or we can do it dumb." But any effective program will have to raise the cost of GHG emissions, particularly the cost of using fossil fuels that put carbon dioxide into the air. A broad range of models place the carbon permit price required to achieve this target in the range of $70 - $200 per ton. This surcharge translates into an increase in the price of gasoline between 18 and 50 cents per gallon and an increase in the price of coal between 250 and 500 percent. Averaging over fuels, these price increases are nine times greater than the BTU tax that was proposed in 1993, and as great as the oil shocks of the 1970s. (The necessary increase in price could be cut if we are able to pay Russia, developing countries, or others to reduce emissions in our place. But the remaining price increase would nevertheless be substantial.)

These increases in the price of energy might or might not have the substantial negative effects on output of the 1970s oil shocks. Whether they do depends on many things, such as whether the policy is implemented efficiently (e.g., by auctioning emissions permits or a carbon tax) or inefficiently (e.g., by command-and-control style regulation), and whether any revenues that may be generated are redistributed by means of tax cuts that lower the cost of capital to firms. In any case, the policy will have substantial negative effects on consumption, in order to free up resources for investment in new low-carbon plant and equipment.

3. The effects of a moderate path, peaking in 2010-2020

One possible more moderate path is specified as follows:

(i) begin to reduce the rate of growth of emissions in the near-term (2000-2010),

(ii) eliminate emissions growth in the medium term (so that emissions at the end of the decade 2010-2020 were the same as at the beginning), and

(iii) return emissions to the 1990 level in the longer term (e.g., 2040).

The overall cost of this approach is much less than that of the more aggressive timetable, 1990 by 2010. Estimates suggest that the price of carbon would be between $5/ton and $12/ton in 2010. (It would have to continue to rise thereafter, as is also true under the first approach.) Gas prices would rise by an estimated 2 to 3 cents in 2010, and coal prices by 25%-35%. Effects on the economy are scaled down accordingly. Estimates of the loss in consumption are roughly 1/10-1/3 the size of the more aggressive approach.

4. Environmental effects of alternative dates for stabilizing emissions

What is the environmental loss that the planet must bear in exchange for economic gain from slowing emissions cuts? The answer depends entirely on emissions during the remainder of the 21st century (and thereafter). Differences in emissions in the early years of the century have virtually no effect on the cumulative concentration levels. But "even the longest journey begins with a single step." Differences in that first step are important to the extent that they begin the journey down different pathways.

Let us consider the environmental effects of four different emissions paths of increasing ambition in controlling GHG emissions. The first path represents emissions growth in the absence of any policy intervention, a.k.a. business as usual (BAU). The second is the moderate path described above, which peaks in 2010, and the third is achieving 1990 by 2010. The final path is even more aggressive and achieves emissions 10% below 1990 levels by 2010. We assume that each path eventually stabilizes annual emissions at the 1990 level (or 10% below, in the last case) through the remainder of the century. Note that this assumption, while it implies a growing gap with the BAU growth path over time, does not cut emissions enough to prevent concentrations in the atmosphere from increasing.

As one can see from the table below, under BAU, estimated temperatures rise 1.06 and 2.36 degrees centigrade in 2050 and 2100, respectively. The moderate path mitigates the warming by 0.06 degrees in 2050 and 0.19 in 2100. The 1990 by 2010 path reduces the warming relative to BAU by an estimated 0.08 and 0.21 degrees, in the respective years, a very small additional effect relative to the moderate path. The most aggressive path has virtually the same small effect. The three policy options postpone by 6 to 9 years the date at which total atmospheric CO2 concentrations reach a level that is double the pre-industrial level (about 550 ppmv).

Environmental effect (degrees centigrade)	Path of emissions of GHG			
	BAU	Moderate path	1990 levels by 2010	10% below 1990 levels by 2010
Temperature increase in 2050, **total**	1.06	.99	.98	.97

Temperature increase in 2100, **total**	2.36	2.17	2.15	2.11
Temperature increase in 2050, **relative to BAU**	0	-.07	-.08	-.09
Temperature increase in 2100, **relative to BAU**	0	-.19	-.21	-.25
Additional years until CO2 doubling, **relative to BAU**	0	6	7	9

5. A big difference in cost for two paths to the same ultimate goal

Perhaps the strongest case against an aggressive path like "1990 in 2010" is that *the same ultimate goal in terms of concentrations* can be achieved far more cheaply by imposing aggressive cuts in emissions later in the 21st century rather than earlier. Recall that estimated concentrations and temperatures continue to rise in subsequent centuries under any of the paths outlined above. In order to put a bound on the eventual climate disruption, one has to put a bound on concentrations, which in turn requires that we reduce emissions below 1990 levels. Modelers can compute the path that minimizes the total economic costs of attaining a given ultimate concentration target, and we can compare it to other paths leading to the same target.

The most important implication of the least cost mitigation path is that it costs the U.S. \$0.124 trillion in terms of lost consumption (present discounted value), as compared to \$0.303 trillion under the "1990 in 2010" path. Thus *the least cost mitigation path generates savings of 60 percent from the 1990 in 2010 path*. Assuming that environmental effects depend on concentrations, there is little or no environmental cost to be weighed against the large economic benefits of going more slowly.

The estimated least-cost path has several other interesting implications. It indicates that emissions rise gradually in the early years and that Annex I countries' emissions peak in the decade 2020-2030 at about 29 percent above 1990 levels. Annex I emissions do not return to their 1990 levels until after 2050. This least cost mitigation path generates quite low values for carbon emissions rights in the early years. The permit price is only \$2/ton in 2010, and slowly rises thereafter. Only in the latter part of the century does it rise significantly, to \$156/ton in

2100.

The experiment assumes that developing countries are successfully brought in to the agreement, with their participation phased in between 2030 and 2050. Emissions from developing countries peak in 2050. Without the participation of the developing countries, attaining the target of 550 ppmv concentrations is virtually impossible, since they are such a rapidly growing share of world emissions.

It is important to keep in mind that all these cost estimates are "best case" scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

6. Political credibility

A path under which emissions peak in the decade 2020-2030 is far more conservative than the paths that have been discussed in international negotiations. The strong argument for moving the timetable forward is the one mentioned above: political credibility. The year 2020 is more than two decades in the future. A path under which emissions peak in the decade 2010-2020 represents early commitment to a tangible target ("eliminate emissions growth"), while estimates suggest that it is almost as beneficial as the least-cost path. The political credibility of the path could be further boosted by commitments at earlier dates such as 2000-2010 ("reduce emissions growth"). Credibility would be particularly enhanced by a specific proposal to raise the price of energy, even if by only a small amount, if domestic political opposition was not overwhelming.

More aggressive paths are likely to arouse greater political opposition, in correspondence to their greater economic cost. Where domestic opposition is sufficiently great to kill a proposal politically, the set-back will be to international political credibility -- and to environmental progress. The last section of the paper, however, discusses one possible option that might have the effect of helping to limit the economic cost and corresponding domestic opposition, for any given target/timetable: an escape clause triggered by the price of carbon emissions.

Predecisional draft. Very preliminary. Close hold. Do not distribute

Targets and Timetables

A U.S proposal for "targets and timetables" for reducing countries' emissions of greenhouse gases (GHG) must be made soon. The U.N. Framework Convention on Climate Change has called for economically cost-effective remedies to the problem [cite? From JY]. Tradeoffs have to be made -- both with respect to the ultimate target and with respect to the timetable under which it is achieved. The subject of this paper is how to do them. (The paper does not directly focus on two other key sets of policy decisions -- domestic implementation, and proposals for developing country participation and other sorts of "when-and-where flexibility".)

It is futile to search for a single comprehensive econometric model within which these questions can be appropriately raised and definitively answered. Even within a given model, answers depend critically on the precise nature of the question asked (e.g., the extent of global participation and international trading, whether and how any revenue is recycled, what is assumed about technological progress, etc.) Furthermore, each model has strengths and weaknesses; each has questions to which it is better or worse suited to answer. Some, for example, model the energy sector in detail. Some allow for the fact that a coal-fired power plant cannot costlessly be converted to one that runs on natural gas. Some have enough tax policy detail to distinguish alternative ways of redistributing tax revenues. Some are capable of showing short-term macroeconomic disequilibria. Some include a long-term "carbon cycle" model that can keep track of the accumulation of GHG concentrations in the atmosphere and their climatological effects. Some break down the rest of the world into regions and so can model international trade. No one model does everything.

The existence of modeling difficulties does not mean that we can abandon rigorous economic analysis. Rather, we must employ a broad set of economic tools to analyze the policy options. The tools employed in this paper include results from models of the energy sector and economy over the next 25 years, including but not limited to the models that were used by the Interagency Analytical Team (IAT) earlier in this year. The survey also includes models that are designed to operate on the longer time frame that is relevant for thinking about climatological effects. Other tools include simple relevant statistics, "meta-analyses" of existing models, historical and sectoral examples, and basic economic reasoning. Drawing on this broad array of analytical tools allows an intelligent evaluation of the policy alternatives.

1. Why do economists estimate high costs to early reductions in emissions?

The large economic impact of aggressive action

The measures necessary to implement serious reductions in GHG emissions would inevitably have very major effects on the U.S. economy. One path that has been widely discussed in the U.S. is to return to 1990 levels in 2010. (Still more aggressive paths seek to cut emissions 10 percent or more below 1990 levels by 2010. Intermediate paths are to return to 1990 levels by 2020, or to 10 percent above 1990 levels by 2010.) Estimates suggest that to reduce 2010 emissions to the level of 1990, it would be necessary to increase the price of energy on the order of $100 per ton of carbon.

This is a rough midpoint, around which there is a great range of uncertainty. The range of estimates in the IAT exercise was $80-$140, for the case without international trading. Some agencies believe that the necessary increase in price would be less than this, others that it would be more. It is anticipated that prices would have to continue to increase after 2010, even if emissions were not brought down any further, because of the widening gap vis-a-vis the business-as-usual case. (Energy modelers often make the assumption that, once the price of carbon goes high enough, some sort of unidentified "back-stop technology" will eventually be developed, thereby putting a limit on how high the price ultimately goes. But there is no way of knowing when or at what price such technology would come in.)

These estimates are representative of the broad economic literature. In a similar exercise, the Energy Modeling Forum, based in Stanford, has assessed a set of targets and timetables with 10 models (EMF-12, 1994; Gaskins and Weyant, 1993; Weyant, 1994; Richels, Edmonds, Gruenspecht, and Wigley, 1996). These models, employing the same benchmark assumptions, assessed the economic effects of achieving carbon emissions stabilization relative to 1990 in the year 2000 (with implementation beginning in 1990). The modeling results all clearly indicate that the tighter the emissions constraint, the higher the price of carbon.

[insert chart on average carbon taxes required to achieve C emission reductions in the U.S., 2000-2020]

The rough estimate of $100/ton in 2010 represents an increase in the price of oil of $11/barrel (52%), an increase in the price of gasoline of 26 cents/gallon, and an increase in the price of coal of 273%. One standard of comparison is the BTU tax that the Administration proposed in 1993. The increase contemplated here is 9 times larger. (This is for a weighted average of fuels. The multiple for coal is greater than this, and for oil is less.)

These large price changes signal major changes in the allocation of resources across activities and sectors. Need they require a reduction in the rate of growth of aggregate income and output? This depends, in particular, on two things. First, adjustment costs can impose a

negative effect on GDP and employment, especially in the short term. Model estimates of GDP losses from "1990 by 2010" reached __ in the IAT exercise under some pessimistic assumptions, and are higher in some other estimates. ___. The EMF-12 exercise also demonstrated that higher permit prices associated with tighter carbon emissions constraints resulted in larger GDP losses in 2010.

[insert chart on GDP losses from EMF-12]

Second, if measures to raise the price of energy result in the generation of revenues for the government, and they are used to reduce the cost of capital to firms (e.g., by means of an investment tax credit), despite the regressive implications for the distribution of income, then negative effects on economic growth can in the long run be moderated, eliminated, or possibly even reversed.[1] The meta-analysis of 162 simulations derived from 16 leading models by Repetto and Austin (1997, p.13) concludes that the negative effect on national income from stabilization in 2020 can be offset or reversed *if*:
(i) tax revenues are recycled so as to reduce the cost of capital to corporations,
(ii) developing countries participate in the agreement, *and*
(iii) optimistic assumptions are made regarding the availability of non-carbon backstop technologies, efficient economic responses, and increased energy and product substitution. If any of these optimistic assumptions fail, the GDP effect turns negative.

However, the best single measure of aggregate economic costs is the appropriate summation over time -- the present discounted value -- of foregone consumption. Even in a case so optimistic that there might be no effect on output, early action to address climate change would require a diversion of resources from consumption to investment. Thus the present discounted value of consumption is likely to fall. By way of analogy, defense build-ups have appreciable economic costs, in terms of foregone consumption, even though there is often little or no negative effect on aggregate GDP.

Analogy with the oil shocks of the 1970s

A standard of comparison for judging the magnitude of the price increases entailed in climate change policy is the oil shocks of the 1970s. The energy price increase now contemplated [an estimated 88 percent] for stabilization by 2010 is on the same order of magnitude as either the 1973-74 or 1979-80 oil price increases. Again, this is for a weighted average of primary fuels. Fossil fuel prices net of inflation doubled between 1972 and 1975, and doubled again by 1981.

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[1] E.g, Jorgenson (1996).

Gasoline prices rose by 30 percent between 1972 and 1974 and by nearly another 50 percent from 1974 to 1981. Coal, as a substitute for oil, also experienced a price increase in the earlier episode, but by much less.

One can check independently how the price increase necessary in the present context compares to those of the oil shock decade . Carbon emissions in the year 2000 will be about 15% percent above 1990 levels (EIA ___). Between 1973 and 1984, U.S. energy use departed from its usual growth trend, and was essentially unchanged in absolute terms. U.S. emissions fell by only 6.2%. This comparison suggests that to return emissions to 1990 levels between 2000 and 2010, a decline of 15%, would require much greater increases in energy prices than took place over the decade of the oil shocks.

Those price increases, which are designated "supply shocks," are widely believed to have led to high levels of inflation that were eventually reversed only by means of high interest rates and very large losses in output over time. More specifically, they are believed to have led directly to the recessions of 1974 and 1980. (Indeed, the contraction in output, as much as the fall in the energy/output ratio, was a prime force reducing energy use below its long-run trend.) Some economists also believe that the oil shocks may have played a role in the abrupt slowdown in the long-term trend of productivity growth evidenced in the U.S. and other industrialized countries after 1973; but that is much less certain.

The large models that have been used to examine climate change policy tend to exclude supply-shock effects. [Only the DRI model is a macro model capable of addressing these effects; and it shows a loss of only 150,000 to 400,000 jobs in 2010.] The idea is that a path of gradual increases in energy prices will be fully built into the expectations of firms and workers, because of clear commitments to future policies. Thus they will be able to plan ahead and avoid serious microeconomic dislocation and macroeconomic disturbance. Furthermore, the 70s oil shocks entailed large transfers from the U.S. and other oil-importing countries to OPEC, thus depressing real income and spending in the former; a self-imposed energy price increase to address global climate change need not entail such a transfer of purchasing power. Still, if it is contemplated to introduce large increases in energy prices over a period as short as a single decade, it is worth remembering the experience of 1972-81.

The role of turnover of the capital stock

Why do economic models consistently find that the cost of major reductions in emissions is much higher if they are implemented by 2010 than if they are stretched out for another decade or more? There are several arguments against early reductions and in favor of waiting. (There are also a number of reasons for wanting to go fast, listed in bullet form in the Section on cost-benefit analysis below.) They include:

(1) the time-value of money (resources not spent on emission reductions early on can be invested at a positive return, so as to purchase more emission reductions later[2]),
(2) allowing for uncertainty to be resolved, and
(3) giving more lead time to develop and implement new technologies. But the most important reason for waiting is :
(4) to allow time for the capital stock to turn over.

The basic point is that it would be very expensive to scrap the entire capital stock, to replace it with more carbon-free plant and equipment, while it is still in the prime of its useful life. But 20 to 40 years out into the future, much of our existing plant and equipment will be ready for replacement anyway, whether because the plant and equipment have depreciated gradually or because they have more suddenly come to the end of their useful life.

[FIGURE 1 GOES HERE]

The effect of the turnover of the capital stock is built into some of the models used to address climate change [e.g., Markal Macro; though not into most "bottom-up" engineering studies, like the Department of Energy's Five-Labs study]. But it may be useful to look at a simple illustration of the point, for the case of the capital stock in power generation.

Figure 1 shows the effects of an accelerated replacement schedule for all of the 7.900 electric power plants built during the last 40 years. [One could skip directly to coal-fired plants (next paragraph), to save space.] Imagine, to take an extreme case, that all power plants had to be shut down within ten years (by 2007), and replaced with less-polluting technology. This would imply replacing 6,330 plants before the end of their normal lifespan, or 80 per cent of the total. Now imagine a policy that required replacement of all power plants in 20 years. This would constitute an accelerated replacement of 4,600 plants, or 58 per cent of the total. If one could wait 30 years, the complete replacement would mean an accelerated replacement of 2,000 plants, 26 per cent of the total. If one waited forty years, under the stylized assumption of a 40-year life there would be no additional cost to replacing them. [We have truncated the distribution at 40 years, the average lifespan of existing electric power plants. There are other plants that are still in use 50, 60, or even 90 years after they were built. But their numbers are small, and by the end of 40 years the cost of shutting them down would in any case be much-reduced, particularly as technology will have advanced in the meantime.]

Figure 2a does the same exercise for the set of power plants that are coal-fired. This is the

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[2] Meanwhile, a higher fraction of carbon emissions will have been naturally removed from the atmosphere by a fixed date, e.g., into the oceans, the earlier those emissions occur. (Manne and Richels (1995, 1997).

class of generators that produce the most carbon and that would thus have to be replaced even under a moderate plan to address climate change. If a complete change-over of coal plants were to be accomplished in 10 years, 799 of the 1,122 coal-fired plants (71 per cent) would have to be replaced before the end of their expected lifespan. If replacement occurs over 20 years, 488 plants would be affected, or 43 percent of the total. If one could wait 30 years, 227 plants would be closed prematurely, or 20 per cent of the total.

Perhaps a comparison between 2010 and 2020 would be most relevant, as these two years figure prominently in the targets-and-timetables debate. In our stylized hypothetical experiment, imagine that all power plants had to be shut down by 2010 (i.e., within 13 years). This would imply replacing 88 percent of the plants before the end of their normal lifespan. Now imagine that all power plants had to be replaced by 2020 (23 years). This would constitute an accelerated replacement of only half the plants.

[FIGURES 2a AND 2b GO HERE]

Figure 2b repeats the exercise on the basis of coal plant *capacity*. Since newer plants tend to have larger capacity, the effects of a rapid replacement schedule are magnified. Closing all plants within 10 years implies that 289 million KW of capacity would be prematurely shut down, or 90 per cent of the total. If one could wait 20 years, 235 million KW of capacity would be affected, or 73 per cent. For 30 years, the capacity that would have to be replaced falls to 116 million KW, or 36 per cent of the total.

This exercise is not intended to be an estimate of the costs of different time-tables, even within this one sector. Rather, the point has been to illustrate concretely the importance of allowing time for the capital stock to turn over, and to illustrate it in a transparent framework that is independent of modeling assumptions over which analysts might differ.

Evaluation of alternative paths

One can pose the question regarding effects of alternative paths in three ways. (I) How do the economic and environmental effects of "1990 by 2010" compare to those of more moderate paths, e.g., in which that level is attained at some later date? (ii) What are the economic effects of alternative paths toward the same ultimate environmental objective, e.g., eventual stabilization of concentrations at twice pre-industrial levels? (iii) What is the optimal unconstrained path to balance estimates of economic costs and environmental benefits? The remainder of the paper considers each question, though in reverse order.

[or would it be better to do it in order
(i) (ii) (iii): 1990-LEVEL RESULTS, THEN 550PPM CONSTRAINT, THEN IA MODELS?]

2. Cost-benefit analysis in the Integrated Assessment models

It is difficult to put economic costs and climate benefits into the same unified analytical framework. This is in part because the effects are so uncertain, especially with regard to climate, and in part because the climate effects take place on a very long time scale. So-called Integrated Assessment models attempt to put everything into one framework. They attempt to quantify the benefits of averted climate change in the distant future, as well as the economic costs of programs to address emissions, and to compare the two.

Integrated Assessment models began with Nordhaus (1989, 1994). By now many of these models exist. An Appendix I to this paper elaborates, and the literature is surveyed by Manne (1996). Those models that can be used for cost-benefit analysis tend to give a similar result: a plan that optimally balances costs and benefits calls for relatively small actions at the beginning, with the result that GHG emissions continue to rise, although at a reduced pace, for at least a century. Concentrations reach ___ ppmv by 21__.

In the simplest case, damage from warming is assumed to rise linearly with temperature. But it is plausible that the costs in fact begin to rise more sharply, e.g., when concentrations and temperature go above a threshold level. Findings by Peck-Tiesberg (1992), using the CETA model and the case of a non-linear damage function (allowing the damage to rise increasingly sharply with the temperature), call for emissions peaking in 2080-2090.

Some of the authors have characterized in a striking way the gap between the optimal paths that their models produce and the frequently heard proposal to return emissions to 1990 levels by 2010: In their models, the economic costs of such a strong early response are so great that, if that were the only alternative, we would be better off doing nothing at all [Jorgenson testimony? Can't find it in there. It's ____ of Stanford?]. In other words, the economic costs of "1990 levels by 2010" outweigh the benefits.

Arguments for earlier action

This conclusion, and the methodology that produced it, have been criticized on a number of grounds.

- Some claim that it gives insufficient weight to the (small, but nonetheless alarming) probability of a discontinuously-large and essentially irreversible catastrophe, such as the melting of the West Antarctic ice sheet [which might raise ocean levels by 5 to 6 meters], a runaway "positive-feedback" greenhouse effect (e.g., from methane release), or structural changes in ocean currents such as the Gulf Stream. [references: Cline (1992, p.34-35, Revelle, 1983, p.442, IPCC 1996a; Schelling AER 1995?]
- Some claim that it gives insufficient weight to the welfare of future generations that will

bear the costs of climate change (that is, the discount rate is too high). [references: Cline (1992) and Howarth (1996).]

- Some claim that it neglects basic uncertainty about all parameters -- the economic effects, the climate effects, and the discount rate necessary to compare the two. [reference: Pizer (1996)]
- Some claim that it omits a basic point about political credibility: an announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 years or more into the future -- will not be credible, and understandably so (Austin, 1997). The arguments for postponing sharp cuts in emissions ten years only work if people use the intervening period to begin adjusting. If they are skeptical of the need to adjust, then ten years later nothing will have been accomplished, and the economy at that point will face the same high costs to early reductions as before. Only early concrete measures will send the signal necessary to move people's patterns of research, investment, and consumption onto the new path. [3]

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3. Estimates of least-cost paths to stabilize concentration levels

For the reasons just enumerated, much of the debate about GHG stabilization takes as given that simply allowing emissions to continue to grow for a long period, even at a reduced rate, as contemplated by the authors referenced in the preceding section, puts the biosphere at too much risk and is not credible politically. An alternative strategy is to reason that the probability of catastrophe may rise to unacceptable levels unless GHG concentrations are capped at some particular level. Such an approach has the disadvantage that the choice of any specific concentration cap is arbitrary, and is inconsistent with the spirit of cost-benefit analysis. But it has the advantage of being analytically tractable, and offers a meaningful focal point for negotiation.

Stabilization of concentrations at 550 ppmv

We will consider the question of the optimal path subject to the constraint that concentrations be stabilized at 550 ppmv (approximately double the pre-industrial level of 275

[3] An opposing credibility point is also made: A proposed agreement that demonstrably imposes much higher costs than an alternative more measured approach, and thereby invites prohibitively great domestic political opposition, will also suffer from credibility problems both here and abroad.

ppmv[4]). One might ask why we need accept a level of concentrations, and corresponding probability of catastrophe, as high as this. Indeed, why accept any probability of catastrophe? It is important to recognize that it is already too late to keep this probability at zero (even if one were to accept that it would have been worth the cost to do so, had we known at the beginning of the Industrial Revolution what we know now). Atmospheric concentrations are already at 365 ppmv, and it is impossible to prevent them rising further in the short run; one would have to reduce emissions almost to zero to do so.

[It would be useful to quantify the implicit gap between this strategy and the strategies resulting from the unconstrained optimization by the Integrated Assessment models. The difference represents the role being accorded to the four bullet points above. In addition, some sensitivity analysis with respect to the level of the concentration constraint would be desirable.]

Results for a less aggressive path

The Energy Modeling Forum evaluated two forms of emissions paths to achieve specified carbon dioxide concentrations (EMF-14). A suite of six models, employing the same set of benchmark assumptions, assessed an aggressive path, the IPCC Working Group I path (WGI), and a more moderate path, based on work by Wigley, Richels, and Edmonds (WRE). Both sets of paths can achieve concentration stabilization at 550 ppmv or other targets levels. WRE argue that a less aggressive path can achieve the same stabilization goal at much lower economic costs.

The aggressive WGI path entails Annex I fossil fuel emissions peaking in 1990, and falling 24 percent worldwide below 1990 levels by 2010.[5] (Of course, it is too late for this scenario to be realized. Seven years have passed during which emissions manifestly have not in fact begun to fall in the overwhelming majority of OECD countries. Below, we will also consider other alternative proposals that, while sufficiently ambitious as to be expensive to achieve, at least have the virtue of not having been ruled out by history.)

For the WRE path, emissions from OECD countries as well as from other Annex I countries (Russia and most of Eastern Europe) peak in the decade 2010-2020. (Annex I emissions do not return to their 1990 levels until sometime early in the decade 2030-2040. The

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[4] The concentration figure refers only to CO2. Emission of other greenhouse gases will raise the carbon-equivalent, or warming potential, above this level.

