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**CARBON SINKS:
MANAGEMENT TOOL OR BOTTOMLESS PIT**

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ABSTRACT

The Kyoto multilateral agreements to control greenhouse gases explicitly include management of sinks as a viable control alternative for nations. By increasing carbon storage in trees and soils, countries could offset emissions. However, managing sinks is difficult. It can be expensive to monitor carbon storage across vast landscapes over long time frames. Countries have an incentive to overstate storage efforts. Storage outcomes are subject to natural cycles beyond human control. Large scale management alternatives to increase storage are expensive because land is scarce and increasing storage per hectare usually involves large opportunity costs. Finally, there are large nonmarket impacts associated with increasing carbon stocks on terrestrial lands which would need to be assessed.

The control of greenhouse gases is one of the most daunting environmental challenges mankind has yet faced. Greenhouse emissions, especially carbon dioxide, are difficult to avoid. Carbon dioxide itself emanates from a basic need for inexpensive energy. Greenhouse emissions are global in nature as they can occur anywhere on the planet and have the same effect (Houghton et al., 1996). The resulting impacts are complex and universal as just about everyone would be affected by changes in climate and carbon dioxide levels. There are many complex scientific uncertainties associated with the problem both in terms of understanding solutions as well as understanding what will happen in the absence of control. Finally, it is a multilateral problem, requiring cooperation across countries which is difficult to achieve and sustain.

As a first step towards control, many countries of the world gathered in Kyoto in 1997 and attempted to negotiate an initial policy response to greenhouse gas emissions. The conference focused on setting near term limits on the greenhouse gas emissions of highly industrialized countries. However, in addition to emission controls, the conference discussed the possibility of controlling the sinks and sources of greenhouse gases as an alternative policy.

Virtually all the greenhouse gases are part of natural cycles which emit and absorb material between the atmosphere, oceans, and land masses. By managing these cycles, it may be possible to absorb some of the gases which would otherwise remain in the atmosphere. For example, if a country planted trees in vacant land, the trees would absorb carbon from the atmosphere and put the carbon into the soils and tree mass. The Kyoto agreement considers

these management alternatives as a viable method to meet national greenhouse gas control goals.

At first glance, controlling sinks looks very attractive. A nation could counterbalance industrial development by emphasizing nature. Unused land could be placed into productive service. Mature forests could be protected. Nature's mechanism to keep cycles in balance by increasing uptake when atmospheric concentrations rise could be reinforced: a gaia program. Forests would be planted throughout the world, returning land to its former natural state, creating new habitat and an enhanced environment. Initial studies suggest all this can be done at a low cost of 1 to 10 \$/ton C (Watson et al., 1996, Chapter 24). In comparison, most serious abatement programs are considering costs of well over a 100 \$/ton C (Bruce et al., 1996, Chapter 9).

Of course, before a sink policy can be analyzed, it must first be defined. First, the policy must establish a baseline from which to measure changes. Second, the policy must determine what changes will be measured and how carbon is credited to a country. Third, the cost of the program should be measured. Finally, the nonmarket effects should be quantified, whether positive or negative.

In this paper, we examine two generic types of sink programs. The physics-based approach looks at carbon as a pool of molecules which cannot be created or destroyed. To a first approximation, any increase in the amount of carbon on terrestrial land is roughly equal to

to
Approaches
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the amount removed from the atmosphere. This is not a precise statement as the oceans also serve as sinks and sources of carbon. In this program, a baseline survey would establish how much carbon is currently stored in each country. Periodic measurements following the baseline would measure how much this terrestrial storage changes over time. Countries would be credited or indebted for any changes between measurements.

An alternative approach would not consider the entire landscape but rather only selected locations. The policy-based approach would measure carbon setasides only in official management projects. Countries would establish projects to increase carbon storage. They would be credited for any increase in carbon stored at these official sites. By making the carbon measurements permanent at official sites, the policy-based approach would resemble the physics based approach except that the sites considered would be selective.

Both of these programs have their strengths and weaknesses, which the paper analyzes. Despite the initial charm of sink policies, there are many potential problems. Sinks are subject to large natural forces. Keeping track of the ebb and flow from these sources is expensive and may leave countries at the mercy of natural and economic forces beyond their control. Managing sinks over the time frame relevant to greenhouse gases, requires being involved in decisions about how land is to be used across the globe. This raises serious questions about monitoring and designing adequate institutions to cope with such a massive undertaking. No land is truly idle. Planners who intend to plant trees in "empty" deserts and grasslands will have to overcome natural barriers which are likely to be quite expensive.

Returning farms to forests will be increasingly difficult in the future as world populations increase, making remaining farms ever more valuable. Increasing the carbon in existing forests is not straightforward and may involve management or planting exotics which may or may not be ideal habitats. Vast programs to increase sinks are likely to affect nonmarket services and these changes should be assessed.

I. TERRESTRIAL CARBON STORAGE

There are many alternative ways of defining a carbon sink program. The most straightforward approach is to take a physics based approach and simply account for all terrestrial carbon. A baseline would be established by an initial inventory of all carbon in terrestrial systems. Taking advantage of the principle that matter is neither created nor destroyed, the amount of carbon in each country's terrestrial systems would be their initial stock. This becomes the baseline. Any increase in this carbon inventory would be considered uptake and any decrease an emission. Every reporting period, the inventory would be updated and changes would be credited or subtracted to each country. Presumably, most of the changes in terrestrial sinks would come at the direct expense of the atmospheric sink, leaving the oceans as a neutral party. Of course, explicit efforts to mine carbon from the oceans would have to be banned as these would not serve greenhouse gas objectives.

One drawback of using terrestrial carbon storage as a baseline is that this quantity is subject to large natural forces. Although we often think of nature as a balanced entity in stasis,

evidence suggests that there are actually large natural swings and movements in carbon cycles.

For example, there is a large seasonal swing in carbon uptake. In the paleological record, there is evidence that carbon dioxide levels have varied in earth's history. Even in the near term, it appears that the carbon stored in regions varies by decade. For example, American forests are currently in a growth phase where they are adding carbon. This is partially due to earlier harvesting activities which have rejuvenated forests across the United States. If left to natural forces, however, these forests would eventually mature, slowing their growth rates down and eventually degrade. Thus, for several decades, the American natural forests will be a sink and that will be followed by a period where they would be a source. If the baseline is defined in terms of total carbon stored in terrestrial systems, these natural swings will have to be counted in the carbon budget. These fluctuations may not be trivial. There are approximately 49 Gt of carbon in vegetation and soils in the US (Watson et al., 1996, Chapter 24). A 2.7% swing in this storage is equivalent to current annual carbon emission levels for the US.

One problem with using carbon storage as a barometer of carbon storage programs is that climate and other environmental forces may have large effects on carbon stocks over which the host country has little control. These swings in stocks could dwarf emission programs. Such accounting may be considered unfair by countries who find themselves victims of forces beyond their control.

A second major problem with using terrestrial carbon storage as a barometer is that it is expensive to measure. Carbon cycle models have not yet identified all the sinks and sources of carbon on the earth. Although there have been excellent measurements of carbon at selected micro-sites across the landscape, carbon has proven to be complex to measure. Carbon flows vary by time of day and season. They are affected by the whims of weather. They are highly sensitive to species mixes and ages. They vary from the forest floor to the tops of trees. Carbon stocks include such stable items as tree trunks and branches, but they also include leaves, litter, roots, and soils. Getting accurate measures of all these components of stock is not straightforward. Since the program would measure the difference in stock from one time period to another, accurate measures would be extremely important. Otherwise, countries would be subject to large random fluctuations in credited emissions simply from fluctuations in measured stock. The carbon stock program would consequently have to devote serious resources to measuring stocks carefully.

An interesting sidelight of counting terrestrial carbon storage is that it is affected by greenhouse gas policies (Sohngen et al., 1998). The increasing levels of carbon dioxide in the atmosphere will stimulate plant growth leading to higher levels of carbon storage. This becomes a bonus of using terrestrial carbon as a measure since every country will get some credit for it. As climate changes, this too will affect the carbon in terrestrial systems, although this effect may be either beneficial or harmful. For example, grassland soils lose carbon with warmer temperatures. These losses would have to be considered emissions under a carbon storage program. In contrast, other ecosystems may be able to store more carbon in a new

climate regime (VEMAP, 1997). Some areas will gain and others will lose from climate change.

An alternative approach to a complete landscape program is to develop a policy-based program which would explicitly measure only official projects to store carbon. The baseline is the initial condition of lands as they enter the program. Rather than determining a physical quantity of storage over the entire landscape, the policy program would focus only on official sink management efforts. Areas enter the sink program when a management project is created, such as a new forest. The country measures the carbon storage at the site at the beginning of the project and is credited with changes in carbon storage for the life of the project.

One advantage of an explicit sink program is that it focuses only on what is under the control of each nation. Natural swings in carbon storage would not be considered unless they were captured in the program area. Countries could control what happens in the sink program. Monitoring could be devoted strictly to sink program areas. Further, simple accounting rules could be used instead of complex carbon measurements. Programs could be credited with a certain amount of carbon simply on the basis of average growth rates or other conventions. Monitoring costs would be more modest with this program.

The problem with including only explicit projects in carbon accounting lies in defining an adequate baseline. There is an incentive for countries to try to count all new forestry planting projects as carbon storage programs. That is, there is an incentive for countries to cut

down trees and then enter the bare land into the programs. All the increased carbon storage in these areas would count as a net gain. Mature areas would not be included in the program until they were harvested. By appearing to start with vast areas of empty land, this could create the appearance of setting aside large amounts of carbon. However, many of these forestry areas would have been planted anyway, so that what appears to be new carbon storage may not be not new at all.

The policy program could be made more honest if there was a way of determining what would happen in the absence of an explicit carbon program and then crediting the carbon program only for marginal changes. The problem is that it is difficult to know what each country would have done in the absence of a carbon program. There are many changes occurring in forests even without carbon controls. Timber plantations are being established in subtropical regions of the world (Sohngen et al., 1998a). More intensive forestry practices are being implemented in productive forest areas (Sohngen and Mendelsohn, 1998). Natural forests are being actively managed in fringe regions (Sohngen et al., 1998a). Farmers are still converting forest land into agricultural sites in tropical regions. All these changes are following a slow dynamic path determined by major economic forces around the world. A carbon sink program is just one more dynamic force on top of these other active agents.

Consequently, it is difficult to know whether a new project is a carbon project, a timber project, an environmental project, or some combination of the above. In reality, most activities will respond to a combination of incentives.

One way of limiting the accounting mischief in establishing baselines is to make all official projects permanent. Countries could add new lands to the sink program whenever they wished but they could not withdraw lands. Countries who use the policy-based approach to bias baselines would exaggerate the marginal contribution of their carbon program. However, this would be a one-time affair occurring at the beginning of each project. Land would be entered when cleared. However, after this point, countries would be responsible for any future loss of carbon at these sites.

This unfortunately would create an incentive for countries to clear forests just to enter them as bare land. Natural mature forests would be cut down just to benefit from the carbon policy. Since this would clearly not help control greenhouse gases, one possible solution is simply to credit countries for the carbon in existing natural forests. That is, one could give countries credit for accumulating the amount of carbon currently in natural forests. They would then be responsible for any change in the amount of carbon in these forests. A country which subsequently cut the forest would have to treat the loss of carbon as an emission. Countries would then have a large incentive to enlist their mature natural forests in the program. Again, this would create a false signal of large setasides, but it would be a one-time effect.

The policy-based approach gives countries a number of credits for carbon control that do not really remove carbon from the atmosphere. In a sense, the sink program delays the

beginning of a serious abatement program as countries first take advantage of these inexpensive credits. This is simply a delay, not a permanent hemorrhage as countries eventually run out of these opportunities to claim new carbon credits. Given that the urgency of starting expensive abatement efforts is not clear, the world may well be able to afford an ineffective startup period as a mechanism for beginning the long road to international cooperation.

An open question for carbon management concerns stocks of carbon in the economy. Although many stock management programs have focused on storing carbon in vivo, it is also important to recognize that substantial quantities of carbon are stored in paper, wood products, and landfills. Including storage in the economy raises new policy options such as moving timber from paper to lumber and extending the lifetimes of buildings. Including landfills raises the possibility of storing carbon at new underground sites. As shown in Sohngen et al., 1998b, doing a complete accounting of carbon can change some conclusions about the magnitude of carbon storage and even whether it is increasing or falling.

II. COSTS

Many carbon mitigation studies suggest that setting aside carbon in forests is cheap.

The IPPC review of forest mitigation costs suggests that most programs would cost 1-10 \$/ton C (Watson et al., 1996). These studies suggest that vast mature forests can be set aside cheaply, large land masses are waiting to become new forests, and that existing forests can handle considerable increases of carbon. Although these assertions are true on the margin, any

attempt to set aside substantial quantities of carbon are likely to be expensive. Further, even initially, carbon set aside programs may turn out to be quite expensive because one cannot differentiate between new actions and actions which would have taken place anyway.

The amount of forests on the earth's surface has shrunk considerably in the last 300 years as society has shifted land use from forests to cropland and grazing. One obvious solution to protecting the stocks of existing carbon is to prevent further deforestation. That is, prevent more mature natural forest land from being converted to cropland. The opportunity costs of preventing further deforestation appears to be low because the productivity of most of the remaining lands are low and they are inaccessible. In recent analyses of future timber needs, Sohngen et al., 1998a calculate that most of the remaining natural inaccessible forests are in the tropics and boreal regions. These areas are low productivity and low valued regions. Sohngen et al predict that these areas will not even be harvested for timber. Despite the fact that the forests in these areas are mature, their economic value is low enough that the timber market does not intend to harvest this wood. Examination of returns from agriculture in the boreal and tropical forests suggest that these values are also very low suggesting that there is little economic pressure to convert to farming. In other words, the opportunity costs of protecting these natural forests are effectively zero. The remaining natural forests should be protected. However, it would appear that they would be protected even without a carbon program.

If the bulk of existing mature natural forests are likely to be left alone by the economic system, what would happen if a program were created to pat countries to protect these stocks.

Countries would not likely admit that only a small fraction of the remaining stocks are vulnerable. Instead, they would ask to be compensated for the entire stock within their borders. Although it might only cost a small amount of money to protect the marginal sites which would have been harvested, a large sum might get spent protecting all of the remaining forest. A potentially inexpensive program to protect the fringes of these forests would turn out to be an expensive program to protect everything.

If new amounts of carbon are to be extracted from the atmosphere, they will have to come from new forests or more intensively managed forests. If we are to convert land from other uses back into forestry, where will the new forest land come from? One solution is to reverse historical trends and plant trees where they used to be. This would be the simplest approach from a biological perspective because one is returning the land to its natural state. A place where trees could compete on their own. The problem is that most of this fertile land is in productive use now. That is, fertile areas where forests have been cleared, such as the Willamette Valley or most of France and Germany, are now farms. In order to plant new forests, these lands must be taken out of cropland. Agricultural subsidy programs in highly industrialized temperate countries have created an excess of agricultural land. The shortrun costs of taking away farmland is currently low. In the future, however, these lands will be needed for agriculture to feed expanding world populations. The long run costs of reforesting substantial amounts of temperate farmland are likely to be high.

An alternative approach is to rely on marginal farmland. That is, grow trees on grazing lands and lands which barely support crops. These lands are inexpensive and account for almost a quarter of the earth's land surface. However, there is a drawback to using these lands; they are less productive. Although one can plant forests in these areas, the trees may grow slowly or they may be subject to high probabilities of fire. Consequently, although these areas may be inexpensive, they may not support large amounts of carbon storage.

Alternatively, one could try to intensify forest management and increase carbon per hectare on existing forest land. One could increase carbon per hectare by lengthening forest rotations, increasing stocking, or stimulating growth. Intensive management is underway on fertile lands. The question for a carbon program is how much intensity to apply and how does intensity and rotation length interact to affect carbon storage. Clearly there are diminishing returns to new inputs suggesting that small programs might be effective but that large programs would have much higher costs. For example, fertilization increases growth rates but at diminishing rates. Further, as trees get larger more quickly, there is an incentive to cut them sooner which defeats the entire purpose of increasing on-site storage. Preliminary attempts to use intensive management to increase on-site storage have not been promising.

An alternative approach is simply to manage for more storage. An obvious approach is to take forest lands and set them aside. As these lands mature, they will store more carbon. Of course, once such lands reach maturity, they will no longer pull any additional carbon from the atmosphere. Further, by setting aside these lands, one obtains no market services from the

trees which is somewhat expensive on productive land. However, this strategy is well suited for marginal commercial timber land which may have little value.

An alternative approach is to manage commercial lands differently. By lengthening rotations beyond economic optimums, one can increase the storage on commercial lands. Further, since these lands are still used for harvest, one can still maintain a timber industry. To illustrate this point, we examine lengthening rotations on Loblolly Pine (Table 1) and Douglas fir (Table 2) plantations in productive and marginal commercial forest. We assume that carbon storage is proportional to trunk volume. Although carbon in forest soils is important, it is not clear that these programs would affect the amount of carbon stored in the soils. Carbon in branches is probably proportional to volume.

It is clear from Tables 1 and 2 that increasing rotation length stores more carbon in trees. By holding trees till they reach larger sizes, there is more above ground carbon being stored. Because larger trees have higher average growth rates, this increase can be sustained without giving up average growth rates. For example, the economically efficient age to harvest Loblolly Pine on a good site is 32 years. Holding onto the trees until they are 100 gives the same average growth rate per hectare. The cost of holding onto the larger trees is the opportunity cost of holding such large volumes in slower growing trees. The present value of rotations falls from the optimum of \$1105 to \$43 as one lengthens the rotation from 32 to 100.

A similar phenomenon occurs with Douglas Fir which is slower growing. The optimal rotation is 58 on a good site with a long rotation of 200. The present value falls from \$610 to -

\$184 by lengthening the rotation. However, for both species, the longer rotation involves holding much bigger trees on average on timber lands. Tree volume would increase by 6 fold for LobLolly Pine and by ten fold for the Douglas Fir.

Examining the marginal cost of lengthening the rotation reveals an interesting phenomenon. Lengthening the rotation to the economic optimum has no cost as the extra growth rewards the owner for waiting. Beyond the economic optimum rotation age, the marginal cost rises as the present value of the trees falls rapidly with longer rotations. Curiously, after one passes the maximum sustained yield rotation, the marginal cost of lengthening the rotations begins to fall. The trees continue to grow but the present value has fallen enough that extending the rotation further becomes less expensive.

Another interesting result is that there are important differences between productive and marginal forest lands. Productive lands are more responsive to lengthening rotations. That is, they can add more wood and thus more carbon per hectare. However, the cost of adding wood to productive lands is higher. Marginal timber lands are actually better suited for longer rotations than productive lands because the opportunity cost of mismanaging marginal lands is lower. Although they cannot set aside as much carbon per hectare, marginal lands cost less per ton of carbon stored.

III. NONMARKET EFFECTS

It is widely thought that carbon storage programs can be nothing but helpful to nature. By lengthening rotations and setting aside lands, one is returning more lands into nature's hands and eliminating the role of management. Many environmentalists believe that whatever changes eliminating management will cause, they are beneficial. It certainly is reasonable to argue that removing lands from management will increase the wilderness quality of lands. As more lands are affected solely by the forces of nature, people who simply want to be in unmanaged lands, will be able to enjoy more spaces. However, official carbon storage programs may decide to manage the lands for carbon by planting exotics or by tending the trees. Further, people looking for specific outcomes in nature, such as wildflowers, mushrooms, game animals, songbirds, or large trees may or may not benefit from the carbon programs. The effect of these programs on nonmarket services needs to be examined. Any large scale change in the way that land is managed across the globe is likely to have myriad but possibly profound effects on nature. We need to examine these nonmarket effects and try to determine whether they are beneficial or harmful, important or trivial.

It is hard to project what effect carbon storage programs will have on the globe since it is not yet clear what these programs will actually do. If the programs merely try to freeze land use in its current form, people may perceive the programs being harmless. However, if the programs prevent land use from shifting to optimal future uses, the programs may have a large effect in the long run. Further, it is not at all clear whether a world designed to store more

carbon provides more or less nonmarket services.

For example, if programs lengthen tree rotations, one can predict that trees will grow larger. People who admire large trees will have more landscape to enjoy. Animals which prosper in older rotations will have more habitat. In contrast, animals which prefer younger trees will have less habitat. People who enjoy early succession habitats will have less landscape. Whether these changes are beneficial or harmful depends upon the magnitude of these changes and people's preferences. Although it is well known that citizens have strong feelings about protecting nature, it is not clear how they would respond to choices between young and mature forests. Social scientists have not done enough research on the details of people's preferences to be able to predict whether such changes would be perceived as improvements or damages.