[5] *Worldwide* emissions rise 8 percent by 2010 [from 5.885 to 6.351]. These numbers come from 8/28 personal communication with Richels. (Earlier information had worldwide emissions rising 13.64% by 2010 under the IPCC path [to 7.798 PgC]. Evidently the former statistic refers only to fossil fuel emissions and the latter to all carbon emissions.)

price of crude oil peaks in 2040.) The peak in worldwide emissions lags two decades behind the peak in Annex I emissions because the developing countries' emissions do not peak until 2050. Both paths stabilize global carbon dioxide concentrations under the same timeframe.

[insert chart with WRE and WGI emissions paths]

To estimate the economic effects of these pathways, the modelers must employ a burden-sharing rule. Carbon dioxide concentrations cannot be stabilized without developing country participation. Consistent with the U.S. negotiating position, these model runs assume that developing countries agree to binding targets in the future. The modelers assumed that developing countries will continue to increase their emissions along the business as usual path until 2030. During this period, Annex I will undertake emissions reductions. In 2030, developing countries will begin to reduce their emissions growth. By 2050, emissions rights will be allocated to countries on a per capita basis.[6]

As noted earlier, the best single measure of aggregate economic costs is the present discounted value, i.e, the appropriate summation over time, of foregone consumption. The following two tables illustrate the conclusions -- robust across various models -- from the comparison of the aggressive and moderate paths to the same environmental goal. The first table indicates that, on average, the moderate path achieves the same environmental goal at only 30% of the cost of the aggressive path. Indeed, with international permit trading, the cost of the moderate path is approximately 20% of the cost of the aggressive path. The second chart, a permutation of the first, clearly demonstrates the value of international permit trading. With one exception, the ratios of the costs of an emissions path with trading, to the same path without trading, are considerably less than one. International permit trading, on average, results in less than half the costs of the same emissions path without trading.

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[6] Based on 1990 populations. This formula could imply large transfers from OECD countries to developing countries. We consider an alternative scenario in the next section -- that the developing countries do not participate at all. It would also be desirable to look at the implications of a plan under which a small number of middle-income countries (particularly Korea and Mexico) begin to limit emissions by 2010. Without China and India, however, the emissions of the middle-income countries are a small fraction of the world total, so that their involvement would be important only in order to point the way for other emerging economies, rather than to reduce emissions perceptibly in their own right. A plan where developing countries ultimately were assigned targets determined by a formula putting equal weight on population, GDP, and past emissions would probably be more realistic (even though more complicated) than simplified extremes such as population alone or past emissions alone. Formulas based on population are probably too generous to poor countries for rich countries to agree, while formulas based on 1990 emissions alone are far too generous to rich countries for the poor countries to agree.

The Effects of Emissions Pathway on Consumption Losses by OECD Countries, 550 ppmv Stabilization Goal, EMF-14

Model	Trading	WRE	WG1	WRE/WG1
CETA	no	1.83	5.94	0.31
CPBRIVM	no	0.64	3.25	0.20
FUND	no	9.82	11.71	0.84
MERGE	no	0.85	6.12	0.14
MiniCAM	no	1.58	6.51	0.24
SGM	no	1.84	6.17	0.30
CETA	yes	1.86	4.03	0.46
CPBRIVM	yes	0.17	0.99	0.17
FUND	yes	1.47	4.97	0.30
MERGE	yes	0.60	3.24	0.19
MiniCAM	yes	0.54	3.44	0.16
SGM	yes	0.13	1.48	0.086
			Average:	0.28

source: Weyant, 1997

The Effects of Trading on Consumption Losses by OECD Countries, 550 ppmv Stabilization Goal, EMF-14

Model	Pathway	Trading	No Trading	Trading/No Trading
CETA	WRE	1.86	1.83	1.02
CPBRIVM	WRE	0.17	0.64	0.27
FUND	WRE	1.47	9.82	0.15
MERGE	WRE	0.60	0.85	0.71
MiniCAM	WRE	0.54	1.58	0.34
SGM	WRE	0.13	1.84	0.07

CETA	WGI	4.03	5.94	0.68
CPBRIVM	WGI	0.99	3.25	0.30
FUND	WGI	4.97	11.71	0.42
MERGE	WGI	3.24	6.12	0.53
MiniCAM	WGI	3.44	6.51	0.53
SGM	WGI	1.48	6.17	0.24
			Average:	0.44

source: Weyant, 1997

The modelers in the EMF-14 exercise did not attempt to calculate the least-cost path for achieving concentration stabilization goals.

The least-cost mitigation path, compared to 2010 constraints

Manne and Richels (1997a,1997b) are believed to be the first researchers to have computed the path that minimizes costs (using the MERGE model), subject to the constraint of stabilizing concentrations at a level such as 550 ppmv.[7] As the EMF-14 results illustrate, the MERGE model generates results on the costs of concentration stabilization that fall among the middle of the economic models. In their papers, they employ the same international burden-sharing rule as EMF-14.

Their model implies that the least cost mitigation path has emissions from Annex I countries peaking in the decade 2020-2030, a bit behind the WRE path. The peak of Annex I emissions is 29 percent above 1990 levels. [Source: personal communication from Richels, 8/21 and 8/28/97.] Emissions do not return to their 1990 levels until after 2050. Emissions from developing countries peak in 2050. The sum of the two, total worldwide emissions, also peaks in 2050. (By mid-century, developing countries are such an important source of emissions that they dominate the global peaking date and the date of return to 1990 levels.) Worldwide emissions return to their 1990 levels shortly before the end of the 21st century.

This least cost mitigation path generates quite low values for carbon emissions rights after implementation in 2000. The permit price is only $2/ton in 2010, and rises slowly to $3/ton in 2020. Only in the latter part of the century does it rise significantly, to $156/ton in 2100.

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[7] Also Manne and Richels (1995). Kosobud, et al (1994) examine alternative paths to achieve a given <u>temperature</u> target in 2100. All three papers find that a return to 1990 emission levels early in the 21st century is a needlessly costly way to attain the 2100 goals for concentration and climate.

The following table, from Manne and Richels (1997b), demonstrates the effect of constraining Annex I emissions relative to 1990 levels in 2010, in contrast to the least cost path. This constraint is imposed over the period 2010-2030. After 2030, further reductions in Annex I emissions occur in order to meet the constraint of concentrations at 550 ppmv.[8] Manne and Richels (1997b) constrained the year 2000 emission levels to the BAU level, under the assumption that treaty implementation could not occur before that date. Developing countries again participate, consistent with the burden sharing formula described above. Thus the permit price estimates presuppose full global participation and trading ("where flexibility") but not intertemporal trading ("when flexibility").

Change in emissions relative to 1990 in 2010	Permit Price in 2010 ($/ton)	Permit Price in 2020 ($/ton)	Consumption Losses (trillions of dollars)[9]		
			U.S.	Annex I	World
+10%	4	65	0.293	0.564	0.782
0%	67	88	0.303	0.619	0.939
-10%	120	112	0.429	1.054	1.276

According to Manne and Richels (1997b), their least cost mitigation path costs the U.S. $0.124 trillion in terms of lost consumption (present discounted value), as compared to $1.28 trillion under the IPCC Working Group path and as compared to $0.303 trillion under the "1990 in 2010" path. Thus the least cost mitigation path generates savings of 90 percent from WG1 and 60 percent from the 1990 in 2010 path.[10]

It is important to keep in mind that all these cost estimates are "best case" (almost utopian) scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if

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[8] The proponents of "1990 by 2010" do not always specify what they would like emissions to do for the remainder of the century. In this section, we assume further reductions in order to meet the 550 ppmv constraint. In the next section of the paper, we instead "straightline" the rest of the century.

[9] The present discounted value of consumption assumes a 5% discount rate and a time horizon of 1990-2100.

[10] Most of this gain is also reflected in the WRE path, which peaks in 2010-2020, as described above.

less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

What if the developing countries do not agree to go along?

It is difficult to imagine that taxpayers in the U.S. and other industrialized countries will agree to transfers to developing countries on the scale implied by the EMF/Manne-Richels burden-sharing schedule. According to one model, transfers under the "1990 by 2010" path would be \$8 ½ billion in 2010, and rise to \$24 billion by 2050. According to another set of estimates (from Battelle), the U.S. would have to pay \$32 billion to other countries in 2035 under the WRE path, and \$181 billion under the WG-1 path. The transfers would then continue to rise, to an estimated \$85 billion or \$170 billion, under the two respective paths, in 2050.

What if rich and poor countries are unable to come to an agreement? How would the absence of the developing countries from an agreement affect the targets-and-timetables decision of industrialized countries? On the one hand, as a matter of arithmetic, meeting the 550ppmv concentration constraint would require more aggressive targets and timetables on the part of the Annex I countries, if indeed it would be possible at all. On the other hand, as a matter of politics, the absence of the developing countries would probably lead the peoples of the Annex I countries to choose a less aggressive path, even though it would produce a higher terminal concentration level. (An analytical balancing of costs and benefits would give the same answer -- a less ambitious target -- once the concentration constraint is relaxed.) [11]

To consider the possibility that developing countries might decline to participate, we ask what would be the effects, both economic and environmental, if the Annex I countries are constrained to the WRE path, but developing countries"free-ride" (i.e., developing countries remain on their BAU path). The welfare losses (in terms of present discounted value) will depend upon whether there is trading in emission rights among Annex I countries. If Annex I trading occurs, then Annex I countries' losses increase from \$0.62 trillion to \$0.91 trillion, or 47%. If emission trading among Annex I countries does not occur, then losses rise to \$1.00 trillion, or 61%. For the U.S., in the absence of developing country participation, welfare losses rise from \$0.28 to \$0.36 trillion, or 29%, assuming Annex I trading. Without Annex I trading, U.S. losses rise to \$0.41 trillion or 46%.[12]

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[11] Conversely, the developing countries are less likely to agree to participate if the Annex I countries have not already taken serious action.

[12] For purposes of this comparison, we assume that if developing countries do participate, there will be full global trading.

Meanwhile, the non-participation of the developing countries means a clear failure to meet the goal of capping global emissions at 550 ppmv. Even if the Annex I countries choose an aggressive path of reducing emissions 10% below 1990 levels by 2010 (and stay at that level thereafter), the effect is to reduce global concentrations only 7 % below BAU levels in the year 2100. This is less than a third of the reductions achieved when the developing countries participate [22%; conversation 8/28] This result illustrates the problem of free riding. Moreover, the estimate does not include an allowance for "leakage" of carbon savings from participating to non-participating countries (e.g., reduced oil demand in the former, via a lower world price of oil, raises oil consumption in the latter). Once leakage effects are added to the free-riding problem, the difficulty of accomplishing meaningful reductions without the help of developing countries are even greater. The savings is only 5 percent in this case. In other words, of the 22 percent reductions achieved when the developing countries participate, 15 percentage points are lost to free-riding, and another 2 points to carbon leakage. [conversation 8/29.] This estimate captures only one of the possible leakage channels, via the world oil and gas market. It omits, for example, the relocation of production in polluting industries to non-participating countries. Indeed, models do not even attempt to measure this effect, because it is so difficult to do.

**

What if there is no international trading?

It is important to keep in mind that the permit price estimates cited earlier assume perfect global trading. Under this assumption, emission reductions occur where it is cheapest to do so regardless of geographic location. What if there is no opportunity to buy emission reductions from lower-cost countries? The following table shows permit prices in 2010 when Annex I emissions are constrained to 1990 levels under alternative assumptions about where flexibility. If the U.S. must attain its target entirely by domestic emission cuts, because developing countries do not participate and there is not trading even among Annex I countries, then the cost rises steeply. These conditions triple the price of the "1990 by 2010" target, in terms of the marginal cost of abatement, from $67/ton to $204.

U.S. Permit Prices in 2010, 1990 Level in 2010 Scenario

Where Flexibility	Global Trading	Annex I Only Trading	Domestic Only Trading
Permit Price in 2010 ($/ton)	67	132	204

It is important also to note that the gains from international trading are highly uncertain. In the case where developing countries do not participate, the extent to which Russia and Eastern Europe are a source of low-cost emission reductions depends heavily on the extent to which they fail in the future to recover from their recent contractions in output. Discussion usually presupposes that the United States will be a net buyer of permits, and several models confirm this. (The SGM shows "1990 by 2010" leading to $8 ½ billion in U.S. permit purchases in 2010, rising to $54 billion in 2050. This is why Annex I trading reduces the permit price in the table.) The U.S., however, is the next lowest-cost major emitter among Annex I countries, after the former Communist bloc. (Europe and Japan already conserve on energy, largely via already-high energy taxes on petroleum products, so they have less scope for further reductions.) If Russia and Eastern Europe begin to grow strongly, the U..S. could become a net *seller* of permits before long. If so, international trading will result in a higher price, not a lower price. McKibbin and Wilcoxen ( ) have built the G-cubed model to explore the international dimensions of climate change policy. They find that the U.S. turns into a net seller of permits by 2020 (to the tune of $38 billion, as opposed to purchases of $2-3 billion in 2010). If this result is right, then the high prediction for the carbon price is the right one, regardless whether there is trading among Annex I countries or not (though trade in permits is still beneficial).

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4. What is the trade-off between the paths currently under discussion?

As we have seen, the Manne-Richels results suggest that the optimal path has Annex I emissions peaking in the decade 2020-2030 and returning to 1990 levels after 2050. The WRE path has Annex I emissions peaking in 2010-2020, and is almost as cost-effective as the least-cost path. Yet the paths for emission reductions that have been discussed in the international negotiations are far more aggressive than these.

What are the additional economic costs, and climatological benefits, of moving from the least-cost path to "1990 levels by 2010"? Table 4, "Climate and Economic Variables under Alternative Emissions Paths," is designed to answer this question. It reports results from the SGM model (on economic variables) and the MAGICC model (on climatic variables), under the assumption that once emissions are returned to their 1990 levels, they are held there for the remainder of the century. The economic costs of the more aggressive path can be measured in several ways. The price of gasoline in 2010 would rise by 26 cents a gallon and coal prices by 273 percent, as compared to only 3 cents per gallon on the less ambitious path, and an increase in coal prices of only 53 per cent. The total economic loss, in the present discounted value of foregone consumption, $206 billion, as compared to only $95 billion on the less ambitious path.

[These figures cumulate lost consumption out only to 2050, and thus are not comparable with the figures cited in the preceding section.] What is accomplished by the more aggressive strategy? The date at which concentrations are doubled is postponed by a mere 3 years (beyond the nine-year postponement achieved by the less aggressive path). The estimated warming in 2100 (2.45 degrees under the business as usual case) is reduced by a mere .03 degrees.. While different observers will weigh the economic costs and climate benefits in different ways, the percentage increase in costs from early action seems large compared to the percentage reduction in concentrations and warming.

This conclusion omits that concentrations continue to rise in subsequent centuries. The way to address such concerns is by means of models (such as Integrated Assessment models) that keep track of economic and environmental effects on a longer time frame. The preceding section of the paper ("Least-cost Paths to Stabilize Concentration Levels") explains how more moderate paths can attain the identical objective, in terms of terminal concentration levels, with lower economic costs than "1990 in 2010." But all these results leave out the major argument for early action mentioned elsewhere: the need for political credibility of an announced long-term plan. This argument suggests that a moderate path should be accompanied by early and specific announcement of serious domestic measures of implementation.

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Table 4: **Climate and Economic Variables under Alternative Emissions Paths ***

		Concentration Level (ppmv)		Year at Which Concentration Reaches 2x Pre-Industrial Level **	Change in Temperature from 1990 Level (Celsius)	
	Year	2050	2100		2050	2100
	Business As Usual (BAU)	502	711	2065	1.06	2.36
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	-21	-66	+9	-0.09	-0.25
	1990 beginning in 2010	-18	-55	+8	-0.08	-0.21
	peak in 2015, 1990 in 2040	-13	-53	+6	-0.06	-0.19
	1990 +10% beginning in 2010	-13	-49	+6	-0.07	-0.18

		Carbon Permit Price ($ per ton) Domestic Trading		Carbon Permit Price ($ per ton) Annex I Trading		Consumption *** (billions of $)
		2010	2050	2010	2050	
	Business As Usual (BAU)	0.00		0.00		121,650
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	+175	+924	+91	+238	-980
	1990 beginning in 2010	+108	+582	+41	+149	-740
	peak in 2015, 1990 in 2040	+12	+563	+11	+153	-270
	1990 +10% beginning in 2010	+60	+310	+17	+113	-460

Summary description

A plan to return carbon emissions to their 1990 levels by 2010 postpones by 9 years the date at which CO_2 concentrations reach twice pre-industrial levels. Global warming would be reduced by 0.21 degrees by the year 2100 versus an estimated 2.36 degrees under BAU. Under this emissions path the value of the estimated foregone consumption is $740 billion.

A less ambitious path -- "eliminate emissions growth by 2010-2020" -- would postpone the doubling date by 2 years less, and would lead to another 0.02 degrees of warming. But, the economics would become much easier: The value of foregone consumption would be only $270 billion.

* Preliminary CEA projections. The origin of these preliminary numbers is described on the accompanying page.

** Pre-industrial concentrations of CO2 were approximately 275 ppmv.

*** Assumes domestic trading only. Annex I or worldwide trading may substantially reduce these costs. Deviations are foregone consumption assuming a 5% discount rate for the time horizon 2000-2050.

September 10, 1997

Sources and Explanations

Sources

Business As Usual (BAU) emissions projections are based on the assumptions employed in the IAT process. These projections incorporate the Annual Energy Outlook and International Energy Outlook projections, and closely mirror the IPCC IS92a emissions profiles with modifications made for the economic decline in the Former Soviet Union and Eastern Europe. BAU concentration and temperature projections are from the MAGICC model. Carbon permit price estimates and foregone consumption figures are from the SGM model. All these results were provided by Jae Edmonds, Marshall Wise, and Chris MacCracken at Battelle, Washington, DC.

Participation Cases

Annex I Participation Only: Assumes full compliance of stated targets and timetables by countries in Annex I; rest of the world behaves as in BAU.

Targets and Timetables

1990 (+/-10%) in 2010: Emissions follow BAU through 2000, reduce to 1990 (+/-10%) levels by 2010, and remain at 1990 (+/-10%) levels thereafter.

Peak in 2015, 1990 in 2040: Emissions follow BAU through 2005, peak at 2010 BAU levels in 2015, and stabilize at 1990 levels in 2040 and into the future. Because of linear interpolation in emissions profile between 2015 and 2040, this scenario may slightly overestimate the deviation of concentration from BAU.

Trading Scenarios

Domestic Trading: Trading only within each country.

Annex I Trading: Permits are grandfathered to Annex I nations based on 1990 emissions levels. All Annex I countries participate in the trading of permits.

Price Assumptions

Carbon: U.S. permit prices for the four policy options are from SGM, which assumes that all revenues are returned to the economy through a lump-sum redistribution.

Consumption: Deviations are present discounted value of foregone consumption differences for United States in billions of dollars between BAU and scenarios. The present discounted value assumes a discount rate of 5% and a time horizon of 2000-2050.
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5. Escape clauses and other flexibility provisions

In addition to the question of the stringency of targets and timetables, there are a number of other important determinants of the economic costs of a program encompassed in the term "flexibility". The U.S. has proposed both "when flexibility" and "where flexibility."

Examples of "when flexibility" are our proposals for targets that are multi-year averages, for multiple target periods, and for banking and borrowing. An example of "where flexibility" is international trading, especially with the participation of developing countries. All of these proposals could substantially reduce the cost of a given level of emissions, and are crucial elements of our ability to attain moderate targets, let alone more ambitious targets. Costs would be far higher without them.

Another possibility that has recently received attention in the inter-agency process is to add one or more escape clauses. The main idea is to safeguard against unexpectedly large economic costs of emissions reductions. These are costs that could turn out to be unexpectedly large if the economic growth rate turned out higher than expected, or if unrealistic estimates regarding the ease of reducing emissions were built into treaty targets. One possible escape clause would focus on the price of energy per ton of carbon.

Nordhaus (1997) and McKibbin and Wilcoxen (1997) have proposed plans under which there is a cap on how much the price of carbon can rise. The proposal is that above a certain level, governments (or perhaps a supranational authority) could make available an indefinite quantity of emission permits at the predetermined price. The system would operate as a "tariff-rate quota," in which countries were allowed to emit up to their assigned share for free, but then bore a penalty for any emissions in excess of that share. Pizer (1997) estimates that, in the presence of uncertainty, the optimal price rule generates gains that are five times greater than the optimal permit (quantity) rule. While the academic proposals tend to call for common policies and measures to be negotiated worldwide, the idea could usefully be integrated into the U.S. proposal for targets and timetables regarding emission quantities, in the form of a conditional

escape clause. The effect would be to convert the quantity limit into a price instrument under circumstances when the burden would otherwise be too burdensome.

Escape clauses could also serve other purposes as well. Possibilities include:

- An escape clause that would be triggered in the future if continued **scientific research** determined that the dangers from GHG concentrations and climate change were much less than previously feared. Presumably the treaty would be renegotiated in such a case anyway. But the arguments for putting this language in now are three: (1) to facilitate the change, should this come to pass, (2) so that we don't look foolish in the eyes of history if this should come to pass, and most importantly, (3) to help allay the fears of today's skeptics.

- An escape clause that would be triggered in the future if **developing country accession** turned out to be less than we expect after Kyoto.

- An escape clause that would be triggered by other Annex I countries' **failure to abide** by their commitments.

Each of these proposals, might be useful in avoiding economic costs that otherwise might be incurred needlessly.

6. Conclusions and Summary

[SEE EXECUTIVE SUMMARY AT THE BEGINNING]

Appendix I: Integrated Assessment Models (M. Toman)

*******2. Cost-benefit analysis in "Integrated Assessment" models

Integrated Assessment (IA) analyses try to bring together assessments of the physical, ecological, economic, and social impacts of climate change with assessments of policies for responding to climate change and their socioeconomic consequences.

Generally speaking, the models can be described schematically as linking economic decisions in the energy (and agriculture) sectors that give rise to GHG emissions (and changes in carbbon sequestration), models of atmospheric composition, climatic change, and changes in oceans, and models that describe the potential impacts of climate change on health, natural resources, coaatal areas, and other factors of socioeconomic interest. Different components of various IA frameworks are represented in differing degrees of detail and sophistication. A few models contain the capacity to be used for a benefit-cost analysis, in which it is possible to evaluate changes in the long-term path of GHG emissions that maximizes the net benefits of GHG control (these benefits are the avoided damages of climate change less the costs of control). A larger number of IA models can evaluate the benefits and costs of specified policies but are unable to indicate what emissions reductions maximize net benefits. IA frameworks are inherently more "top-down" in their characterization of economic decisionmaking, though some models contain a fair amount of energy sector detail.

A very striking feature of IA models is that they tend to indicate the desirability -- from the perspective of maximizing net benefits over time -- of emissions continuing to rise well into the next century, if not beyond. (For a recent comparison of IA model results, see Manne 1996. By 2010, the models indicate only small deviations downward from a business as usual (BAU) path (see also IPCC 1996b, Chapter 10). In some cases the emissions do stabilize toward the middle of the next century, but in other cases they continue rising (though more slowly than with business as usual) even beyond 2100. These emissions paths clearly imply increases in atmospheric concentrations of GHGs well beyond the kinds of targets that have been considered in current policy debates (e.g., 550 ppm). One important consequence is that the models indicate costs of near-term emissions stabilization well in excess of the avoided damage costs.

Criticisms of the results in the Integrated Assessment models

As noted in the text, number of criticisms have been levelled at these IA results. These criticisms include:

Failure to consider the possibility of unlikely but catastrophic events that could result from climate change (e.g., catastrophic sea level rise from melting of the Antarctic ice sheet, runaway global warming from frozen methane releases, or relocation of the Gulf Stream).

Failure to give adequate consideration to the scale of potential damages, even in the absence of catastrophe. Cline (1992), for example, argues that damages are much higher than is incorporated in most IA models (see also IPCC 1996a, Chapter 6 for various estimates). One specific concern that has been raised is that the IA models do not account adequately for the costs of a less stable climatic and ecological systems in the face of GHG accumulations.

Failure to consider the adverse consequences of less aggressive abatement policies for future generations + in the context of IA models themselves, the criticism is that discounting of future generations' well-being is excessive. Cline (1992) also raises this concern, as does Howarth (1996).

Failure to consider how uncertainty about all these effects affects the "optimal" decision (Pizer 1996).

Failure to consider how lack of early action will jeopardize the achievement of any longer-term mitigation by signalling a lack of political will, or how lack of early action will retard induced technical progress that is needed to make mitigation affordable (Grubb *et al* 1995).

Sensitivity analyses carried out with IA models suggest that at least some of these criticisms are not major concerns; others may be serious concerns, but empirical judgments are not possible given the current state of knowledge. The Manne (1996) survey referred to above considered scenarios in which the climate's sensitivity to accumulating GHGs was greater than is typically assumed, or the the damages are larger (by a factor of almost 8) for a given change in the atmosphere. In either case emissions should (from the perspective of maximizing net benefits) be lower, but the extra degree of emissions reductions required by 2010 is significant (on the order of 25 percent or more) only if climate damages are much higher than expected (the sensitivity of the atmosphere to GHG emissions seems much less important in these analyses). And even in this case, emissions still will be higher than 1990 levels unless the atmosphere and the ecological-economic systems both are quite sensitive. (Broadly similar conclusions follow if, instead of looking at higher damages, one looked at damages that grew proportionately faster as atmospheric GHG concentrations grew (Peck and Teisberg 1993). Thus, the IA models give little support for a policy of near-term emissions stabilization unless damages turn out to be much higher than at least some experts expect.