Although programs to set aside land for natural forests would enhance wilderness, other programs to increase storage may require management. For example, many analysts are pushing to plant trees in locations where they have never been before. With management, for example, one could plant trees in grasslands and deserts. Afforestation in unnatural locations would require irrigation and planting. They may provide habitat or they may turn out to be poor sites for wildlife which has never seen trees in such locations before. Carbon programs may turn to exotics. The purpose is to try to maximize carbon storage. Certain trees may prove to be better than natural stocks for storing carbon. The exotics, however, may or may not be good habitat.

Since one is potentially considering managing the entire global terrestrial surface, nonmarket services from these lands are likely to be important. Before large scale programs are put in place, the effect of these programs on nonmarket services should be assessed. If the programs appear to be harmless, then nonmarket services may prove to be unimportant. However, it is far more likely that nonmarket services will be affected. In fact, the larger the programs, the more likely nonmarket services should be considered. The important point to remember is that we would be foolish to institute solutions to the greenhouse gas problem which turn out to be more harmful than climate change.

IV. CONCLUSION

This paper notes that managing sinks has been brought forward as a promising mechanism to control greenhouse gases. There is certainly merit to the idea that stocks could be managed to extract some amounts of greenhouse gas from the atmosphere. However, as with all things, it is likely to be difficult to institute programs which will extract large quantities of greenhouse gases. As the programs expand in scale, they will become increasingly expensive. Not only will they require increasing amounts of valuable resources, but they are likely to have increasingly serious nonmarket consequences.

This paper also notes that policies to control stocks could be expensive to monitor. Complete accounting of the carbon cycle is expensive requiring extensive knowledge of land

use and carbon consequences. More limited programs focused on official carbon projects is more feasible. However, this project focus has its own problems of bias and incentives.

Although countries may well want to pursue carbon stock management as part of an overall strategy to control greenhouse gases, they should be aware of how difficult this will prove to be in the long run. Policies should be carefully evaluated not only for their short term political expedience, but also for their long term consequences. Controlling greenhouse gases is different from most environmental problems. The key to greenhouse gas control is to be effective in the long run. Managing terrestrial stocks of carbon can contribute to greenhouse gas control in the long run, if the programs are carefully designed today.

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TABLE 1

Cost of Carbon Mitigation From Lengthening Tree Rotations

Loblolly Pine				
High Site Quality			Low Site Quality	
Age	Avg Vol	M.Cost	Avg Vol	M.Cost
Years	MBD/yr	\$/MBD	MBD/yr	\$/MBD
30	9.6	-10.9	1.9	-14.4
40	17.2	23.2	4.8	-17.9
50	24.9	30.7	8.5	6.6
60	32.1	29.9	12.8	14.3
70	38.9	26.3	17.3	15.6
80	45.1	21.9	21.8	14.3
90	50.7	17.7	26.2	12.2
100	55.9	14.0	30.4	9.9

a

The yield function for Loblolly pine is $\ln V = 12.11 - 92.71/n$ for 80 site quality and $\ln V = 12.09 - 52.9/n$ for 120 site quality. The price is \$100 per thousand board feet, regeneration costs are \$150 per acre, and the interest rate is 4%. The Faustmann rotation is 32 years for the high site and 46 years for the low site.

TABLE 2

Cost of Carbon Mitigation From Lengthening Tree Rotations

Age Years	High Site Quality		Douglas Fir Low Site Quality	
	Avg Vol MBD/yr	M.Cost \$/MBD	Avg Vol MBD/yr	M.Cost \$/MBD
60	10.5	2.9	1.8	-34.4
80	22.8	17.6	5.7	4.0
100	37.0	14.5	11.4	8.7
120	51.8	9.5	18.4	6.8
140	66.4	5.7	26.2	4.3
160	80.3	3.2	34.3	2.5
180	93.6	1.7	41.5	1.4
200	106.1	0.9	50.8	0.8

a

The yield function for Douglas fir is $\ln V = 12.91 - 223.71/n$ for 110 site quality and $\ln V = 13.06 - 145.61/n$ for 160 site quality. The price is \$200 per thousand board feet, regeneration costs are \$200 per acre, and the interest rate is 4%. The Faustmann rotation is 58 years for the high site and 75 years for the low site.

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What to Expect from an International System of Tradable Permits for Carbon Emissions

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ABSTRACT

We use an econometrically-estimated multi-region, multi-sector general equilibrium model of the world economy to examine the effects of using a system of internationally-tradable emissions permits to control world carbon dioxide emissions. We focus, in particular, on the effects of the system on flows of trade and international capital. Our results show that international trade and capital flows significantly alter projections of the domestic effects of emissions mitigation policy, compared with analyses that ignore international capital flows, and that under some systems of international permit trading the United States is likely to become a significant permit *seller*, the opposite of the conventional wisdom.

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The views expressed in this paper are those of the authors and should not be interpreted as reflecting the views of the organizations with which they are affiliated.

1 Introduction

One of the leading proposals for controlling global climate change is an international system of tradable permits for carbon dioxide emissions. In fact, the Kyoto Protocol to the United Nations Framework Convention on Climate Change, signed in Kyoto in December 1997, includes provisions for setting up just such a system among industrial ("Annex I") countries. The theoretical attraction of permit trading is that it is efficient: it guarantees that emissions reductions will be obtained at minimum cost. As a political matter, especially in the United States, an equally important virtue of a permit system is that it does not involve new taxes.

Despite the enthusiasm for international permit trading, little empirical work has been done on estimating the effects of such a policy. In this paper we attempt to fill that gap by using a multi-region, multi-sector intertemporal general equilibrium model of the world economy called "G-Cubed".¹ We examine and compare three potential policies: (1) unilateral stabilization of U.S. carbon emissions at 1990 levels, (2) stabilization of OECD emissions at 1990 levels on a country by country basis without international permit trading, and (3) joint stabilization of OECD emissions with full international permit trading. We focus particularly on the effects of the policies on output, exchange rates and international flows of goods and capital. In addition, by comparing the second and third simulations we are able to calculate the gains from allowing international permit trading.²

¹ G-Cubed stands for "Global General Equilibrium Growth".

² We examine trading within the OECD rather than within the broader "Annex I" group which includes Eastern Europe and the states of the former Soviet Union. The reason is that we want to measure the efficiency gains from trading and in order to do that we need the overall level of abatement to be the same with or without trading. That would not be the

① Note to Table in exp. Repd: some of the gains from trade w/Ann. I come from volatility not gains from trade

② Ask - side - give estimate of leakage to 75%/60% "not as" traded.

2 Model Structure

At the most abstract level G-Cubed consists of a set of eight general equilibrium models, each corresponding to a geographic region, linked by international flows of goods and assets. We assume the regions each consist of a representative household, a government sector, a financial sector, twelve industries, and a sector producing capital goods. The regions and sectors are listed in Table 1. Although the regions are similar in structure (that is, they consist of similar agents solving similar problems), they differ in endowments, behavioral parameters and government policy variables.³ In the remainder of this section we present the key features of the regional models.⁴ To keep the notation from becoming cumbersome, we will generally not subscript variables by country. The complete model, however, consists of eight regional modules linked by trade and asset flows.

2.1 Producer Behavior

Within a region, each producing sector is represented by a single firm which chooses its inputs and its level of investment in order to maximize its stock market value subject to a multiple-input production function and a vector of prices it takes to be exogenous. We assume that output can be represented by a constant elasticity of substitution (CES) function of inputs of

case if we examined Annex I trading because the former Soviet Union is currently about 300 million metric tons below its 1990 emissions. If we included it in the trading regime, moving from independent stabilization to trading would essentially just relax the emissions constraint by 300 million metric tons.

³ This is enough to allow the regions to be quite different from one another. For example, even though all of the regions consist of the twelve industries in Table 2 we do not impose any requirement that the output of a particular industry in one country be identical to that of another country. The industries are themselves aggregates of smaller sectors and the aggregation weights can be very different across countries: the output of the durable goods sector in Japan will not be identical to that of the United States. The fact that these goods are not identical is reflected in the assumption (discussed further below) that foreign and domestic goods are generally imperfect substitutes.

⁴ A more complete description of the model is contained in McKibbin and Wilcoxon (forthcoming).

capital, labor, energy and materials. Energy and materials, in turn, are CES aggregates of inputs of intermediate goods: energy is composed of the first five goods in Table 1 and materials is composed of the remaining seven.

We used a nested system of CES equations rather than a more flexible functional form because data limitations make even the CES model a challenge to estimate. In principle we need price and quantity data for 14 inputs (twelve goods plus capital and labor) in each of 96 industries (12 industries in 8 regions). Moreover, data on intermediate inputs (which is published in the form of input-output tables) is not collected annually in any major country and is collected infrequently, if at all, in developing countries. For many of our regions we had access to only a single input-output table. There is simply too little data for a more flexible specification to be feasible.

In fact, the scarcity of input-output data requires us to restrict the model further by imposing the assumption that the substitution elasticities for each industry be identical across countries (although they may differ across industries). In other words, we assume that each industry has the same energy, materials and KLEM substitution elasticities no matter where it is located. This is consistent with the econometric evidence of Kim and Lau in a number of papers (see for example Kim and Lau, 1994).

Although the substitution elasticities are identical across countries, the overall production models are not identical because we obtain the CES input weights from the latest available input-output data for each country or region.⁵ Thus, the durable goods sectors in the United States and

⁵ Input-output tables were not available for the regions in the model larger than individual countries. The input weights for those regions were based on data for the United States.

Japan, for example, have identical substitution elasticities but different sets of input weights. The consequence of this is that the cost shares of inputs to a given industry are based on data for the country in which the industry operates, but the industry's response to price changes is identical across countries.

In effect we are assuming that all regions share production methods that differ in first-order properties but have identical second-order characteristics. This is intermediate between one extreme of assuming that the regions share common technologies and the other extreme of allowing the technologies to differ across regions in arbitrary ways. The regions also differ in their endowments of primary factors, their government policies, and patterns of final demands, so although they share some common parameters they are not simple replicas of one another.

To estimate the elasticities we constructed time-series data on prices, industry inputs, outputs and value-added for the country for which we were able to obtain the longest series of input-output tables: the United States. The following is a sketch of the approach we followed; complete details are contained in McKibbin and Wilcoxon (1995).

We began with the benchmark input-output transactions tables produced by the Bureau of Economic Analysis (BEA) for years 1958, 1963, 1967, 1972, 1977 and 1982.⁶ The conventions used by the BEA have changed over time, so the raw tables are not completely comparable. We transformed the tables to make them consistent and aggregated them to twelve sectors. We then shifted consumer durables out of final consumption and into fixed investment.⁷ We also increased

⁶ A benchmark table also exists for 1947 but it has inadequate final demand detail for our purposes. Subsequent to our estimation work a 1987 table has become available.

⁷ The National Income and Product Accounts (and the benchmark input-output tables as well) treat purchases of consumer durables as consumption rather than investment.

the capital services element of final consumption to account for imputed service flows from durables and owner-occupied housing. Finally, we used a data set constructed by Dale Jorgenson and his colleagues to decompose the value added rows of the tables,⁸ and a data set produced by the Office of Employment Projections at the Bureau of Labor Statistics to provide product prices.

Table 2 presents estimates of the substitution elasticities for each industry; standard errors are shown in parentheses.⁹ A number of the estimates had the wrong sign or could not be estimated (the estimation procedure failed to converge). In such cases we examined the data and imposed elasticities that seemed appropriate; these values are shown in the table without standard errors.¹⁰ For most of the imposed parameters, the data suggest complementarities among inputs, which is incompatible with the CES specification. If more data were available, it would be worthwhile to use a more flexible functional form.

Maximizing the firm's short run profit subject to its capital stock and the production functions above gives the firm's factor demand equations. At this point we add two further levels of detail: we assume that domestic and imported inputs of a given commodity are imperfect substitutes, and that imported products from different countries are imperfect substitutes for each other. As noted earlier, given the model's level of aggregation these are more a simple acknowledgment of reality than an assumption.¹¹ Thus, the final decision the firm must make is

⁸ This data set is the work of several people over many years. In addition to Dale Jorgenson, some of the contributors were Lau Christiansen, Barbara Fraumeni, Mun Sing Ho and Dae Keun Park. The original source of data is the Fourteen Components of Income Tape produced by the Bureau of Economic Analysis. See Ho (1989) for more information.

⁹ The parameters were estimated using systems of factor demand equations derived from the KLEM portion of the production function and the dual versions of the energy and materials tiers.

¹⁰ For this study we also imposed lower KLEM substitution elasticities on a few of the energy industries where it seemed that the estimated elasticities might overstate the true ability of the industry to shift factors of production.

¹¹ This approach is based on the work of Armington (1969).

the fraction of each of its inputs to buy from each region in the model (including the firm's home country). Due to data constraints we represent this decision using a Cobb-Douglas function.¹² Moreover, we assume that all agents in the economy have identical preferences over foreign and domestic varieties of each particular commodity.¹³ We parameterize this decision using trade shares based on aggregations of the United Nations international trade data for 1987.¹⁴ The result is a system of demand equations for domestic output and imports from each other region.

In addition to buying inputs and producing output, each sector must also choose its level of investment. We assume that capital is specific to each sector, it depreciates geometrically at rate δ , and that firms choose their investment paths in order to maximize their market value. Following the cost of adjustment models of Lucas (1967), Treadway (1969) and Uzawa (1969) we assume that the investment process is subject to rising marginal costs of installation. To formalize this we adopt Uzawa's approach by assuming that in order to install J units of capital the firm must buy a larger quantity, I , that depends on its rate of investment (J/K) as follows:

$$(1) \quad I = \left(1 + \frac{\phi}{2} \frac{J}{K} \right) J$$

where ϕ is a non-negative parameter and the factor of two is included purely for algebraic convenience. The difference between J and I may be interpreted many ways; we will view it as installation services provided by the capital vendor.

Setting up and solving the firm's investment problem yields the following expression for

¹² This assumption is far from ideal and we intend to relax it in future work.

¹³ Anything else would require time-series data on imports of products from each country of origin to each industry, which is not only unavailable but difficult to imagine collecting.

¹⁴ Specifically, we aggregate up from data at the 4-digit level of the Standard International Trade Classification.

investment in terms of parameters, the current capital stock, and marginal q (the ratio of the marginal value of a unit of capital to its purchase price):

$$(2) \quad I = \frac{1}{2\phi} (q^2 - 1)K$$

In this expression τ_2 is the corporate tax rate and τ_4 is rate of the investment tax credit. Following Hayashi (1979), we extend (2) and write I as a function not only of q , but also of the firm's current profit π :

$$(3) \quad I = \alpha_2 \frac{1}{2\phi} (q^2 - 1)K + (1 - \alpha_2) \frac{\pi}{(1 - \tau_4)P^I}$$

This improves the empirical behavior of the specification and is consistent with the existence of firms that are unable to borrow and therefore invest purely out of retained earnings. The parameter α_2 was taken to be 0.3 based on a range of empirical estimates reported by McKibbin and Sachs (1991).

In addition to the twelve industries discussed above, the model also includes a special sector that produces capital goods. This sector supplies the new investment goods demanded by other industries. Like other industries, the investment sector demands labor and capital services as well as intermediate inputs. We represent its behavior using a nested CES production function with the same structure as that used for the other sectors, and we estimate the parameters using price and quantity data for the final demand column for investment. As before, we use U.S. data to estimate the substitution elasticities and country or region data to determine the γ parameters.

2.2 Households

Households consume goods and services in every period and also demand labor and

capital services. Household capital services consist of the service flows of consumer durables plus residential housing. Households receive income by providing labor services to firms and the government, and from holding financial assets. In addition, they receive imputed income from ownership of durables and housing, and they also may receive transfers from their region's government.

Within each region we assume household behavior can be modeled by a representative agent with an intertemporal utility function of the form:

$$(4) \quad U_t = \int_t^{\infty} (\ln C(s) + \ln G(s)) e^{-\theta(s-t)} ds$$

where $C(s)$ is the household's aggregate consumption of goods at time s , $G(s)$ is government consumption, which we take to be a measure of public goods supply, and θ is the rate of time preference and is equal to 2.5 percent.¹⁵ The household maximizes its utility subject to the constraint that the present value of consumption be equal to human wealth plus initial financial assets. Human wealth, H , is the present value of the future stream of after-tax labor income and transfer payments received by households. Financial wealth, F , is the sum of real money balances, real government bonds in the hands of the public (Ricardian neutrality does not hold in this model because some consumers are liquidity-constrained; more on this below), net holdings of claims against foreign residents and the value of capital in each sector. Under this specification, the desired value of each period's consumption is equal to the product of the time preference rate and household wealth:

¹⁵ This specification imposes the restriction that household decisions on the allocations of expenditure among different goods at different points in time be separable. Also, since utility is additive in the logs of private and government

$$(5) \quad P^C C = \theta(F + H)$$

There has, however, been considerable debate about whether the actual behavior of aggregate consumption is consistent with the permanent income model.¹⁶ Based on the evidence cited in Campbell and Mankiw (1990), we assume that only a fraction β of all consumers choose their consumption to satisfy (5) and that the remainder consume based entirely on current after-tax income. This could be interpreted in various ways, including the presence of liquidity-constrained households or households with myopic expectations. For the purposes of this paper we will not adopt any particular explanation and will simply take β to be an exogenous constant.¹⁷

This produces the final consumption function shown below:

$$(6) \quad P^C C = \beta\theta(F_t + H_t) + (1 - \beta)\gamma INC$$

where γ is the marginal propensity to consume for the households consuming out of current income. Following McKibbin and Sachs (1991) we take β to be 0.3 in all regions.¹⁸

Within each period, the household allocates expenditure among goods and services in order to maximize $C(s)$, its intratemporal utility index. In this version of the model we assume that $C(s)$ may be represented by a nested CES function. At the top tier, consumption is composed of inputs of capital services, labor, energy and materials. Energy and materials, in turn, are CES

consumption, changes in government consumption will have no effect on private consumption decisions.

¹⁶ Some of the key papers in this debate are Hall (1978), Flavin (1981), Hayashi (1982), and Campbell and Mankiw (1990).

¹⁷ One side effect of this specification is that it will prevent us from using equivalent variation or other welfare measures derived from the expenditure function. Since the behavior of some of the households is implicitly inconsistent with (8), either because the households are at corner solutions or for some other reason, aggregate behavior is inconsistent with the expenditure function derived from our utility function.

¹⁸ Our value is somewhat lower than Campbell and Mankiw's estimate of 0.5.

aggregates of inputs of individual goods.¹⁹ The elasticities of substitution at the energy and materials tiers were estimated to be 0.8 and 1.0, respectively. In this version of the model the top tier elasticity has been imposed to be unity.

Finally, the supply of household capital services is determined by consumers themselves who invest in household capital. We assume households choose the level of investment to maximize the present value of future service flows (taken to be proportional to the household capital stock), and that investment in household capital is subject to adjustment costs. In other words, the household investment decision is symmetrical with that of the firms.

2.3 Labor Market Equilibrium

We assume that labor is perfectly mobile among sectors within each region but is immobile between regions. Thus, within each region wages will be equal across sectors. The nominal wage is assumed to adjust slowly according to an overlapping contracts model where nominal wages are set based on current and expected inflation and on labor demand relative to labor supply. In the long run labor supply is given by the exogenous rate of population growth, but in the short run the hours worked can fluctuate depending on the demand for labor. For a given nominal wage, the demand for labor will determine short-run unemployment.

Relative to other general equilibrium models, this specification is unusual in allowing for involuntary unemployment. We adopted this approach because we are particularly interested in the transition dynamics of the world economy. The alternative of assuming that all economies are always at full employment, which might be fine for a long-run model, is clearly inappropriate

¹⁹ This specification has the undesirable effect of imposing unitary income and price elasticities. There is abundant

during the first few years after a shock.

2.4 Government

We take each region's real government spending on goods and services to be exogenous and assume that it is allocated among final goods, services and labor in fixed proportions, which we set to 1987 values for each region. Total government spending includes purchases of goods and services plus interest payments on government debt, investment tax credits and transfers to households. Government revenue comes from sales, corporate, and personal income taxes, and by issuing government debt. In addition, there can be taxes on externalities such as carbon dioxide emissions.

The difference between revenues and total spending gives the budget deficit, which is endogenous. Deficits are financed by sales of government bonds. We assume that agents will not hold bonds unless they expect the bonds to be serviced, and accordingly impose a transversality condition on the accumulation of public debt in each region that has the effect of causing the stock of debt at each point in time to be equal to the present value of all future budget surpluses from that time forward. This condition alone, however, is insufficient to determine the time path of future surpluses: the government could pay off the debt by briefly raising taxes a lot; it could permanently raise taxes a small amount; or it could use some other policy. We assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt. In effect, therefore, any increase in government debt is financed by consols, and future taxes are raised enough to accommodate the increased interest costs. Thus, any increase in

empirical evidence against this assumption and we intend to generalize it in future work.

the debt will be matched by an equal present value increase in future budget surpluses. Other fiscal closure rules are possible such as always returning to the original ratio of government debt to GDP. These closures have interesting implications but are beyond the scope of this paper.

Finally, because our wage equation depends on the rate of expected inflation, we need to include money supply and demand in the model. The supply of money is determined by the balance sheet of the central bank and is exogenous. We assume that money demand arises from the need to carry out transactions and takes the following form:

$$(7) \quad M = PY i^\epsilon$$

where M is money, P is the price level, Y is aggregate output, i is the interest rate and ϵ is the interest elasticity of money demand. Following McKibbin and Sachs (1991) we take ϵ to be -0.6.

2.5 International Trade and Asset Flows

The eight regions in the model are linked by flows of goods and assets. Each region may import each of the 12 goods from potentially all of the other seven regions. In terms of the way international trade data is often expressed, our model endogenously generates a set of twelve 8x8 bilateral trade matrices, one for each good. The values in these matrices are determined by the import demands generated within each region.

Trade imbalances are financed by flows of assets between countries. We assume that asset markets are perfectly integrated and that financial capital is freely mobile.²⁰ Under this

²⁰ The mobility of international capital is a subject of considerable debate; see Gordon and Bovenberg (1994) or Feldstein and Horioka (1980). Also, this assumption should not be confused with our treatment of *physical* capital, which we assume to be specific to sectors and regions and hence completely immobile. The consequence of assuming mobile financial capital and immobile physical capital is that there can be windfall gains and losses to owners of physical capital. For example, if a shock adversely affects profits in a particular industry, the physical capital stock in that sector

assumption, expected returns on loans denominated in the currencies of the various regions must be equalized period to period according to a set of interest arbitrage relations of the following form:

$$(8) \quad i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j}$$

where i_k and i_j are the interest rates in countries k and j , μ_k and μ_j are exogenous risk premiums demanded by investors (possibly zero), and E_k^j is the exchange rate between the two currencies. The risk premiums are calculated in the course of generating the model's baseline and are generally held constant in simulations. Finally, we also assume that OPEC chooses its foreign lending in order to maintain a desired ratio of income to wealth subject to a fixed exchange rate with the U.S. dollar.

2.6 Constructing the Base Case

To solve the model, we first normalize all quantity variables by the economy's endowment of effective labor units. This means that in the steady state all real variables are constant in these units although the actual levels of the variables will be growing at the underlying rate of growth of population plus productivity. Next, we must make base-case assumptions about the future path of the model's exogenous variables in each region. In all regions we assume that the long run real interest rate is 5 percent, tax rates are held at their 1990 levels and that fiscal spending is allocated according to 1990 shares. Population growth rates vary across regions as shown in Table 3.

will initially be unaffected. Its value, however, will immediately drop by enough to bring the rate of return in that sector back to into equilibrium with that in the rest of the economy.

A crucial group of exogenous variables are productivity growth rates by sector and country. The baseline assumption in G-Cubed is that the pattern of technical change at the sector level is similar to the historical record for the United States (where data is available). In regions other than the United States, however, the sector-level rates of technical change are scaled up or down in order to match the region's observed rate of aggregate productivity growth. This approach attempts to capture the fact that the rate of technical change varies considerably across industries while reconciling it with regional differences in overall growth. This is clearly a rough approximation; if appropriate data were available it would be better to estimate productivity growth for each sector in each region.

Given these assumptions, we solve for the model's perfect-foresight equilibrium growth path over the period 1990-2050. This a formidable task: the endogenous variables in *each* of the sixty periods number over 6,000 and include, among other things: the equilibrium prices and quantities of each good in each region, intermediate demands for each commodity by each industry in each region, asset prices by region and sector, regional interest rates, bilateral exchange rates, incomes, investment rates and capital stocks by industry and region, international flows of goods and assets, labor demanded in each industry in each region, wage rates, current and capital account balances, final demands by consumers in all regions, and government deficits.²¹ At the solution, the budget constraints for all agents are satisfied, including both intratemporal and intertemporal constraints.

²¹ Since the model is solved for a perfect-foresight equilibrium over a 60 year period, the numerical complexity of the problem is on the order of 60 times what the single-period set of variables would suggest. We use software developed by McKibbin (1992) for solving large models with rational expectations on a personal computer.

3 The Effects of Tradable Emissions Permits

We now explore the effects of international trading in carbon permits by considering three scenarios. As a benchmark for comparison, we begin by examining the effects of unilateral stabilization by the United States. In this scenario, the U.S. government holds annual auctions of carbon emissions permits in each of the years from 2010 to 2020.²² The permits are required for the use of primary fossil fuels (coal and crude oil and gas) and the quantity is set equal to U.S. emissions in 1990. Revenues from the permit sales are returned to households via a deficit-neutral lump sum rebate.²³ The policy is announced in 2000 so that agents have a decade to anticipate the policy and adapt to it.

In the second scenario, all countries in the OECD follow similar policies. Each country auctions permits equal to its 1990 emissions and returns the revenue to its citizens as a lump sum rebate. The permits can be traded within countries but not from one country to another.²⁴ This simulation allows us to measure the heterogeneity of the OECD regions. Differences in baseline emissions growth and initial fossil fuel prices mean that the regions face substantially different costs of achieving stabilization. This will be reflected in the pattern of permit prices (which will indicate the cost of stabilization at the margin) and GDP losses across regions.

²² Beyond 2020 the supply of permits is allowed to increase at such a rate as to leave the real permit price at its 2020 value.

²³ The rebate is chosen to leave the deficit unchanged. It is not necessarily equal to the revenue raised by permit sales because other changes in the economy may raise or lower tax revenue. This formulation is not equivalent to free distribution of permits (“grandfathering”) – that would be represented in a similar fashion in the model but would involve a 100% lump-sum recycling, with no revenues retained to maintain deficits at baseline levels.

²⁴ Even though there is no trading *between* regions, trading is implicitly allowed between the countries *within* a region. In particular, the “Other OECD” region lumps together the European Union, Canada and New Zealand, so trading is implicitly allowed between these countries.

The third scenario is identical to the second except that we allow international trading in emissions permits among OECD countries. The effect of allowing trading will be that arbitrage will cause the price of a permit to be equal throughout the OECD. This will ensure that marginal costs of carbon abatement will be equal across countries and that OECD stabilization will be achieved at minimum cost. Countries with relatively low abatement costs will sell permits and abate more than in the previous scenario; countries with high costs will buy permits and do less abatement. Comparing scenarios 2 and 3 will allow us to estimate the gains to be had from international permit trading.

3.1 Unilateral Emissions Stabilization by the United States

Key results for the unilateral U.S. policy are shown in Table 4. In order to achieve stabilization, emissions would need to drop by 24 percent relative to the baseline in 2010 and 35 percent in 2020.²⁵ The resulting price of carbon emissions permits would be \$51 per tonne in 2010 rising to \$59 per tonne in 2020.²⁶ Most of the drop in emissions comes about through a decline in coal consumption as total energy use drops and the fuel mix shifts toward natural gas, the least carbon-intensive fuel. This is reflected in the industry-level results shown in Table 5: the after-tax price of coal rises by more than 100 percent and coal output declines by nearly 40 percent in 2010 and by more than 50 percent in 2020. The crude oil and gas sector is also strongly affected: output declines by 12 to 26 percent over the period.

²⁵ Some of the emissions eliminated within the United States – roughly 10% in 2010 – are offset by increases in emissions elsewhere. Initially, over half of this “leakage” is due to the fact that other countries buy and burn the oil that the U.S. stops importing. This effect diminishes over time: by 2020 about two-thirds of the leakage is due to higher energy demand resulting from greater economic activity.

²⁶ Throughout the paper carbon will be measured in metric tons (tonnes) and prices will be in 1995 U.S. dollars.

Outside the energy industries prices and output are affected very little. The only noteworthy result is that investment rises by about one percent during the period before the policy is implemented (2001-2009). This stems from the fact that the demand for services increases slightly when households and firms substitute away from energy. As a result, investment by the service industry increases as well. The increase in investment is financed by an inflow of foreign capital, which causes the exchange rate to appreciate by about 1.6 percent during that time. The exchange rate appreciation hurts exports, primarily of durable goods.

The international effects of the policy vary across regions. Most OECD countries experience mild decreases in GDP on the order of -0.1 percent, mild exchange rate depreciations, and increases in their net investment positions. The exception is Australia, which benefits from taking up the slack in U.S. coal exports. China and the former Soviet Union are almost completely unaffected. Other developing countries receive minor capital inflows after 2010, experience slight exchange rate appreciation and slightly higher GDP, but also have lower production and exports of durable goods due to the change in exchange rates.

3.2 OECD Emissions Stabilization Without Permit Trading

OECD stabilization without trading produces the results shown in Table 6. The effects of the policy differ substantially across the regions: in 2010, permit prices range from a low of \$60 in the United States to a high of \$213 in the “Other OECD” region. (To avoid ambiguity we will refer to the “Other OECD” region as “Europe” in the remainder of the text).²⁷ The effect on

²⁷ This is a misnomer since the “Other OECD” region also includes Canada and New Zealand. We adopt it, however, in order to avoid ambiguity in certain comparisons. For example, “Permit prices in the US are lower than in the rest of the OECD” compares the US to Japan, Australia and the “Other OECD” region as a group but could easily be confused

GDP follows a similar pattern: U.S. GDP is essentially unchanged from its baseline value while GDP in Japan and Europe falls by 1.5 and 1.7 percent, respectively. These results show that both marginal and average costs of abating carbon emissions differ substantially across countries. The differences among regions stem in part from differences in the fuel mix: stabilization is cheapest in coal-intensive countries like the United States and Australia; in Japan and Europe, stabilization requires larger cuts in oil and gas consumption.

Comparing this simulation with the previous one shows that the United States is significantly better off under the OECD policy than it is when it stabilizes on its own. In 2010, U.S. GDP remains at its baseline value while under the unilateral policy it would have fallen by 0.6 percent. In 2020, U.S. GDP is actually above its baseline value by 0.1 percent; under the unilateral policy it would have fallen by 0.5 percent. The reason for this lies in the fact that the United States has substantially lower marginal costs of abating carbon emissions. This causes rates of return in the U.S. to fall less than in other OECD countries, which induces investors to shift their portfolios toward U.S. assets, leading to an increase in U.S. investment. The effect is particularly apparent in the years immediately before the policy takes effect: U.S. investment is 7.4 percent above baseline in 2005. In addition, the U.S. also benefits from lower world oil prices as OECD oil demand falls. The boost in investment and lower oil prices both tend to raise energy demand and cause permit prices to rise relative to the unilateral stabilization scenario – from \$51 to \$60 in 2010 and from \$59 to \$67 in 2020. Although U.S. GDP rises slightly relative to the baseline, it would be wrong to conclude that the policy was actually good for the United States.

with a comparison between the US and the “Other OECD” region alone. When the latter comparison is intended we will phrase it as “Permit prices in the US are lower than in Europe”.

Much of the additional resources are owned by foreigners and the results for GNP are generally less positive or actually negative.

Examining the effect of the policy on different regions, Japan and especially Europe – which face the greatest costs of stabilizing emissions – have large capital outflows, accumulating to roughly a trillion 1995 dollars by 2020. Most of this goes to the United States, although some capital flows to Australia, which has comparatively low costs of abatement, and some to developing countries, which are not controlling emissions at all. Capital flows to developing countries are limited by adjustment costs, however: it is expensive for a region with a relatively small capital stock to absorb a large flow of new capital.

Capital flows cause the U.S., Australian and developing country exchange rates to appreciate and the Japanese and European currencies to depreciate. These changes lead directly to changes in export patterns. Japanese and European exports of durable goods increase by about 13% and 18%, respectively, over baseline; U.S. exports of durables fall by 15% to 18% and exports from developing countries fall by 25% to 35%.²⁸ At the same time, capital flows cause Japanese and European GNP to fall by less than GDP.

Overall, the effect of stabilization on countries with high abatement costs (Japan and Europe) is to reduce GDP, cause an outflow of capital, depreciate the exchange rate and stimulate exports. The effect on low cost countries is the opposite: capital inflows tend to raise GDP, appreciate the exchange rate and diminish exports. Australia is somewhat of an exception: capital inflows benefit it slightly but the economy is substantially hurt by the impact of Japanese carbon

²⁸ Even though capital inflows to developing countries raise overall economic activity, the durables sector declines slightly because exports are adversely affected by exchange rate appreciation. This effect limits the “leakage” of

controls on Australian coal exports. Finally, oil exports from OPEC countries decline about 10 percent and world oil prices decline by about 10 percent as well.

3.3 OECD Emissions Stabilization With Permit Trading

Results for this scenario are shown in Table 7. In contrast to independent stabilization, international permit trading leads to a uniform permit price throughout the OECD that rises from about \$91 per tonne in 2010 to \$108 per tonne in 2020. Because it has the lowest abatement costs, the United States reduces emissions further than in the previous scenario in order to sell permits on the world market. U.S. carbon emissions decline by over 40%, significantly more than the 25% reduction needed to return U.S. emissions to their 1990 levels. Annual permit sales exceed 300 million tonnes (\$30 billion) in 2010 and reach nearly 600 million tonnes (\$64 billion) in 2020. Cumulative payments to the U.S. over the 2010-2020 period are on the order of \$500 billion. The largest purchaser by far is Europe.

Because energy prices are substantially higher in the U.S. than in the previous case, GDP during the 2010-2020 period is significantly lower (excluding permit revenue). Exchange rate changes are similar in sign but generally larger in magnitude. The Japanese and European currencies, in particular, depreciate somewhat more. This depreciation, combined with lower energy costs in those countries, causes exports from Japan and Europe to expand more than in the previous simulation. In fact, the Japanese and European trade surpluses grow by amounts roughly comparable to what each country spends on emissions permits. This leaves the pattern

emissions arising from redirection of trade away from emissions-controlling regions to developing countries.

and magnitude of net international capital flows similar to those from the previous scenario. In effect, these countries pay for their emissions permits with exports of durables.

The overall gains from emissions trading total about \$50 billion in 2010 and between \$80 and \$90 billion in 2020. These gains reduce OECD GDP losses from about \$270 billion (1.1% of the total) to about \$220 billion (0.9%) in 2010; and from about \$340 billion (1.1%) to \$250 billion (0.8%) in 2020. Trading thus reduces overall OECD losses by 20% to 25%. The gains from trading are unevenly distributed: in 2010, Europe gains about \$50 billion in GDP from trading; Australia and Japan together gain about \$10 billion; and the U.S. loses about \$10 billion.²⁹ By 2020, the U.S. gains about \$10 billion from trading; Japan and Australia together experience gains of about \$15 billion, and Europe gains about \$60 billion.

4 Conclusion

The theoretical appeal of an international permits program is strongest if participating countries have very different marginal costs of abating carbon emissions – in that situation, the potential gains from trade are largest. Our results show that within the OECD, abatement costs are indeed quite heterogeneous: the marginal cost of stabilizing emissions in Japan and Europe is nearly four times that of stabilizing emissions in the United States. Because of these differences, under a trading regime the U.S. emerges as a large seller of emissions permits and ends up doing far more abatement than if it had stabilized its emissions unilaterally. The shift of abatement to the

²⁹ The small U.S. GDP loss from trading in 2010 is due to business cycle effects stemming from our assumption that wages adjust slowly: the sharp increase in U.S. energy prices under the trading scenario temporarily reduces labor demand relative to the no-trading case.

United States provides total gains to the OECD as a group of \$50 billion to \$90 billion a year.

International trading, in other words, provides significant gains in efficiency.

Because the United States (and to a lesser extent, Australia) can reduce carbon emissions at relatively low cost, under any OECD stabilization policy – with or without trading – it will benefit from a significant inflows of international financial capital. This will cause the dollar to appreciate which will reduce exports of durable goods. Japan and Europe, as high cost countries, will see capital outflows, exchange rate depreciation, and increased exports of durables. Total flows of capital will be substantial, accumulating to about one trillion dollars over the period between 2000 and 2020.

Finally, it is important to note that OECD trading has only a modest effect on the costs of stabilizing emissions, and that it causes the United States to do more abatement than it would otherwise. Although this is efficient, it is the opposite of what many U.S. proponents of international permit trading seem to expect. Much of the political support for trading seems to be founded on the hope that it would allow the U.S. to do substantially *less* abatement. Our results show that in order for U.S. abatement to fall under a trading regime (that is, for the U.S. to become an importer of permits), permits would have to be available at a price below \$60 per tonne and in sufficiently large quantity (substantially more than 300 million tonnes) as to be able to supply the demands of Europe and Japan as well as the United States. This will only be possible if China, Brazil and other developing countries join the trading program *and* they are given very large allotments of permits, or if the countries of the former Soviet Union are allowed to sell their 300 million tonnes of unneeded permits. The latter case, however, would do almost nothing to control emissions.

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Table 1: Regions and Sectors in G-Cubed

Regions	Sectors
1. United States	1. Electric utilities
2. Japan	2. Gas utilities
3. Australia	3. Petroleum refining
4. Other OECD countries	4. Coal mining
5. China	5. Crude oil and gas extraction
6. Former Soviet Union	6. Other mining
7. Oil exporting developing countries	7. Agriculture
8. Other developing countries	8. Forestry and wood products
	9. Durable goods
	10. Nondurables
	11. Transportation
	12. Services

Table 2: Production Elasticities

Sector	Energy	Materials	Output	
			Estimated	Imposed
Electricity	0.200	1.000	0.763 (0.076)	0.200
Natural Gas	0.933 (0.347)	0.200	0.810 (0.039)	0.200
Petroleum Refining	0.200	0.200	0.543 (0.039)	0.200
Coal Mining	0.159 (0.121)	0.529 (0.018)	1.703 (0.038)	0.493
Crude Oil & Gas	0.137 (0.034)	0.200	0.493 (0.031)	
Other Mining	1.147 (0.136)	2.765 (0.028)	1.001 (0.315)	
Agriculture	0.628 (0.051)	1.732 (0.105)	1.283 (0.047)	
Forestry & Wood	0.938 (0.138)	0.176 (0.000)	0.935 (0.080)	
Durables	0.804 (0.058)	0.200	0.410 (0.019)	
Nondurables	1.000	0.057 (0.000)	1.004 (0.012)	
Transportation	0.200	0.200	0.537 (0.070)	
Services	0.321 (0.045)	3.006 (0.073)	0.256 (0.027)	

Table 3: Population Growth Rates

Region	Population Growth Rate
United States	0.5
Japan	0.0
Australia	0.8
Other OECD	0.7
China	1.5
Former Soviet Union	0.5
Other developing countries	1.0

Table 4: Aggregate Effects of Unilateral U.S. Stabilization

	2001	2005	2010	2020
Permit price	--	--	\$51	\$59
Carbon emissions	0.0%	0.1%	-24%	-35%
Coal consumption	0.0%	0.1%	-39%	-53%
Oil consumption	0.0%	0.3%	-7%	-11%
Gas consumption	0.0%	0.3%	-2%	-3%
GDP	0.0%	0.1%	-0.6%	-0.5%
Consumption	0.1%	0.3%	-0.7%	0.2%
Investment	1.0%	0.9%	-0.9%	-1.0%
Exchange rate	1.7%	1.6%	0.7%	3.2%
Exports	-1.8%	-1.9%	-0.9%	-3.5%
Imports	0.0%	0.0%	-0.9%	-1.0%
Net foreign assets (Bil.)	\$0	-\$39	-\$117	\$28
GNP	0.0%	0.0%	-0.6%	-0.5%

Table 5: Industry Effects of Unilateral U.S. Stabilization

	2005		2010		2020	
	<i>Price</i>	<i>Qty</i>	<i>Price</i>	<i>Qty</i>	<i>Price</i>	<i>Qty</i>
<i>Energy Industries</i>						
Electric utilities	-0.0%	0.2%	3.2%	-3.0%	6.7%	-5.0%
Gas utilities	-0.1%	0.2%	3.4%	-1.9%	6.4%	-3.6%
Petroleum refining	-0.2%	0.1%	6.5%	-7.4%	10.9%	-13.1%
Coal mining	0.1%	0.0%	111.2%	-38.8%	157.4%	-52.5%
Oil and gas extraction	-0.0%	0.0%	17.2%	-12.0%	25.3%	-25.6%
<i>Other Sectors</i>						
Other mining	-0.2%	0.0%	0.9%	-1.2%	0.4%	-1.7%
Agriculture	-0.0%	0.1%	0.4%	-1.0%	-0.2%	-0.3%
Forestry and wood	-0.3%	0.0%	0.3%	-0.6%	-0.6%	-0.4%
Durable goods	-0.6%	-0.2%	0.2%	-0.7%	-1.0%	-0.8%
Nondurables	-0.2%	0.1%	0.5%	-1.3%	-0.2%	-0.6%
Transportation	-0.1%	0.2%	0.2%	-1.0%	-0.3%	-0.5%
Services	-0.0%	0.2%	-0.4%	-0.3%	-0.6%	0.4%