As noted, one of the criticisms of many integrated assessments (IAs) is that they do not incorporate the possibility of catastrophe. Recent extensions of the IA literature include the possibility of a major, discontinuous jump inh the damages caused by climate change. For example, a European paper by Gjerde et al (1997) incorporates the risk that climate change will sudenly cause damages equal to a significant share of global GDP. The risk is assumed to rise with an increase in temperatre from global warming; following Nordhaus (1994b), the benchmark risk scenario assumes a 12% chance of a loss equal to 25% of GDP (the scale of the great depression) in 2090 if climate has warmed by 3 degrees C. Incorporating this risk into the IA framework causes the optimal path for global emissions to be reduced, but not by that much in the early years. By 2060, optimal emissions are only somewhat over half what they would have been without the risk of catastrophe, but the reduction by 2020 is on the order of 15% below the no-catastrophe case and still above emissions in 1990.[13] Even sharper emissions reductions are implied if the catastrophe is truly shattering (on the order of the entire GDP), or if the discount rate is extremely low (high intergenerational egalitarianism.)

It is also true that the results of IA models are sensitive to the choice of discount rate used to compare consumption today and in the future. A very low discount rate will imply greater weight on damages accruing over time to future generations, and thus the need for a more aggressive abatement strategy. This tradeoff is influenced by the rate of economic growth, since growth will make future generations better off and thus better able to afford and respond to the damages of climate change (Schelling 1995). However, there are numerous economic and ethical controversies surrounding the appropriate way to discount future damages in IA models, and no clear consensus has emerged. One important point that is often ignored in this debate is how much *today's* generation is willing to sacrifice to provide for the increased protection of future generations through GHG abatement; this is a critical unknown since it is today's generation that must necessarily must decide to pay the bill. All that can be said analytically, therefore, is that intergenerational equity *might* be an argument for more aggressive abatement.

Uncertainty about future damages or other influences on the costs and benefits of abatement can make a difference. However, Pizer's (1996) analysis suggests that the most important source of uncertainty concerns the nature of our preferences for consumption

[13] The no-catastrophe optimal path is substantially below BAU in this analysis, an artifact of the assumptions of low abatement cost and high damage cost.

and environmental protection. (Unlike the Manne (1996) analysis, Pizer considers the possibility that damages may be lower as well as larger.) A recent paper by Gjerde *et al* (1997) considers the risk of a sudden loss of economic output and well-being on the scale of the Great Depression from climate change. While their analysis indicates more aggressive abatement than other IA analyses without this risk, the introduction o the risk has little relative effect on the desirable level of emissions reduction by 2010, and little effect for a number of years thereafter (unless the loss is much larger even than the Depression).

This leaves the issues of political credibility and induced technical change. As for the latter, it is true that sending a less strong signal to energy markets will slow up technical progress. However, there is great uncertainty about how much of a loss this would be in practice, and the loss would have to be greater than most models seem to indicate before the substantial costs of near-term stabilization could be justified. This does *not* mean, however, that *no* actions are justified on cost-benefit grounds to reduce emissions or stimulate technical progress. Aside from initial steps to curb emissions growth, which signal the need for technical change, longer-term measures to promote the development of new technology are warranted. Political credibility is a more complicated issue.

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First Steps Toward a Credible and Effective Long-Term Strategy

As noted, the intertemporally flexible alternative approach to achieving a long-term emissions reductions target has been criticized in some quarters as being akin to a license for indefinite postponement of emissions reductions, making the proposal noncredible in terms of the long-term enforceability of domestic emissions reductions (Won't those who want to delay now just want more delay later? Why would anyone be motivated to pursue emissions reductions early with this expectation?) and in terms of the signal sent to the international community. There also has been criticism that these policies will not stimulate enough near-term innovation to lower the cost of long-term emissions reductions. These are important concerns that need to be addressed in a complete analysis of intertemporally flexible policy options.

As for reduced innovation incentives, there may indeed be some negative effect, but the size of this effect is unknown and may be minor and/or transient if emitters do see the long-term policy goal as credible. It can also be lessened by appropriate policy commitments to the funding of GHG-reducing R&D programs.

The credibility issue is more complicated, but even here there are several sides to the issue. A policy of significantly larger and more expensive near-term emissions reductions is by no means automatically more credible, from either an economic or political perspective. Moreover, intertemporal flexibility is not the same as doing nothing for a period of many years. Some near-term reductions can still be implemented, to build confidence in the commitment to longer-term reductions and to gain experience with the process of and opportunities for emissions reductions. We would thus advocate that a policy of cost-effective intertemporal flexibility in the timing of emissions reductions be coupled with a mandate for some modest but concrete initial emissions reductions, relative to business as usual, that grow over time as the economy makes the transition toward leveling off and reducing its emissions. Again, this can be coupled with a policy of support for R&D that lowers the cost of future GHG emissions reductions.

"Safe corridors"

Several recent studies have used the "safe corridors" concept for specifying desirable paths of emissions reductions over time. This concept seeks to indicate which time paths of emissions satisfy not only a limit on long-term concentrations of GHGs, but also other constraints. Common additional constraints are that the rate of temperature rise should not exceed a certain amount per decade, ostensibly as a proxy for avoiding environmental damages that might be produced by more rapid temperature rises; and that emissions reductions should not be larger than a certain percentage per year, ostensibly as a proxy for not imposing too large a cost burden on the economy.

These studies generally call for relatively significant near-term emissions reductions, largely as a result of the constraint on the decadal rate of temperature increase. However, this approach to damage avoidance is entirely ad hoc. While some scientists have expressed concerns about environmental stress from rapid temperature change, the IPCC does not provide a strong scientific basis for concluding that certain decadal rates of temperature increase are unacceptably risky (indeed, even specifying a more continuous relationship between the rate of temperature change and damages, like the relationships in IA models between the long-term change in temperature and damages, can only be done on the basis of analyst judgments). In addition, the arbitrary constraints on the rate of emissions reduction do not in any way capture the links between the shape of the emissions path and the costs to the economy, as discussed in Section 3 ("Estimates of least-cost paths to stabilize concentration levels"). Accordingly, we do not believe the safe corridors approach offers a sound basis for public policy evaluation of emission control strategies.

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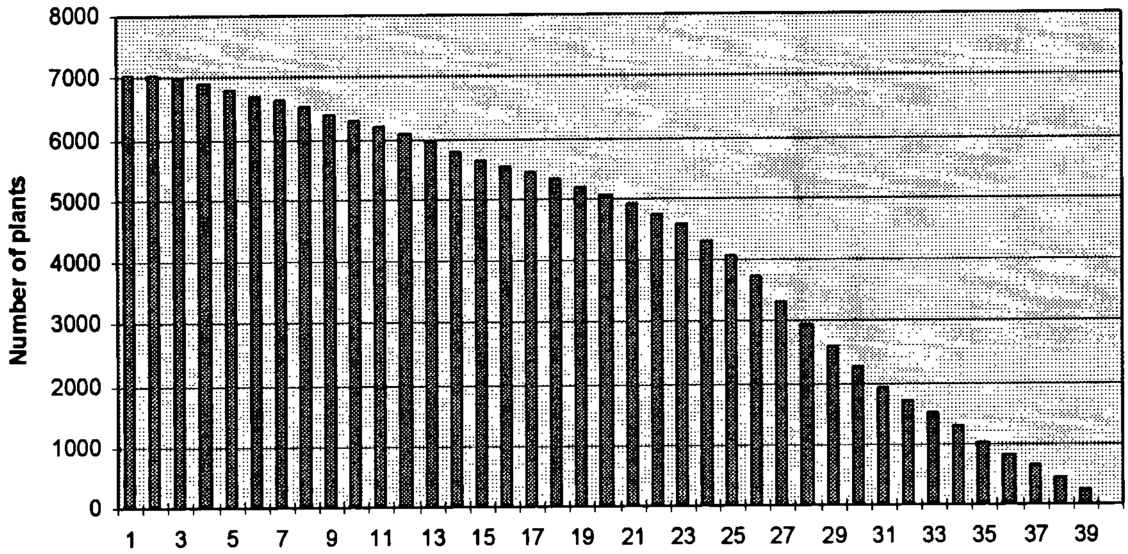
Figure 1. Accelerated Replacement of Electric Power Plants



Bar height shows number of plants to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

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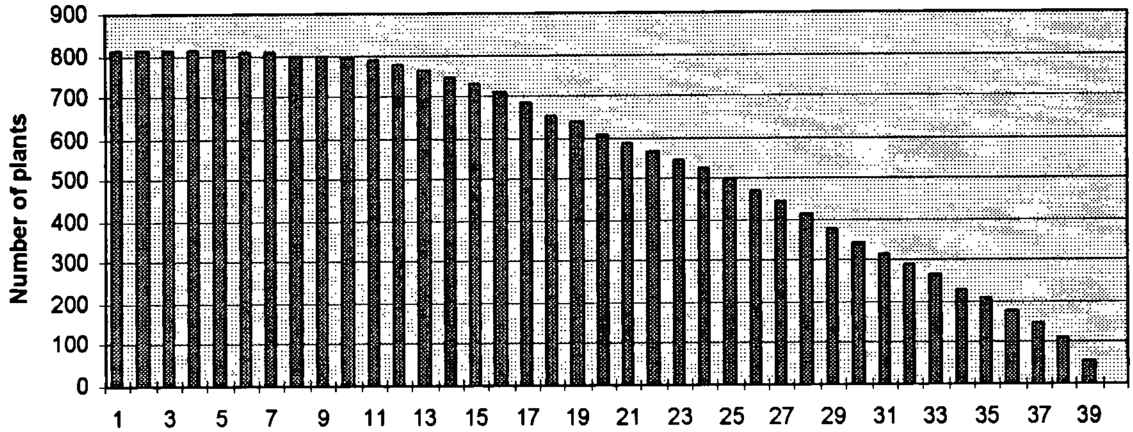
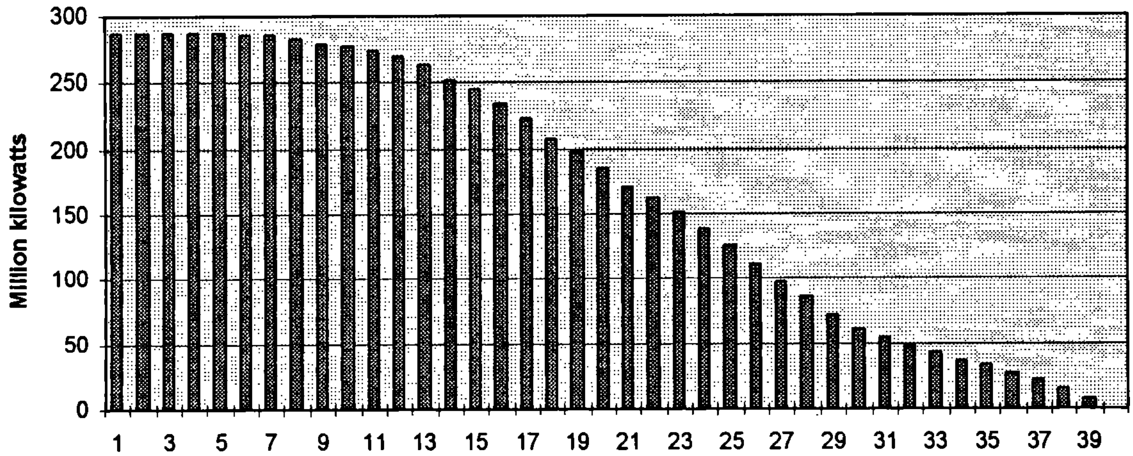
Peck, S. C. and T. J. Teisberg. 1993. "Global Warming Uncertainties and the Value of Information: An Analysis Using CETA," *Resource and Energy Economics* vol. 15, no. 1 (March): 71-97.

Figure 2a: Accelerated Replacement of Coal Plants



Bar height shows number of plants to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

Figure 2b: Accelerated Replacement of Coal Plant Capacity



Bar height shows coal capacity to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

New Richels results (MERGE)

1. Table 1 shows peak years for emissions and years in which emissions return to 1990 levels for WG1, WRE and least-cost scenario.

2. Table 2 and Figure 1 show Annex 1 carbon emissions for the above three cases and the reference case.

3. Table 3 and Figure 2 shows the global least-cost path for each region.

4. For WG1 case, global emissions rise approximately 8% between 1990 and 2010 while Annex 1 emissions fall approximately 24% over same period.

5. When Annex 1 emissions level off at 10% below 1990 levels by 2010 and Non Annex 1 adheres to their baseline, concentrations decrease by approximately 7% in 2100. In the least-cost 550 case, concentrations decrease by 22% in 2100.

6. Table 4 and Figure 3 show taxes required to meet alternative reductions.
(Annex I target maintained 2010-2030, followed by transition to burden-sharing scheme for developing-country participation.)

Figure 1. Annex 1 Carbon Emissions

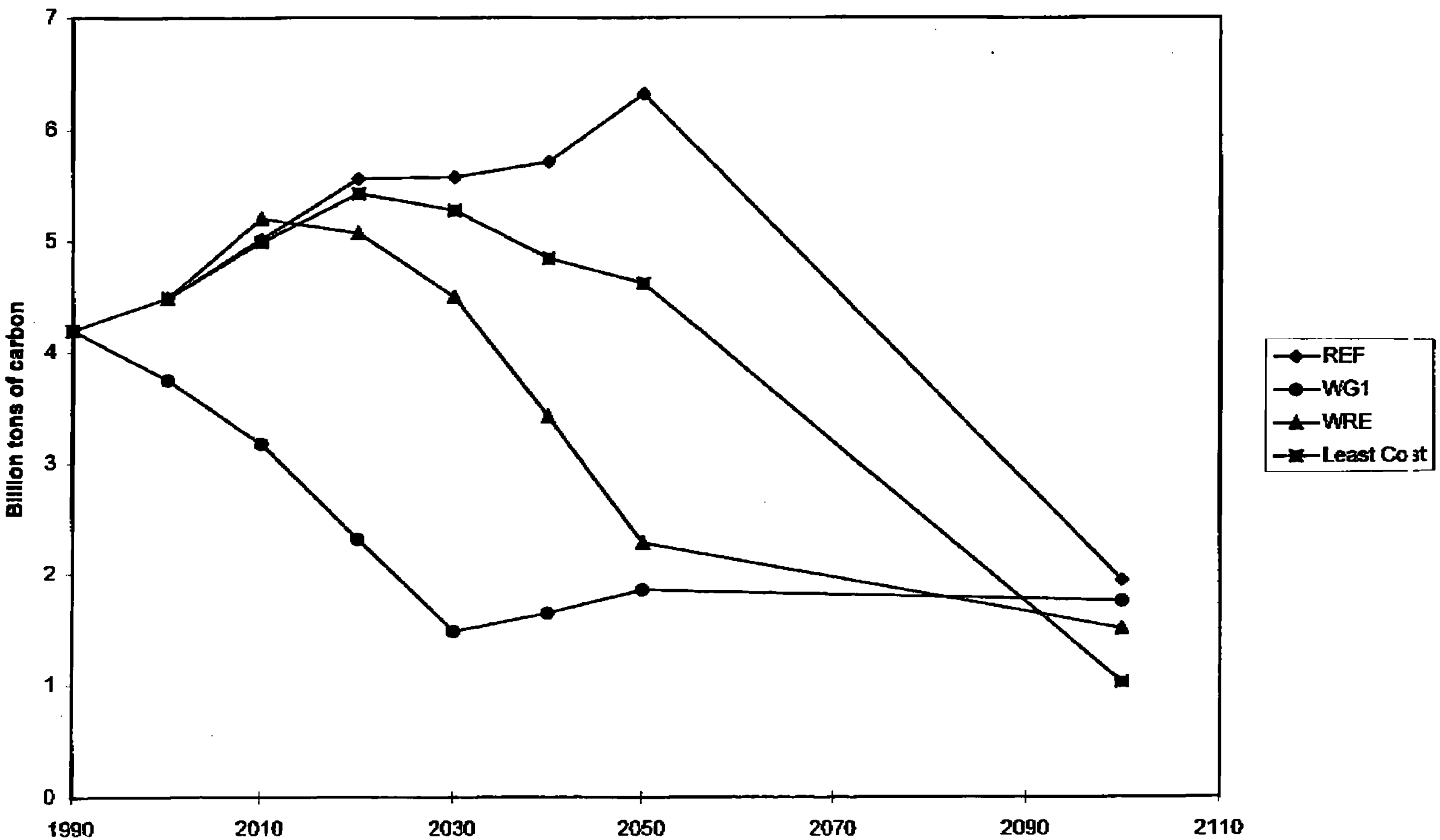


Table1. Peak Years

	WG1	WRE	Least-cost
Annex 1	1990	2010	2020
Non Annex 1	2100	2050	2050
Global	2075	2030	2050
Year return to 1990 levels	post-2100	post-2100	pre-2100 (2090)

Table 2. Annex 1 carbon emissions in billions of tons

	REF	WG1	WRE	Least Cost
1990	4.196	4.196	4.196	4.196
2000	4.488	3.752	4.488	4.488
2010	5.018	3.177	5.204	4.993
2020	5.563	2.315	5.073	5.429
2030	5.576	1.483	4.496	5.277
2040	5.714	1.649	3.423	4.845
2050	6.321	1.859	2.282	4.622
2100	1.945	1.758	1.509	1.03

Table 3. Carbon Emissions for Least-Cost Mitigation Case in Billions of Tons

	ref	global	OECD	EEFSU	Non Annex 1
1990	5.885	5.885	2.91	1.286	1.689
2000	6.663	6.808	3.425	1.063	2.32
2010	8.164	8.149	3.897	1.096	3.156
2020	9.708	9.572	4.149	1.28	4.143
2030	10.925	10.413	3.811	1.466	5.136
2040	12.558	10.846	3.259	1.586	6.001
2050	14.987	12.111	3.078	1.544	7.489
2100	19.757	4.717	0.478	0.552	3.687

Figure 2. Least-Cost Mitigation Paths

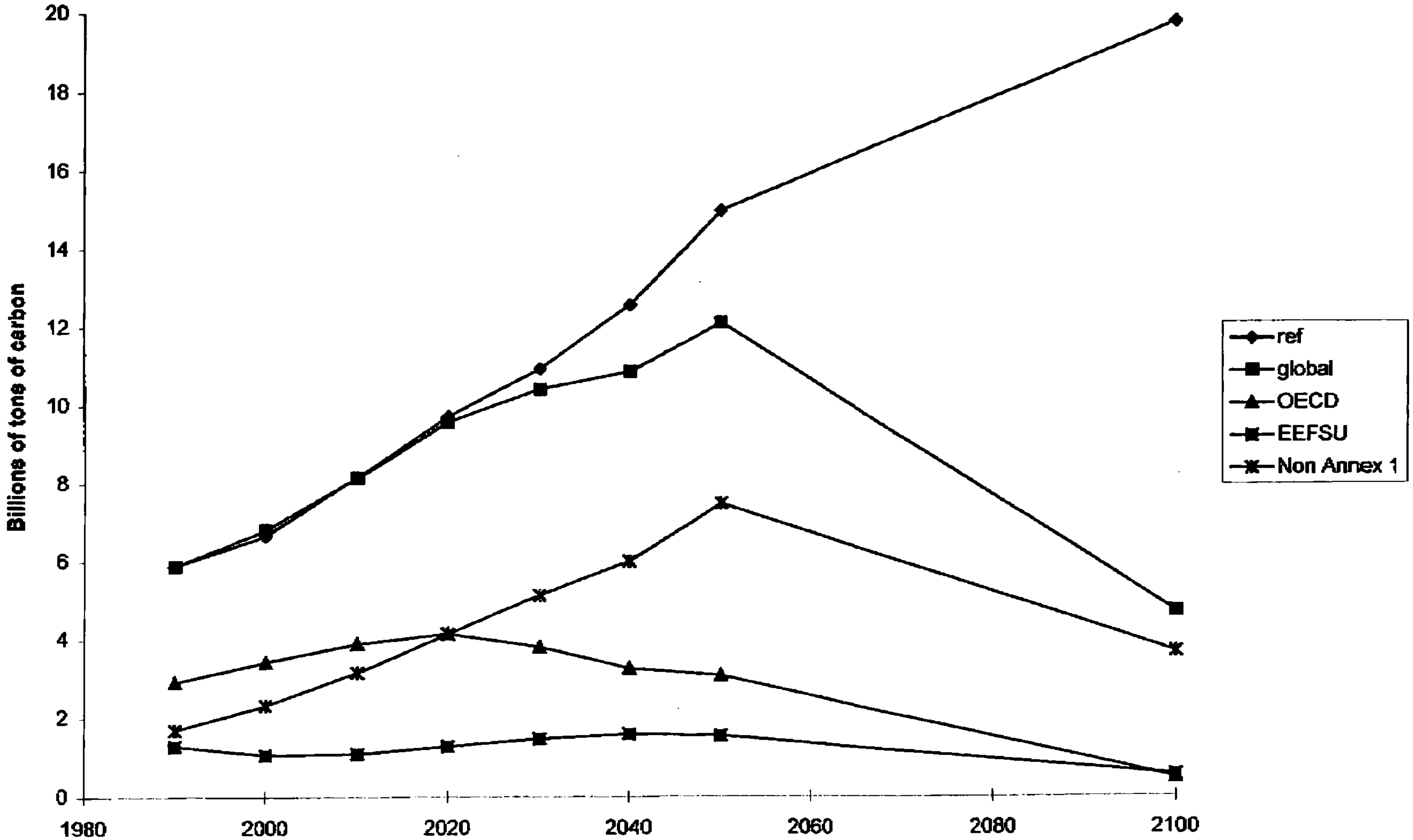


Figure 3. Value of Carbon Emission Rights

Table 4. Value of Carbon Emission Rights in Dollars/Ton

	minus 10	1990 level	plus 10%	least-cost
1990	0	0	0	0
2000	29.717	20.261	8.247	1.161
2010	54.019	36.834	14.929	1.998
2020	102.839	70.08	28.208	3.48
2030	94.134	64.772	27.954	6.126
2040	4.925	4.932	8.115	8.129
2050	9.629	9.629	16.447	16.445
2100	123.826	123.829	128.388	128.394

Table 4

Climate and Economic Variables under Alternative Emissions Paths *

		Concentration Level (ppmv)		Year at Which Concentration Reaches 2x Pre-Industrial Level **	Change in Temperature from 1990 Level (Celsius)	
	Year	2050	2100		2050	2100
Business As Usual (BAU)		502	711	2064	1.06	2.36
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	-21	-66	+10	-0.09	-0.25
	1990 beginning in 2010	-18	-55	+9	-0.08	-0.21
	peak in 2015, 1990 in 2040	-13	-52	+7	-0.06	-0.19
	1990 +10% beginning in 2010	-14	-47	+7	-0.07	-0.18

		Carbon Permit Price ($ per ton) Domestic Trading		Annex I Trading		Consumption *** (billions of $)
		2010	2050	2010	2050	
Business As Usual (BAU)		0.00		0.00		121,650
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	+175	+924	+91	+238	-980
	1990 beginning in 2010	+109	+582	+41	+149	-740
	peak in 2015, 1990 in 2040	+12	+563	+11	+153	-270
	1990 +10% beginning in 2010	+60	+310	+17	+113	-460

Summary description

A plan to return carbon emissions to their 1990 levels by 2010 postpones by 9 years the date at which CO_2 concentrations reach twice pre-industrial levels. Global warming would be reduced by 0.21 degrees by the year 2100 versus an estimated 2.36 degrees under BAU. Under this emissions path the value of the estimated foregone consumption is $740 billion.

A less ambitious path -- "eliminate emissions growth by 2010-2020" -- would postpone the doubling date by 2 years less, and would lead to another 0.02 degrees of warming. But, the economics would become much easier: The value of foregone consumption would be only $270 billion.

* Preliminary CEA projections. The origin of these preliminary numbers is described on the accompanying page.
** Pre-industrial concentrations of CO2 were approximately 275 ppmv.
*** Assumes domestic trading only. Annex I or worldwide trading may substantially reduce these costs. Deviations are foregone consumption assuming a 5% discount rate for the time horizon 2000-2050.

September 10, 1997

Sources and Explanations

Sources

Business As Usual (BAU) emissions projections are based on the assumptions employed in the IAT process. These projections incorporate the Annual Energy Outlook and International Energy Outlook projections, and closely mirror the IPCC IS92a emissions profiles with modifications made for the economic decline in the Former Soviet Union and Eastern Europe. BAU concentration and temperature projections are from the MAGICC model. Carbon permit price estimates and foregone consumption figures are from the SGM model. All these results were provided by Jae Edmonds, Marshall Wise, and Chris MacCracken at Battelle, Washington, DC.

Participation Cases

Annex I Participation Only: Assumes full compliance of stated targets and timetables by countries in Annex I; rest of the world behaves as in BAU.

Targets and Timetables

1990 (+/-10%) in 2010: Emissions follow BAU through 2000, reduce to 1990 (+/-10%) levels by 2010, and remain at 1990 (+/-10%) levels thereafter.

Peak in 2015, 1990 in 2040: Emissions follow BAU through 2005, peak at 2010 BAU levels in 2015, and stabilize at 1990 levels in 2040 and into the future. Because of linear interpolation in emissions profile between 2015 and 2040, this scenario may slightly overestimate the deviation of concentration from BAU.

Trading Scenarios

Domestic Trading: Trading only within each country.

Annex I Trading: Permits are grandfathered to Annex I nations based on 1990 emissions levels. All Annex I countries participate in the trading of permits.

Price Assumptions

Carbon: U.S. permit prices for the four policy options are from SGM, which assumes that all revenues are returned to the economy through a lump-sum redistribution.

Consumption: Deviations are present discounted value of foregone consumption differences for United States in billions of dollars between BAU and scenarios. The present discounted value assumes a discount rate of 5% and a time horizon of 2000-2050.