Table 6: OECD Stabilization Without Permit Trading

	United States	Japan	Australia	Other OECD
2005				
Permit price	--	--	--	--
Carbon emissions	1.4%	-3.3%	1.6%	-2.3%
Coal consumption	1.0%	-0.6%	1.1%	-0.7%
Oil consumption	3.1%	-5.9%	3.7%	-4.1%
Gas consumption	2.2%	-2.3%	0.9%	-2.0%
GDP	0.5%	-0.4%	5.6%	-0.4%
Investment	7.4%	-5.0%	5.5%	-6.1%
Exchange rate	13.7%	-23.4%	17.9%	-26.0%
Net foreign assets (Bil.)	-\$306	-\$65	-\$35	\$267
GNP	0.3%	0.0%	-0.3%	-0.3%
2010				
Permit price	\$60	\$205	\$105	\$213
Carbon emissions	-25%	-21%	-37%	-30%
Coal consumption	-46%	-24%	-55%	-57%
Oil consumption	-4%	-15%	-3%	-15%
Gas consumption	1%	-6%	-2%	-6%
GDP	0.0%	-1.5%	-0.4%	-1.7%
Investment	6.2%	-6.2%	-6.8%	-9.4%
Exchange rate	11.8%	-23.7%	27.9%	-24.4%
Net foreign assets (Bil.)	-\$842	\$54	-\$101	\$662
GNP	-0.4%	-0.8%	-5.3%	-1.6%
2020				
Permit price	\$67	\$237	\$128	\$264
Carbon emissions	-37%	-31%	-53%	-44%
Coal consumption	-60%	-31%	-75%	-78%
Oil consumption	-9%	-24%	-12%	-24%
Gas consumption	-1%	-8%	-7%	-10%
GDP	0.1%	-1.4%	-1.7%	-1.9%
Investment	5.4%	-6.4%	-2.1%	-9.2%
Exchange rate	14.3%	-23.1%	11.9%	-24.4%
Net foreign assets (Bil.)	-\$838	\$92	-\$249	\$965
GNP	-0.2%	-0.3%	-6.1%	-1.8%

Table 7: OECD Stabilization With Permit Trading

	United States	Japan	Australia	Other OECD
2005				
Permit price	--	--	--	--
Annual permit sales (Bil.)	--	--	--	--
Carbon emissions	1.2%	-3.3%	1.6%	-2.5%
Coal consumption	0.9%	-0.6%	1.1%	-0.8%
Oil consumption	2.9%	-6.0%	3.5%	-4.6%
Gas consumption	2.3%	-2.3%	0.9%	-2.3%
GDP	0.5%	-0.3%	0.9%	-0.4%
Investment	7.5%	-5.1%	5.6%	-6.7%
Exchange rate	13.5%	-24.2%	17.8%	-29.0%
Net foreign assets (Bil.)	-\$312	-\$68	-\$34	\$292
GNP	0.3%	0.1%	-0.4%	-0.4%
2010				
Permit price	\$91	\$91	\$91	\$91
Annual permit sales (Bil.)	\$30	-\$4	-\$1	-\$25
Carbon emissions	-41%	-11%	-32%	-14%
Coal consumption	-70%	-11%	-48%	-25%
Oil consumption	-9%	-11%	-2%	-9%
Gas consumption	-1%	-4%	-2%	-4%
GDP	-0.4%	-1.3%	-0.1%	-1.1%
Investment	4.8%	-4.5%	-6.0%	-7.2%
Exchange rate	10.9%	-25.2%	27.6%	-28.5%
Net foreign assets (Bil.)	-\$864	\$52	-\$100	\$750
GNP	-0.8%	-0.7%	-3.2%	-0.9%
2020				
Permit price	\$108	\$108	\$108	\$108
Annual permit sales (Bil.)	\$64	-\$8	-\$2	-\$55
Carbon emissions	-62%	-16%	-44%	-19%
Coal consumption	-96%	-15%	-62%	-33%
Oil consumption	-18%	-15%	-10%	-12%
Gas consumption	-3%	-6%	-6%	-6%
GDP	-0.3%	-1.0%	-1.3%	-1.1%
Investment	4.1%	-5.1%	-1.3%	-7.3%
Exchange rate	15.8%	-24.4%	11.7%	-28.3%
Net foreign assets (Bil.)	-\$830	\$82	-\$240	\$1052
GNP	-0.7%	0.1%	-5.6%	-1.1%



Benefits and Costs of Kyoto

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Conference Paper

Climate Change Policy: The Road to Buenos Aires

American Enterprise Institute
September 14, 1998

9568

Jason Shogren
University of Wyoming
8 September 1998

The Tempest
Act 2, Scene 1

SEBASTIAN
What a strange drowsiness possesses them!
ANTONIO
It is the quality o' the climate.

I. Introduction

By now you have probably read or heard the reviews about the climate change protocol emerging from Kyoto last December—some experts in the rules of civilized engagement see the accord as a crucial first step, others see it as a serious misstep, few see it as the answer. The protocol's short-term comeback to a long-term question has left most reviewers demanding either deeper emission reductions or broader emission coverage or both. The complexities and frustrations are manifest in the comment from Bert Bolin, former chair of the Intergovernmental Panel on Climate Change: "The Kyoto conference did not achieve much with regard to limiting the buildup of greenhouse gases in the atmosphere....Only if the new cooperation among countries succeeds will the Kyoto conference represent a step toward the ultimate objective of the convention."¹

But regardless of your view, the 1997 Kyoto accord did signal a new earnestness of intent toward addressing the perceived risk of climate change. Kyoto demands that developed nations turn their economies so as to hit differentiated, sub-1990 level carbon emission targets within the next decade or so. Meanwhile, developing nations sit on the sideline uncommitted, serious in their refusal to stifle economic growth by controlling their swelling emissions. The Kyoto protocol asks for immediate action to address an uncertain, long-term, global threat in which the nations soon to be the world's largest emitters may never participate. Think of trying to turn a battleship on a dime with a third of the crew on-board. Improbable, but doable...but for what benefit...and at what cost?

This essay examines the benefits and costs of Kyoto. My task is to take the Kyoto protocol at face value, consider what the accord asks for and allows, and evaluate the potential benefits and costs that might accrue if it enters into force in 1999. My attempt to remain dispassionate occasionally wavers; a remnant from lively White House discussions past while serving as the senior economist for environmental policy at the Council of Economic Advisers during the run-up to Kyoto. The negotiating pressure

* This paper draws on work with M. Toman forthcoming in Climate Change Policy, *Public Policies for Environmental Protection* (P. Portney and R. Stavins, eds.), 2nd edition, Washington, D.C., Resources for the Future. All views herein are mine. Thanks to Sally Kane for her helpful comments.

¹ B. Bolin, The Kyoto Negotiations on Climate Change: A Science Perspective, *Science*, vol. 279, January 16, 1998, pp. 330-331.

during that time made me appreciate the force of Dales' remark that "[t]he politicians must decide what the public wants and stake their political lives on their decision; they are in a much better position to assess the benefits and costs of their action (or inaction) than any body of experts."²

Still economists are not shy about saying that behavior matters more to climate policy than many people think; and that wealth spent here is not spent somewhere else; and that with more reasonable policy, it is possible to provide more human and environmental health with less wealth. So understanding the benefit and costs can help frame the climate change debate by identifying the elements of Kyoto that inflate costs with no additional benefits. We consider what the literature says about estimating the benefits and costs for the US and the world; consider the key modeling assumptions that drive these estimates—e.g., the stringency of the abatement policy, the flexibility of policy instruments such as international emission trading systems sinks; and the development and diffusion of technology. Not surprisingly, the benefits and costs of Kyoto depend on what one *chooses to believe* about the nature of climate protection.

II. The Kyoto Protocol

Achieving more financial and commercial well-being while preventing untold global catastrophe—what madman would be against that goal? Essentially this was what the representatives of some 150 countries supposedly set out to do when they met in Kyoto, Japan on December 1997 at the third Conference of the Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC). Their task was to create a legally binding international agreement for climate protection—the so-called Kyoto Protocol. The protocol will enter into force 90 days after the date on which “not less than 55 Parties to the convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex on have deposited their instruments of ratification, acceptance, approval or accession” (Article 24). The protocol is open for signatures by Parties between 16 March 1998 and 15 March 1999.

The Kyoto conference culminated years of negotiations to strengthen the first international climate change treaty signed by over 160 countries at the 1992 Earth Summit in Rio de Janeiro. The original treaty, UNFCCC, called on industrial nations to voluntarily reduce their greenhouse gas emissions to 1990 levels by 2000 (see Table 1). Emissions from most nations, however, have actually risen since Rio. Since voluntary actions did not do the job, many advocates of climate protection saw the Kyoto protocol as the way to correct this perceived misdirection.

The Kyoto protocol takes a "deep, then broad" stand. "Deep" in that the emission targets require what many observers consider a rapid reduction in carbon emissions for industrial nations; "then broad" in that developing nations have no obligations at this

² J. Dales, *Pollution, Property, and Prices*, University of Toronto Press, 1968

time, but are hoped to join the agreement eventually once someone convinces them that it is in their best interest to join. It is this "deep, then broad" angle that has left many experts unimpressed by the protocol, which seems to some as a quick political fix rather than a serious response driven by the natural sciences and economics.³

So what does the Kyoto protocol say?

- *Targets and Timetables* (Article 3). The protocol set a legally-binding target for 39 of the world's most developed countries to reduce greenhouse gas emissions in aggregate by 5.2% from a 1990 baseline for the period 2008-2012. The targets are differentiated by nation, ranging from an 8 percent reduction (the European Union) to a 10 percent increase (Iceland) from 1990 levels. The United States agreed to a target of 7% reduction; Japan a 6% reduction (see Table 2). Each party must show demonstrable progress towards meeting its target by 2005.
- *Nations can act jointly to hit their target* (Article 4). The protocol lets a group of nations form a multi-country "bubble" in which the group has an overall target to reach. Each nation inside the bubble has its own commitment to the rest of the group. The bubble met the demand of the European Union (EU) that it should be able to comply as a group. The bubble does require the EU to adjust its commitment if its membership enlarges.
- *Greenhouse gases* (Article 3-Annex A). The protocol covers six greenhouse gases, carbon dioxide, methane, nitrous oxide, hypdrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexaflouride (SF6) as a "basket." The latter three use a 1995 baseline instead of 1990. The inclusion of the six gases allows for some flexibility in reaching the target. Reductions in one gas can be used to substitute for reductions in other gases.
- *Emission trading* (Article 16). The protocol allows for emission trading among the nations to fulfill their commitments. An emission-trading program provides greater flexibility to a nation to achieve its target. The domestic government can issue "greenhouse gas emission permits" to the private sector that equal the target set by the protocol. The permits can then be freely bought and sold between firms, and it is left unclear as to whether firms can trade uninhibited across borders. The trading price forces sources to reduce its greenhouse gas emissions so long as the tax exceeded the incremental cost of emissions reduction. This would stimulate fossil fuel users to improve energy efficiency, use less carbon-intensive fuels, and consume less of the goods and services produced in the carbon-intensive ways. Apparently, disagreements about trading were

³ See, for example, H. Jacoby, R. Prinn, and R. Schmalensee, Kyoto's Unfinished Business, *Foreign Affairs*, July/August 1998, pp. 54-66.

almost enough to deflate the conference. In return for emission trading, the US gave up its opposition to the EU bubble.

- *Joint Implementation/Clean Development Mechanism* (Articles 6 & 12). Joint Implementation (JI) is when one nation gets credit for implementing a project to reduce carbon emissions in another country. JI is limited to the Parties. A new device, the Clean Development Mechanism (CDM), was developed for joint projects with developing nations through the payment of a special administrative fee by developed nations. According to the protocol, "[t]he purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3." A small portion of proceeds from the special fee is to be used to help the poorest of the poor nations, such as the island states, adapt to climate change.
- *Carbon Sinks*. The protocol allows for carbon sinks—land and forestry practices that remove carbon emissions from the atmosphere. Sinks could play an important role for some nations because they represent a low-cost option. Sinks are ambiguously defined in the protocol, and will be a challenge to measure. Sinks might even turn out to be an escape value for the US since little is known with certainty the net uptake of the terrestrial sinks in North America. According to the State Department, once one adjusts the US's accounting method, sinks will account for about 3 percent of the 7 percent reduction below 1990 levels as asked for by Kyoto.⁴
- *No Harmonization of actions*. The protocol allows each nation to figure out its own best strategy to meet its commitment. No everyone sees this as a good thing—some critics have argued that the world would have been better served by a common action rather than a common target.⁵

What didn't the Kyoto protocol achieve?

- *Developing country participation*. No agreement was reached in Kyoto on what commitments developing countries should assume to reduce their greenhouse gas emissions. And Kyoto does not include a separate article for nations to voluntarily assume binding targets. But it is clear to everyone that climate protection requires the participation on the developing countries because by the middle of the next century, they are

⁴ US Department of State, *The Kyoto Protocol on Climate Change: State Department Fact Sheet*, 15 January 1998.

⁵ R. Cooper, *Toward a Real Global Warming Treaty*, *Foreign Affairs* 1998, March/April 66-79.

predicted to generate the largest share of carbon emissions. But they remain unmoved by the protocol. Developing nations have no incentive to reduce their economic growth. China, for example, is the second largest emitter after the US, but its per capita emissions are about a seventh of those in the United States. A Chinese delegate captured the sentiment underlying the opposition: "[w]hat they [developed nations] are doing is luxury emissions, what we are doing is survival emissions."⁶ Substantial compensation might be required to induce their necessary participation.

- *Specifics on emission trading and the Clean Development Mechanism.* The protocol also left the specific rules and regulations about international emissions trading to be defined at a future date. Although both trading and the mechanism have the potential to generate low-cost emissions reductions for developed countries and tangible benefits to the host country, two factors limit their scope—transaction costs and additionality. Transaction costs are the time, effort, and other resources needed to search out, negotiate, consummate, and get governmental approvals for heterogeneous deals. How the rules are eventually defined will determine the friction in these flexibility tools. Additionality reflects the fear that people will try to get credit for emissions changes that would have happened anyway in spite of some reduction project. Options to address additionality range from detailed scrutiny of every project before approval to the development of simple formulae applied across all projects. An obvious tradeoff exists between reliability and cost among these options. The developers of the Mechanism need to define and pre-test the institutional, administrative, and financial arrangements, the guidelines on the criteria for eligibility and certification, and verification and monitoring of emission reductions.
- *Specifics on compliance and enforcement.* Both emissions trading and the Clean Development Mechanism require measures to assess compliance and to hold participants responsible for noncompliance. Under the Framework Convention and the Kyoto Protocol, the Annex I capped countries are ultimately responsible for achieving their emissions targets, whether they are net buyers or sellers of permits or credits. Presumably the Protocol Parties will then reassign this responsibility to the domestic private sector through strategies to monitor emissions and spot check specific investment projects. The protocol says enforcement procedures to deal with non-compliance will be established at the first meeting of the Parties to the Protocol. But until the details are fleshed out and this uncertainty is resolved, those firms falling under a trading system will remain skeptical about the workability of the scheme. For instance, whether the buyer or seller should be liable for the penalty of trading a permit that should not have been traded remains a major question mark.

⁶ Quoted in S. Huber and C. Douglass, *Two Perspectives on Global Climate Change. A Briefing Book*, Center for the Study of American Business, Washington University of St. Louis, July 1998.

III. Benefits from Kyoto

The potential benefits from Kyoto are captured by the avoided damages from climate change. Potential climate risks avoided include more severe weather patterns, hobbled ecosystems, less biodiversity, less potable water, loss of coastal areas from rising sea levels, rises in mean temperature, more infectious diseases such as malaria, yellow fever, and cholera. On the plus side, climate change might benefit agriculture and forestry by increasing productivity with longer growing seasons and more fertilization. These gains (or losses) can be categorized into four broad sets, increasingly difficult to quantify—the avoided losses to market goods and services, non-market goods, secondary impacts, and catastrophes.

Traditionally, people have judged the benefits of climate protection as the incremental reduction in human and environmental risks from the *business-as-usual* (BAU) baseline. Under BAU, modelers have estimated that carbon concentrations might be expected to double pre-industrial levels within the next half century, with mean temperatures predicted to rise by about 1 degrees Celsius by 2050, and 2.5 degrees by 2100. With Kyoto, concentrations are still likely to double with temperatures increasing by about 0.1 degrees Celsius by 2050 and 0.5 degrees by 2100.

Researchers have estimated the estimated impact on Gross World Product from climate change around 1 or 2 percent. The impact on Gross Domestic Product (GDP) in the United States has been estimated to be around plus or minus 1 percent. Most industries in the developed nations are separate from climate—less than 3 percent of US livelihoods, for instance, are earned in agriculture and other climate-sensitive outdoor activities.⁷ And even if we include the potential non-market damages, Nordhaus has argued that the market and non-market benefits to the US are probably at most about 2 percent of GDP.⁸ These impacts are not trivial, but the impact on economic output is not likely to cause the next global depression either.

Thomas Schelling views climate protection as a political problem, whose costs will be relatively low: “a few trillion dollars over the next 30 or 40 years, out of an OECD GDP rising from \$15 trillion to \$30-40 trillion annually.”⁹ Although doable, he wonders whether this is really the right question. He points out that climate policy really amounts to a wealth transfer from today’s industrial nations to the future generations in the developing nations. The benefits from Kyoto are most likely to accrue to the future generations in developing nations because their economies depend more on favorable

⁷ These aggregate estimates also mask significant variability in impacts across regions, economic sectors, and industries.

⁸ R. Nordhaus, To Slow or not to Slow: The Economics of the Greenhouse Effects, *Economic Journal*, 1991, 101, 920-937.

⁹ T. Schelling, the Costs of combating Global Warming, *foreign affairs*, 1997, November/December, 8-14. Also see T. Schelling, “Some Economics of Global Warming,” *American Economic Review* 82, 1992, 1-14.

climate for agriculture, forestry, and fishing. He wonders whether it would be better to invest in development today than pay for climate relief tomorrow.

Two topics in non-market valuation are likely to trigger major debates about the likely magnitude of potential benefits—human health and ecosystem/endangered species services. First, consider health. There are numerous lists on the potential threats to human health including old scourges like cholera, plague, yellow and dengue fever, tuberculosis, malaria, and thirty diseases new to medicine, like E. coli, hantavirus and HIV.¹⁰ But there is less talk about the odds the events will come to pass. What are the odds, what is the variability around these odds, how credible are these odds?

Despite the warnings, the cause and effects are still uncertain. It is not clear that malaria rates will increase if those mosquito fail to adapt to changes in temperature, humidity or precipitation.¹¹ And attached to these threats must be advances in technology and nutrition and medical care. Adaptation may be the key to prevention. Once we acknowledge that adaptation plays a key role, we must account for the fact that risk depends on private and collective choices. The economic variables that drive adaptation, such as relative price and wealth, must be considered in the estimation of health risk. Given the relative marginal effectiveness of different self-protection actions, how people confront risk differs across individuals and situations, even though the natural phenomena that trigger these actions apply equally to everyone.

More information is needed to determine the bias in assessing health risks solely in terms of natural science information given that the sources of systematic variation are relative prices, incomes, and other economic and social parameters. If economists are going to be effective in the debate over setting health-based standards, they must insert themselves into the econometrics of epidemiology.¹² Biases associated with measurement and specification errors are prevalent. When account is taken of self-protection behaviors, ambient concentrations are not synonymous with exposure. Economic variables affect behavior which affect the risks faced by people, and exclusion of these variables from risk assessment biases predictions. Studies have shown that people persistently below the poverty line are far more likely to become sick than wealthy people for a variety of reasons including habits, lifestyle, less medical screening, and the ability to self-protect. The evidence suggests that behavioral choices frequently

¹⁰ See for example, P. Epstein, "Climate, Ecology, and Human Health, *Consequences*, 3, 1997, 3-19.

¹¹ A. Krupnick, Climate change, health risks, and Economics, Weathervane, www.weathervane.rff.org. May 1998.

¹² See for example Crocker, Thomas D. and Jason F. Shogren. 1997. Endogenous Risk and Environmental Program Evaluation. *Environmental Program Evaluation. A Primer* (G. Knaap and T.J. Kim, eds.) Urbana, IL: University of Illinois Press, pp. 255-269; Duncan, Greg, et al. 1997. Does Poverty Affect the Life Chances of Children? *American Sociological Review* (forthcoming); Atkinson, Scott and Thomas D. Crocker. 1992. *Journal of Environmental Economics and Management* 22: 12-24. Kremer, Michael 1996. Integrating Behavioral Choice into Epidemiological Models of AIDS. *Quarterly Journal of Economics* 111: 549-574; Korenman, Sanders and Jane E. Miller. 1997. Effects of Long-term Poverty on Physical Health of Children in the National Longitudinal Survey of Youth. Photocopy.

associated with poverty (e.g., high discount rates) are the most significant threat to health. Wealth equals health, even in warmer or colder climates.