Joseph E. Aldy
09/05/97 03:20:03 PM

Record Type: Record

To: Jeffrey A. Frankel/CEA/EOP

cc:

Subject: summary table of some of MERGE outputs

These outputs are from the faxes and phone conversations with Richels.

RICHELS2.WK4

	A	B	C	D	E	F
1	Foregone Consumption (trillions$, 5% discount rate, 1990-2100)					
2	Path	LDC Part.	Where	When	U.S.	Annex I
3	WRE	yes	global	no	0.28	0.62
4	WRE	no	annex I	no	0.36	0.91
5	WRE	no	domestic	no	0.41	1
6	Least Cost	yes	global	yes	0.124	0.282
7	1990 in 2010	yes	global	no	0.303	0.619
8	1990+10%	yes	global	no	0.293	0.564
9	1990-10%	yes	global	no	0.429	1.054
10	WGI	yes	domestic	no		
11	WGI	yes	global	no	1.28	
12						
13	Permit Prices					
14	Path	Where	When	2000	2010	2020
15	Least Cost	global	yes		2	3.4
16	1990 in 2010	domestic	no		204	
17	1990 in 2010	annex I	no		132	
18	1990 in 2010	global	no		67	88
19	1990+10%	global	no		4	65
20	1990-10%	global	no		120	112
21						
22	early runs	Where	When	2000	2010	2020
23	Least Cost	global	yes	1.161	1.998	3.48
24	1990 in 2010	global	yes	20.261	36.834	70.08
25	1990+10%	global	yes	8.247	14.929	28.208
26	1990-10%	global	yes	29.717	54.019	102.839

	G	H	I	J	K
1					
2	World				
3	0.77				
4					
5	1.57				
6	0.556				
7	0.939				
8	0.782				
9	1.276				
10	8.6				
11	3.3				
12					
13					
14	2030	2040	2050	2100	
15	5.9	9.8	20	156	
16					
17					
18				129	
19				129	
20				129	
21					
22	2030	2040	2050	2100	
23	6.126	8.129	16.445	128.394	different from
24	64.772	4.932	9.629	123.829	
25	27.954	8.115	16.447	128.388	
26	94.134	4.925	9.629	123.826	

A.A.

DRAFT **09/21/97**

Additional Analysis of the Costs of Stabilizing CO2 Concentrations[a]

by Alan Manne[b] and Richard Richels[c]

1. Introduction

The Berlin Mandate calls for further commitments on the part of Annex 1 to reduce greenhouse gas emissions. These commitments are to be negotiated and prepared for approval at COP-3 in December of 1997. As the deadline approaches, the signatories to the Climate Convention are struggling to determine what might constitute sensible next steps in terms of emission paths. Proposals range from slowing the rate of growth to deep and immediate cuts. These deliberations are being supported, in part, by an "analysis and assessment" phase designed to assist policy makers in understanding the environmental and economic implications of alternative proposals.

As part of this process, we recently examined the costs of complying with alternative constraints on CO2 emissions.[1] Our effort differed from most previous economic analyses in that we explored the emission constraints in the context of possible long-term concentration targets. The ultimate goal of the Climate Convention is the stabilization of atmospheric concentrations -- at a level yet to be determined. Rather than focus on arbitrary emission limits, it seemed to make more sense to examine future targets and timetables in the context of possible concentration goals. In this way, we can explore the sensitivity of near-term mitigation decisions, to the long-term objective.

This note extends our earlier work in several ways. We begin by modifying our previous emission profiles to encompass several proposals which have recently come under consideration. In each instance, we calculate costs under alternative assumptions about the timing and the magnitude of the emission reductions, and examine the implications for future atmospheric concentrations. We also explore what would happen if non-Annex 1 countries fail to participate. How would welfare losses be affected? What would be the implications for atmospheric concentrations?

The primary focus of our analysis is on mitigation costs. This, of course, is only part of the story. Sensible climate policy not only requires consideration of mitigation costs, it also requires consideration of what might be gained in terms of reducing the undesirable consequences of global climate change. In this paper, we make no attempt to estimate the potential benefits of slowing climate change, nor do we try to determine what might constitute a societally desirable concentration level. We do, however, in

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[a]The analysis from which the present research is derived (ref. 1) was undertaken as part of the authors' participation in Stanford University's Energy Modeling Forum-14 Study. Support was provided by the Electric Power Research Institute. The views expressed here, however, are solely those of its authors.
[b] Stanford University
[c] Electric Power Research Institute

addition to calculating costs, attempt to assess the impact of alternative policies on future atmospheric concentrations.

2. The model

The analysis is based on the MERGE model (a model for evaluating the regional and global effects of greenhouse gas reduction policies).[2,3] MERGE is an intertemporal optimization model. It combines a bottom-up representation of the energy supply sector together with a top-down perspective on the remainder of the economy.

The present version of the model, known as MERGE 3.0, divides the world into nine regions: 1) the USA, 2) OECDE (Western Europe), 3) Japan, 4) CANZ (Canada, Australia and New Zealand), 5) EEFSU (Eastern Europe and the Former Soviet Union), 6) China, 7) India, 8) MOPEC (Mexico and OPEC) and, 9) ROW (the rest of world). Note that the OECD (regions 1 through 4) together with EEFSU constitute Annex 1.

Each of the model's regions maximizes the discounted utility of its consumption subject to an intertemporal budget constraint. Each region's wealth includes not only capital, labor and exhaustible resources, but also its negotiated international share in carbon emission rights.

Particularly relevant for the present analyses, MERGE provides a general equilibrium formulation of the global economy. We model international trade in carbon emission rights, allowing regions with high marginal abatement costs to purchase emission rights from regions with low marginal abatement costs.

When mitigation is limited to a subset of regions, so-called carbon "leakage" effects may become an issue. Here, we refer to the impacts of the emission policies of abating regions upon the emission levels of non-abating regions. In MERGE, we model international trade in oil and natural gas, but not in energy intensive basic materials. Hence, carbon leakage is detected only as it occurs through fuel markets.

In calibrating MERGE for the present analysis, several supply- and demand-side parameters for the energy-economy submodel were adjusted so that the global emissions baseline approximates the Intergovernmental Panel on Climate Change (IPCC) central case "no policy" scenario (IS92a) through the year 2100. See ref. 1 for our original estimates of Annex 1 and non-Annex 1 baseline emissions and total primary energy use by fuel type.

For constrained scenarios, it was also necessary to make assumptions about the allocation of emission rights across regions. Few issues are likely to be as contentious for international negotiators. For the present analysis, we have tried to be consistent with the Berlin Mandate. We assume that the burden will fall on Annex 1 countries during the early decades of the next century.

Specifically, we assume that: 1) non-Annex 1 countries will be permitted to emit up to their baseline through 2030 (that is, no constraints will be placed on their emissions until that date), 2) there will be a gradual transition to equal per capita emission rights (based on 1990 population) between 2030 and 2050, and 3) the equal per capita burden sharing rule will be maintained thereafter.

3. Three emission paths for stabilizing concentrations at 550 ppmv

A "prudent" concentration level has yet to be determined. Hence, in ref. 1 we examined a range of possible targets (i.e., 450-750 ppmv). For the present analysis, we concentrate on 550 ppmv. Most of the general insights gained from the analysis, however, should apply to other targets as well.

Figure 1 shows three pathways for stabilizing concentrations at 550 ppmv by the middle of the 22nd century. The first, developed by IPCC Working Group 1 (WG1)[4] involves a rapid departure from the baseline. The second, developed by Wigley, Richels and Edmonds (WRE)[5] entails a more gradual transition to a less carbon intensive economy. The third identifies the least-cost mitigation path for stabilizing atmospheric concentrations at the prescribed level.

The least-cost pathway incorporates both "where" and "when" flexibility. Economic efficiency requires that emission reductions be made both where and when it is cheapest to do so. The first requires international cooperation (for example, through trade in emission rights across all regions). The second requires flexible timing (reallocation of emission rights across generations).

Figure 2 shows the regional distribution of emissions for the least-cost mitigation path. Under this scenario, Annex 1 (OECD and EEFSU) emissions peak in 2030. The rate of growth, however, is relatively slow by historical standards. This is because anticipated improvements on both the supply- and demand-sides of the energy system are expected to lead to less carbon intensive economies. Hence, the fact that Annex 1 emissions tend to follow the baseline during the early decades should not be confused with a "business-as-usual" future in which carbon emissions grow at historical rates.

Table 1 presents an economic comparison of our three pathways for stabilizing concentrations at 550 ppmv. In the least-cost scenario, the value of emission rights begins at a relatively low level and increases gradually over time. This is consistent with a gradual transition away from the baseline. Such a transition provides valuable time: 1) to adapt the energy-using and energy-producing capital stock, 2) to develop low-cost substitutes to carbon intensive technologies, and 3) to draw the CO2 out of the atmosphere via the carbon cycle. In addition with the economy, yielding a positive return on capital, future reductions can be made with a smaller commitment of today's resources. For a more detailed discussion of these factors, see ref. 5.

The WRE and WG1 pathways place progressively increasing pressure on global emissions. The implications for welfare losses are shown in the rightmost columns of Table 1. The WRE path follows the least-cost path fairly closely in the early years. The associated welfare losses are therefore much closer to the least-cost scenario than to WG1. Nevertheless, from a global perspective, they are still 38% higher than the least-cost path. The increase in welfare losses is even greater when we focus on Annex 1 countries. Here, losses rise by more than 100% when we shift from the least-cost to the WRE path.

Welfare losses are highest under WG1. The tight near-term constraint drives up the value of emission rights. Global losses rise accordingly. Note, however, that non-Annex 1 comes out ahead under WG1 if there is trade in carbon emission rights. The sale of permits during the early decades of the 21st century would result in a large wealth transfer from Annex 1 to non-Annex 1. This should not obscure the fact that from a global perspective, losses are far higher under WG1.

4. Alternative emission constraints

We next modify the WRE emissions pathway to explore several additional scenarios currently under consideration. Specifically, we examine scenarios in which Annex 1 emissions: 1) are allowed to increase by 10% above 1990 levels in 2010, 2) are returned to 1990 levels in 2010, and 3) are reduced by 10% below 1990 levels in 2010. For each of these scenarios, the 2010 target is maintained through 2030. At that point, Annex 1 emissions are determined by our burden sharing formula.

Figure 3 compares the global emission paths for the various scenarios. The WRE emission path was calibrated so that it would achieve the prescribed target of 550 ppmv. The modifications to the WRE path results in lower concentration levels. However, at most, the modified scenarios differ from the initial WRE concentration path by approximately 1% in 2100.

In calculating the welfare losses associated with the modified WRE scenarios, we assume global trading. That is, we assume that emission reductions will take place wherever it is cheapest to do so -- regardless of their geographical location. Hence, Annex 1 can purchase emission rights from non-Annex 1 and exceed its year-by-year emission constraint as defined above. We do not allow for intertemporal trading, however. There is no provision for shifting emission reductions into the future. Hence, we provide for where, but not when flexibility.

Table 2 summarizes the results. As we saw earlier, the value of carbon emission rights rises gradually under the least-cost scenario. This is in contrast to the modified WRE scenarios where the constraint on emissions is tightened during the early decades of the next century. This raises the value of emission rights in the early years..

Similarly, the modified WRE scenarios result in higher welfare losses. From a global perspective, the increases relative to the least-cost scenario range from 39% to 129% depending upon which of the three scenarios we adopt. The losses are even more pronounced in the case of Annex 1. Here the increases relative to the least-cost scenario range from 100% to 275%. The larger increases (in percentage terms) reflect the fact that the increased reductions fall on Annex 1.

5. The value of "where" flexibility

Thus far, the calculations for the modified WRE scenarios have been made under the assumptions that there will be global trading in carbon emission rights. Some have questioned whether such a market will actually materialize. They argue that the potential wealth transfers, together with troublesome implementation issues, pose formidable, if not insurmountable obstacles.

A discussion of the feasibility of global trading is beyond the scope of this analysis. However, we will explore the implications of restricting international trading to Annex 1 only or of eliminating it altogether. We will focus on the case where Annex 1 emissions are returned to 1990 levels in 2010.

Table 3 summarizes our results. Not surprisingly, welfare losses increase substantially in the absence of global trading. The explanation lies in the value of carbon emission rights. Prior to 2030, non-Annex 1 can emit below their baseline and sell their excess emission rights to Annex 1. This allows Annex 1 countries to substitute high marginal cost options internally with low marginal cost options elsewhere in the world.

If this option is foreclosed and Annex 1 countries can only trade among themselves, they will have to forego cost-effective options in non-Annex 1. This is reflected in the higher value of emission rights. The problem is further exacerbated when international trading is eliminated altogether. In this case, each country must move up or down its own marginal cost curve to achieve the desired target.

6. Delaying the Target

In the above, we assumed that the modified WRE scenarios would take effect in 2010. What would be the implications of shifting the date by 10 years? That is, suppose we first constrain emissions relative to 1990 levels in 2020. For this set of experiments, we maintain our previous assumptions about non-Annex 1 involvement. We also assume full global trading.

Figure 4 shows what happens to emissions in 2010 when the constraint is postponed 10 years. Notice that the increase in emissions is relatively small. This is because MERGE is an intertemporal optimization model. In 2010, producers and consumers are able to foresee the impending constraint in 2020 and beyond. As a result, they begin moving towards a less carbon intensive economy prior to the imposition of the constraint. Otherwise, the energy-using and energy producing capital stock will be inappropriate for the future slate of fuel prices.

From Table 4, notice that when the constraint is postponed until 2020, the value of carbon emission rights in 2010 falls to zero. This is because the constraint in 2010 is no longer binding. Rather than having to reduce emissions relative to1990 levels, Annex 1 can now emit up to their baseline. This is an option it does not choose to exercise.

The increases in concentrations that result from the 10 year delay are small. For example, even in the case where emissions are reduced by 10% below 1990 levels, the increase in concentrations in 2100 due to a 10 year delay is less than 1%. So in effect we have delayed taxes (either explicit or implicit) to 2020, decreased mitigation costs somewhat (depending upon the case), and incurred only a small increase in future concentrations relative to implementing the constraint in 2010.

Postponing the constraint until 2020 compares unfavorably, however, to the least-cost mitigation scenario. Global welfare losses are still 39% to 92% higher depending upon which of the three scenarios we adopt. Losses to Annex 1 are 96% to 242% higher.

7. The effect of non-Annex 1 participation on welfare losses

Finally, we examine the case where non-Annex 1 does not choose to participate. Suppose, for example, that Annex 1 adopts the WRE path, but non-Annex 1 continues to follow its baseline. What are the implications for Annex 1 welfare losses?

From Table 5, we see that the welfare losses will depend upon whether there is trade in carbon emission rights among Annex 1 countries. If this is the case, Annex 1 losses rise from \$.62 trillion to \$.91 trillion or 47%. If emission trading among Annex 1 countries is prohibited, then losses rise to \$1.10 trillion or 77%. Turning to the US, assuming Annex 1 trading, welfare losses rise from \$.28 to \$.36 trillion or 29%. In the absence of Annex 1 trading, losses rise to \$.41 trillion or 46%.

Figure 5 shows the implications for CO2 concentrations. We consider two cases. In the first, non-Annex 1 countries are unaffected by actions taken in Annex 1. They continue to follow their initial baseline. In the second, there are so-called "leakage" effects. Here, actions on the part of Annex 1 lead to increases in non-Annex 1 emissions. For example, a carbon constraint on the part of Annex 1 will depress its demand for oil and hence lower its price. This will lead to increased demand for oil in oil importing developing countries. The result will be increased emissions on their part. It is important to note, however, that although MERGE tracks leakages via fuel markets, it does not account for the migration of carbon intensive industries. It therefore leads to an underestimation of the overall leakage effect.

From Figure 5, we see that if mitigation is limited to Annex 1 only, this can slow the growth in atmospheric concentrations, but not lead to stabilization. According to our calculations concentrations drop by between 7% and 9% in the year 2100. Clearly, Annex 1 cannot accomplish a 550 ppmv target by itself. The projected growth in non-Annex 1 emissions is too large.

References

[1] Our original paper, entitled "On Stabilizing CO2 Concentrations - Cost-Effective Emission Reduction Strategies" is being published in the Proceedings of the IPCC Asia Pacific Workshop on Integrated Assessment Models, the United Nations University, Tokyo, Japan, 10-12 March 1997.

[2] Manne, A, Mendelsohn, R, and Richels, R (1995). "MERGE: a model for evaluating regional and global effects of GHG reduction policies", *Energy Policy* 3 (1).

[3] Manne, A, and Richels, R (1995). "The Greenhouse Debate: economic efficiency, burden sharing and hedging strategies", *The Energy Journal* 16 (4).

[4] Intergovernmental Panel on Climate Change (1995). *Climate Change 1994,* Cambridge University Press.

[5] Wigley, TML, Richels, R, and Edmonds, J (1996). "Economic and Environmental Choices in the Stabilization of CO2 Concentrations", *Nature* 379 (6562).

Table 1. Comparison of Least-Cost, WRE and WGI Emission Reduction Scenarios

Scenario	Value of carbon emission rights ($/ton of carbon)			Welfare losses (trillion dollars of consumption discounted between 1990 and 2100 at 5%)		
	2010	2020	2100	Global	Annex 1	USA
Least-cost (includes "where" and "when" flexibility)	2	3	156	.56	.28	.12
WRE (includes "where" flexibility)	0	27	129	.77	.62	.28
WGI (includes "where" flexibility)	184	270	129	3.32	3.83	1.42

Table 2. Comparison of Least-Cost and Modified-WRE Emission Reduction Scenarios

Scenario	Value of carbon emission rights ($/ton of carbon)			Welfare losses (trillion dollars of consumption discounted between 1990 and 2100 at 5%)		
	2010	2020	2100	Global	Annex 1	USA
Least-cost mitigation path (includes "where" and "when" flexibility)	2	3	156	.56	.28	.12
Constrain Annex 1 emissions to 10% above 1990 levels by 2010 (includes "where" flexibility)	4	65	129	.78	.56	.29
Constrain Annex 1 emissions to 1990 levels by 2010 (includes "where" flexibility)	67	88	129	.94	.62	.30
Constrain Annex 1 emissions to 10% below 1990 levels by 2010 (includes "where" flexibility)	120	112	129	1.28	1.05	.43

Table 3. Sensitivity of Welfare Losses to "Where" Flexibility
(Annex 1 emissions returned to 1990 levels in 2010)

"Where" flexibility	Value of carbon emission rights ($/ton of carbon)		Welfare losses (trillion dollars of consumption discounted between 1990 and 2100 at 5%)		
	2010	2020	Global	Annex 1	USA
Global	67	88	.94	.62	.30
Annex 1 only	131	134	1.76	1.04	.42
None	204	120	2.40	1.59	.43

Table 4. Sensitivity of Welfare Losses to Ten-Year Change in Implementation Date

Scenario	Value of carbon emission rights ($/ton of carbon)			Welfare losses (trillion dollars of consumption discounted between 1990 and 2100 at 5%)		
	2010	2020	2100	Global	Annex 1	USA
Least-cost mitigation path (includes "where" and "when" flexibility)	2	3	156	.56	.28	.12
Constrain Annex 1 emissions to 10% above 1990 levels by 2020 (includes "where" flexibility)	0	68	129	.78	.55	.28
Constrain Annex 1 emissions to 1990 levels by 2020 (includes "where" flexibility)	0	111	129	.88	.64	.29

Constrain Annex 1 emissions to 10% below 1990 levels by 2020 (includes "where" flexibility)	0	151	129	1.08	.96	.40

Table 5. Effect of Non-Annex 1 Non-Participation on Welfare Losses
(Annex 1 follows WRE Scenario)

Non-Annex 1 participation	Trading	Welfare losses (trillion dollars of consumption discounted between 1990 and 2100 at 5%)		
		Global	Annex 1	USA
Yes	Global	.77	.62	.28
No	Annex 1 only	.79	.91	.36
No	None	.97	1.10	.41

Figure 1. Alternative Emission Pathways for Stabilizing Concentrations at 550 ppmv