Estimating the social value of ecosystem services and endangered species is also a challenge. The main point of contention is over trying to put a monetary value on these preferences. The primary tool for trying to accomplish this are public opinion surveys, known as contingent evaluation surveys, which use a sequence of questions to put a monetary value on personal preferences. As one might expect, this method is highly contentious, because people are responding to a survey rather than facing their own budget constraint and actually spending their own money. To illustrate, if one summed the stated preferences from various endangered species surveys as a crude measure of benefits, the average person was willing to pay about \$1000 to protect 18 different species. Multiplying \$1000 by the number of U.S. households, suggest that we would be willing to pay over 1 percent of GDP to preserve less than 2 percent of the endangered species.¹³ Many will find these values to be suspiciously high. It seems implausible that private benefits of preserving endangered species, including commercial and consumptive use, will be sufficient to justify preservation efforts that would be as extensive as many would like. Despite the extraordinary analytical difficulties associated with measuring the social value that should be placed on preserving each species, determining at least a plausible range for these values would seem to be essential if we are to make judgments about the benefits of preservation.

One way to amplify the benefits of the Kyoto protocol is to consider the potential secondary impacts that come from discouraging coal and other fossil fuel consumption. The Kyoto protocol would reduce emissions of such air pollutants as carbon monoxide, sulfur and nitrogen oxides, and toxic trace pollutants in exhaust gases. By reducing BTUs generated by fossil fuel consumption, emissions of these pollutants would inevitably fall, reducing damages to health, visibility, materials, and crops. Studies in Europe and the U.S. have estimated that the non-climate benefits might be as large or larger than the benefits from avoiding climate change. The estimated secondary benefits range from \$3 to \$78 per ton carbon reduction (\$1992).¹⁴ The benefits from reducing air pollution damages could offset 30 to 100 percent of carbon abatement costs. Most of these pollutants are already regulated, but such regulation usually takes the form of a maximum rate of emissions per million BTUs.

But should these secondary impacts count when considering the level of climate protection? Imagine you are a Boy or Girl Scout thinking about the costs and benefits of helping an elderly lady cross the street. If you stop traffic to help her, you also reduce the odds that a car will not hit some neighborhood kid who might happen to chase his ball into the street at that same moment. Should your *ex ante* decision to help the lady be influenced by the *ex post*-reduced risk to the kid? I do not think so. Benefit-cost analysis is more than an accounting system; it has a behavioral motive to help set control

¹³ G. Brown and J. Shogren, "Economics of the Endangered Species Act," *Journal of Economic Perspectives*, 1998.

¹⁴ D. Burtraw and M. Toman, *The Benefits of Reduced Air Pollutants in the US From Greenhouse Gas Mitigation Policies*, Climate Issues Brief No. 7, Resources for the Future, October 1997.

strategies to address pollution. And it is the *ex ante* behavior that drives how decisions are made, not the *ex post* results.¹⁵ The secondary impacts are an *ex-post* effect from an *ex ante* decision to control greenhouse gases, they are irrelevant when considering how the benefits match up to the costs per ton of carbon reduced.

Finally, researchers, policymakers, politicians have raised the specter of catastrophe and surprise. Modelers often presume climate change will be gradual—a slow and steady rise in temperature or precipitation. But many people warn that this steady flow ignores the real risk of a sudden rupture or a straw-camel-back scenario, e.g., a catastrophe such as a structural change in ocean currents like the Gulf Stream, the melting of the Western Antarctic ice sheet, waves of environmental refugees. These threats are enough to scare most people into action.

While careful to not making any causal link, some point to El Niño as an illustrative example of the damages one might expect with climate change. Stuart Eizenstat, Under Secretary of State for Economic, Business, and Agricultural Affairs, said “[f]or a preview of the type of severe weather...look at the devastation wrought by this winter’s El Niño.”¹⁶ But according to FEMA, the El Niño winter was no costlier than the previous two winters in the US—\$289 million in 1997-98 compared to \$294 million in 1996-97 and \$280 million in 1995-96.¹⁷

The problem is that researchers do not have any reasonable estimates of the odds that these events will come to pass. The best these researchers are willing to say is that these severe events are “uncertain.”¹⁸ But all “all severity-no probability” scenarios can lead people to knee-jerk reactions. The challenge is to get researchers to quantify these odds for more informed policy judgments. It matters whether the odds are 10 percent or one-tenth of 0.1 percent.

In addition, the BAU baseline is not the only benchmark in town to judge the benefits of Kyoto. In fact, the BAU path is less credible after Kyoto since the developed world has already agreed to do something to address climate change.¹⁹ According to Article 2 of the Framework Convention on Climate Change, the objective is to stabilize “greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” Numerous different emissions reduction scenarios can work to stabilize concentrations at some level, including the “broad, then deep” pathway recommended by many researchers and policymakers: broad

¹⁵ J. Buchanan, *Cost and Choice*, University of Chicago Press, Chicago, 1969.

¹⁶ S. Eizenstat, Stick With Kyoto, *Foreign Affairs* 77, 1998, 119-121.

¹⁷ J. Allen, El Niño’s Price Tag Sets No Disaster Record, *Washington Post*, 5 April 1998.

¹⁸ E. Barron, Written Testimony, Committee on Environment and Public Works, US Senate, 11 July 1997; E. Barron, climate models: how reliable are their predictions, *consequences* 1, 1995, 16-27.

¹⁹ In fact, some companies are being quite aggressive. British Petroleum, world’s 3rd largest Petroleum Company, has taken on emission trading themselves, and has opened a new solar manufacturing facility. See S. Percy, “Making Progress beyond Kyoto,” *How Workable is the Kyoto Protocol*, Weathervane, www.weathervane.rff.org. March 1998.

participation by both developed and developing countries, and a gradual emission reduction path to achieve a desired long-term concentration target.²⁰

Delay is not denial, some say.²¹ The "broad, then deep" represents the view that we can allow emissions to grow at least for the next few decades before serious reductions are necessary.²² And while advocates of this policy run the risk of being dubbed irrelevant to the process, the moderate reduction baseline calls for a emission path that peaks around 2020 and would result in essentially the same concentration level in 2100 as Kyoto, at a fraction of the costs. Implementation of this benchmark would require an initial, modest increase in the price of carbon emissions, and a credible commitment to increase the price over time. Shifting emissions reductions into the future allows time for a gradual adaptation of the energy capital stock, developing low cost and low carbon technology substitutes, removing carbon from the atmosphere via the carbon cycle, and, since the economy yields a positive return on capital, future reductions can be made with a smaller commitment of today's resources.

The benefits generated by this moderate benchmark are nearly identical to those produced by the Kyoto protocol, even accounting for secondary and catastrophic impacts. The temperature difference between the Kyoto protocol and the moderate baseline are less than 0.1 degrees Celsius at any time over the next century. This small difference reflects the long lags in emission flows and concentration stocks over the century, and that the most serious emissions will come later in the century from the expanding economies of the developing nations. The net result is that Kyoto did not gain any benefits over the next best alternative.

IV. Costs of Kyoto

As expected, the costs of Kyoto are all over the board. Some studies suggest the US could meet its target at negligible or modest cost; others call Kyoto an "economic disarmament" driven by rank political opportunism. And to assume the costs are somewhere in-between puts the theorist at risk of being compared to a cigarette manufacturer stealing the life out of children or to a fool who has bestowed long lasting economic advantages to his international competitors. It's wild out there.

On the modest side sits the report on the Kyoto protocol from the President's Council of Economic Advisers (CEA). Again relative to the BAU baseline, the CEA report states the costs to the US to meet its Kyoto target are "likely to be

²⁰ The "broad, then deep" seems to be consistent with one side of the domestic US political strategy reflected in the non-binding Byrd-Hagel resolution, passed in the Senate 95-0, that stated that the US should accept no climate agreement that did not demand comparable sacrifices of all participants.

²¹ R. Schmalensee, "Greenhouse Policy Architectures and Institutions," MIT Joint Program on the Science and Policy of Global Climate Change, Report No. 13, November 1996; S. Schneider and L. Goulder, "Achieving Carbon Dioxide Targets Cost-Effectively: What Needs to be Done Now?," *Nature* 1997.

²² T. Wigley, R. Richels, and J. Edmonds, "Economic and environmental choices in the stabilization of atmospheric CO₂ concentrations, *Nature*, 379, 1996, 240-243. A. Manne and R. Richels, "On Stabilizing CO₂ Concentrations--Cost-effective Emission Reduction Strategies," EMF 14, April 1997.

modest if those reductions are undertaken in an efficient manner employing the flexibility measures of emissions trading (both domestic and international), joint implementation, and the Clean Development Mechanism." By modest, the CEA means an annual GDP drop of less than 0.5 percent—roughly some \$10 billion dollars; no expected negative effect on the trade deficit; increase gasoline prices by about 5 cents a gallon; lower electricity rates; and no "significant aggregate employment effect."²³ Essentially, a "broad and deep" baseline is built right into the CEA's estimates of costs. And these estimates might be plausible if all goes exactly right with the world; a big "if."

In contrast, forecasts from the economic consulting firms, WEFA Inc., DRI/McGraw Hill Inc., and Charles Rivers Associates, estimate the US GDP could take an annual hit of nearly 3 percent of GDP, or about \$250 billion a year—with intra-nation emission trading. Plus the trade deficit would increase by tens of billions of dollars; gasoline prices would increase by nearly 50 cents a gallon; electricity prices would nearly double; and two million U.S. jobs would disappear. The impact on energy use is analogous to that felt during the decade of OPEC price shocks. These estimates obviously do not see all going right with Kyoto. Rather they see trouble in premature assumptions of rapid technological improvement, and in the likely friction imposed on any emission trading or technology transfer system by the institutions that eventually might see the light of day.

Other observers are more in the middle of the pain distribution.²⁴ Kyoto will not destroy national economies, but it will not be painless either, they say. Researchers at Resources for the Future, for instance, estimate that Kyoto could cost about 1 percent of GDP annually, at a worst 2 percent.²⁵ Plus energy costs would increase for an average U.S. household (about \$2,500/yr) by about 25 percent, this includes a gasoline price rise of 30 cents a gallon. The Australian government estimated global losses at about 1 percent annually globally at 2020.²⁶ Prior to Kyoto, the Energy Modeling Forum (EMF) estimated the short-term costs of a 1990 by 2010 strategy at 0.5 - 1.5 percent annual drop in US GDP; and the medium term costs between 0.6 - 2.6 percent drop in GDP by the year 2020.²⁷ The post-Kyoto EMF estimates have yet to be released.

²³ The pre-Kyoto results from the President's Interagency Analysis Team (IAT) are within this range as well. An exception is that the IAT estimates that reducing emissions to 1990 levels by 2010 would cost 900,000 jobs in 2005, and 400,000 jobs by 2010. Also see J. Yellen, *The Economics of the Kyoto Protocol*, Statement before the Committee on Agriculture, Nutrition, and Forestry, US Senate, 5 March 1998.

²⁴ See for example Nordhaus (1991), M. Grubb et al., "The Costs of Limiting Fossil-Fuel CO₂ Emissions: A Survey and Analysis," *Annual Review of Energy and the Environment* 18 1993, 397-478.), EMF Results, Stanford, 1994, Hourcade et al. (1996), J. Edmonds et al., "Return to 1990: The Costs of Mitigating United States Carbon Emissions in the Post-2000 Period," Battelle, October 1997; W. McKibbin and P. Wilcoxon, "A Better Way to Slow Global Climate Change," Brookings Institute, March 1997.

²⁵ M. Hamilton and C. Chandler, "Cures that Involve a World of Pain," *Washington Post*, 13 November 1997.

²⁶ S. Brown et al., "The Economic Impact of International climate change policy," ABARE 1997.

²⁷ These estimates are robust across different modeling runs. The EMF compares a diverse group of economic models employing different methodologies. Standardizing these models by assuming common exogenous parameters yielded similar results. This suggests that the choice of method is secondary to the

Another interesting story emerges when we compare the costs of Kyoto relative to the more moderate "broad, then deep" emission path baseline. Nordhaus and Boyer have used the RICE-98 model to address the relative benefits and costs of the Kyoto protocol to a moderate or "optimal" baseline.²⁸ While preliminary, their results suggest that while both paths yield nearly identical emission reductions, the Kyoto accord without global trading could be 8 to 14 times more expensive than the moderate path.

In general and for all models, cost estimates are likely to be on the low side for several reasons—models presume the most efficient possible climate control program, even though today only one such program is on-going; models assume the control program is announced early and maintained indefinitely, even though a government will be hard pressed to maintain consistent control over the decades; many models focus on long-term equilibrium and ignore the short-run adjustments such as the oil shocks of the 1970s. There are good reasons to believe that any international or domestic emission trading program or Clean Development Mechanism will have significant transaction costs due to market friction. Some economists think these factors would raise cost estimates by a factor of one to four. This factor would cause Kyoto to reduce GDP by 1-10 percent from baseline. For comparison, the US now spends about two percent of GDP on all environmental programs combined.²⁹

Finally, what about the common charge that modelers habitually overestimate the costs of environmental regulations, and thus it is likely that the costs of Kyoto are also too high by definition. This blanket assertion is not supported by the facts. Granted economist did predict the control costs for sulfur dioxide could be \$1500 per ton, when today a ton actually costs \$100. And good reasons exist as for this gap—unanticipated technology breakthroughs, railroad deregulation, many permits were given out for free. Ray Squitieri at the Department of Treasury has compiled the actual evidence. He finds that costs just as often on the low side. For instance, predictions straddle actual costs for asbestos, coke ovens, vinyl chloride regulation; numerous unpredicted changes in technology and the economy occurred to lower the cost of CFCs, cotton dust, SO₂ control; recall that the National Ambient Air Quality Standards were estimated to be achieved by 1977, but these standards are still not attained in 75 areas with 75 million people.

V. What You Choose to Believe

choice of values for population growth, per capita income, energy intensity, and technical progress.

²⁸ W. Nordhaus and J. Boyer, *Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol*, Yale University, 29 June 1998.

²⁹ Discussions with Ray Squitieri.

How one sees the benefits and costs of Kyoto depends on what one chooses to believe about the nature of three elements that underlie climate protection—the cusp of a catastrophe, the degree of flexibility, and the origins of technological advance.³⁰

The Cusp of Catastrophe

What you choose to believe about the benefits of Kyoto depends on how you perceive the risk of catastrophe. If you believe disaster is imminent, emission reductions cannot come soon or fast enough. If you don't, it is hard to justify the likely costs of the Kyoto protocol without global trading. Reliable information is needed to guide people from their diffuse priors about catastrophe. Whether the information will be forthcoming between now and potential ratification fights is unclear.

Numerous unanswered questions persist about the structure of atmospheric systems and their potential thresholds. As Schelling and many others note, uncertainties abound. We do not know which regions will get warmer or cooler; which will get wetter or drier; which will get stormier or calmer. Climate policy debates eventually reach the point in which the modeler is asked whether he or she has accounted for the likelihood of that a change in the ecosystem will be discontinuous—a catastrophe. Most modelers acknowledge their models do not address the potential for discontinuous shocks, like a sudden shift in the Gulf Stream due, or an unraveling of the web of life due to the loss of some keystone species.

Some observers view the increased temperature over the past century as well within the bounds of natural variability. Others such as Vice President Gore have been known to point out the evidence of global warming keeps "piling up, month after month, week after week. How long is it going to take before these people in Congress get the message?"³¹ John Holdren, a member of the president's scientific advisory committee, agrees: "every day the evidence becomes more persuasive that global warming is underway." However, daily weather and seasonal means are highly variable making it challenging to discern trends—i.e., separating signals from natural noise.

But does this mean that society is on the cusp of catastrophe? Not necessarily—the doomsayers have a terrible track record. In addition, numerous risk perception studies have revealed that people commonly overestimate the chance that they will suffer from a low probability/high severity event, e.g., a nuclear power accident.³² When the outcome is potentially very bad, people inflate the chance that the outcome will be realized. Policymakers are not immune to this human fallibility either. Overestimation of risk can multiply throughout the general public. For example, people pondering the storage of nuclear waste can transform images of a fortified storage facility containing

³⁰ Also see R. Repetto and D. Austin, *The Costs of Climate Protection*, WRI 1997.

³¹ J. Warrick, "'People are Sweltering,' says Gore, Tying Record Heat to Global Warming," *Washington Post*, 15 July 1998.

³² Lichtenstein, S. et al. "The Judged Frequency of Lethal Events," *Journal of Experimental Psychology* 1978, 4, 551-578; Viscusi, W. K., *Fatal Tradeoffs*, Oxford University Press, 1992.

sanitized, air-tight receptacles into an abandoned dump site teeming with rusty, leaking vats of toxic material. The images induce vivid perceptions, both of which can persist in a community, causing considerable disagreement about how to regulate the risk.

Experience tells people little about low-probability risks like climate change. They must rely on outside sources of information to help them make judgments about the likelihood that a bad event will actually come to pass. And if that outside information stresses severity without giving some notion of the odds, people systematically bias their risk perceptions upward. Other evidence suggests that when people are given good news with the bad, the bad news often dominates.³³

Of course, sticking ones head in the sand is not particularly useful either. Climate protection is viewed as hedging against uncertainty--i.e., planet insurance.³⁴ As such, it is important that we understand the range of potential impacts, not just the expected value. Peck and Teisberg explore how risks of large losses affect the estimated costs of given climate protection strategies.³⁵ Working off of Nordhaus's survey of expert opinions about the odds of losses,³⁶ they create eight states of nature by assigning either a "high or low" value to three key parameters that reflect uncertainty--the probability of a loss, the climate sensitivity, and the utility discount rate. Their results suggest that the optimal policy under uncertainty is about the same as the policy for the lowest-loss state of nature. This occurs in part because the lowest-state receives the greatest likelihood of coming to pass. Also see Roughgarden who creates a probabilistic damage function based on the same expert opinion survey, emphasizing the mean relative pessimism of the respondents.³⁷ He finds that in the case of the extreme damage estimates opined by the natural scientists, the climate protection is six times more stringent than that of Nordhaus's original prediction.

Finally, uncertainty about the underlying physical processes and random variability requires policymakers to decide whether to control for potential catastrophe now or wait for more information about the climate. Kyoto reduces emissions, and consequently causes learning to slow down because less information now exists about the cause-and-effect. Using an integrated assessment model with endogenous learning, Kelly and Kolstad show that uncertainties are resolved in 90-160 years, far longer than most people expect.³⁸ A tradeoff exists between emission policy and learning--the more emission reductions, the less learning about the system. Policies of climate protection based on a presumption of complete information can be off by as much as 25 percent in either direction once learning is accounted for. Elements of truth exist in both sides of the

³³ For example, Fox et al., "Consumer Preferences for Irradiation given Alternative Information," Working paper, Kansas State University, July 1998.

³⁴ See for example, A. Blinder, "Needed: Planet Insurance," *New York Times*, 22 October 1997.

³⁵ S. Peck and T. Teisberg, "Uncertainty and the Value of Information with Stochastic Losses from Global Warming," *Risk Analysis* 16, 1996, 227-235.

³⁶ W. Nordhaus, "Expert Opinion on Climatic Change," *American Scientist* 1994, 45-51.

³⁷ T. Roughgarden, Quantifying the Damage of Climate Change: Implications for the DICE Model, Stanford University, 14 March 1997.

³⁸ D. Kelly and C. Kolstad, "Bayesian Learning and Accumulation of Stock Externalities," UC-Santa Barbara, 1996.

debate. Policymakers would serve a more useful role as arbiters that help reconcile risk perceptions, rather than inflame the differences.

The Degree of Flexibility

What you choose to believe about the costs of Kyoto can be framed by focusing on how you think the flexibility provisions will pan out, and how many nations will actually be included in any exchange system. The costs to meet a policy depend on a firm's legal ability to use low cost carbon reductions and how quickly society wants to change the energy systems and capital structure of the US economy. A stringent, inflexible carbon policy will induce greater economic burden than a loose, flexible policy. Obviously more flexibility and more trading partners can reduce costs, as a firm can search out the lowest-cost alternative. One can expect the opposite with ridged rules and few trading partners. It is estimated that any agreement without the cost flexibility provided by trading will at least double the US costs.

Flexibility can be measured as the ability to reduce carbon at the lowest cost, either domestically and internationally, including so-called "when and where" flexibility—which assumes a world emissions budget could be spent optimally over space and time to capture all potential intra- and inter-temporal efficiencies. This would allow the banking and borrowing of allowable carbon emissions. Providing a firm or nation more flexibility to reach a given target and timetable also will reduce costs. Almost all studies of the costs of Kyoto already presume that carbon reductions are implemented domestically with well-designed, cost-effective policy tools like a carbon tax or tradable permits system. International flexibility is also key for US firms to meet domestic targets at lower cost by financing the upgrading of inefficient energy facilities in developing countries. Limiting such opportunities for flexibility – due to poor policy design, inherent problems in administering international policies, or lack of interest on the part of other countries – will mean potentially much higher costs. The key is to distribute emissions internationally so as to minimize the costs of climate policy.