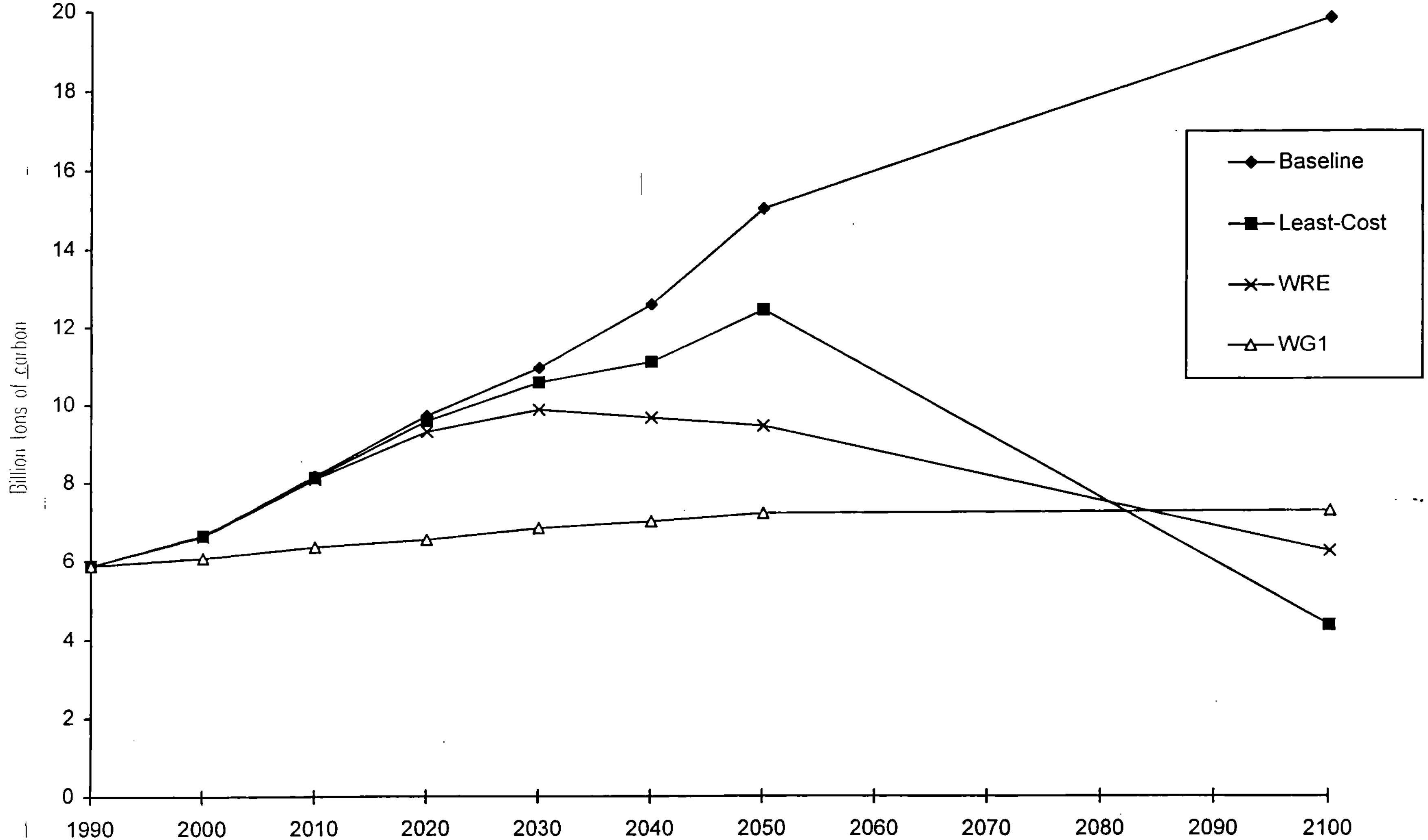


Figure 2. Least-Cost (L-C) Mitigation Path

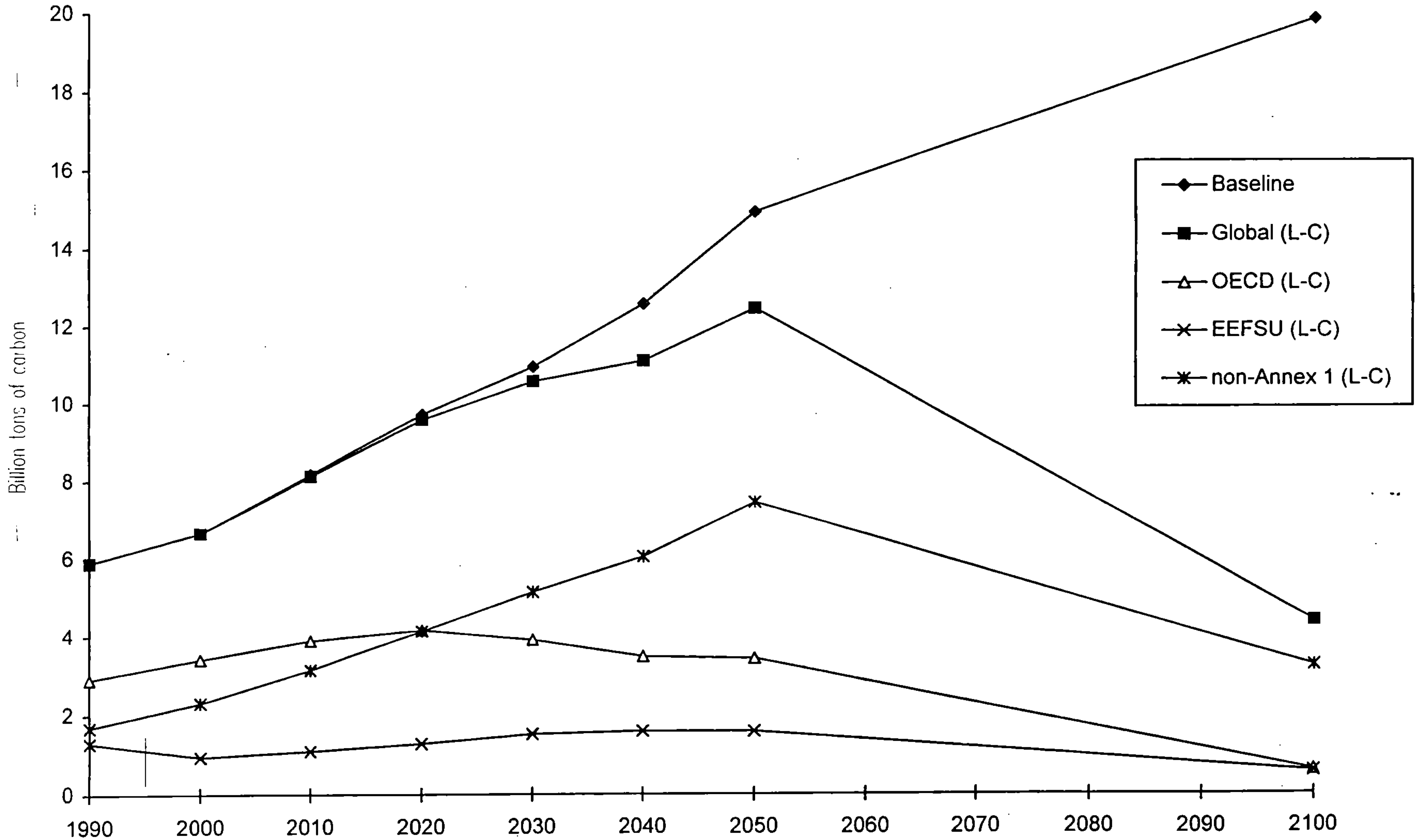


Figure 3. Alternative Emission Constraints

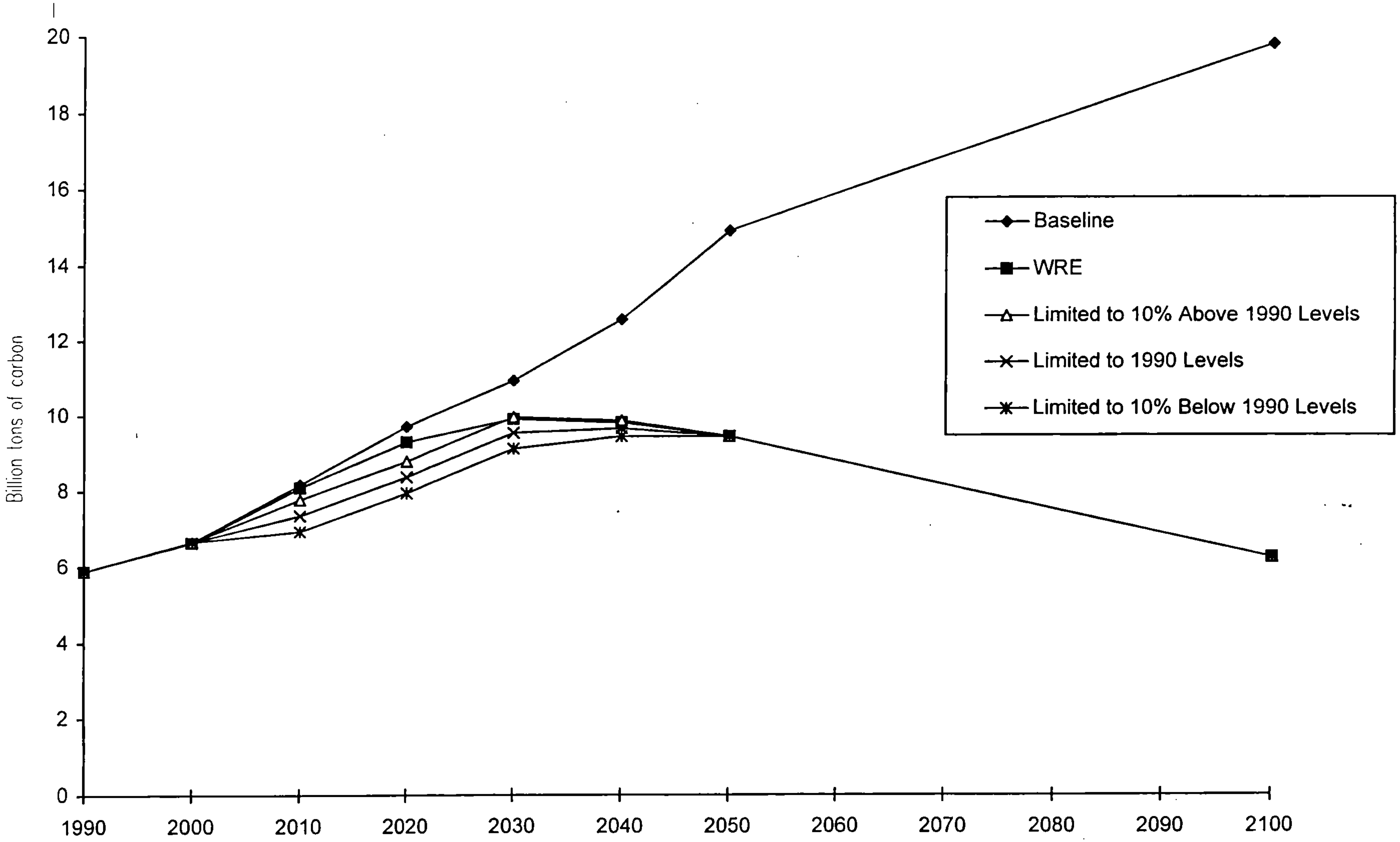


Figure 4. Emissions in 2010

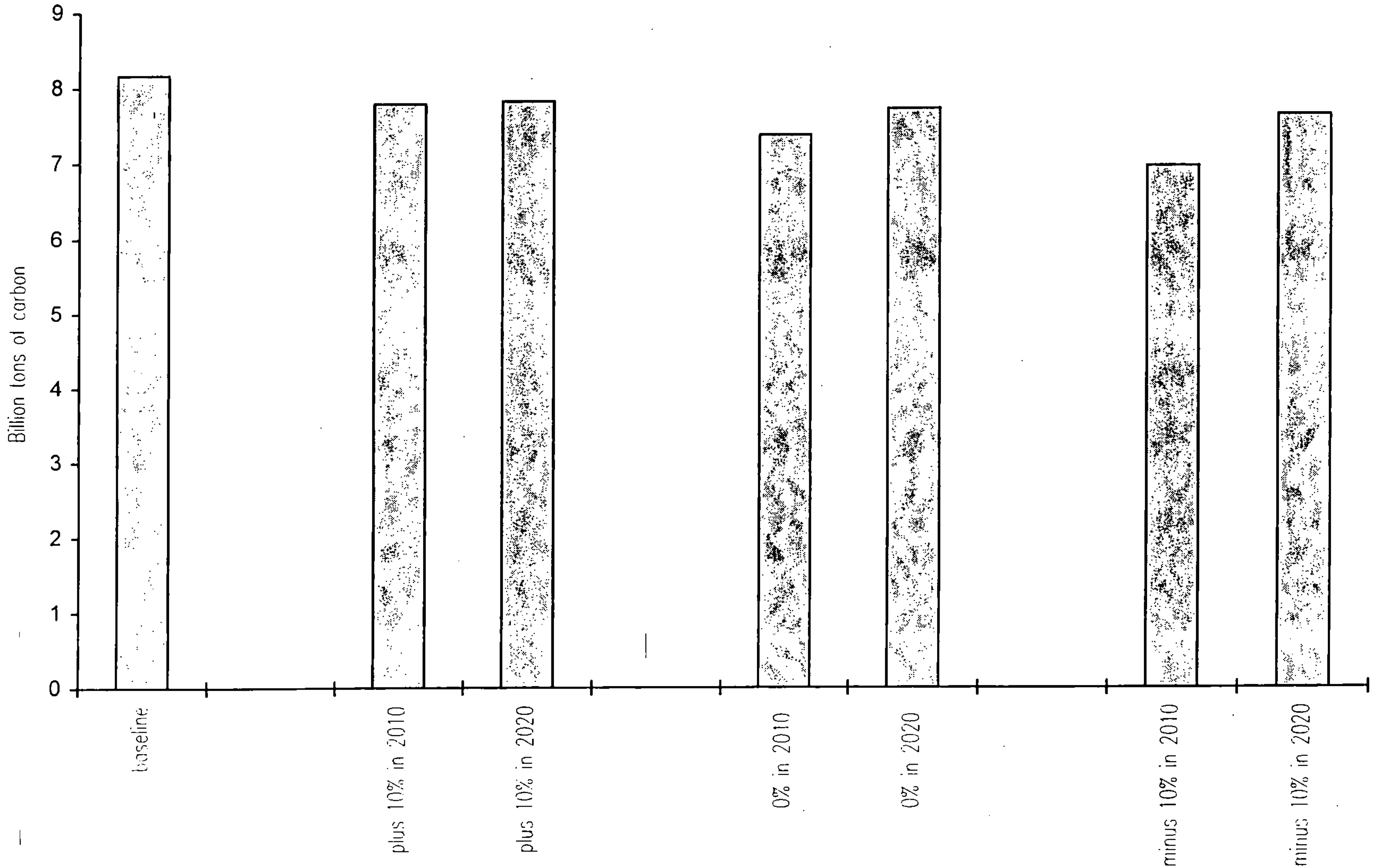
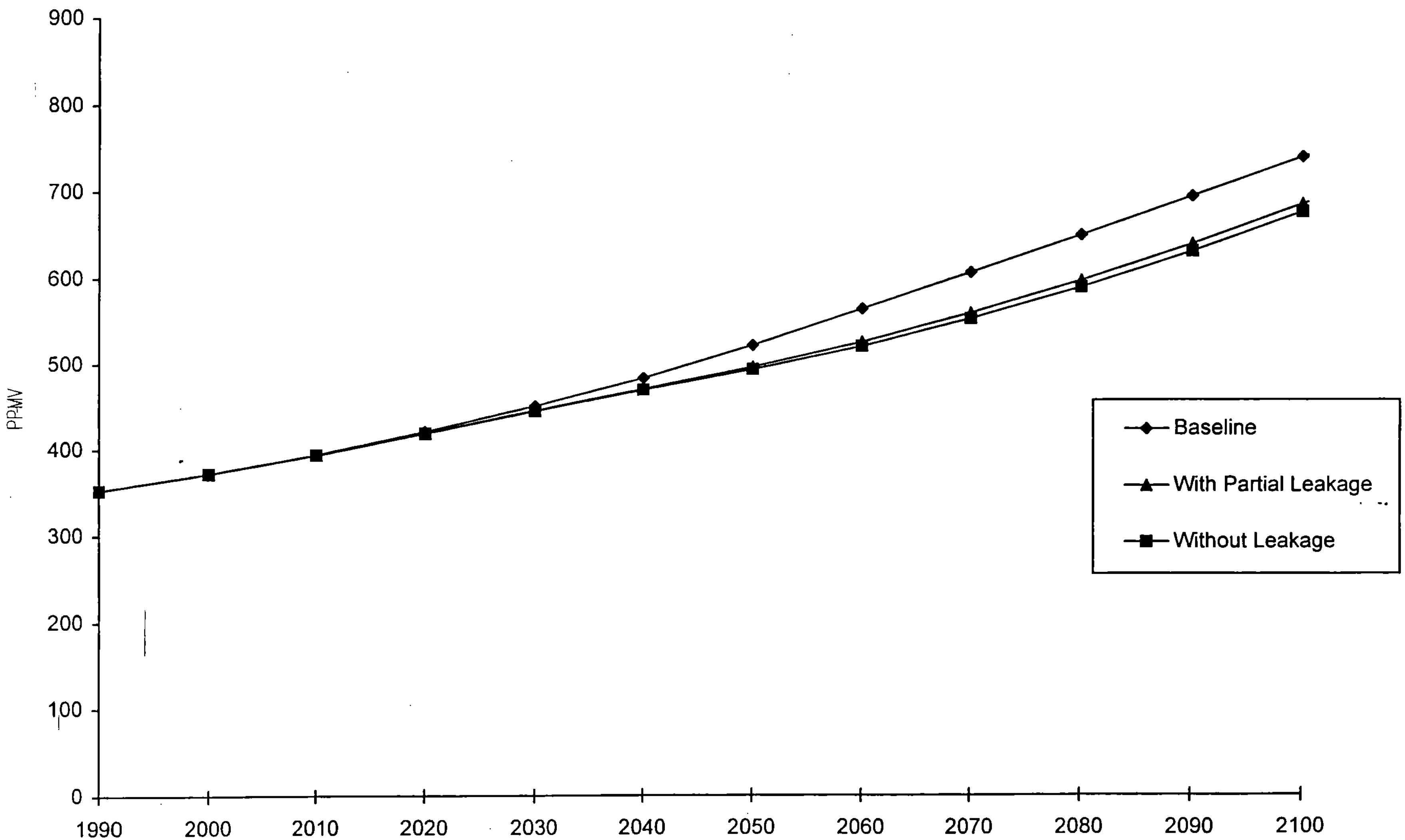


Figure 5. Atmospheric CO2 Concentrations



Predecisional draft. Preliminary. Close hold. Do not distribute. 8/29; rev. 9/16/97,am19,jf21

Targets and Timetables : Executive Summary

How ambitious should we be in seeking to ameliorate global climate change? Is it more advisable to reduce emissions of greenhouse gases (GHG) early and rapidly, or more gradually? This paper examines policy options for GHG emissions targets and timetables and reviews the academic literature and other relevant information and analysis to compare them. We find that a given environmental goal, expressed in terms of the level at which atmospheric GHG concentrations are induced to level off, can be attained at far lower economic costs if emission reductions are phased in gradually rather than suddenly. More specifically, we conclude that a moderate path such as "eliminate emissions growth by 2010-2020, and return emissions to 1990 levels by 2040," seems to be preferable on economic grounds to the more aggressive alternative "return emissions to 1990 levels by 2010."

1. Tradeoffs between front-loading and back-loading emissions reductions

It is easy to state the basic forces at work in the trade-off between front-loaded (reducing emissions earlier) and back-loaded emissions reductions (allowing emissions reductions over longer periods).

Four factors work in favor of back-loading:

- allowing time for the capital stock to turn over. By way of stylized illustration, scrapping all coal-fired power plants by 2010 would mean writing off 88% of the capital stock in this sector; waiting until 2020 would necessitate scrapping only 49% of the plants before the end of their normal useful life.
- the time-value of money. Resources not spent on emission reductions early on can be invested at a positive return, so as to purchase more emission reductions later.
- allowing for uncertainty to be resolved.
- giving more lead time to develop and implement new technologies.

The most important argument in favor of front-loading:

- political credibility. An announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 years or more into the future -- will not be credible. Only early concrete measures will send the signal necessary to move patterns of research, investment, and consumption onto the new path.

2. The costs of "1990 levels by 2010"

The costs of reducing emissions to 1990 levels by 2010, as the cost of any path, depend heavily on the international regime and domestic implementation. "We can do it smart or we can do it dumb." But any effective program will have to raise the cost of GHG emissions, particularly the cost of using fossil fuels that put carbon dioxide into the air. A broad range of models place the carbon permit price required to achieve this target in the range of $70 - $200 per ton. This surcharge translates into an increase in the price of gasoline between 18 and 50 cents per gallon and an increase in the price of coal between 250 and 500 percent. Averaging over fuels, these price increases are nine times greater than the BTU tax that was proposed in 1993, and as great as the oil shocks of the 1970s. (The necessary increase in price could be cut if we are able to pay Russia, developing countries, or others to reduce emissions in our place. But the remaining price increase would nevertheless be substantial.)

These increases in the price of energy might or might not have the substantial negative effects on output of the 1970s oil shocks. Whether they do depends on many things, such as whether the policy is implemented efficiently (e.g., by auctioning emissions permits or a carbon tax) or inefficiently (e.g., by command-and-control style regulation), and whether any revenues that may be generated are redistributed by means of tax cuts that lower the cost of capital to firms. In any case, the policy will have substantial negative effects on consumption, in order to free up resources for investment in new low-carbon plant and equipment.

3. The effects of a moderate path, peaking in 2010-2020

One possible more moderate path is specified as follows:

(i) begin to reduce the rate of growth of emissions in the near-term (2000-2010),

(ii) eliminate emissions growth in the medium term (so that emissions at the end of the decade 2010-2020 were the same as at the beginning), and

(iii) return emissions to the 1990 level in the longer term (e.g., 2040).

The overall cost of this approach is much less than that of the more aggressive timetable, 1990 by 2010. Estimates suggest that the price of carbon would be between $5/ton and $12/ton in 2010. (It would have to continue to rise thereafter, as is also true under the first approach.) Gas prices would rise by an estimated 2 to 3 cents in 2010, and coal prices by 25%-35%. Effects on the economy are scaled down accordingly. Estimates of the loss in consumption are roughly 1/10-1/3 the size of the more aggressive approach.

4. Environmental effects of alternative dates for stabilizing emissions

What is the environmental loss that the planet must bear in exchange for economic gain from slowing emissions cuts? The answer depends entirely on emissions during the remainder of the 21st century (and thereafter). Differences in emissions in the early years of the century have virtually no effect on the cumulative concentration levels. But "even the longest journey begins with a single step." Differences in that first step are important to the extent that they begin the journey down different pathways.

Let us consider the environmental effects of four different emissions paths of increasing ambition in controlling GHG emissions. The first path represents emissions growth in the absence of any policy intervention, a.k.a. business as usual (BAU). The second is the moderate path described above, which peaks in 2010, and the third is achieving 1990 by 2010. The final path is even more aggressive and achieves emissions 10% below 1990 levels by 2010. We assume that each path eventually stabilizes annual emissions at the 1990 level (or 10% below, in the last case) through the remainder of the century. Note that this assumption, while it implies a growing gap with the BAU growth path over time, does not cut emissions enough to prevent concentrations in the atmosphere from increasing.

As one can see from the table below, under BAU, estimated temperatures rise 1.06 and 2.36 degrees centigrade in 2050 and 2100, respectively. The moderate path mitigates the warming by 0.06 degrees in 2050 and 0.19 in 2100. The 1990 by 2010 path reduces the warming relative to BAU by an estimated 0.08 and 0.21 degrees, in the respective years, a very small additional effect relative to the moderate path. The most aggressive path has virtually the same small effect. The three policy options postpone by 6 to 9 years the date at which total atmospheric CO_2 concentrations reach a level that is double the pre-industrial level (about 550 ppmv).

Environmental effect (degrees centigrade)	Path of emissions of GHG			
	BAU	Moderate path	1990 levels by 2010	10% below 1990 levels by 2010
Temperature increase in 2050, **total**	1.06	.99	.98	.97

Temperature increase in 2100, **total**	2.36	2.17	2.15	2.11
Temperature increase in 2050, **relative to BAU**	0	-.07	-.08	-.09
Temperature increase in 2100, **relative to BAU**	0	-.19	-.21	-.25
Additional years until CO2 doubling, **relative to BAU**	0	6	7	9

5. A big difference in cost for two paths to the same ultimate goal

Perhaps the strongest case against an aggressive path like "1990 in 2010" is that *the same ultimate goal in terms of concentrations* can be achieved far more cheaply by imposing aggressive cuts in emissions later in the 21st century rather than earlier. Recall that estimated concentrations and temperatures continue to rise in subsequent centuries under any of the paths outlined above. In order to put a bound on the eventual climate disruption, one has to put a bound on concentrations, which in turn requires that we reduce emissions below 1990 levels. Modelers can compute the path that minimizes the total economic costs of attaining a given ultimate concentration target, and we can compare it to other paths leading to the same target.

The most important implication of the least cost mitigation path is that it costs the U.S. $0.124 trillion in terms of lost consumption (present discounted value), as compared to $0.303 trillion under the "1990 in 2010" path. Thus *the least cost mitigation path generates savings of 60 percent from the 1990 in 2010 path.* Assuming that environmental effects depend on concentrations, there is little or no environmental cost to be weighed against the large economic benefits of going more slowly.

The estimated least-cost path has several other interesting implications. It indicates that emissions rise gradually in the early years and that Annex I countries' emissions peak in the decade 2020-2030 at about 29 percent above 1990 levels. Annex I emissions do not return to their 1990 levels until after 2050. This least cost mitigation path generates quite low values for carbon emissions rights in the early years. The permit price is only $2/ton in 2010, and slowly rises thereafter. Only in the latter part of the century does it rise significantly, to $156/ton in

2100.

The experiment assumes that developing countries are successfully brought in to the agreement, with their participation phased in between 2030 and 2050. Emissions from developing countries peak in 2050. Without the participation of the developing countries, attaining the target of 550 ppmv concentrations is virtually impossible, since they are such a rapidly growing share of world emissions.

It is important to keep in mind that all these cost estimates are "best case" scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

6. Political credibility

A path under which emissions peak in the decade 2020-2030 is far more conservative than the paths that have been discussed in international negotiations. The strong argument for moving the timetable forward is the one mentioned above: political credibility. The year 2020 is more than two decades in the future. A path under which emissions peak in the decade 2010-2020 represents early commitment to a tangible target ("eliminate emissions growth"), while estimates suggest that it is almost as beneficial as the least-cost path. The political credibility of the path could be further boosted by commitments at earlier dates such as 2000-2010 ("reduce emissions growth"). Credibility would be particularly enhanced by a specific proposal to raise the price of energy, even if by only a small amount, if domestic political opposition was not overwhelming.

More aggressive paths are likely to arouse greater political opposition, in correspondence to their greater economic cost. Where domestic opposition is sufficiently great to kill a proposal politically, the set-back will be to international political credibility -- and to environmental progress. The last section of the paper, however, discusses one possible option that might have the effect of helping to limit the economic cost and corresponding domestic opposition, for any given target/timetable: an escape clause triggered by the price of carbon emissions.

Predecisional draft. Very preliminary. Close hold. Do not distribute

Targets and Timetables

A U.S proposal for "targets and timetables" for reducing countries' emissions of greenhouse gases (GHG) must be made soon. The U.N. Framework Convention on Climate Change has called for economically cost-effective remedies to the problem [cite? From JY]. Tradeoffs have to be made -- both with respect to the ultimate target and with respect to the timetable under which it is achieved. The subject of this paper is how to do them. (The paper does not directly focus on two other key sets of policy decisions -- domestic implementation, and proposals for developing country participation and other sorts of "when-and-where flexibility".)

It is futile to search for a single comprehensive econometric model within which these questions can be appropriately raised and definitively answered. Even within a given model, answers depend critically on the precise nature of the question asked (e.g., the extent of global participation and international trading, whether and how any revenue is recycled, what is assumed about technological progress, etc.) Furthermore, each model has strengths and weaknesses; each has questions to which it is better or worse suited to answer. Some, for example, model the energy sector in detail. Some allow for the fact that a coal-fired power plant cannot costlessly be converted to one that runs on natural gas. Some have enough tax policy detail to distinguish alternative ways of redistributing tax revenues. Some are capable of showing short-term macroeconomic disequilibria. Some include a long-term "carbon cycle" model that can keep track of the accumulation of GHG concentrations in the atmosphere and their climatological effects. Some break down the rest of the world into regions and so can model international trade. No one model does everything.

The existence of modeling difficulties does not mean that we can abandon rigorous economic analysis. Rather, we must employ a broad set of economic tools to analyze the policy options. The tools employed in this paper include results from models of the energy sector and economy over the next 25 years, including but not limited to the models that were used by the Interagency Analytical Team (IAT) earlier in this year. The survey also includes models that are designed to operate on the longer time frame that is relevant for thinking about climatological effects. Other tools include simple relevant statistics, "meta-analyses" of existing models, historical and sectoral examples, and basic economic reasoning. Drawing on this broad array of analytical tools allows an intelligent evaluation of the policy alternatives.

1. Why do economists estimate high costs to early reductions in emissions?

The large economic impact of aggressive action

The measures necessary to implement serious reductions in GHG emissions would inevitably have very major effects on the U.S. economy. One path that has been widely discussed in the U.S. is to return to 1990 levels in 2010. (Still more aggressive paths seek to cut emissions 10 percent or more below 1990 levels by 2010. Intermediate paths are to return to 1990 levels by 2020, or to 10 percent above 1990 levels by 2010.) Estimates suggest that to reduce 2010 emissions to the level of 1990, it would be necessary to increase the price of energy on the order of $100 per ton of carbon.

This is a rough midpoint, around which there is a great range of uncertainty. The range of estimates in the IAT exercise was $80-$140, for the case without international trading. Some agencies believe that the necessary increase in price would be less than this, others that it would be more. It is anticipated that prices would have to continue to increase after 2010, even if emissions were not brought down any further, because of the widening gap vis-a-vis the business-as-usual case. (Energy modelers often make the assumption that, once the price of carbon goes high enough, some sort of unidentified "back-stop technology" will eventually be developed, thereby putting a limit on how high the price ultimately goes. But there is no way of knowing when or at what price such technology would come in.)

These estimates are representative of the broad economic literature. In a similar exercise, the Energy Modeling Forum, based in Stanford, has assessed a set of targets and timetables with 10 models (EMF-12, 1994; Gaskins and Weyant, 1993; Weyant, 1994; Richels, Edmonds, Gruenspecht, and Wigley, 1996). These models, employing the same benchmark assumptions, assessed the economic effects of achieving carbon emissions stabilization relative to 1990 in the year 2000 (with implementation beginning in 1990). The modeling results all clearly indicate that the tighter the emissions constraint, the higher the price of carbon.