The Kyoto protocol established a narrow coalition of developed nations who now must reach out to the developing countries to join later. This approach begins with a narrow participation by a limited set of nations in a relatively ambitious agreement that involves considerable costs and hence requires fairly sophisticated policy instruments. People have to judge the odds that developing nations will eventually join the protocol. The most continuous issue in Kyoto was how to encourage or pressure developing nations to commit to emission reductions. The US pushed for a voluntary system, but the EU maintained that discussions on developing countries should only begin after the developed nations took the lead. China, Brazil, and other nations stopped several efforts in Kyoto to create a voluntary opt-in process for the developing nations to adopt binding commitments. China also successfully opposed putting the issue on the agenda for COP-4 in Buenos Aires in November. The difference in outlook is obvious—the developing

nations are looking into the future and seeing the other side of the Environmental Kuznets Curve; the developed nations are looking at today and seeing the steep climb up the same Curve. Rich nations got rich through carbon, poor nations want the same opportunity. Who can blame them.

Kyoto runs the risk that the developing countries will never join later because the costs of doing so will be too high. By increasing the relative costs of carbon in the narrow coalition, carbon-intensive industries will be tempted move to developing countries, thereby making these economies even more carbon-dependent as they try to grow their way past the real health problems they face now.³⁹ Their addiction to carbon-based growth increases the costs of joining the treaty. The suppliers of carbon-intensive energy will look for existing markets and will create new markets. If developing countries do not alter their emissions path, global emissions levels will continue to increase even if all the developed nations completely eliminate all their emissions. Without China or India and the rest of the developing world, the Kyoto protocol will not work. The Administration has indicated that they would not submit the protocol to the Senate until "meaningful participation" from developing nations was obtained. Unskilled as I am in affairs of state, my guess is that the debate over whether climate change policy is really backdoor foreign aid will stall serious proposals to pay for meaningful participation over the next decade.

Second, we need to work through the details how the system would be designed before alternative policies can be usefully evaluated. The Kyoto protocol does not have a set position as to what either a domestic or international trading system would look like. What is curious about carbon emissions trading is that its biggest supporters have been the environmental activists rather than economists. The environmental community prefers emissions trading over carbon taxes because the quantity of carbon flowing into the atmosphere is fixed, thereby shifting risk to the economy in the form of price uncertainty. Some advocates have pushed for relatively high transaction costs that would limit the cost-savings of a trading system; others have argued for a flexible system that allows for banking and borrowing of permits. But many economists have questioned the feasibility of carbon trading because the international market is likely to be thin as most nations have indicated inaudible interest in the system, and the costs of monitoring and enforcing the system are likely to be high.

Defining the rules for flexibility incentive systems is wide-open, and experimental economists could play an important role in reducing the associated uncertainty. This holds for joint implementation and the Clean Development Mechanism as well. A testbed carbon emission trading system designed in laboratory markets can evaluate the institutional factors that will influence the effectiveness of carbon trading. Experimentalists can consider how flexibility in trading, imperfect information, multi-gas trading, links between domestic and international trading, and other factors affect the potential efficiency of trading.

³⁹ One guess is that carbon leakage would probably be between 10 and 50 percent. See T. Rutherford, "International Competitiveness and National Plans," University of Colorado, 1995.

A serious effort is vital to understand what aspects of emission trading can reduce the costs of climate change policy. The effort should first design and parameterize a market that reflects the costs and productivity of the countries or regions expected to participate in a emission trading initiative as suggested in the Kyoto Protocol. Researchers can then use the parameters of the nations to design World Wide Web market experiments; to testbed various trading proposals that have been described to meet the Kyoto Protocol objectives using the market parameterization; to evaluate the robustness of emission trading market institutions to market "frictions"- impediments to efficient, cost-minimizing market outcomes; and to evaluate how the scope of the market affects market performance.

Third, carbon sinks are a wild card in the search for flexible, low-cost solutions. Recall that a carbon sink is a process that destroys or absorbs greenhouse gases, such as the absorption of atmospheric carbon dioxide by terrestrial (e.g., trees) and oceanic biota. The main anthropogenic sink is tree planting and other forest management actions. Soils and other types of vegetation also provide a potential sink. It is estimated that forests around the world contain about 830 Pg of carbon in their vegetation and soil, with about 1.5 times as much in soil as in vegetation. For the US, forests are an important terrestrial sink given that they cover about 750 million acres. Land use changes in the US have increased the uptake of carbon to an estimated 200 MMTCE.

A few studies have found that carbon sequestration through sinks could cost as little as \$25/ton in the US. But serious uncertainties remain about how to measure and account for estimates of net carbon. For example, how forest management activities affect soil carbon is unknown, and since forest soils contain over 50 percent of the total stored forest carbon in the U.S., this difference can have a significant impact on estimates. And some researchers have shown that sinks are not as effective as predicted when one accounts for the interaction of forest reserves and the timber market. The more land that is set-aside for carbon sinks, the quicker the cycle of harvesting on other forestland, the less total net carbon sequestration.⁴⁰ Some fear that these ambiguities about sinks could divert attention from first-order priorities to second-order technicalities.⁴¹

Fourth, the costs of climate protection are also amplified by pre-existing distortions created by the existing tax system for labor and capital income. Labor and capital taxes distort behavior because they reduce employment and investment levels below what they would have been otherwise. Now add on a carbon tax (or permit) that discourages consumption and production, and you further reduce employment and investment, which then exacerbates the labor and capital tax distortions. One estimate is that this amplified distortion will inflate the control costs by some 400 percent.⁴² One

⁴⁰ Discussion with Brent Sohngen, Ohio State University, August 1998.

⁴¹ H. Jacoby, R. Prinn, and R. Schmalensee, Kyoto's Unfinished Business, *Foreign Affairs*, July/August 1998, pp. 54-66.

⁴² I.W.H. Parry, Reducing Carbon Emissions: Interactions with the Tax System Raise Costs, *Resources*, summer 1997, 128, 9-12.

could reduce these extra costs by channeling the revenue from the carbon tax, if any existed, to reduce the labor and capital taxes, and thereby reduce the pre-existing distortions. Revenue recycling could shave control costs to 75 percent. But the political reality is that the odds of a tax or permit system that raises revenues to be recycled is as likely as seeing a Democratic Senator from Wyoming. Carbon permits most likely would be given away for free to producers because as it has been put: "if it don't bring no revenue to the government, it ain't no tax."

Fifth, costs will increase if proposals to further restrict flexibility by requiring that nations do some fixed percentage of emissions cuts at home. The EU environmental ministers met after Kyoto to define a strategy to restrict US efforts to use emission trading to reduce the costs of hitting its target. Seeing trading as flight from responsibility, the EU drafted text for the next negotiations to prevent "loopholes" in the protocol. Although no consensus was reached, some ministers argued that 50 percent of emission reductions must come from domestic cuts. Peter Jorgensen, spokesman for the EU commission, stated: "[a]s it is the leading emitter of greenhouse gases, the United States needs to take tough domestic measures...[the US] is going to try and buy its way out of its Kyoto commitments, and we are determined to prevent that from happening."⁴³ This quantity constraint of 50 percent do-it-domestic will inflate the costs to hit the target. "The burdens of global leadership are sometimes heavy, indeed."⁴⁴

The Origins of Technological Advance

What you choose to believe about the origins of technological advance will color the costs of Kyoto. For any given target and set of policy provisions, costs decline when consumers and firms have more plentiful low-cost substitutes for high-carbon technologies. Engineering studies suggest 20-25 percent of existing carbon emissions could be eliminated at low costs if people switched to new technologies like compact fluorescent light bulbs, improved thermal insulation, heating and cooling systems, and energy-efficient appliances. Engineers argue that the origins of technological advance are firmly rooted in non-price responses—people do the right thing for the right reason. And once they understand the potential benefits of low-carbon technologies, they will just switch.

Economists disagree. They see the origins of advance as drive by changes in relative price. Even if new technologies are available, people do not switch unless prices induce them to switch. They are unwilling to experiment with new devices at current prices. People behave as if their time horizons are short, perhaps reflecting their uncertainty about future energy prices and the reliability of the technology. Plus factors other than energy efficiency also matter to consumers, i.e., quality and features, and the time and effort required to learn about a new technology and how it works.

⁴³ Europe Union Starts planning Strategy to Stress Domestic Action Under Kyoto Pact, *Daily Environment Report* 1060-2976/98, 31-3-98.

⁴⁴ J. Firor, "US Needs to Lead by Example in Reducing Emissions," How workable is the Kyoto Protocol, Weathervane, www.weathervane.rff.org. March 1998

The difference in views on the origin is revealed in the debate about the autonomous rate of improvement in the energy-to-GDP ratio underlying all models of climate economics. Modelers debate the appropriate rate of "autonomous energy efficiency improvement" (AEEI), the approximation of the rate of change in the energy/GDP ratio when energy prices remain relatively flat. Although historical evidence suggests that the autonomous change is about 0.5 percent per year, some people argue the announcement of the Kyoto protocol will prompt businesses to accelerate the implementation of energy efficient methods of production. This "announcement effect" has been argued to increase the autonomous rate to 2 percent per year or more. These significant leaps are hard to justify, however, after examining the evidence. The Climate Change Action Plan (CCAP) thus far has spent a half-a-billion dollars thus far to reduce carbon emissions in the US by about 14MMTCE. Given we have to reduce emissions by over 400MMTCE, one would have to believe in that we are on the cusp of a very steep s-shape diffusion curve.⁴⁵

Economists remain wary of claims that alternative energy-saving technologies are readily available at no extra cost to consumers. People do not always take advantage of cost-effective, energy-efficient technologies that, in the long run, are good for both the pocketbook and the environment. At current prices, many consumers may not be willing to experiment with compact fluorescent light bulbs, improved thermal insulation, better heating and cooling systems, and energy-efficient appliances. Several studies have estimated that when consumers buy air conditioners, space-heaters, water-heaters, and refrigerators they implicitly apply a substantial discount to future cost-savings.⁴⁶ Their implicit time horizon is much shorter than the time horizon reflected in market interest rates. And even when they are presented with estimates of the likely future cost savings they pay more attention to immediate outlays. As our experience with the oil shocks of the 70s shows, choices do change when prices rise. Thus, to economists the most effective way to curb excessive energy consumption is to raise its price to reflect the harmful effects on the environment of burning fossil fuels.

But at the White House conference on climate change last October, President Clinton made it clear that he did not think Americans would not tolerate higher energy taxes to combat climate change.⁴⁷ His answer was to promote new energy-efficient technologies rather than impose steep energy price increases. The President's plan to devote \$6 billion for research subsidies and tax credits over the next five years. The Congressional Budget Office estimated that the US currently spends nearly \$5 billion annually on programs directly or indirectly related to climate protection. The CBO also concluded that the effect of current programs and tax policies "on total emissions was unclear...[but] it would probably be small....Since most of the funds are spent to learn

⁴⁵ *United States Climate Action Report*—1997, Department of State, July 1997.

⁴⁶ G. Metcalf and K. Hassett, Measuring the energy Savings from Home Improvements Investments: Evidence from Monthly billing Data, NBER working paper 6074, June 1997.

⁴⁷ Anonymous, "Clinton Opposes Higher Energy Taxes to Curb Global Warming," *New York Times* 7 October 1997.

more about [climate change] and to improve energy efficiency in the future, the short-term effect is minimal."⁴⁸

The theory of non-price policy response to technology adoption must recognize that preferences can prevent adoption to the levels predicted by engineering studies. High adoption rates will be realized once prices go high enough to eliminate the barrier, e.g., high carbon prices can provide the stimulus for some technologies to clear the barrier. Second, policies could be designed to try and eliminate barriers, but firms have found that these technologies are not cost-effective for them. Subsidies that increase their adoption will generate benefits less than the policies' costs.

Although economists do not see the average person switching energy sources just for the sake of switching, they do accept that the search for profits can create R&D breakthroughs that reduce the costs of backstop technologies. These breakthroughs change the relative prices that can induce energy users to switch from fossil fuels to solar. Based on a Hotelling model of scarcity rents, for example, Chakravorty et al. show that if historical rates of cost reduction in the production of solar energy are maintained—30-50 percent per decade, more than 90 percent of the world's coal will never be used.⁴⁹ The world will make the transition to the backstop technology: to solar from coal and oil even without a carbon tax. Global temperatures will increase by 1.5-2 degrees Celsius by around 2050, and will then decline steady back to pre-industrial levels.

Finally, what you choose to believe about technology depends on how you think about the interaction of the technologies of risk reduction. Climate change discussions usually separate human responses to potential threats into two broad categories—mitigation and adaptation. By mitigating, humans reduce the *odds* that a bad event happens; by adapting, they reduce the *consequences* when a bad event actually does occur. But for the most part, the climate change literature has modeled mitigation and adaptation separately. This is unfortunate since significant interactions are likely to exist between how people choose to mitigate and adapt. These risk reduction strategies probably complement or negate each other. Understanding the interaction between the two can help formulation what you think of Kyoto. The benefits of mitigation will be lower the more people can adapt to the climate.

People can privately and collectively affect the threats they confront. This realization may have profound impacts on the formal evaluation of climate change policy. First, researchers need to rethink the traditional risk assessment-risk management bifurcation currently applied to the research and management of climate change risk. Second, we should also acknowledge that both private and collective risk reduction actions be considered in benefit-cost analysis and program evaluations to avoid the under-valuation of risk reductions. Third, researchers should also consider the implications of when a person passes along a risk to someone else across time and space.

⁴⁸ Congressional Budget Office, *Climate Change: The Policy Challenge and Current Programs*, CBO August 1998.

⁴⁹ U. Chakravorty, J. Roumasset, and K. Tse., *Endogenous Substitution among Energy Resources and Global Warming*, *Journal of Political Economy*, 105, 1201-1234.

VI. A Choice of Vision

A moderate "broad, then deep" approach with gradual emission reductions made sense before Kyoto and it still makes sense today. Kyoto provides no additional benefits for the extra cost it will impose relative to this alternative benchmark. One might claim that this additional cost is the price of building international trust and securing a politically credible "first step." This might well be the case. But it is not obvious to everyone that this step would not have occurred anyway, or that the billions of redirect dollars could not be spent more usefully on a dozen other environmental, health, or safety issues.

But whether one thinks this matters depends on what Thomas Sowell calls your choice of vision. People with an unconstrained vision believe we all have a vast untapped morality buried within waiting to emerge with the right direction. Thus solutions like the Kyoto protocol are primary; the trade-offs involved are secondary. As Sowell puts it, "every closer approximation to the ideal should be preferred. Costs are regrettable, but by no means decisive." People with a constrained vision, however, weigh ideals against the costs of achieving them. Real incentives will be needed to get people to take on the goals of Kyoto intentionally. For now and the foreseeable future, the uncertainties of climate change leaves enough latitude so that whether you choose to believe the benefits justify the costs of Kyoto rests on your choice of vision.

Where to now? If climate change is really just about the developed world picking up the tab for benefits accruing to future generations in the developing world, there must be a better way—a more direct way—to do this than Kyoto. But if climate change is about more than this, we need to consider questions to forge a larger middle ground on benefits and costs. We need to find the price to induce the developing countries to come on board. Define the odds for catastrophe and surprise concepts. Quickly examine the nature of sinks to sort out whether the costs of measurement, verification, and enforcement problem exceed the benefits, thereby reducing the odds that this discussion degenerates into a sideshow distraction. Commission testbed studies on emission markets because effective institutional design requires no less; it worked for the spectrum markets, it can work for emission markets as well. Carefully evaluate the tradeoff frontier of flexibility and stringency within political constraints. Give more consideration to the incentives for technological progress created by different climate policies over the long term, including the opportunity cost of inducing innovation in climate protection versus other deserving goals. Finally, be vigilant that we aren't only talking to ourselves as we sharpen the benefit and cost estimates as events unfold and new research results come forth.

**Table 1: Total carbon dioxide emissions of Annex I Parties in 1990,
for the purposes of Article 25 of the Kyoto Protocol**

Party	Emissions (Gg)	Percentage
Australia	288,965	2.1
Austria	59,200	0.4
Belgium	113,405	0.8
Bulgaria	82,990	0.6
Canada	457,441	3.3
Czech Republic	169,514	1.2
Denmark	52,100	0.4
Estonia	37,797	0.3
Finland	53,900	0.4
France	366,536	2.7
Germany	1,012,443)	7.4
Greece	82,100	0.6
Hungary	71,673	0.5
Iceland	2,172	0.0
Ireland	30,719	0.2
Italy	428,941	3.1
Japan	1,173,360	8.5
Latvia	22,976	0.2
Liechtenstein	208	0.0
Luxembourg	11,343	0.1
Monaco	71	0.0
Netherlands	167,600	1.2
New Zealand	25,530	0.2
Norway	35,533	0.3
Poland	414,930	3.0
Portugal	42,148	0.3
— Romania	171,103	1.2
— Russian Federation	2,388,720	17.4
Slovakia	58,278	0.4
Spain	260,654	1.9
Sweden	61,256	0.4
Switzerland	43,600	0.3
United Kingdom of Great Britain and Northern Ireland	584,078	4.3
United States of America	4,957,022	36.1
Total	13,728,306	100.0

Data based on the information from the 34 Annex I Parties that submitted their first national communications on or before 11 December 1997, as compiled by the secretariat in several documents (A/AC.237/81; FCCC/CP/1996/12/Add.2 and FCCC/SB/1997/6). Some of the communications included data on CO2 emissions by sources and removals by sinks from land-use change and forestry, but since different ways of reporting were used these data are not included.

**Source: REPORT OF THE CONFERENCE OF THE PARTIES ON ITS THIRD
SESSION, HELD AT KYOTO FROM 1 TO 11 DECEMBER 1997
FCCC/CP/1997/7/Add.1. 18 March 1998.**

Table 2. Annex B

Quantified emission limitation or reduction commitment	
Party	(percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

*Countries that are undergoing the process of transition to a market economy.

Encouraging Early Actions Through Credits: How Many Reductions Are Possible?

Because the Kyoto target implies a significant reduction in US greenhouse gas (GHG) emissions in the first budget period (2008-2012), it is useful to consider incentives that government could offer to encourage voluntary emission reductions prior to 2008, thus helping the economy "ramp up" to the Kyoto target. One such incentive is permit distribution: the government could commit to distribute permits during the first budget period for actions taken prior to 2008. The strength of this incentive would depend on firms' expectations that a climate policy would be implemented in first budget period, and on the expected value of the permits. The expected permit value, in turn, depends on

- the cost of emission reductions (the higher the cost of achieving a given quantity of reductions, the more valuable the emission permits);
- the stringency of the target (the more reductions required, the greater the permit value); and
- the extent of international permit trading (the more extensive is permit trading, the lower the domestic permit price).

Consider a case in which firms believe with certainty that the government will issue permits on a ton-for-ton basis for early actions, and that there will be no international permit trading. Imagine that firms know that the economy will have to reduce emissions by 400 million metric tons (MMTCe) in 2008. Imagine further that firms also know that the economy's emission reduction cost curve never changes, and that it is linear: there are opportunities to reduce 200 MMTCe for \$50/MTCe or less, 400 MMTCe for \$100/MTCe or less, and so on.

In this case, firms know that if they take reductions prior to 2008, they will receive permits worth \$100/MTCe in 2008. If a firm reduces emissions by one ton in 2007 at a cost of \$50/MTCe, and receives a permit in 2008, it will make a 100% profit. By the same logic, if firms wanted to make, say, a 10% profit, in 2007 they would take any action that reduced emissions at a cost of less than \$90.91/MTCe in 2007, because these \$90.91 investments in 2007 would earn them \$100 in 2008. Using the linear cost curve, this turns out to be 364 MMTCe of reductions in 2007. Doing a little arithmetic, we can figure out that firms that wanted a 10% return on their investments would find it profitable to take 2,134 MMTCe of reductions between 2000 and 2007 if they believed they would receive \$100/MTCe permits in 2008.

In contrast, consider a case where there will be international trading, which will reduce the quantity of domestic emission reductions to 200 MMTCe. In this case, permits will be worth only \$50/MTCe in 2008. If a firm reduces emissions by one ton in 2007 at a cost of \$50/MTCe, and receives a permit in 2008, it will make not make any profit at all. By the same logic, if firms wanted to make a 10% profit, in 2007 they would take any action that reduced emissions at a cost of less than \$45.45/MTCe in 2007, in 2006 less than \$41.32/MTCe, and so on. Firms would take only half as many reductions as they would if the permits were going to be worth \$100/MTCe. So international trading, by reducing the value of domestic permits, reduces the incentive for firms to undertake early actions in order to earn permits.

The situation gets more complicated if firms do not know for sure whether there will be any regulation or not; whether there will be international trading or not; whether they will be guaranteed permits in exchange for early actions or not; or if they don't know exactly what the cost curve will look like. In principle, the analysis could be extended to take these contingencies into account. However, there is an additional problem: for such a scheme to work well, regulators would need to be able to distinguish between actions undertaken at a cost, that would not have been undertaken in the absence of the incentive, and actions that would have been undertaken anyway (so-called "anyway" tons).