[insert chart on average carbon taxes required to achieve C emission reductions in the U.S., 2000-2020]

The rough estimate of $100/ton in 2010 represents an increase in the price of oil of $11/barrel (52%), an increase in the price of gasoline of 26 cents/gallon, and an increase in the price of coal of 273%. One standard of comparison is the BTU tax that the Administration proposed in 1993. The increase contemplated here is 9 times larger. (This is for a weighted average of fuels. The multiple for coal is greater than this, and for oil is less.)

These large price changes signal major changes in the allocation of resources across activities and sectors. Need they require a reduction in the rate of growth of aggregate income and output? This depends, in particular, on two things. First, adjustment costs can impose a

negative effect on GDP and employment, especially in the short term. Model estimates of GDP losses from "1990 by 2010" reached __ in the IAT exercise under some pessimistic assumptions, and are higher in some other estimates. ___. The EMF-12 exercise also demonstrated that higher permit prices associated with tighter carbon emissions constraints resulted in larger GDP losses in 2010.

[insert chart on GDP losses from EMF-12]

Second, if measures to raise the price of energy result in the generation of revenues for the government, and they are used to reduce the cost of capital to firms (e.g., by means of an investment tax credit), despite the regressive implications for the distribution of income, then negative effects on economic growth can in the long run be moderated, eliminated, or possibly even reversed.[1] The meta-analysis of 162 simulations derived from 16 leading models by Repetto and Austin (1997, p.13) concludes that the negative effect on national income from stabilization in 2020 can be offset or reversed *if*:
(i) tax revenues are recycled so as to reduce the cost of capital to corporations,
(ii) developing countries participate in the agreement, *and*
(iii) optimistic assumptions are made regarding the availability of non-carbon backstop technologies, efficient economic responses, and increased energy and product substitution. If any of these optimistic assumptions fail, the GDP effect turns negative.

However, the best single measure of aggregate economic costs is the appropriate summation over time -- the present discounted value -- of foregone consumption. Even in a case so optimistic that there might be no effect on output, early action to address climate change would require a diversion of resources from consumption to investment. Thus the present discounted value of consumption is likely to fall. By way of analogy, defense build-ups have appreciable economic costs, in terms of foregone consumption, even though there is often little or no negative effect on aggregate GDP.

Analogy with the oil shocks of the 1970s

A standard of comparison for judging the magnitude of the price increases entailed in climate change policy is the oil shocks of the 1970s. The energy price increase now contemplated [an estimated 88 percent] for stabilization by 2010 is on the same order of magnitude as either the 1973-74 or 1979-80 oil price increases. Again, this is for a weighted average of primary fuels. Fossil fuel prices net of inflation doubled between 1972 and 1975, and doubled again by 1981.

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[1] E.g, Jorgenson (1996).

Gasoline prices rose by 30 percent between 1972 and 1974 and by nearly another 50 percent from 1974 to 1981. Coal, as a substitute for oil, also experienced a price increase in the earlier episode, but by much less.

One can check independently how the price increase necessary in the present context compares to those of the oil shock decade . Carbon emissions in the year 2000 will be about 15% percent above 1990 levels (EIA ___). Between 1973 and 1984, U.S. energy use departed from its usual growth trend, and was essentially unchanged in absolute terms. U.S. emissions fell by only 6.2%. This comparison suggests that to return emissions to 1990 levels between 2000 and 2010, a decline of 15%, would require much greater increases in energy prices than took place over the decade of the oil shocks.

Those price increases, which are designated "supply shocks," are widely believed to have led to high levels of inflation that were eventually reversed only by means of high interest rates and very large losses in output over time. More specifically, they are believed to have led directly to the recessions of 1974 and 1980. (Indeed, the contraction in output, as much as the fall in the energy/output ratio, was a prime force reducing energy use below its long-run trend.) Some economists also believe that the oil shocks may have played a role in the abrupt slowdown in the long-term trend of productivity growth evidenced in the U.S. and other industrialized countries after 1973; but that is much less certain.

The large models that have been used to examine climate change policy tend to exclude supply-shock effects. [Only the DRI model is a macro model capable of addressing these effects; and it shows a loss of only 150,000 to 400,000 jobs in 2010.] The idea is that a path of gradual increases in energy prices will be fully built into the expectations of firms and workers, because of clear commitments to future policies. Thus they will be able to plan ahead and avoid serious microeconomic dislocation and macroeconomic disturbance. Furthermore, the 70s oil shocks entailed large transfers from the U.S. and other oil-importing countries to OPEC, thus depressing real income and spending in the former; a self-imposed energy price increase to address global climate change need not entail such a transfer of purchasing power. Still, if it is contemplated to introduce large increases in energy prices over a period as short as a single decade, it is worth remembering the experience of 1972-81.

The role of turnover of the capital stock

Why do economic models consistently find that the cost of major reductions in emissions is much higher if they are implemented by 2010 than if they are stretched out for another decade or more? There are several arguments against early reductions and in favor of waiting. (There are also a number of reasons for wanting to go fast, listed in bullet form in the Section on cost-benefit analysis below.) They include:

(1) the time-value of money (resources not spent on emission reductions early on can be invested at a positive return, so as to purchase more emission reductions later[2]),
(2) allowing for uncertainty to be resolved, and
(3) giving more lead time to develop and implement new technologies. But the most important reason for waiting is :
(4) to allow time for the capital stock to turn over.

The basic point is that it would be very expensive to scrap the entire capital stock, to replace it with more carbon-free plant and equipment, while it is still in the prime of its useful life. But 20 to 40 years out into the future, much of our existing plant and equipment will be ready for replacement anyway, whether because the plant and equipment have depreciated gradually or because they have more suddenly come to the end of their useful life.

[FIGURE 1 GOES HERE]

The effect of the turnover of the capital stock is built into some of the models used to address climate change [e.g., Markal Macro; though not into most "bottom-up" engineering studies, like the Department of Energy's Five-Labs study]. But it may be useful to look at a simple illustration of the point, for the case of the capital stock in power generation.

Figure 1 shows the effects of an accelerated replacement schedule for all of the 7.900 electric power plants built during the last 40 years. [One could skip directly to coal-fired plants (next paragraph), to save space.] Imagine, to take an extreme case, that all power plants had to be shut down within ten years (by 2007), and replaced with less-polluting technology. This would imply replacing 6,330 plants before the end of their normal lifespan, or 80 per cent of the total. Now imagine a policy that required replacement of all power plants in 20 years. This would constitute an accelerated replacement of 4,600 plants, or 58 per cent of the total. If one could wait 30 years, the complete replacement would mean an accelerated replacement of 2,000 plants, 26 per cent of the total. If one waited forty years, under the stylized assumption of a 40-year life there would be no additional cost to replacing them. [We have truncated the distribution at 40 years, the average lifespan of existing electric power plants. There are other plants that are still in use 50, 60, or even 90 years after they were built. But their numbers are small, and by the end of 40 years the cost of shutting them down would in any case be much-reduced, particularly as technology will have advanced in the meantime.]

Figure 2a does the same exercise for the set of power plants that are coal-fired. This is the

[2] Meanwhile, a higher fraction of carbon emissions will have been naturally removed from the atmosphere by a fixed date, e.g., into the oceans, the earlier those emissions occur. (Manne and Richels (1995, 1997).

class of generators that produce the most carbon and that would thus have to be replaced even under a moderate plan to address climate change. If a complete change-over of coal plants were to be accomplished in 10 years, 799 of the 1,122 coal-fired plants (71 per cent) would have to be replaced before the end of their expected lifespan. If replacement occurs over 20 years, 488 plants would be affected, or 43 percent of the total. If one could wait 30 years, 227 plants would be closed prematurely, or 20 per cent of the total.

Perhaps a comparison between 2010 and 2020 would be most relevant, as these two years figure prominently in the targets-and-timetables debate. In our stylized hypothetical experiment, imagine that all power plants had to be shut down by 2010 (i.e., within 13 years). This would imply replacing 88 percent of the plants before the end of their normal lifespan. Now imagine that all power plants had to be replaced by 2020 (23 years). This would constitute an accelerated replacement of only half the plants.

[FIGURES 2a AND 2b GO HERE]

Figure 2b repeats the exercise on the basis of coal plant *capacity*. Since newer plants tend to have larger capacity, the effects of a rapid replacement schedule are magnified. Closing all plants within 10 years implies that 289 million KW of capacity would be prematurely shut down, or 90 per cent of the total. If one could wait 20 years, 235 million KW of capacity would be affected, or 73 per cent. For 30 years, the capacity that would have to be replaced falls to 116 million KW, or 36 per cent of the total.

This exercise is not intended to be an estimate of the costs of different time-tables, even within this one sector. Rather, the point has been to illustrate concretely the importance of allowing time for the capital stock to turn over, and to illustrate it in a transparent framework that is independent of modeling assumptions over which analysts might differ.

Evaluation of alternative paths

One can pose the question regarding effects of alternative paths in three ways. (I) How do the economic and environmental effects of "1990 by 2010" compare to those of more moderate paths, e.g., in which that level is attained at some later date? (ii) What are the economic effects of alternative paths toward the same ultimate environmental objective, e.g., eventual stabilization of concentrations at twice pre-industrial levels? (iii) What is the optimal unconstrained path to balance estimates of economic costs and environmental benefits? The remainder of the paper considers each question, though in reverse order.

[or would it be better to do it in order
(i) (ii) (iii): 1990-LEVEL RESULTS, THEN 550PPM CONSTRAINT, THEN IA MODELS?]

2. Cost-benefit analysis in the Integrated Assessment models

It is difficult to put economic costs and climate benefits into the same unified analytical framework. This is in part because the effects are so uncertain, especially with regard to climate, and in part because the climate effects take place on a very long time scale. So-called Integrated Assessment models attempt to put everything into one framework. They attempt to quantify the benefits of averted climate change in the distant future, as well as the economic costs of programs to address emissions, and to compare the two.

Integrated Assessment models began with Nordhaus (1989, 1994). By now many of these models exist. An Appendix I to this paper elaborates, and the literature is surveyed by Manne (1996). Those models that can be used for cost-benefit analysis tend to give a similar result: a plan that optimally balances costs and benefits calls for relatively small actions at the beginning, with the result that GHG emissions continue to rise, although at a reduced pace, for at least a century. Concentrations reach ___ ppmv by 21__.

In the simplest case, damage from warming is assumed to rise linearly with temperature. But it is plausible that the costs in fact begin to rise more sharply, e.g., when concentrations and temperature go above a threshold level. Findings by Peck-Tiesberg (1992), using the CETA model and the case of a non-linear damage function (allowing the damage to rise increasingly sharply with the temperature), call for emissions peaking in 2080-2090.

Some of the authors have characterized in a striking way the gap between the optimal paths that their models produce and the frequently heard proposal to return emissions to 1990 levels by 2010: In their models, the economic costs of such a strong early response are so great that, if that were the only alternative, we would be better off doing nothing at all [Jorgenson testimony? Can't find it in there. It's ____ of Stanford?]. In other words, the economic costs of "1990 levels by 2010" outweigh the benefits.

Arguments for earlier action

This conclusion, and the methodology that produced it, have been criticized on a number of grounds.

- Some claim that it gives insufficient weight to the (small, but nonetheless alarming) probability of a discontinuously-large and essentially irreversible catastrophe, such as the melting of the West Antarctic ice sheet [which might raise ocean levels by 5 to 6 meters], a runaway "positive-feedback" greenhouse effect (e.g., from methane release), or structural changes in ocean currents such as the Gulf Stream. [references: Cline (1992, p.34-35, Revelle, 1983, p.442, IPCC 1996a; Schelling AER 1995?]
- Some claim that it gives insufficient weight to the welfare of future generations that will

bear the costs of climate change (that is, the discount rate is too high). [references: Cline (1992) and Howarth (199_).]

- Some claim that it neglects basic uncertainty about all parameters -- the economic effects, the climate effects, and the discount rate necessary to compare the two. [reference: Pizer (1996)]
- Some claim that it omits a basic point about political credibility: an announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 years or more into the future -- will not be credible, and understandably so (Austin, 1997). The arguments for postponing sharp cuts in emissions ten years only work if people use the intervening period to begin adjusting. If they are skeptical of the need to adjust, then ten years later nothing will have been accomplished, and the economy at that point will face the same high costs to early reductions as before. Only early concrete measures will send the signal necessary to move people's patterns of research, investment, and consumption onto the new path. [3]

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3. Estimates of least-cost paths to stabilize concentration levels

For the reasons just enumerated, much of the debate about GHG stabilization takes as given that simply allowing emissions to continue to grow for a long period, even at a reduced rate, as contemplated by the authors referenced in the preceding section, puts the biosphere at too much risk and is not credible politically. An alternative strategy is to reason that the probability of catastrophe may rise to unacceptable levels unless GHG concentrations are capped at some particular level. Such an approach has the disadvantage that the choice of any specific concentration cap is arbitrary, and is inconsistent with the spirit of cost-benefit analysis. But it has the advantage of being analytically tractable, and offers a meaningful focal point for negotiation.

Stabilization of concentrations at 550 ppmv

We will consider the question of the optimal path subject to the constraint that concentrations be stabilized at 550 ppmv (approximately double the pre-industrial level of 275

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[3] An opposing credibility point is also made: A proposed agreement that demonstrably imposes much higher costs than an alternative more measured approach, and thereby invites prohibitively great domestic political opposition, will also suffer from credibility problems both here and abroad.

ppmv[4]). One might ask why we need accept a level of concentrations, and corresponding probability of catastrophe, as high as this. Indeed, why accept any probability of catastrophe? It is important to recognize that it is already too late to keep this probability at zero (even if one were to accept that it would have been worth the cost to do so, had we known at the beginning of the Industrial Revolution what we know now). Atmospheric concentrations are already at 365 ppmv, and it is impossible to prevent them rising further in the short run; one would have to reduce emissions almost to zero to do so.

[It would be useful to quantify the implicit gap between this strategy and the strategies resulting from the unconstrained optimization by the Integrated Assessment models. The difference represents the role being accorded to the four bullet points above. In addition, some sensitivity analysis with respect to the level of the concentration constraint would be desirable.]

Results for a less aggressive path

The Energy Modeling Forum evaluated two forms of emissions paths to achieve specified carbon dioxide concentrations (EMF-14). A suite of six models, employing the same set of benchmark assumptions, assessed an aggressive path, the IPCC Working Group I path (WGI), and a more moderate path, based on work by Wigley, Richels, and Edmonds (WRE). Both sets of paths can achieve concentration stabilization at 550 ppmv or other targets levels. WRE argue that a less aggressive path can achieve the same stabilization goal at much lower economic costs.

The aggressive WGI path entails Annex I fossil fuel emissions peaking in 1990, and falling 24 percent worldwide below 1990 levels by 2010.[5] (Of course, it is too late for this scenario to be realized. Seven years have passed during which emissions manifestly have not in fact begun to fall in the overwhelming majority of OECD countries. Below, we will also consider other alternative proposals that, while sufficiently ambitious as to be expensive to achieve, at least have the virtue of not having been ruled out by history.)

For the WRE path, emissions from OECD countries as well as from other Annex I countries (Russia and most of Eastern Europe) peak in the decade 2010-2020. (Annex I emissions do not return to their 1990 levels until sometime early in the decade 2030-2040. The

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[4] The concentration figure refers only to CO2. Emission of other greenhouse gases will raise the carbon-equivalent, or warming potential, above this level.

[5] *Worldwide* emissions rise 8 percent by 2010 [from 5.885 to 6.351]. These numbers come from 8/28 personal communication with Richels. (Earlier information had worldwide emissions rising 13.64% by 2010 under the IPCC path [to 7.798 PgC]. Evidently the former statistic refers only to fossil fuel emissions and the latter to all carbon emissions.)

price of crude oil peaks in 2040.) The peak in worldwide emissions lags two decades behind the peak in Annex I emissions because the developing countries' emissions do not peak until 2050. Both paths stabilize global carbon dioxide concentrations under the same timeframe.

[insert chart with WRE and WGI emissions paths]

To estimate the economic effects of these pathways, the modelers must employ a burden-sharing rule. Carbon dioxide concentrations cannot be stabilized without developing country participation. Consistent with the U.S. negotiating position, these model runs assume that developing countries agree to binding targets in the future. The modelers assumed that developing countries will continue to increase their emissions along the business as usual path until 2030. During this period, Annex I will undertake emissions reductions. In 2030, developing countries will begin to reduce their emissions growth. By 2050, emissions rights will be allocated to countries on a per capita basis.[6]

As noted earlier, the best single measure of aggregate economic costs is the present discounted value, i.e, the appropriate summation over time, of foregone consumption. The following two tables illustrate the conclusions -- robust across various models -- from the comparison of the aggressive and moderate paths to the same environmental goal. The first table indicates that, on average, the moderate path achieves the same environmental goal at only 30% of the cost of the aggressive path. Indeed, with international permit trading, the cost of the moderate path is approximately 20% of the cost of the aggressive path. The second chart, a permutation of the first, clearly demonstrates the value of international permit trading. With one exception, the ratios of the costs of an emissions path with trading, to the same path without trading, are considerably less than one. International permit trading, on average, results in less than half the costs of the same emissions path without trading.

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[6] Based on 1990 populations. This formula could imply large transfers from OECD countries to developing countries. We consider an alternative scenario in the next section -- that the developing countries do not participate at all. It would also be desirable to look at the implications of a plan under which a small number of middle-income countries (particularly Korea and Mexico) begin to limit emissions by 2010. Without China and India, however, the emissions of the middle-income countries are a small fraction of the world total, so that their involvement would be important only in order to point the way for other emerging economies, rather than to reduce emissions perceptibly in their own right. A plan where developing countries ultimately were assigned targes determined by a formula putting equal weight on population, GDP, and past emissions would probably be more realistic (even though more complicated) than simplified extremes such as population alone or past emissions alone. Formulas based on population are probably too generous to poor countries for rich countries to agree, while formulas based on 1990 emissions alone are far too generous to rich countries for the poor countries to agree.

The Effects of Emissions Pathway on Consumption Losses by OECD Countries, 550 ppmv Stabilization Goal, EMF-14

Model	Trading	WRE	WG1	WRE/WG1
CETA	no	1.83	5.94	0.31
CPBRIVM	no	0.64	3.25	0.20
FUND	no	9.82	11.71	0.84
MERGE	no	0.85	6.12	0.14
MiniCAM	no	1.58	6.51	0.24
SGM	no	1.84	6.17	0.30
CETA	yes	1.86	4.03	0.46
CPBRIVM	yes	0.17	0.99	0.17
FUND	yes	1.47	4.97	0.30
MERGE	yes	0.60	3.24	0.19
MiniCAM	yes	0.54	3.44	0.16
SGM	yes	0.13	1.48	0.086
			Average:	0.28

source: Weyant, 1997

The Effects of Trading on Consumption Losses by OECD Countries, 550 ppmv Stabilization Goal, EMF-14

Model	Pathway	Trading	No Trading	Trading/No Trading
CETA	WRE	1.86	1.83	1.02
CPBRIVM	WRE	0.17	0.64	0.27
FUND	WRE	1.47	9.82	0.15
MERGE	WRE	0.60	0.85	0.71
MiniCAM	WRE	0.54	1.58	0.34
SGM	WRE	0.13	1.84	0.07

CETA	WGI	4.03	5.94	0.68
CPBRIVM	WGI	0.99	3.25	0.30
FUND	WGI	4.97	11.71	0.42
MERGE	WGI	3.24	6.12	0.53
MiniCAM	WGI	3.44	6.51	0.53
SGM	WGI	1.48	6.17	0.24
			Average:	0.44

source: Weyant, 1997

The modelers in the EMF-14 exercise did not attempt to calculate the least-cost path for achieving concentration stabilization goals.

The least-cost mitigation path, compared to 2010 constraints

Manne and Richels (1997) is believed to be virtually the first paper to compute the path that minimizes costs (using the MERGE model), subject to the constraint of stabilizing concentrations at a level such as 550 ppmv.[7] As the EMF-14 results illustrate, the MERGE model generates results on the costs of concentration stabilization that fall among the middle of the economic models. In their paper, they employ the same international burden-sharing rule as EMF-14.

In calculating the least cost path, Manne and Richels [were asked for a run that] constrained the year 2000 emission levels to the BAU level, under the assumption that treaty implementation could not occur before that date. Their model implies that the least cost mitigation path has emissions from OECD countries, as well as from other Annex I countries in general, peaking in the decade 2020-2030, a bit behind the WRE path. The peak of Annex I emissions is 29 percent above 1990 levels. [Source: personal communication from Richels, 8/21 and 8/28/97.] Emissions do not return to their 1990 levels until after 2050. Emissions from developing countries peak in 2050. The sum of the two, total worldwide emissions, also peaks in 2050. (By mid-century, developing countries are such an important source of emissions that they dominate the global peaking date and the date of return to 1990 levels.) Worldwide emissions return to their 1990 levels shortly before the end of the 21st century.

[7] Also Manne and Richels (1995). Kosobud, et al (1994) examine alternative paths to achieve a given <u>temperature</u> target in 2100. All three papers find that a return to 1990 emission levels early in the 21st century is a needlessly costly way to attain the 2100 goals for concentration and climate.

This least cost mitigation path generates quite low values for carbon emissions rights after implementation in 2000. The permit price is only $2/ton in 2010, and rises slowly to $3/ton in 2020. Only in the latter part of the century does it rise significantly, to $156/ton in 2100.

The following table demonstrates the effect of constraining Annex I emissions relative to 1990 levels in 2010, in contrast to the least cost path. This constraint is imposed over the period 2010-2030. After 2030, further reductions in Annex I emissions occur in order to meet the constraint of concentrations at 550 ppmv.[8] Developing countries again participate, consistent with the burden sharing formula described above. Thus the permit price estimates presuppose full global participation and trading ("where flexibility") but not intertemporal trading ("when flexibility").

Change in emissions relative to 1990 in 2010	Permit Price in 2010 ($/ton)	Permit Price in 2020 ($/ton)	Consumption Losses (trillions of dollars)[9]		
			U.S.	Annex I	World
+10%	4	65	0.293	0.564	0.782
0%	67	88	0.303	0.619	0.939
-10%	120	112	0.429	1.054	1.276

According to Manne and Richels, their least cost mitigation path costs the U.S. $0.124 trillion in terms of lost consumption (present discounted value), as compared to $1.28 trillion under the IPCC Working Group path and as compared to $0.303 trillion under the "1990 in 2010" path. Thus the least cost mitigation path generates savings of 90 percent from WG1 and 60 percent from the 1990 in 2010 path.[10]

It is important to keep in mind that all these cost estimates are "best case" (almost utopian) scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if

[8] The proponents of "1990 by 2010" do not always specify what they would like emissions to do for the remainder of the century. In this section, we assume further reductions in order to meet the 550 ppmv constraint. In the next section of the paper, we instead "straightline the rest of the century.

[9] The present discounted value of consumption assumes a 5% discount rate and a time horizon of 1990-2100.

[10] Most of this gain is also reflected in the WRE path, which peaks in 2010-2020, as described above.

less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

What if the developing countries do not agree to go along?

It is difficult to imagine that taxpayers in the U.S. and other industrialized countries will agree to transfers to developing countries on the scale implied by the EMF/Manne-Richels burden-sharing schedule. What if rich and poor countries are unable to come to an agreement? How would the absence of the developing countries from an agreement affect the targets-and-timetables decision of industrialized countries? On the one hand, as a matter of arithmetic, meeting the 550ppmv concentration constraint would require more aggressive targets and timetables on the part of the Annex I countries, if indeed it would be possible at all. On the other hand, as a matter of politics, the absence of the developing countries would probably lead the peoples of the Annex I countries to choose a less aggressive path, even though it would produce a higher terminal concentration level. (An analytical balancing of costs and benefits would give the same answer -- a less ambitious target -- once the concentration constraint is relaxed.) [11]

To consider the possibility that developing countries might decline to participate, we ask what would be the effects, both economic and environmental, if the Annex I countries were constrained to the WRE path, but developing countries"free-ride" (i.e., developing countries remain on their BAU path). The welfare losses (in terms of present discounted value) will depend upon whether there is trading in emission rights among Annex I countries. If Annex I trading occurs, then Annex I countries' losses increase from $0.62 trillion to $0.91 trillion, or 47%. If emission trading among Annex I countries does not occur, then losses rise to $1.00 trillion, or 61%. For the U.S., in the absence of developing country participation, welfare losses rise from $0.28 to $0.36 trillion, or 29%, assuming Annex I trading. Without Annex I trading, U.S. losses rise to $0.41 trillion or 46%.[12]

Meanwhile, the non-participation of the developing countries means a clear failure to meet the goal of capping global emissions at 550 ppmv. Even if the Annex I countries choose an aggressive path of reducing emissions 10% below 1990 levels by 2010 (and stay at that level thereafter), the effect is to reduce global concentrations only 7 % below BAU levels in the year 2100. This is less than a third of the reductions achieved when the developing countries participate [22%; conversation 8/28] This result illustrates the problem of free riding. Moreover, the estimate does not include an allowance for "leakage" of carbon savings from participating to

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[11] Conversely, the developing countries are less likely to agree to participate if the Annex I countries have not already taken serious action.

[12] For purposes of this comparison, we assume that if developing countries do participate, there will be full global trading.

non-participating countries (e.g., reduced oil demand in the former, via a lower world price of oil, raises oil consumption in the latter). Once leakage effects are added to the free-riding problem, the difficulty of accomplishing meaningful reductions without the help of developing countries are even greater. The savings is only 5 percent in this case. In other words, of the 22 percent reductions achieved when the developing countries participate, 15 percentage points are lost to free-riding, and another 2 points to carbon leakage. [conversation 8/29.] This estimate captures only some of the possible leakage channels; it omits, for example, the relocation of production in polluting industries to non-participating countries. Indeed, models do not even attempt to measure this effect, because it is so difficult to do.

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What if there is no international trading?

It is important to keep in mind that the permit price estimates cited earlier assume perfect global trading. Under this assumption, emission reductions occur where it is cheapest to do so regardless of geographic location. What if there is no opportunity to buy emission reductions from lower-cost countries? The following table shows permit prices in 2010 when Annex I emissions are constrained to 1990 levels under alternative assumptions about where flexibility. If the U.S. must attain its target entirely by domestic emission cuts, because developing countries do not participate and there is not trading even among Annex I countries, then the cost rises steeply. These conditions triple the price of the "1990 by 2010" target, in terms of the marginal cost of abatement, from $67/ton to $204.

U.S. Permit Prices in 2010, 1990 Level in 2010 Scenario

Where Flexibility	Global Trading	Annex I Only Trading	Domestic Only Trading
Permit Price in 2010 ($/ton)	67	132	204

It is important also to note that the gains from international trading are highly uncertain. In the case where developing countries do not participate, the extent to which Russia and Eastern Europe are a source of low-cost emission reductions depends heavily on the extent to which they fail in the future to recover from their recent contractions in output. Discussion usually presupposes that the United States will be a net buyer of permits, and several models confirm this. (The SGM shows "1990 by 2010" leading to $8 ½ billion in U.S. permit purchases in 2010, rising to $54 billion in 2050. This is why Annex I trading reduces the permit price in the table.) The

U.S., however, is the next lowest-cost major emitter among Annex I countries, after the former Communist bloc. (Europe and Japan already conserve on energy, largely via already-high energy taxes on petroleum products, so they have less scope for further reductions.) If Russia and Eastern Europe begin to grow strongly, the U..S. could become a net *seller* of permits before long. If so, international trading will result in a higher price, not a lower price. McKibbin and Wilcoxen ( ) have built the G-cubed model to explore the international dimensions of climate change policy. They find that the U.S. turns into a net seller of permits by 2020 (to the tune of $38 billion, as opposed to purchases of $2-3 billion in 2010). If this result is right, then the high prediction for the carbon price is the right one, regardless whether there is trading among Annex I countries or not (though trade in permits is still beneficial).

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4. What is the trade-off between the paths currently under discussion?

As we have seen, the Manne-Richels results suggest that the optimal path has Annex I emissions peaking in the decade 2020-2030 and returning to 1990 levels after 2050. The WRE path has Annex I emissions peaking in 2010-2020, and is almost as cost-effective as the least-cost path. Yet the paths for emission reductions that have been discussed in the international negotiations are far more aggressive than these.

What are the additional economic costs, and climatological benefits, of moving from the least-cost path to "1990 levels by 2010"? Table 4, "Climate and Economic Variables under Alternative Emissions Paths," is designed to answer this question. It reports results from the SGM model (on economic variables) and the MAGICC model (on climatic variables), under the assumption that once emissions are returned to their 1990 levels, they are held there for the remainder of the century. The economic costs of the more aggressive path can be measured in several ways. The price of gasoline in 2010 would rise by 26 cents a gallon and coal prices by 273 percent, as compared to only 3 cents per gallon on the less ambitious path, and an increase in coal prices of only 53 per cent. The total economic loss, in the present discounted value of foregone consumption, $206 billion, as compared to only $95 billion on the less ambitious path. [These figures cumulate lost consumption out only to 2050, and thus are not comparable with the figures cited in the preceding section.] What is accomplished by the more aggressive strategy? The date at which concentrations are doubled is postponed by a mere 3 years (beyond the nine-year postponement achieved by the less aggressive path). The estimated warming in 2100 (2.45 degrees under the business as usual case) is reduced by a mere .03 degrees.. While different observers will weigh the economic costs and climate benefits in different ways, the percentage increase in costs from early action seems large compared to the percentage reduction in concentrations and warming.

This conclusion omits that concentrations continue to rise in subsequent centuries. The way to address such concerns is by means of models (such as Integrated Assessment models) that keep track of economic and environmental effects on a longer time frame. The preceding section of the paper ("Least-cost Paths to Stabilize Concentration Levels") explains how more moderate paths can attain the identical objective, in terms of terminal concentration levels, with lower economic costs than "1990 in 2010." But all these results leave out the major argument for early action mentioned elsewhere: the need for political credibility of an announced long-term plan. This argument suggests that a moderate path should be accompanied by early and specific announcement of serious domestic measures of implementation.

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Table 4: **Climate and Economic Variables under Alternative Emissions Paths ***

		Concentration Level (ppmv)		Year at Which Concentration Reaches 2x Pre-Industrial Level **	Change in Temperature from 1990 Level (Celsius)	
	Year	2050	2100		2050	2100
	Business As Usual (BAU)	502	711	2065	1.06	2.36
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	-21	-66	+9	-0.09	-0.25
	1990 beginning in 2010	-18	-55	+8	-0.08	-0.21
	peak in 2015, 1990 in 2040	-13	-53	+6	-0.06	-0.19
	1990 +10% beginning in 2010	-13	-49	+6	-0.07	-0.18

		Carbon Permit Price ($ per ton): Domestic Trading		Carbon Permit Price ($ per ton): Annex I Trading		Consumption *** (billions of $)
		2010	2050	2010	2050	
	Business As Usual (BAU)	0.00		0.00		121,650
Deviation from BAU:						
Annex I Participation Only	1990 -10% beginning in 2010	+175	+924	+91	+238	-980
	1990 beginning in 2010	+108	+582	+41	+149	-740
	peak in 2015, 1990 in 2040	+12	+563	+11	+153	-270
	1990 +10% beginning in 2010	+60	+310	+17	+113	-460

Summary description

A plan to return carbon emissions to their 1990 levels by 2010 postpones by 9 years the date at which CO_2 concentrations reach twice pre-industrial levels. Global warming would be reduced by 0.21 degrees by the year 2100 versus an estimated 2.36 degrees under BAU. Under this emissions path the value of the estimated foregone consumption is $740 billion.

A less ambitious path -- "eliminate emissions growth by 2010-2020" -- would postpone the doubling date by 2 years less, and would lead to another 0.02 degrees of warming. But, the economics would become much easier: The value of foregone consumption would be only $270 billion.

* Preliminary CEA projections. The origin of these preliminary numbers is described on the accompanying page.

** Pre-industrial concentrations of CO2 were approximately 275 ppmv.

*** Assumes domestic trading only. Annex I or worldwide trading may substantially reduce these costs.
Deviations are foregone consumption assuming a 5% discount rate for the time horizon 2000-2050.

September 10, 1997

Sources and Explanations

Sources

Business As Usual (BAU) emissions projections are based on the assumptions employed in the IAT process. These projections incorporate the Annual Energy Outlook and International Energy Outlook projections, and closely mirror the IPCC IS92a emissions profiles with modifications made for the economic decline in the Former Soviet Union and Eastern Europe. BAU concentration and temperature projections are from the MAGICC model. Carbon permit price estimates and foregone consumption figures are from the SGM model. All these results were provided by Jae Edmonds, Marshall Wise, and Chris MacCracken at Battelle, Washington, DC.

Participation Cases

Annex I Participation Only: Assumes full compliance of stated targets and timetables by countries in Annex I; rest of the world behaves as in BAU.

Targets and Timetables

1990 (+/-10%) in 2010: Emissions follow BAU through 2000, reduce to 1990 (+/-10%) levels by 2010, and remain at 1990 (+/-10%) levels thereafter.

Peak in 2015, 1990 in 2040: Emissions follow BAU through 2005, peak at 2010 BAU levels in 2015, and stabilize at 1990 levels in 2040 and into the future. Because of linear interpolation in emissions profile between 2015 and 2040, this scenario may slightly overestimate the deviation of concentration from BAU.

Trading Scenarios

Domestic Trading: Trading only within each country.

Annex I Trading: Permits are grandfathered to Annex I nations based on 1990 emissions levels. All Annex I countries participate in the trading of permits.

Price Assumptions

Carbon: U.S. permit prices for the four policy options are from SGM, which assumes that all revenues are returned to the economy through a lump-sum redistribution.

Consumption: Deviations are present discounted value of foregone consumption differences for United States in billions of dollars between BAU and scenarios. The present discounted value assumes a discount rate of 5% and a time horizon of 2000-2050.

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5. Escape clauses and other flexibility provisions

In addition to the question of the stringency of targets and timetables, there are a number of other important determinants of the economic costs of a program encompassed in the term "flexibility". The U.S. has proposed both "when flexibility" and "where flexibility."

Examples of "when flexibility" are our proposals for targets that are multi-year averages, for multiple target periods, and for banking and borrowing. An example of "where flexibility" is international trading, especially with the participation of developing countries. All of these proposals could substantially reduce the cost of a given level of emissions, and are crucial elements of our ability to attain moderate targets, let alone more ambitious targets. Costs would be far higher without them.

Another possibility that has recently received attention in the inter-agency process is to add one or more escape clauses. The main idea is to safeguard against unexpectedly large economic costs of emissions reductions. These are costs that could turn out to be unexpectedly large if the economic growth rate turned out higher than expected, or if unrealistic estimates regarding the ease of reducing emissions were built into treaty targets. One possible escape clause would focus on the price of energy per ton of carbon.

Nordhaus (1997) and McKibbin and Wilcoxen (1997) have proposed plans under which there is a cap on how much the price of carbon can rise. The proposal is that above a certain level, governments (or perhaps a supranational authority) could make available an indefinite quantity of emission permits at the predetermined price. The system would operate as a "tariff-rate quota," in which countries were allowed to emit up to their assigned share for free, but then bore a penalty for any emissions in excess of that share. Pizer (1997) estimates that, in the presence of uncertainty, the optimal price rule generates gains that are five times greater than the optimal permit (quantity) rule. While the academic proposals tend to call for common policies and measures to be negotiated worldwide, the idea could usefully be integrated into the U.S. proposal for targets and timetables regarding emission quantities, in the form of a conditional

escape clause. The effect would be to convert the quantity limit into a price instrument under circumstances when the burden would otherwise be too burdensome.

Escape clauses could also serve other purposes as well. Possibilities include:

- An escape clause that would be triggered in the future if continued **scientific research** determined that the dangers from GHG concentrations and climate change were much less than previously feared. Presumably the treaty would be renegotiated in such a case anyway. But the arguments for putting this language in now are three: (1) to facilitate the change, should this come to pass, (2) so that we don't look foolish in the eyes of history if this should come to pass, and most importantly, (3) to help allay the fears of today's skeptics.

- An escape clause that would be triggered in the future if **developing country accession** turned out to be less than we expect after Kyoto.

- An escape clause that would be triggered by other Annex I countries' **failure to abide** by their commitments.

Each of these proposals, might be useful in avoiding economic costs that otherwise might be incurred needlessly.

<u>6. Conclusions and Summary</u>

[SEE EXECUTIVE SUMMARY AT THE BEGINNING]

<u>Appendix I: Integrated Assessment Models (M. Toman)</u>

Integrated Assessment (IA) analyses try to bring together assessments of the physical, ecological, economic, and social impacts of climate change with assessments of policies for responding to climate change and their socioeconomic consequences. Generally speaking, the models can be described schematically as linking economic decisions in the energy (and agriculture) sectors that give rise to GHG emissions (and changes in carbbon sequestration), models of atmospheric composition, climatic change, and changes in oceans, and models that describe the potential impacts of climate change on health, natural resources, coastal areas, and other factors of socioeconomic interest. Different components of various IA frameworks are represented in differing degrees of detail and sophistication. A few models contain the capacity to be used for a benefit-cost analysis, in which it is possible to evaluate changes in the long-term path of GHG emissions that maximizes the net benefits of GHG control (these benefits are the avoided damages of climate change less the costs of control). A larger number of IA models can evaluate the benefits and costs of specified policies but are unable to indicate what emissions reductions maximize net benefits. IA frameworks are inherently more "top-down" in their characterization of economic decisionmaking, though some models contain a fair amount of energy sector detail.

A very striking feature of IA models is that they tend to indicate the desirability – from the perspective of maximizing net benefits over time -- of emissions continuing to rise well into the next century, if not beyond. (For a recent comparison of IA model results, see Manne 1996.) By 2010, the models indicate only small deviations downward from a business as usual (BAU) path (see also IPCC 1996b, Chapter 10). In some cases the emissions do stabilize toward the middle of the next century, but in other cases they continue rising (though more slowly than with business as usual) even beyond 2100. These emissions paths clearly imply increases in atmospheric concentrations of GHGs well beyond the kinds of targets that have been considered in current policy debates (e.g., 550 ppm). One important consequence is that the models indicate costs of near-term emissions stabilization well in excess of the avoided damage costs.

Criticisms of the results of the Integrated Assessment models

As noted in the text, a number of criticisms have been levelled at these IA results. These criticisms include:

Failure to consider the possibility of unlikely but catastrophic events that could result from climate change (e.g., catastrophic sea level rise from melting of the Antarctic ice sheet, runaway global warming from frozen methane releases, or relocation of the Gulf Stream – see IPCC 1996a, Chapter __).

Failure to give adequate consideration to the scale of potential damages, even in the absence of catastrophe. Cline (1992), for example, argues that damages are much higher than is incorporated in most IA models (see also IPCC 1996a, Chapter 6 for various estimates). One specific concern that has been raised is that the IA models do not account adequately for the costs of a less stable climatic and ecological systems in the face of GHG accumulations.

Failure to consider the adverse consequences of less aggressive abatement policies for future generations – in the context of IA models themselves, the criticism is that discounting of future generations' well-being is excessive. Cline (1992) also raises this concern, as does Howarth (199_).

Failure to consider how uncertainty about all these effects affects the "optimal" decision (Pizer 1997).

Failure to consider how lack of early action will jeopardize the achievement of any longer-term mitigation by signalling a lack of political will (Austin, 1997), or how lack of early action will retard induced technical progress that is needed to make mitigation affordable (Grubb 1995).

Sensitivity analyses carried out with IA models suggest that at least some of these criticisms are not major concerns; others may be serious concerns, but empirical judgments are not possible given the current state of knowledge. The Manne (1996) survey referred to above considered scenarios in which the climate's sensitivity to accumulating GHGs was greater than is typically assumed, or the damages are larger (by a factor of almost 8) for a given change in the atmosphere. In either case emissions should (from the perspective of maximizing net benefits) be lower, but the extra degree of emissions reductions required by 2010 is significant (on the order of 25 percent or more) only if climate damages are much higher than expected (the sensitivity of the atmosphere to GHG emissions seems much less important in these analyses). And even in this case, emissions still will be higher than 1990 levels unless the atmosphere and the ecological-economic systems both are quite sensitive. (Broadly similar conclusions follow if, instead of looking at higher damages, one looked at damages that grew proportionately faster as atmospheric GHG concentrations grew [CETA cite]). Thus, the IA models give little support for a policy of near-term emissions stabilization unless damages turn out to be much higher than at least some experts expect.

As noted, one of the criticisms of many integrated assessments (IAs) is that they do not incorporate the possibility of catastrophe. Recent extensions of the IA literature include the possibility of a major, discontinuous jump inh the damages caused by climate change. For example, a European paper by Gjerde et al (1997) incorporates the risk that climate change will sudenly cause damages equal to a significant share of global GDP. The risk is assumed to rise with an increase in temperatre from global warming; following Nordhaus (1994b), the benchmark risk scenario assumes a 12% chance of a loss equal to 25% of GDP (the scale of the great depression) in 2090 if climate has warmed by 3 degrees C. Incorporating this risk into the IA framework causes the optimal path for global emissions to be reduced, but not by that much in the early years. By 2060, optimal emissions are only somewhat over half what they would have been without the risk of catastrophe, but the reduction by 2020 is on the order of 15% below the no-catastrophe case and still above emissions in 1990.[13] Even sharper emissions reductions are implied if the catastrophe is truly shattering (on the order of the entire GDP), or if the discount rate is extremely low (high intergenerational egalitarianism.)

It is also true that the results of IA models are sensitive to the choice of discount rate used to compare consumption today and in the future. A very low discount rate will imply greater weight on damages accruing over time to future generations, and thus the need for a more aggressive abatement strategy. This tradeoff is influenced by the rate of economic growth, since growth will make future generations better off and thus better able to afford and respond to the damages of climate change (Schelling 1995). However, there are numerous economic and ethical controversies surrounding the appropriate way to discount future damages in IA models, and no clear consensus has emerged. One important point that is often ignored in this debate is how much *today's* generation is willing to sacrifice to provide for the increased protection of future generations through GHG abatement; this is a critical unknown since it is today's generation that must necessarily must decide to pay the bill. All that can be said analytically, therefore, is that intergenerational equity ***might*** be an argument for more aggressive abatement.

[13] The no-catastrophe optimal path is substantially below BAU in this analysis, an artifact of the assumptions of low abatement cost and high damage cost.

Uncertainty about future damages or other influences on the costs and benefits of abatement can make a difference. However, Pizer's (1996) analysis suggests that the most important source of uncertainty concerns the nature of our preferences for consumption and environmental protection. (Unlike the Manne (1996) analysis, Pizer considers the possibility that damages may be lower as well as larger.) A recent paper by Gjerde et al (1997) considers the risk of a sudden loss of economic output and well-being on the scale of the Great Depression from climate change. While their analysis indicates more aggressive abatement than other IA analyses without this risk, the introduction o the risk has little relative effect on the desirable level of emissions reduction by 2010, and little effect for a number of years thereafter (unless the loss is much larger even than the Depression).

This leaves the issues of induced technical change, and political credibility. In the case of the former, it is true that sending a less strong signal to energy markets will slow up technical progress. However, there is great uncertainty about how much of a loss this would be in practice, and the loss would have to be greater than most models seem to indicate before the substantial costs of near-term stabilization could be justified. This does *not* mean, however, that *no* actions are justified on cost-benefit grounds to reduce emissions or stimulate technical progress. Aside from initial steps to curb emissions growth, which signal the need for technical change, longer-term measures to promote the development of new technology are warranted. Political credibility is a more complicated issue.

First Steps Toward a Credible and Effective Long-Term Strategy

As noted, the intertemporally flexible alternative approach to achieving a long-term emissions reductions target has been criticized in some quarters as being akin to a license for indefinite postponement of emissions reductions, making the proposal noncredible in terms of the long-term enforceability of domestic emissions reductions (Won't those who want to delay now just want more delay later? Why would anyone be motivated to pursue emissions reductions early with this expectation?) and in terms of the signal sent to the international community. There also has been criticism that these policies will not stimulate enough near-term innovation to lower the cost of long-term emissions reductions. These are important concerns that need to be addressed in a complete analysis of intertemporally flexible policy options.

As for reduced innovation incentives, there may indeed be some negative effect, but the size of this effect is unknown and may be minor and/or transient if emitters do see the long-term policy goal as credible. It can also be lessened by appropriate policy commitments to the funding of GHG-reducing R&D programs.

The credibility issue is more complicated, but even here there are several sides to the issue. A policy of significantly larger and more expensive near-term emissions reductions is by no means automatically more credible, from either an economic or political perspective. Moreover, intertemporal flexibility is not the same as doing nothing for a period of many years. Some near-term reductions can still be implemented, to build confidence in the commitment to longer-term reductions and to gain experience with the process of and opportunities for emissions reductions. We would thus advocate that a policy of cost-effective intertemporal flexibility in the timing of emissions reductions be coupled with a mandate for some modest but concrete initial emissions reductions, relative to business as usual, that grow over time as the economy makes the transition toward leveling off and reducing its emissions. Again, this can be coupled with a policy of support for R&D that lowers the cost of future GHG emissions reductions.

"Safe corridors"

Several recent studies have used the "safe corridors" concept for specifying desirable paths of emissions reductions over time. This concept seeks to indicate which time paths of emissions satisfy not only a limit on long-term concentrations of GHGs, but also other constraints. Common additional constraints are that the rate of temperature rise should not exceed a certain amount per decade, ostensibly as a proxy for avoiding environmental damages that might be produced by more rapid temperature rises; and that emissions reductions should not be larger than a certain percentage per year, ostensibly as a proxy for not imposing too large a cost burden on the economy.

These studies generally call for relatively significant near-term emissions reductions, largely as a result of the constraint on the decadal rate of temperature increase. However, this approach to damage avoidance is entirely ad hoc. While some scientists have expressed concerns about environmental stress from rapid temperature change, the IPCC does not provide a strong scientific basis for concluding that certain decadal rates of temperature increase are unacceptably risky (indeed, even specifying a more continuous relationship between the rate of temperature change and damages, like the relationships in IA models between the long-term change in temperature and damages, can only be done on the basis of analyst judgments). In addition, the arbitrary constraints on the rate of emissions reduction do not in any way capture the links between the shape of the emissions path and the costs to the economy, as discussed in Section 3 ("Estimates of least-cost paths to stabilize concentration levels"). Accordingly, we do not believe the safe corridors approach offers a sound basis for public policy evaluation of emission control strategies.

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Targets and Timetables

A U.S proposal for "targets and timetables" for reducing countries' emissions of greenhouse gases (GHG) must be made soon. No matter what the choice, the decision will inevitably be a tradeoff between costs and benefits. A path of very aggressive reductions, relative to the business as usual path (BAU), is likely to entail higher economic costs, but also higher benefits in terms of averted GHG concentrations in the atmosphere and disruption to the climate. A less aggressive path is likely to entail lower economic costs, and lower climate benefits. The tradeoffs have to be made -- both with respect to the ultimate target and with respect to the timetable under which it is achieved. The subject of this paper is how to do them.

1. Why do economists estimate high costs to early reductions in emissions?

The large economic impact of aggressive action

The measures necessary to implement serious reductions in GHG emissions would inevitably have very major effects on the U.S. economy. Estimates suggest that to reduce 2010 emissions to the level of 1990, it would be necessary to increase the price of energy on the order of $100 per ton of carbon.

This is a rough midpoint, around which there is a great range of uncertainty. The range of estimates in the IAT exercise was $80-$140, for the case without international trading. Some agencies believe that the necessary increase in price would be less than this, others that it would be more.[1] Prices would have to continue to increase after 2010, even if emissions were not brought down any further, because of the widening gap vis-a-vis the business-as-usual case. Energy modelers often make the assumption that, once the price of carbon goes high enough, some sort of "back-stop technology" will eventually be developed, thereby putting a limt on how the price ultimately goes.

The estimate of $100/ton in 2010 represents an increase in the price of oil of $11/barrel (52%), an increase in the price of gasoline of 26 cents/gallon, and an increase in the price of coal of 273%. One standard of comparison is the BTU tax that the Administration proposed in 1993. The increase now contemplated is 9 times larger. (This is for a weighted average of fuels. The multiple for coal is greater than this, and for oil is less.)

Analogy with the oil shocks of the 1970s

Another standard of comparison is the oil shocks of the 1970s. The energy price increase now contemplated [an estimated 88 percent, for stabilization by 2010] is on the same order of magnitude as the 1973-74 and 1979-80 oil price increases combined. Again, this is for a weighted average of primary fuels. Fossil fuel prices net of inflation doubled between 1972 and 1975, and doubled again by 1981. Gasoline prices rose by 30 percent between 1972 and 1974 and by nearly another 50

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[1] The range of variation across models reported by the Energy Modeling Forum, based in Stanford, is at least as large. Gaskins and Weyant (1993) and EMF (1994).

percent from 1974 to 1981. Coal, as a substitute for oil, also experienced a price increase in the earlier episode, but by much less.

Those price increases, which are designated "supply shocks," are widely believed to have led to high levels of inflation that were eventually reversed only by means of high interest rates and very large losses in output over time. More specifically, they are believed to have led directly to the recessions of 1974 and 1980. (Some economists also believe that the oil shocks may have played a role in the abrupt slowdown in the long-term trend of productivity growth evidenced in the U.S. and other industrialized countries after 1973; but that is much less certain.)

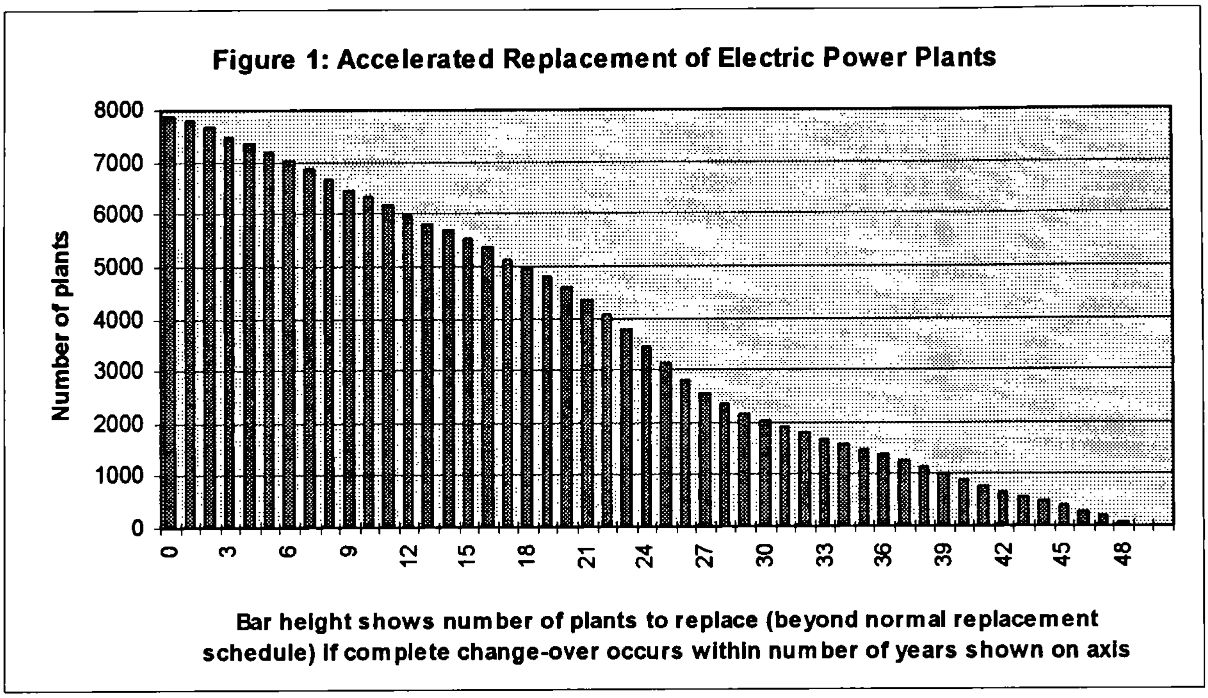
The large models that have been used to examine climate change policy tend to exclude supply-shock effects. [Only the DRI model is a macro model capable of addressing these effects; and it shows a loss of only 150,000 to 400,000 jobs in 2010.] The idea is that a path of gradual increases in energy prices that are announced well ahead of time will be fully built into the expectations of firms and workers. Thus they will be able to plan ahead and avoid serious microeconomic dislocation and macroeconomic disturbance. Still, if it is contemplated to introduce large increases in energy prices over a period as short as a single decade, it is worth remembering the experience of 1972-81. [Some further details are available in a separate memo.]