A simple quantitative analysis. The table below summarizes a simple analysis of the actions that firms might undertake prior to 2008 to receive early reduction credits, assuming that they believed that early reductions would entitle them to permits during the first budget period (2008-2012), on a ton-for-ton basis.

Summary: Analysis of Early Reduction Credits Using SGM/OAR Costs				
1) Reductions 2000-2007 in Response to Permit Distribution (MMTCE)				
Discount Rate	3%	5%	7%	10%
No Int'l Trading	4050	3742	3464	3095
Annex I Trading	1823	1684	1559	1393
Global Trading	607	561	519	464
2) Reductions 2000-2007 in Response to Permit Distribution (Share of Reductions Required to Meet Kyoto Target 2000-2007)				
Discount Rate	3%	5%	7%	10%
No Int'l Trading	124%	115%	106%	95%
Annex I Trading	56%	52%	48%	43%
Global Trading	19%	17%	16%	14%
3) Reductions 2000-2007 in Response to Permit Distribution (Share of Permits to be Distributed 2008-2012)				
Discount Rate	3%	5%	7%	10%
No Int'l Trading	52%	48%	45%	40%
Annex I Trading	24%	22%	20%	18%
Global Trading	8%	7%	7%	6%
4) Bank/Borrowing Permit Price 2010 (\$1995/MTCE)				
Discount Rate	3%	5%	7%	10%
No Int'l Trading	\$ 149	\$ 149	\$ 149	\$ 149
Annex I Trading	\$ 43	\$ 43	\$ 43	\$ 43
Global Trading	\$ 8	\$ 8	\$ 8	\$ 8
5) Total Value of Permits Distributed 2008-2012 (\$1995 Billions, Discounted to 2010)				
Discount Rate	3%	5%	7%	10%
No Int'l Trading	\$ 1,154	\$ 1,154	\$ 1,152	\$ 1,149
Annex I Trading	\$ 333	\$ 332	\$ 332	\$ 331
Global Trading	\$ 60	\$ 60	\$ 60	\$ 60

The analysis is based on the following assumptions:

- The mitigation cost curve is based on a combination of the Second Generation Model's (SGM) 2010 fossil carbon cost curve and the EPA Air Office's (OAR) 2010 mitigation cost curves for other GHGs. To simplify the analysis, the curve used is actually a power curve that closely fits the data from these cost curves (this power curve somewhat understates the cost of the lowest-cost reductions). The mitigation cost curve is assumed to hold for each year from 2000 to 2012 and is assumed not to be affected by mitigation actions, either positively or negatively. That is, early reductions neither raise nor lower the mitigation cost curve in subsequent years.
- Total US GHG emissions grow by about 1.3% per year from roughly 1,860 million metric tons of carbon equivalents MMTCe in 2000 to roughly 2,160 MMTCe in 2012, requiring about 2,860 MMTCe in emission reductions in the first budget period to reach the annual target of 1,546 MMTCe. About 7730 MMTCe of permits are distributed in the first budget period.
- The analysis makes three separate assumptions about the extent of international permit trading (none, Annex I only, and full global trading) and four separate assumptions about the discount rate applied (3%, 5%, 7% and 10%).
- With no international permit trading, the marginal mitigation cost to achieve the required 577 MMTCe of reductions is \$151/MTCe (\$95). With Annex I trading, only 268 MMTCe of domestic cuts are required, at a marginal cost of \$44/MTCe. With full global trading, only 87 MMTCe of domestic reductions are needed, at a marginal cost of \$8/MTCe (the low cost being a function of the power curve fit to SGM/OAR data).
- The analysis also assumes that regulators can reliably distinguish between "real" reductions and baseline actions that appear to reduce emissions, and reward only real reductions.

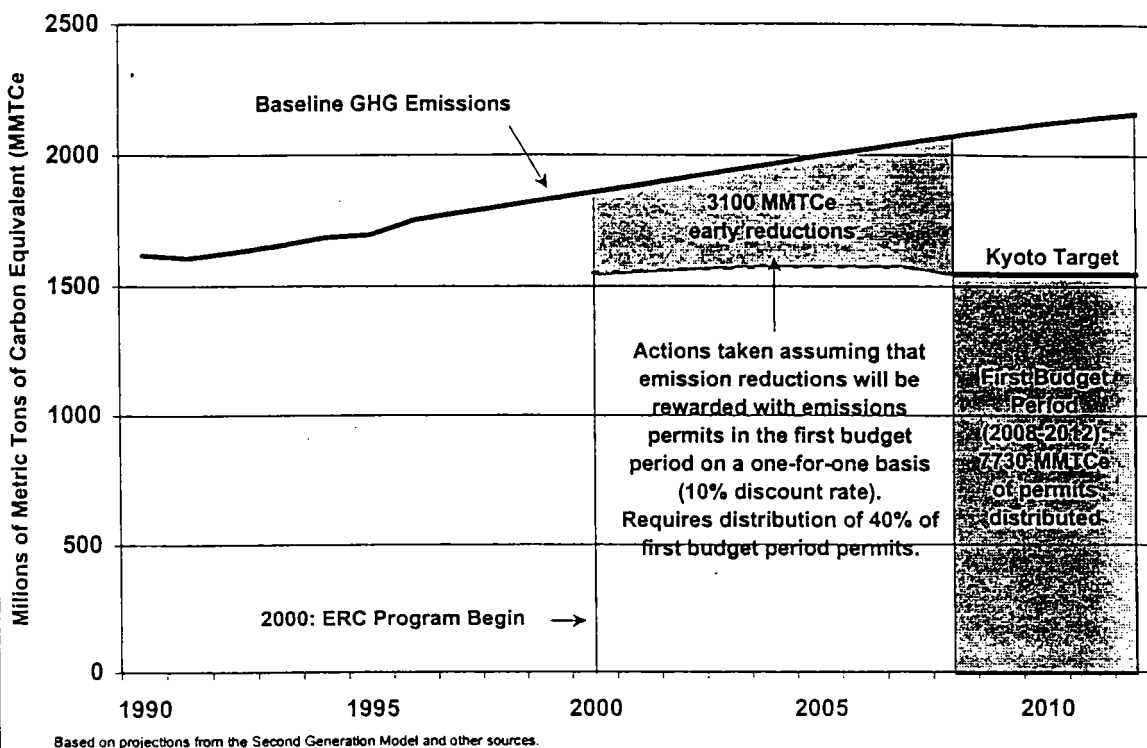
The analysis suggests that in the absence of international permit trading, the certain prospect of permits for early action would motivate firms to take a considerable quantity of reductions, because the permits are expected to be worth \$151/MTCe in 2010. Even if individuals and firms require a 10% profit (and thus apply a 10% discount rate to the future value of permits), they would still find it profitable to take nearly 400 MMTCe per year in reductions – over 3 billion MTce in reductions prior to 2008 – to qualify for permits. In this case, they would receive 40% of the permits handed out in the first budget period, and nearly meet the Kyoto target between 2000 and 2007. (See the graphs below.)

Even with full global trading, early reduction credits could spur firms to reduce emissions by nearly 60 MMTCe per year – over 460 MMTCe prior to 2008 – achieving roughly 15% of the reductions needed to achieve the Kyoto target prior to 2008, and requiring as compensation the

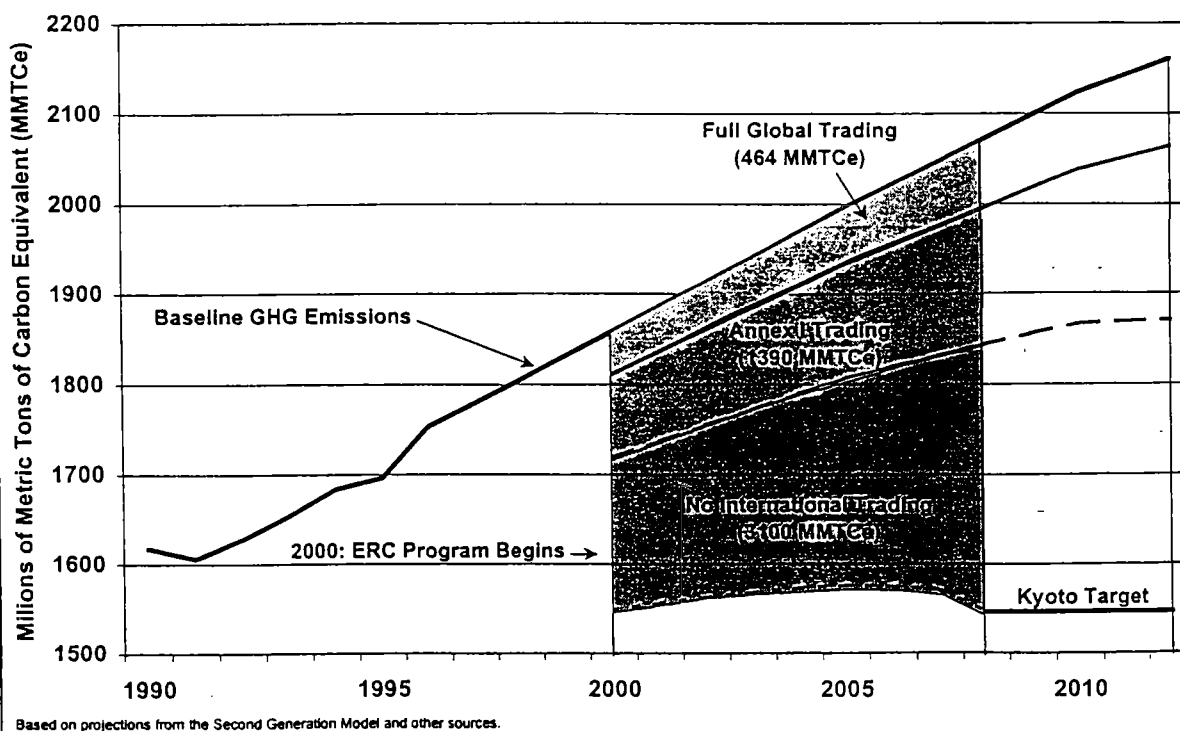
distribution of roughly 6% to 8% of the permits that would be distributed during the first budget period.

The results are partially dependent on the rather strong nonlinearity of the SGM/OAR cost curve, which allows for a fairly large number of reductions at low cost – over 100 MMTCe at a cost of \$10/MTCe. Nevertheless, even assuming a perfectly linear cost curve that has the same permit price at 600 MMTCe as the SGM/OAR curve yields roughly 300 MTCe in reductions in the full global trading case, more than 10% of the reductions needed to meet the Kyoto target in the 2000-2007 period at a cost of less than 4% of the permits to be distributed in the first budget period.

Early Reduction Credits With No International Permit Trading



Early Reduction Credits Under Different Trading Assumptions



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From: Jon Gruber

Re: Early Credit Memo - Revision

Here is my last crack at the early action memo. The major change is the addition of Section II, on baseline protection vs. credits for early action. I hope that this reflects our conversations.

I unfortunately have not been able to work on an "outside" version of this memo. Bob Cumby, who will be joining Economic Policy shortly, will be taking the lead on this issue. Until Bob joins us, comments can be referred to David Wilcox.

It has been a pleasure working with all of you. Please stay in touch.

Jon

Towards a Proposal for an Early Credit Mechanism

I. BACKGROUND ISSUES

Why Early Credit?

The motivation for an early credit mechanism is threefold:

- To reduce the costs to the U.S. economy of compliance with the Kyoto Protocol. Economic costs are minimized when firms adjust more slowly over time to their required changes in production patterns, rather than suddenly in 2008. By acting early, firms can incorporate carbon considerations into their natural pattern of capital turnover.
- To provide the environmental benefit of earlier emissions reductions. While it is the ultimate concentration of greenhouse gasses in the atmosphere that determines global warming, there are still some small benefits to reductions sooner rather than later. By reducing emissions a decade or more before the end of the first commitment period, we reap these benefits.
- To build support in the business community for the Kyoto Protocol, and motivate their action.

Why Should We Provide Incentives for Early Action?

If early action will lower the costs of compliance with the Kyoto Protocol, why won't firms in the U.S. simply take these actions themselves? What is the role for a government inducement to early action? There are at least two rationales for such a governmental role.

- Catalytic Effect: Firms face two types of uncertainties about the Kyoto Protocol:
 - Uncertainty about the seriousness of these reduction targets. We cannot commit future Administrations or Congresses to the same seriousness that we have demonstrated on this topic.
 - Uncertainty about the ultimate allocation mechanism. Firms cannot be sure about how permits will be allocated in 2008: by auction or grandfathering; and, if the latter, to whom they will be grandfathered. As a result, the value of emissions reductions today is unclear: if there were definitely going to be an auction, then emissions reductions today would be of value to reduce the cost of meeting the 2008-2012 target; but if there is going to be grandfathering at the firm level, then there is no great need to reduce emissions (indeed, firm wealth may be maximized by having high emissions, to establish a baseline).

Given these uncertainties, firms may be reluctant to make investments in emissions reductions now, even if these investments are cost effective from the perspective of 2008. Thus, providing a credible early credit incentive can have a catalytic effect, promoting firms to undertake these investments despite the residual uncertainties.

- Technological Pioneering: In a context in which cost-reduction strategies are to some extent unknown and uncertain, it may be useful to induce some firms to act as pioneers, discovering what works and providing demonstration projects for other firms.

How Much Early Credit?

As is discussed below, we will cap the level of early action credit. But the overarching question is the ease of qualifying for these early credits, given the level of the cap.

- The advantage of making it easy to qualify is that it increases the extent to which firms can take advantage of this program. This could increase the base of support for climate change action in the long run. Moreover, making it easy to qualify avoids the administrative burden of the alternative, which requires the determination of whether the tons claimed are actually additional.
- The disadvantage of making it easy to qualify is that, with a given cap, it devalues the early credits that are given. This may reduce the environmental and economic gains from early credit, since there is a smaller economic incentive on the margin to undertake real action to incrementally reduce emissions. That is, to the extent that firms can qualify for actions that are not additional (producing "anyway" reductions), we reduce the value to firms who want to take truly additional actions.
- On the other hand, if we make it too difficult to qualify, then we may actually reduce total early actions to reduce emissions -- since actions with modest environmental benefits aren't rewarded.

Do We Prejudge the Allocation Mechanism for 2008?

An important consideration with an early credit mechanism is whether its structure, or indeed its very existence, prejudices the allocation mechanism that we will be using in 2008.

- At this point, we want to keep our options open both as to whether there will be an auction or some other allocation system, and, if the latter, where in the production/distribution chain the allocation will take place.
- In theory, an early credit mechanism does not prejudice the allocation structure for 2008. The mechanism will allocate *credits* redeemable for permits during the first budget period. These permits can then be traded in the permit trading system, regardless of

whether the holder is at the level at which trading will occur. That is, if a utility holds an early credit, and permit redemption is upstream, then the utility will sell that credit to upstream holders of permits for its value in the trading system.

- In practice, it might be natural to infer from the very existence of an early credit system that allocation will be achieved by grandfathering at that level in the production/distribution chain. Care should be taken to make clear that the early credits are not permits, and that the early credit approach does not in fact prejudge our decisions for 2008.

II. THE FORMS OF EARLY CREDIT - BASELINE PROTECTION VS. CREDITS

Baseline Protection

We can distinguish two forms of early credit. The first is *baseline protection*. This is an assurance that firms will not be penalized through the ultimate allocation system for acting early to reduce emissions. Assurances against penalizing early actors can be provided several ways:

- If emissions allowances are allocated as a percentage of emissions (or activity such as fuel sales) in a reference year, by choosing a year prior to the start of the cap and trade.
- By allocating allowances in terms of a performance-based benchmark (e.g., greenhouse gas emissions per kWh output).
- By auctioning allowances.

It would not be necessary to specify what means would be chosen, but only to provide assurances that the approach ultimately adopted will not penalize early action.

Baseline protection has three advantages:

- It provides automatic rewards for firms that are early actors
- It removes the uncertainty about allocation mechanism described above, which inhibits early action
- As a result, it removes any incentive for firms to resist early action because it might reduce their allocation in 2008 -- or even to raise emissions in the hopes of having more permit wealth allocated to them in 2008.

But committing today to our baseline for 2008 also has four disadvantages:

- It may be politically untenable to commit today to such an enormous wealth reallocation 10 years from now.

- It may compromise our ability to choose an auction mechanism in 2008, since it will automatically create a class of opponents who feel that they already have claims on the system, and for whom this allocation is their primary reward for early action.
- It may be unwise from a policy perspective to commit now to the allocation of a valuable property right that may be critical to successfully paving the way for implementation in 2008.
- The ultimate allocation mechanism in 2008 may only be able to reward actors at one point in the production chain, whereas an early credit program of the type described below may be able to reward actors at different points in the production chain. Thus, there are actors who may benefit from early action but not baseline protection.

If we choose to provide some baseline protection, we may also want to speak to the year that we will use for the baseline. There are two strong arguments, on policy grounds, for *using a year after 1998*:

- The first is data. There are not consistent data systems across all firms today that would allow for an effective uniform measurement of emissions levels or rates in order to provide for allocation in 2008.
- The second is incentives. Providing a base year after today does lead to potential incentives to increase emissions between now and the base year. But there is no such incentive in choosing today vs. 1993 (for example), since actions before today have already been taken. This implies that we should shift our reward structure towards actions taken from today onward, to maximize incentives for early reductions.

The political consequences of choosing a year after today are mixed.

- There are constituencies that have been taking actions under CCAP that expect to be rewarded with baseline protection, and who will protest a baseline later than 1993 (or even 1990).
- But there are also additional political disadvantages to choosing such an early year, as firms with growing emissions since 1990 or 1993 can complain that they are being penalized for actions that they took before the Kyoto Protocol was even in place.

Credits for Early Actions

The second type of early credit is to explicitly provide *credits for early actions*. These would be explicit credits for actions taken before 2008, that could be redeemed in some fashion for permits in 2008 (according to details described below). The sum amount of permits that are given away through an early credit program would be removed from the amount of permits allocated in 2008 through other mechanisms (such as grandfathering or an auction). But it is important to recognize that an early credit program does not reduce the total amount of permits available in

2008; it simply reallocates the wealth by shifting some from those who would be allocated permits in 2008 to those who took early actions.

Combining Baseline Protection with Credits for Early Action

Combining these two concepts may or may not lead to "double-dipping".

- For example, if we commit to a 1993 baseline for allocation in 2008, then we have already rewarded firms for their actions to reduce emissions since 1993. If we then had an early credit program, it would doubly-reward those firms that took early actions.
- On the other hand, if we commit to a 2000 baseline, then early credit for years before 2000 would be the only net reward for emissions reductions in that era.

One option here that would provide maximum flexibility to firms, but avoid doubly-rewarding early emissions reductions, would be to give firms a choice of baseline protection or credits for early action. That is, firms could choose one of:

- 1993 baseline, no early credits
- 2000 baseline, early credits only for 1993-1999
- No baseline protections, early credits from 1993-2007

Recommendation: There is no clear consensus on the appropriate combination of baseline protection and early credit. There is majority, but not unanimous, support for having baseline protection that uses a base year no earlier than today.

III. IMPLEMENTATION ISSUES

A Two Part Early Credit System

The working group recommends that we implement a two part system

- In the first part, we will give credit for actions taken before the system is announced, for example, January 1, 1999. Since firms will already have committed the resources to take these actions, these *very early action credits* will not affect firms' decisions. Instead, the goal of very early action credit is to make good on our commitments to those who have already acted early, and to lay a foundation for a post-announcement early action system.
- There should be a separate cap for credits for this period. This part will rely on the best available data from firms for the past, and will involve auditing firm-specific reports on emissions.

- In the second part, we will give credit for actions taken between today and 2008. This part will have its own cap, but the value of that cap may depend on the level of early credits claimed for the first period. Before the beginning of the second part, we will put into place a common data reporting system to ease the monitoring and measurement of early credit. This system will form the basis of our ultimate reporting, and possibly allocation, system in 2008.

Setting the Caps

It is clear that a cap on the total value of early credit is required to ensure that we do not today make our ultimate allocation decision for 2008. This cap becomes particularly important if there is a relatively loose definition of what activities qualify for early credit.

There are two open issues with a cap:

First Come First Served vs. "Truing Up" at End of Period

One alternative is to provide credits which have a full, predetermined value (such as one credit equals one ton of emissions). Given a binding cap, these credits would have to be allocated on a first-come-first-served basis.

Pros:

- Provides firms certainty over the value of their actions, if they act early.
- Gives an incentive for very early action.

Cons:

- No incentive for earlier action for period ending today, since actions have been taken.
- Could create substantial inequities between firms who apply for credits only days or weeks apart, once the cap is hit.
- Going forward, this approach is incompatible with approaches other than project-by-project evaluation, and therefore is susceptible to gaming of the type described below (firms could qualify for early credit for a project in 2000, and then undo these gains with other environmentally unsound projects later).

The other alternative is to "true up" the value of credits at the end of the period, by comparing the number of credits claimed with the level of the cap. The credits would be worth up to one ton each, and perhaps less if there are more credits claimed than the size of the cap.