The role of turnover of the capital stock

Why do economic models consistently find that the cost of major reductions in emissions is much higher if they are implemented by 2010 than if they are stretched out for another decade or more? There are several arguments for waiting. They include allowing for uncertainty to be resolved, and giving more lead time to develop and implement new technologies. (There are also a number of reasons for wanting to go fast, listed in bullet form in Section 2 below.) But the most important reason for waiting is to allow time for the capital stock to turn over.

The basic point is that it would be very expensive to scrap the entire capital stock, to replace it with more carbon-free plant and equipment, while it is still in the prime of its useful life. But 20 to 40 years out into the future, much of our existing plant and equipment will be ready for replacement anyway, whether because the plant and equipment have depreciated gradually or because they have more suddenly come to the end of their useful life.

The effect of the turnover of the capital stock is built into some of the models used to address climate change [e.g., Markal Macro; though not into most "bottom-up" engineering studies, like the Five-Labs study]. But it may be useful to look at a simple illustration of the point, for the case of the capital stock in power generation. Figure 1 shows the effects of an accelerated replacement schedule for all of the 7.900 electric power plants built during the last 50 years. Imagine, to take an extreme case, that all power plants had to be shut down within ten years (by 2007), and replaced with less-polluting technology. This would imply replacing 6,330 plants before the end of their normal lifespan, or 80 per cent of the total. Now imagine that all power plants had to be replaced in 20 years. This would constitute an accelerated replacement of 4,600 plants, or 58 per cent of the total. If one could wait 30 years, the complete replacement would mean an accelerated replacement of 2,000 plants, 26 per cent of the total. If one waited fifty years, under the stylized assumption of a 50-year life there would be no additional cost to replacing them. [We have truncated the distribution at 50 years, the average lifespan of existing electric power plants. There are other plants that are still in use 60, 70, or even 90 years after they were built. But their numbers are small, and by the end of 50 years the

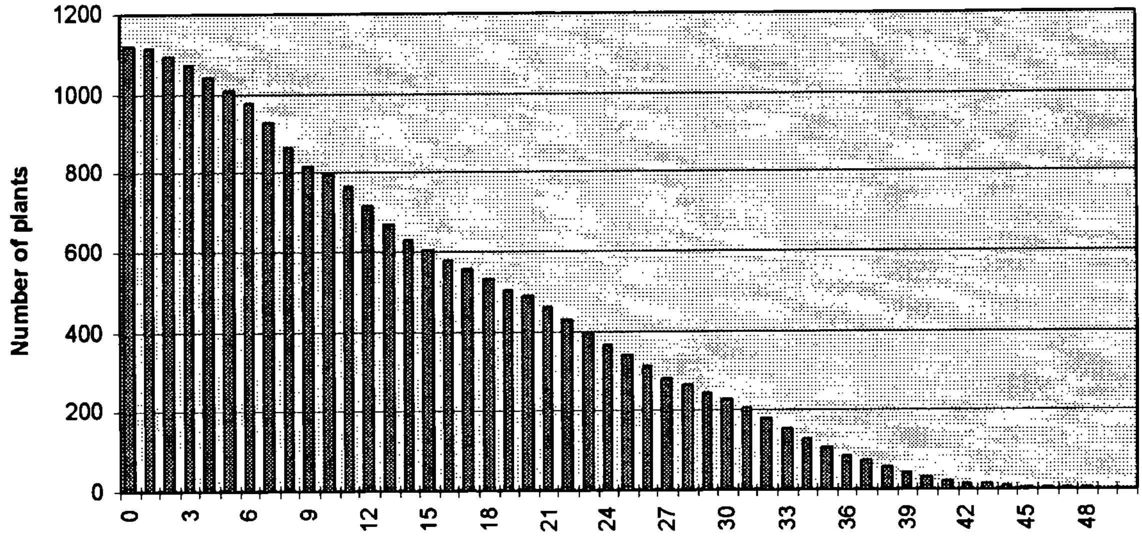


cost of shutting them down would in any case be much-reduced.]

Figure 2a does the same exercise for the set of power plants that are coal-fired. This is the class of generators that produce the most carbon and that would thus have to be replaced even under a moderate plan to address climate change. If a complete change-over of coal plants were to be accomplished in 10 years, 799 of the 1,122 coal-fired plants (71 per cent) would have to be replaced before the end of their expected lifespan. If replacement occurs over 20 years, 488 plants would be affected, or 43 percent of the total. If one could wait 30 years, 227 plants would be closed prematurely, or 20 per cent of the total. Figure 2b repeats the exercise on the basis of coal plant capacity. Since newer plants tend to have larger capacity, the effects of a rapid replacement schedule are magnified. Closing all plants within 10 years implies that 289 million KW of capacity would be prematurely shut down, or 90 per cent of the total. If one could wait 20 years, 235 million KW of capacity would be affected, or 73 per cent. For 30 years, the capacity that would have to be replaced falls to 116 million KW, or 36 per cent of the total.

This exercise is not intended to be an estimate of the costs of different time-tables, even within this one sector. Rather, the point has been to illustrate concretely the importance of allowing time for the capital stock to turn over, and to illustrate it in a transparent framework that is independent of modeling assumptions over which analysts might differ.

Figure 2a: Accelerated Replacement of Coal Plants



Bar height shows number of plants to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

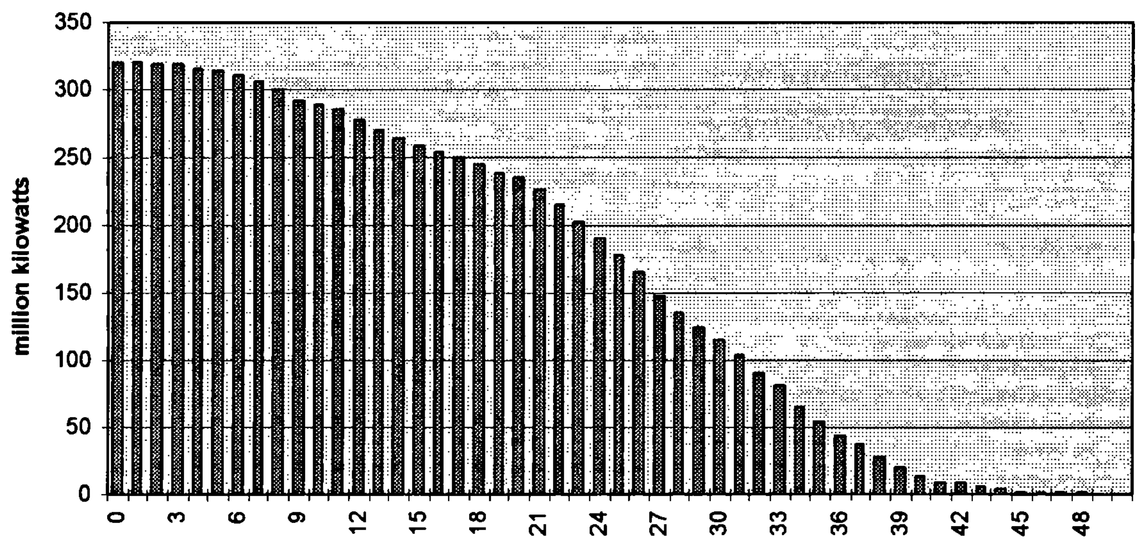
2. Cost-benefit analysis in the Integrated Assessment models

It is difficult to put economic costs and climate benefits into the same unified analytical framework. This is in part because the effects are so uncertain, especially with regard to climate, and in part because the climate effects take place on a very long time scale. So-called Integrated Assessment models attempt to put everything into one framework. They attempt to quantify the costs of climate change in the distant future, as well as the economic costs of programs to address emissions, and to compare the two.

By now many of these models exist. They tend all to give a similar result: a plan that optimally balances costs and benefits calls for relatively small actions at the beginning, with the result that GHG emissions continue to rise, although at a reduced pace, for at least a century. [a bit of elaboration on Nordhaus, IPCC summary, Peck-Tiesberg (CETA) and others, with footnotes. Do any call for emissions peaking, e.g., in the 22nd century?]

Some of the authors have characterized in a striking way the gap between the optimal paths that their models produce and the frequently heard proposal to return emissions to 1990 levels by 2010: In their models, the economic costs of such a strong early response are so great that, if that were the only alternative, we would be better off doing nothing at all [Jorgenson testimony? Can't find it in there____]. In other words, the economic costs of "1990 levels by 2010" outweigh the benefits.

Figure 2b: Accelerated Replacement of Coal Plant Capacity



Bar height shows coal capacity to replace (beyond normal replacement schedule) if complete change-over occurs within number of years shown on axis

Arguments for earlier action

This conclusion, and the methodology that produced it, have been criticized on a number of grounds.

- Some claim that it gives insufficient weight to the (small, but nonetheless alarming) probability of a discontinuously-large catastrophe, such as the melting of the West Antarctic ice sheet [which might raise ocean levels by __], a runaway greenhouse effect (e.g., from methane release), or structural changes in ocean currents such as the Gulf Stream. [references: Schelling AER ___; __]
- Some claim that it gives insufficient weight to the welfare of future generations that will bear the costs of climate change (that is, the discount rate is too high). [reference : Cline...]
- Some claim that it neglects basic uncertainty about all parameters -- the economic effects, the climate effects, and the discount rate necessary to compare the two. [ref.: Pizer..]
- Some claim that it omits a basic point about political credibility: an announcement by the world's governments that they are committing to a serious agreement -- but that stringent policy measures will not be taken until 50 [?] years or more into the future -- will not be credible, and understandably so. Only early concrete measures will send the signal necessary to move people's patterns of research, investment, and consumption onto the new path.

3. Estimates of optimal paths to stabilize concentration levels

An alternative strategy is to reason that the probability of catastrophe may rise to unacceptable levels unless GHG concentrations are capped at some particular level. Such an approach has the disadvantage that the choice of any specific concentration level is arbitrary, and is inconsistent with the spirit of cost-benefit analysis. But it has the advantage of being analytically tractable.

Stabilization of concentrations at 550 ppmv

We will consider the question of the optimal path subject to the constraint that concentrations be stabilized at 550 ppmv (approximately double the pre-industrial level of 275 ppmv[2]). One might ask why we need accept a level of concentrations, and corresponding probability of catastrophe, as high as this. Indeed, why accept <u>any</u> probability of catastrophe? It is important to recognize that it is already too late to keep this probability at zero (even if one were to accept that it would have been worth the cost to do so, had we known at the beginning of the Industrial Revolution what we know now). Concentrations are already at 365 ppmv, and it is impossible to prevent them rising further in the short run; one would have to reduce emissions virtually to zero to do so.

It would be useful to quantify the implicit gap between this strategy and the strategies resulting from the unconstrained optimization by the Integrated Assessment models. The difference represents the role being accorded to the four bullet points above. In addition, some sensitivity analysis with respect to the level of the concentration constraint would be desirable.

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[2] The concentration figure refers only to CO_2. Emission of other greenhouse gases will raise the warming potential, or carbon-equivalent,above this level.

is that the developing countries do not participate at all. It would also be desirable to look at the implications of a plan under which a small number of middle-income countries (particularly Korea and Mexico) begin to limit emissions by 2010. Without China and India, however, the emissions of the middle-income countries are a small fraction of the world total, so that their involvement would be useful only in order to point the way for other emerging economies, rather than to reduce emissions perceptibly in their own right.] fn

The global numbers that Manne and Richels reported in their paper need to be broken down by region. In addition, we asked them to constrain the year 2000 emission levels to the BAU level, under the theory that a treaty that reduces emissions beginning in 1990 has already been ruled out by history, and that even a start in 1998 is ~~so~~ unlikely. Their model implies that the optimal path has emissions from OECD countries, as well as from other Annex I countries, peaking in the decade 2020-2030, a bit behind the WRE path. [Source: personal communication from Richels, 8/21 and 8/28/97.] Emissions do not return to their 1990 levels until the decade after 2050. Emissions from developing countries peak in 2050. As noted, the sum of the two, total worldwide emissions, also peaks in 2050. Worldwide emissions return to their 1990 levels shortly before the end of the 21st century. By mid-century, developing countries are such an important source of emissions that they dominate the global peaking date and the date of return to 1990 levels.

The peak of Annex I emissions is 29% above 1990 levels

The optimal path shows the value of carbon emission rights starting at quite low levels after implementation in 2000, a mere \$2.0/ton in 2010, and rising only gradually through the first half of the 21st century. Only in the latter part of the century does it rise strongly, ~~in excess of~~ to \$128 ton. This is a sharp contrast to what happens if one imposes an arbitrary constraint on the level of emissions in 2010. If emissions are constrained to 10% ~~below~~ above 1990 levels, the price jumps to \$36/ton. If the constraint is the much-discussed target of 1990 levels by 2010, the price rises more steeply, to \$91/ton. If the constraint is a still more ambitious target of cutting emissions 10%, the price goes to \$161/ton. Under these alternatives, if no constraints are imposed for the remainder of the century, other than the constraint of terminal concentrations at 550 ppmv, then the price of carbon {and the level of emissions?} snaps back ~~virtually~~ almost to the same low level as under the optimal path. This reflects that the 2010 emission constraints -- any of the three possibilities -- are ~~a~~ sharp deviations from the economically efficient least-cost path.

According to Manne and Richels, their optimal path costs \$0.545 trillion in terms of lost consumption (present discounted value), as compared to \$3.3 trillion under the IPCC Working Group path. Thus the saving under the optimal path is 83 percent. (Most of this gain is also reflected in the WRE path, as described above.) It is important to keep in mind that all these cost estimates are "best case" scenarios, in the sense that they assume efficient market implementation, international trading, and full international participation and enforcement. Actual costs could be much higher if less efficient command-and-control mechanisms of implementation are used, if there is not effective international trading, or if some countries do not accede to or abide by a treaty.

These paths allow emissions in 2000 to fall below BAU.

What if the developing countries do not agree to go along?

It is difficult to imagine that the industrialized countries will be able to extract commitments from developing countries much more serious than ~~these~~ those we have been assuming. What if, as is more likely, the commitments extracted from developing countries are less strong than this the Manne-Richels burden-sharing schedule, rather than more? On the one hand, as a matter of arithmetic, meeting the 550ppmv concentration constraint would require more aggressive targets and timetables on the part of the Annex I countries,

Results for a less aggressive path

Wigley, Richels and Edmonds (1996) [WRE] examined alternative paths to reach 550 ppmv and other concentration levels. They considered a path where global emissions peaked in 2030 and did not return to 1990 levels until some date past 2100. Manne-Richels (1997) use the MERGE model to examine the implications of the WRE path in more detail. In their model, emissions from OECD countries as well as from other Annex I countries (most of the former Soviet Union and Eastern Europe) peak in the decade 2010-2020. (Annex I emissions do not return to their 1990 levels until sometime early in the decade 2030-2040. The price of crude oil peaks in 2040.) The reason that the peak in worldwide emissions lags two decades behind the peak in Annex I emissions is that the developing countries do not peak until 2050.

WRE argue that this path has much lower economic costs than proposed paths that are more aggressive in terms of timing, while producing the same terminal effects on concentration and climate. The proposed path they examine is the IPCC Working ~~Group path 1 [---], which entails~~ Annex I fossil fuel emissions peaking in 1990, and falling 24 worldwide below 1990 levels by 2010.[3] (Below we will also consider other alternative proposals that, while sufficiently ambitious as to be expensive to achieve, at least have the virtue of not having been ruled out by the passage of seven years during which emissions manifestly have not in fact begun to fall.)

of course it is too late for this scenario to be realized,

The best single measure of aggregate economic costs is the present discounted value, i.e, the appropriate summation over time, of foregone consumption. The IPCC Working Group path shows a total consumption loss of $8.6 trillion. (The number would be lower if international trading were allowed -- $3.3 trillion. On the other had, the cost would be higher if the developing countries do not agree to the targets envisioned. Indeed, if the developing countries do not participate at all, then the goal would be impossible to attain at any cost.) The more moderate WRE path toward the same concentration goal entails far smaller costs: a total cost of $1.776 trillion. (With global trading, it is $0.77 trillion.) Thus the saving from letting emissions continue to rise as late as 2010 is more than three-quarters of the cost.

WRE do not consider whether other paths might reach the same goals at still lower costs.

The optimal path

Manne and Richels (1997) is believed to be the first paper to compute the economically-optimal path (again, using the MERGE model) subject to the constraint of stabilizing concentrations at a level such as 550 ppmv. They must necessarily make some assumption about international burden-sharing. The particular question is as follows: how much can we insist that developing countries (who are poor, but in many cases rapidly growing) reduce their emissions, relative to their (low, but often rapidly growing) paths? For the case of 550 ppmv concentrations, they assume that non-Annex I countries can plausibly be expected to begin to limit emissions in 2030, and to complete a transition to a regime under which their per-capita emission rights are equal to those of the industrialized countries by 2050. [We consider alternative scenarios in Appendix _.. One alternative

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[3] Worldwide emissions are up 8 percent in 2010 [from 5.885 to 6.351]. These numbers come from 8/28 personal communication with Richels. (Earlier communication had worldwide emissions rising 13.64% by 2010 under the IPCC path [to 7.798 PgC]. Evidently the former statistic refers only to fossil fuel emissions and the latter to all carbon emissions.)

if indeed it would be possible at all. On the other hand, as a matter of politics, the absence of the developing countries would probably lead the peoples of the Annex I countries to choose a less aggressive path, even though it would produce a higher terminal concentration level.[4] (An analytical balancing of costs and benefits would give the same answer -- a less aggressive path -- once the concentration constraint is relaxed.)

To consider the possibility that developing countries might decline to participate, or decide to participate only to a lesser degree than the Manne-Richels burden-sharing formula, we ask what would be the effects, both economic and climatological, if the Annex I countries remained on the same path (peaking in 2010-2020 [?]). The economic effects are not very different from the case where developing countries do participate. The world price of oil is higher [by __], because the developing countries do not curb their consumption. This affects the Annex I countries as follows ... Overall, concerns about adverse effects on the competitiveness of energy-intensive manufactures do not show up at the aggregate level...

The effects on concentrations of omitting the developing countries, however, are large. Global emissions continue to grow at... Global concentrations go to __ in 2050 and __ in 2100. Even if the Annex I countries choose an aggressive path of reducing emissions 10% below 1990 levels by 2010 (and stay at that level thereafter), the effect is to reduce global emissions only 7 % below BAU levels in the year 2100. This is less than a third of the emission reductions achieved when the developing countries participate [22% or 26%, depending the definition of emissions; conversation 8/28] ~~It~~ This result illustrates the problem of free riding. The estimate does not include an allowance for "leakage" of carbon savings from participating to non-participating countries (e.g., reduced oil demand in the former, via a lower world price of oil, raises oil consumption in the latter). Once leakage effects are added to the free-riding problem, the difficulty of accomplishing meaningful reductions without the help of developing countries ~~is apparent~~ would be even greater. [The difference for concentrations can be crudely translated into an estimate of the effect on temperature in 2050 or 2100 by means of simple interpolation of IPCC estimates...]

4. What is the trade-off between the paths currently under discussion?

As we have seen, the Manne-Richels results suggest that the optimal path has Annex I emissions peaking in the decade ~~2010-2020 [?]~~ 2020-2030 and returning to 1990 levels ~~in 20__~~ after 2050. The paths for emission reductions that have been discussed in the international negotiations are more aggressive. One that has been widely discussed in the U.S. is to return to 1990 levels in 2010. (Still more aggressive paths seek to cut emissions 10 percent or more below 1990 levels by 2010.) Intermediate paths are to return to 1990 levels by 2020, or to 10 percent above 1990 levels by 2010.

What are the additional economic costs, and climatological benefits, of moving from the optimal path to "1990 levels by 2010"? Table 4, "Climate and Economic Variables under Alternative Emissions Paths," is designed to answer this question. The economic costs of the more aggressive path can be measured in several ways. The price of gasoline in 2010 would rise by 26 cents a gallon and coal prices by 273 percent, as compared to only 3 cents per gallon on the less ambitious path, and an increase in coal prices of only 53 per cent. The total economic loss, in the present discounted

[4] Conversely, the developing countries are less likely to agree to participate if the Annex I countries have not already taken serious action.

if indeed it would be possible at all. On the other hand, as a matter of politics, the absence of the developing countries would probably lead the peoples of the Annex I countries to choose a less aggressive path, even though it would produce a higher terminal concentration level.[4] (An analytical balancing of costs and benefits would give the same answer -- a less aggressive path -- once the concentration constraint is relaxed.)

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The effects on concentrations of omitting the developing countries, however, are large. Global emissions continue to grow at... Global concentrations go to __ in 2050 and __ in 2100. (These are the effects of leakage and free-riding.) The difference for concentrations can be crudely translated into an estimate of the effect on temperature in 2050 or 2100 by means of simple interpolation of IPCC estimates...

4. What is the trade-off between the paths currently under discussion?

As we have seen, the Manne-Richels results suggest that the optimal path has Annex I emissions peaking in the decade 2010-2020 [?] and returning to 1990 levels in 20__. The paths for emission reductions that have been discussed in the international negotiations are more aggressive. One that has been widely discussed in the U.S. is to return to 1990 levels in 2010. (Still more aggressive paths seek to cut emissions 10 percent or more below 1990 levels by 2010.) Intermediate paths are to return to 1990 levels by 2020, or to 10 percent above 1990 levels by 2010.

What are the additional economic costs, and climatological benefits, of moving from the optimal path to "1990 levels by 2010"? Table 4, "Climate and Economic Variables under Alternative Emissions Paths," is designed to answer this question. The economic costs of the more aggressive path can be measured in several ways. The price of gasoline in 2010 would rise by 26 cents a gallon and coal prices by 273 percent, as compared to only 3 cents per gallon on the less ambitious path, and an increase in coal prices of only 53 per cent. The total economic loss, in the present discounted value of foregone consumption, $206 billion, as compared to only $95 billion on the less ambitious path. [These figures cumulate lost consumption out only to 2050, and thus are not comparable with the figures cited in the preceding section.] What is accomplished by the more aggressive strategy? The date at which concentrations are doubled is postponed by a mere 3 years (beyond the nine-year postponement achieved by the less aggressive path). The estimated warming in 2100 (2.45 degrees under the business as usual case) is reduced by a mere .03 degrees.. While different observers will weight the economic costs and climate benefits in different ways, the percentage increase in costs from early action seems far greater than the percentage reduction in concentrations and warming.

[4] Conversely, the developing countries are less likely to agree to participate if the Annex I countries have not already taken serious action.

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5. Escape clauses and other flexibility provisions

In addition to the question of the stringency of targets and timetables, there are a number of other important determinants of the economic costs of a program encompassed in the term "flexibility". The U.S. has proposed both "when flexibility" and "where flexibility."

Examples of "when flexibility" are our proposals for targets that are multi-year averages, for multiple target periods, and for banking and borrowing. Ab Example~~s~~ of "where flexibility" is international trading, especially with the participation of developing countries. All of these proposals could substantially reduce the cost of a given level of emissions, and are crucial elements of our ability to attain moderate targets, let alone more ambitious targets.

Another possibility that has recently received attention in the inter-agency process is to add one or more escape clauses. The main idea is to safeguard against unexpectedly large economic costs of emissions reductions. These are costs that could turn out to be unexpectedly large if the economic growth rate turned out higher than expected, or if unrealistic estimates regarding the ease of reducing emissions were built into treaty targets. One possible escape clause would focus on the price of energy per ton of carbon.

Nordhaus (1997) and McKibbin and Wilcoxen (1997) have proposed plans under which there is a cap on how much the price of carbon can rise. The proposal is that above a certain level, governments (or perhaps a supranational authority) ~~can~~ would make available an indefinite quantity of emission permits at the predetermined price. While the academic proposals tend to call for common policies and measures to be negotiated worldwide, the idea could usefully be integrated into the U.S. proposal for targets and timetables regarding emission quantities, in the form of a conditional escape clause. The effect would be to convert the quantity limit into a price instrument under circumstances when the burden would otherwise be too burdensome.

Escape clauses could also serve other purposes as well. Possibilities include:

- An escape clause that would be triggered in the future if continued **scientific research** determined that the dangers from GHG concentrations and climate change were much less than previously feared. Presumably the treaty would be renegotiated in such a case anyway. But the arguments for putting this language in now are three: (1) to facilitate the change, should this come to pass, (2) so that we don't look foolish in the eyes of history if this should come to pass, and most importantly, (3) to help allay the fears of today's skeptics.

- An escape clause that would be triggered in the future if **developing country accession** turned out to be less than we expect after Kyoto.

- An escape clause that would be triggered by other Annex I countries' **failure to abide** by their commitments.

Each of these proposals, might be useful in avoiding economic costs that wee incurred

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