Pros:

- Compatible with other evaluation approaches, such as comparing net emissions or emission rate changes over the period to a baseline value.
- Doesn't create inequities, since credits to all firms have same value.

Cons:

- If we go with a project-by-project evaluation approach, creates uncertainty over the value of that project.

Recommendation: The general sense of the working group is that *we should use a "truing up" approach*. A first-come-first-served approach should only be considered if we decide for other reasons to use a project-by-project evaluation methodology

The Level of the Cap

Setting the cap at a relatively high level will maximize the value of the early credit program. But, at the same time, it limits the amount of credit that we have to allocate in 2008.

- If we allocate by auction in 2008, this implies less revenue for the government at that time.
- Even if we use another allocation mechanism, there may be political or economic reasons why we want to be able to decide in 2008 how to allocate, rather than being precommitted due to an early action plan.

How large might early credit claims be? One industry estimate concludes that early credit claims are unlikely to amount to even 10% of our 2008-2012 emissions budget. Analysis based on results from Battelle's Second Generation Model (SGM) suggests that the totals could be larger. The analysis assumes that firms will undertake any early actions that make a profit, calculating that with Annex 1 trading, firms would find it profitable to undertake 1.5 billion tons of reductions between 2000 and 2007 -- about 20 percent of the permits the US will have in the first budget period.

*The Appropriate Measure for Early Credit*Emissions Levels

Pros:

- The level of emissions is the ultimate metric for meeting our Kyoto target.
- Could be appealing to higher-emitting industries, which present the greatest opposition to our efforts.

Cons:

- Rewards firms simply for shrinking, and penalizes firms simply for growing.
- May reward firms for reductions that would have occurred anyway.
- Potentially difficult data problems with firms that split apart or merge, and with outsourcing.
- Some potential for gaming across firms, whereby they strategically combine assets to take advantage of program with little or no real environmental benefit.

Emissions Rates (e.g. carbon per unit of output)

Pros:

- Appropriately adjusts for changes in scale of business to reward firm efforts to reduce carbon intensity.
- Can eliminate most "anyway tons."

Cons:

- Doesn't solve problems with firm definition or with potential for gaming across firms.
- Depending on the specific definition, can create measurement problems.
- Begins to build constituency around an emissions-rate approach, which is inconsistent with our obligations internationally.

Project-by-Project Evaluation (akin to JI)

Pros:

- Limits problems with defining the firm, since doesn't require firmwide baseline measurement and emissions tracking (as project is evaluated assuming no change in other firms' behavior).

Cons:

- Could be administratively unwieldy to evaluate each project for qualification for early credit.
- Ignores increases in emissions, as firms claim credits for projects that reduce emissions but at the same time don't report projects that increase them.
- Could lead to a long list of individual projects and higher transaction costs.
- Government seen as poor at picking technological winners and losers.
- Could be perceived as akin to "policies and measures" approach that the US business community opposed internationally.

Recommendation: The general sense of the working group is that *emissions rates are the preferred approach here*. In particular, EPA has data from several electric utilities that show that emissions levels vary widely due to factors such as production spikes and plant sell-offs, leading to inequities and potentially large amounts of "anyway tons". But we should remain open on this pursuant to consultation with other interested parties.

Defining the Baseline

Changes from Starting Point: Under this scenario, reductions in emissions levels or rates from some base year (e.g. from 1993) would be credited for early action.

Pros:

- Provides relatively easy qualification for early credit, particularly using emissions rate metric.
- Rewards firms that recognized the President's policy directions and kept good data.

Cons:

- Apart from electric utilities, historical emissions information not readily available at the firm level, making implementation during first period difficult.
- For emissions levels, this approach penalizes firms that grow, and rewards firms that shrink.
- Broad participation unlikely, and some industries would be discouraged by low baseline.

Changes from Business As Usual: Under this scenario, we would project business as usual trajectories for emissions levels or rates, and reward only improvements from those business as usual projections. This requires forecasting what would have occurred.

Pros:

- Allows us to account for firm growth or shrinkage in using emissions levels.
- May allow us to more accurately account for "anyway" reductions that arise from natural evolution of the business, and guarantee that more additional reductions will get credit.

Cons:

- Administratively an order of magnitude more difficult than simply using starting points. Very difficult to define business as usual.

Changes from a Projected Reduction Schedule: Some have suggested that, rather than reward firms that have simply reduced from baseline, we instead reward only firms that have reduced on a schedule that realistically moves them towards a Kyoto target. This would take the form, for example, of giving early credit only to those firms that reduce emissions rates by more than x% per year, or for firms that reduce emissions levels below a path that would take them to x% below (above) 1990 levels by 2008.

Pros:

- Minimizes credit for "anyway" tons.

Cons:

- Flip side of making it tough to qualify is that it reduces the number of firms that can benefit from early credit.
- Hard to determine the right baseline trajectory.
- Harder to administer than a simple change from a starting point, although probably easier than a business-as-usual approach
- Depending on how it is implemented, still may not solve the problem with emissions levels of penalizing growing firms or rewarding shrinking firms.

Predefined set of eligible actions or technologies: Another approach would set up a menu of actions that would be eligible to receive credit (e.g., improving the carbon efficiency of a boiler by a prespecified amount, installing a high efficiency chiller, etc.). This is the same approach that was taken in the CCTI program of tax incentives. For any action on the menu, a particular amount of credit would be granted according to a predetermined schedule.

Pros:

- Easy to administer once list of actions is developed and crediting schedules established.
- With a list of actions that are clearly off the BAU path, can move towards ensuring that we are not rewarding "anyway" tons.
- Rewards specific pioneering activities.

Cons:

- Fundamental difficulties with picking winners. Very effective if the activities are truly incremental, but potential to err in picking activities that are too difficult to accomplish (and thus limiting appeal and total impact of program) or in picking "anyway" activities, perhaps due to interest group pressure.
- May exclude legitimate but harder to define actions, limiting participation.
- May be difficult to respond to evolution of approaches to emissions reductions with this predefined menu.
- Fails to reward innovation and creativity.

Recommendation: The working group has expressed some preference for granting early credits for emissions rates reductions that exceed a 1 to 2% reduction in emissions rates from the starting point. There is also some uneasiness among many members about picking predefined sets of eligible technologies, while others emphasize the administrative feasibility advantages of this approach.

Hybrid Approaches

A hybrid approach could address both the issues of defining a baseline, and setting the appropriate measure. For example:

- Firms could choose whether to use emissions levels or rates.
- If they choose emissions levels, they receive credits only for reductions in emissions below a level required to take them to 1990 levels by 2008.
- If they choose emission rates, they receive credits only for reductions in rates beyond a baseline reduction of 1% per year from the starting year.

Pros:

- Avoid imposing one-size-fits-all solution to menu of choices above.

Cons:

- Increases gaming opportunities.
- Dilutes value of early reduction credits, reducing incentive to take real actions.

The Scope of Emissions Measurement

Direct and Indirect Emissions from Production

Firms are responsible for both direct emissions (those coming out of their stacks) and indirect emissions (those emissions occurring beyond the boundary of the firm as a result of the firm's activity). The question of whether to include these indirect emissions raises a standard tradeoff between comprehensiveness and administrability.

- Including direct emissions and only the most obvious, indirect emission sources (e.g. electricity-related emissions) may preclude cost-effective reduction opportunities, or lead to increases in emissions that are not identified at the company level.
 - For example, a company may decide to switch from trucks to rail (or rail to trucks) for shipping; in theory the associated emissions reductions (increases) should be rewarded (penalized). Similar issues arise with firms' actions to reduce employee commuting through mechanisms such as parking cash-out.
- However, as companies are required to include more sources of indirect emissions, reporting requirements will become more burdensome.
- An additional complication here is that any firm's indirect emissions are presumably another firm's direct emissions. If a producer shifts from trucks to rail, that producer will have fewer emissions, as will the trucking firm, but the rail company will have more. So any firm can be put in the position of having emissions which are their direct responsibility, but also emissions which are not. Who will make the determination that some of a firm's emissions reductions are not eligible because those reductions have been credited to another firm?

Emissions From Production vs. Consumption

Firms would qualify for their own energy use in production. This covers most of the industrial/energy sector, but is not very useful for autos and other manufacturers of consumer products, who will want credits for reducing the carbon intensity of their products.

- For the auto sector, we could also consider providing credits for the carbon intensity of cars -- e.g. credits for increasing energy efficiency above CAFE levels. In practice, the auto industry might want to not even have this benefit, due to concerns about increased

CAFE (as witnessed by the debate over our current proposed tax credit).

- This distinction between passive and active reductions also arises with demand side management policies of utilities. These policies will lower industrial or residential electricity use. Should the utility get credit for this reduction? Or, should credit be given to the industrial consumer? If we don't reward the utilities themselves for these activities, then we will reduce incentives for efficiency-enhancing activities that are currently a very important component of CCAP. Further, granting credit for passive reductions (e.g. for high-efficiency kilowatt hours purchased by a utility's customers) would greatly complicate the system.

Recommendation: The working group has expressed a preference for direct production-related emissions only, but recognizes the difficulties with excluding indirect and consumption-related emissions.

Data Issues

Defining a Firm

For using either emissions levels or energy efficiency indicators, it is critical that the unit of observation be the entire firm, rather than sub-units (such as plants); otherwise, there is expanded potential for gaming, whereby firms submit for early credit those units that are performing well on emissions or efficiency, and do not submit those units that are not.

How should a firm be defined for purposes of an early credit program? In general, environmental regulations do not apply to firms (although enforcement does); they apply to devices located at particular plants or facilities in a particular geographic location. In the industrial sector, regulations apply to individual facilities defined by legal property boundaries. In the electric sector, an individual electric generating unit (of which there may be several in a single plant) is usually the point of regulation. Under a voluntary program, however, focusing solely on individual facilities or units could lead to emissions leakage. As such, reporting, monitoring and verification may be required both at the facility and the firm level.

Defining a firm is not simple (which is why most environmental regulations apply to facilities). For example, a single parent firm may own several individual electric utility companies. In other cases, plants may be owned and operated by two or more different companies, or individual facilities may be jointly owned. Mergers and divestitures will make it even more difficult to track company-level emissions over time. In order to avoid leakage and obvious gaming strategies such as rearranging assets or outsourcing, it may be necessary to require firms to report any changes in ownership of facilities, or even to maintain comprehensive GHG accounting systems in order to participate in the early credit program.

It will be difficult to define rules for crediting actions taken between 1993 and 1998. With the

exception of electric utilities, firm specific emissions information is limited. In addition, many firms have reported emission reduction actions on a project specific basis under Section 1605(b) of the Energy Policy Act of 1992. This program allows entities to select their own baseline for reporting and likely consists of a large number of "anyway tons."

Measuring Carbon Efficiency

The basic concept of carbon efficiency is to compare carbon utilization to production. If production is measured by dollars of sales, this is fairly straightforward; but dollars of sales has a number of problems, such as the fact that changes in market prices which have nothing to do with energy or carbon efficiency will change the measured efficiency. For example, how would we account for the fact that auto prices are rising over time while computer prices are falling. If production is measured by units of sales or production, we face a new issue of how to measure units when a company's product mix may be changing.

Other Logistical Issues

Different Gasses: We could give credits for all types of gasses, or only for CO2. Because measurement protocols exist for such gases and there are some extremely cost-effective early action opportunities, inclusion of non-CO2 gasses is warranted. This would also expand the eligibility for the program to a wider set of actors.

Sinks: The program could include sinks, although in this instance the inclusion would have to be on a project-by-project basis, which may raise issues of consistency if we don't choose this approach for other sectors. Again, there appear to be many cost-effective opportunities for taking action, and inclusion of sinks would also expand the eligibility for the program to a wider set of actors. However, any decision must be taken with careful consideration of its implications for the international negotiations regarding sinks. Options include:

- No credits for sinks
- A limit on the amount of credit (e.g., 25%) for sink enhancement within the overall early reduction/credit program
- Equal treatment of sinks

Interaction with CDM Early Credits: Under the Kyoto Protocol, after the year 2000 firms can qualify for early credit for CDM activities. These credits are added to the first period budget. This can easily be integrated with the domestic early action program by separately accounting for CDM credits, giving the party involved a full emissions credit (as opposed to a credit which is worth some fraction of a credit in 2008), and adding that credit to our budget in 2008.

DEPARTMENT OF THE TREASURY
WASHINGTON, D.C. 20220

October 22, 1997

MEMORANDUM TO: DEPUTY SECRETARY SUMMERS

FROM: JONATHAN GRUBER

RE: Responses to Your Questions on Climate Change

You had asked nine questions related to the economic analysis of the administration's climate change proposal:

Variation in Gas and Energy Prices Over Time

Depending on the ultimate rise in carbon permit prices, the increase in gasoline prices expected from the President's plan may be no larger than the normal month-to-month and year-to-year variation in these prices.

Retail gasoline prices vary considerably from one month to the next. For example, in November 1995, new rules requiring oxygenated fuels in the winter months went into effect in Washington and several other metropolitan areas. This caused the price of gasoline at the pump in the Washington area jumped by 10 cents per gallon overnight — an increase equivalent to a \$40 per ton carbon tax, yet few consumers noticed. In the same way, the seasonal increase in summertime demand raises gasoline prices by several cents per gallon for several months each year.

Year-to-year changes have often been greater than the price change expected to result from the President's plan. We attach to this memo (TAB A) a graph of gas and energy prices since 1970, as well as a printout of the underlying data points.

- The table shows: real gas prices; the year to year change; the energy price index; and the year to year percentage change in that index.
- The average of the absolute value of year to year changes since 1970 for gas prices is 11 cents; this is equivalent to the gas price increase from a \$42/ton price of carbon. There are five years over this period in which price changes exceeded 26 cents, or the equivalent of \$100/ton
- The average from 1983 to 1997 is 8 cents, equivalent to a \$31/ton price of carbon; there is only one large change over this period.
- The changes in overall energy prices is much less pronounced year to year, and does not seem to make the point as well.

Moreover, the effects of the President's plan would not all be felt in one year, further dampening

the effect on prices.

We should note, however, that this argument *appears to contradict the comparison you have drawn with the OPEC oil shocks throughout the internal Administration debate.*

Historical Perspective on Energy and Resource Utilization

After both oil shocks, we heard predictions of the catastrophes that lay ahead -- oil prices would continue to climb, and the economy would crash. For example:

- On March 31, 1979, President Carter said, "There is a dwindling supply of energy sources. Prices are going to rise in the future no matter which party occupies the administration in Washington, no matter what we do." Actually, prices then fell for five straight years, from 1981 through 1986. In 1982, the economy launched its longest postwar expansion, which continues today, 15 years later. The Clinton Administration's climate policy is not expected to have nearly the effect on energy prices than the oil shocks.
- The 1972 bestseller, *The Limits to Growth*, contained dire predictions of impending resource depletion: the world would run out of gold by 1981, mercury by 1985, tin by 1987, zinc by 1990, petroleum by 1992, and copper, lead, and natural gas by 1993. None of these predictions came true; indeed the real prices of natural resources have been steadily dropping.

We attach (TAB B) a list of other recent resource forecasts that turned out to be very wide of the mark.

Detailed Evaluation of the Emissions Implications of Electricity Restructuring

We attach to this memo (TAB C) a draft memo from the Energy Department on carbon emissions implications of restructuring, including the administration add-ons of the RPS, the Public Benefits Fund, and green marketing. Under pressure from EPA, the Energy Department has presented a broad estimate, ranging from an emissions increase of 20 MMT to an emissions reduction of 84 MMT. This consists of a narrower range of effects of retail restructuring itself (-25 to +33 MMT), along with modest impacts of administration add-ons (-36 to -13 MMT). The consensus among economics experts such as Paul Joskow is that the *best guess for the long run is a small emissions reduction* (on the order of 20-40 MMT).

Relative to trend emissions in this sector, *this consensus is plausible.* Current emissions in the electric sector are 506 MMT, projected to rise to 626 MMT in 2010. So the consensus estimate of a 20-40 MMT reduction represents a reduction in emissions growth of one-sixth to one-third; even the upper bound estimate would have emissions growing by almost 10% above today's level.

The Potential for Worldwide Trading

We attach to this memo (TAB D) a qualitative analysis describing the great potential of international cooperation for reducing carbon abatement costs. In particular, the attachment discusses how the energy inefficiency and greater expected growth of non-OECD countries make joint implementation (JI) and permit trading important avenues for reducing costs. We note in particular that a World Bank study suggests that emissions reductions in China before 2020 could save roughly as much in carbon emission as the U.S. would have to reduce to achieve 1990 levels by 2010. Anecdotal evidence describes the untapped potential for efficiency gains in developing and transitional economies and also highlights the success of JI pilot projects.

How do we Distinguish Our "Phase I" Plan from the Climate Change Action Plan?

Phase I of the president's plan calls for new technology spending of roughly \$1 billion per year, but no explicit price of carbon. The question is whether this represents a real step beyond the Climate Change Action Plan, which has been regarded by some as a failure. The White House has produced a good set of talking points on this issue, which we draw on and expand here:

- The President's plan includes substantially *more funding*: \$5 billion over 5 years--about 6 times as much funding as for the Climate Change Action Plan (Note on funding: the President's plan has about 3 times more funding than CCAP plus the Partnership for a New Generation of Vehicles).
- The President's proposal now includes *binding* targets. In expectation of these binding targets, firms and households will begin to adjust their behavior today -- a factor not present in the Climate Change Action Plan.
- To provide further incentives for firms to take action now, the President has indicated his strong support for developing an *early credit* program of appropriate rewards for those who take prompt early action.
- The President has indicated his support for environmentally-friendly *electricity restructuring*, which has the potential to reduce emissions significantly.
- The President has announced that the US will provide \$1 billion over the next 5 years to *help developing nations* and countries in transition to reduce the threat of climate change.

What are the Assumptions of the Models that Generate Small Economic Effects?

The White House talking points cite model results that suggest that with worldwide permit trading, the United States could reach 1990 emissions levels by 2010 with a permit price of \$25 in 2010, and a loss of only 0.1% of GDP.

These results come from Battelle's Second Generation Model (SGM), used in the IAT's work earlier this year. SGM is a 12-region model that includes 10 supply sectors (of which 8 are energy-related),

with capital modeled as "putty-clay". SGM includes 2 end-use sectors, households and government, which consume final products, provide labor, land, and capital to the markets, and determine the savings rate. The model allows regions to trade goods. SGM models energy as a depletable, graded resource for both fossil and non-fossil fuels.

Can Other Examples be Used to Demonstrate that our Assumptions are Overly Pessimistic?

As you know, a recent article in the American Prospect highlighted a number of other environmental control programs where the initial cost estimates turned out to be overly pessimistic. Unfortunately, most of their examples have fundamental flaws in one way or another. There are three examples that do bear scrutiny:

- *Cotton dust.* Actual costs were below estimated costs in part because estimates were based on models that did not include the effects of technical change in the industry, which was accelerated by the new standards.
- *Strip mining.* Early costs estimates referred to reclamation at mines in operation at the time. In response to the law, however, producers expanded operations at sites where reclamation costs were lower, often on flatter terrain.
- *Vinyl chloride.* Early estimates were based on static cost models, and did turn out to be too high.

A number of examples are not relevant, as discussed in the attached memo. In particular, you asked about CFCs. EPA's estimates for the cost of reducing CFC production fell from \$3.55 per kg (1988) to \$2.45 per kg (1996), with the latter price for a more stringent standard. But the well-publicized problem of CFC smuggling indicates that control costs at the margin, which is what counts, are much higher than these estimates. CFC-12, the most common form, now has a street value of about \$50/kg. By one estimate, 10 thousand tons of CFCs are now smuggled into the US every year; by comparison, legal production is 100 thousand tons this year.

We attach (TAB E) a memo that describes this conclusion in more detail, as well as the American Prospect article itself.

What Assumptions Underlie the Estimates of Massive Job Loss from the President's Plan?

The widely publized recent job loss estimates come from the EPI, a labor union think-tank, which projects job losses of 1.7 million by 2010. These estimates are implausible, for a number of reasons:

- Many IAT reviewers, including Nordhaus and Jorgenson, note that short-term macro models, such as the EPI-GRI model, are not appropriate for long-term predictions.
- The DRI model used in this study is very sensitive to changes in assumptions. In this study, DRI ran a short-term macro model with assumptions that would provide a worst-case result: a \$200 permit price, increased emissions baseline, and decreased rate of efficiency

improvements.

- The study also ignores Annex I trading, JI, or worldwide trading; worldwide trading has been estimated to lower costs by 50-75% in other models.
- A key contributor to the large unemployment effects appears to be large trade effects, which are inconsistent with other models and probably reflects weak trade modelling.
- It is worth noting that this is not the first time that EPI has staked out this position on job loss; their estimates of the effects of NAFTA have been proven to be wildly pessimistic.

We attach a detailed critique of the EPI-DRI study as TAB F.

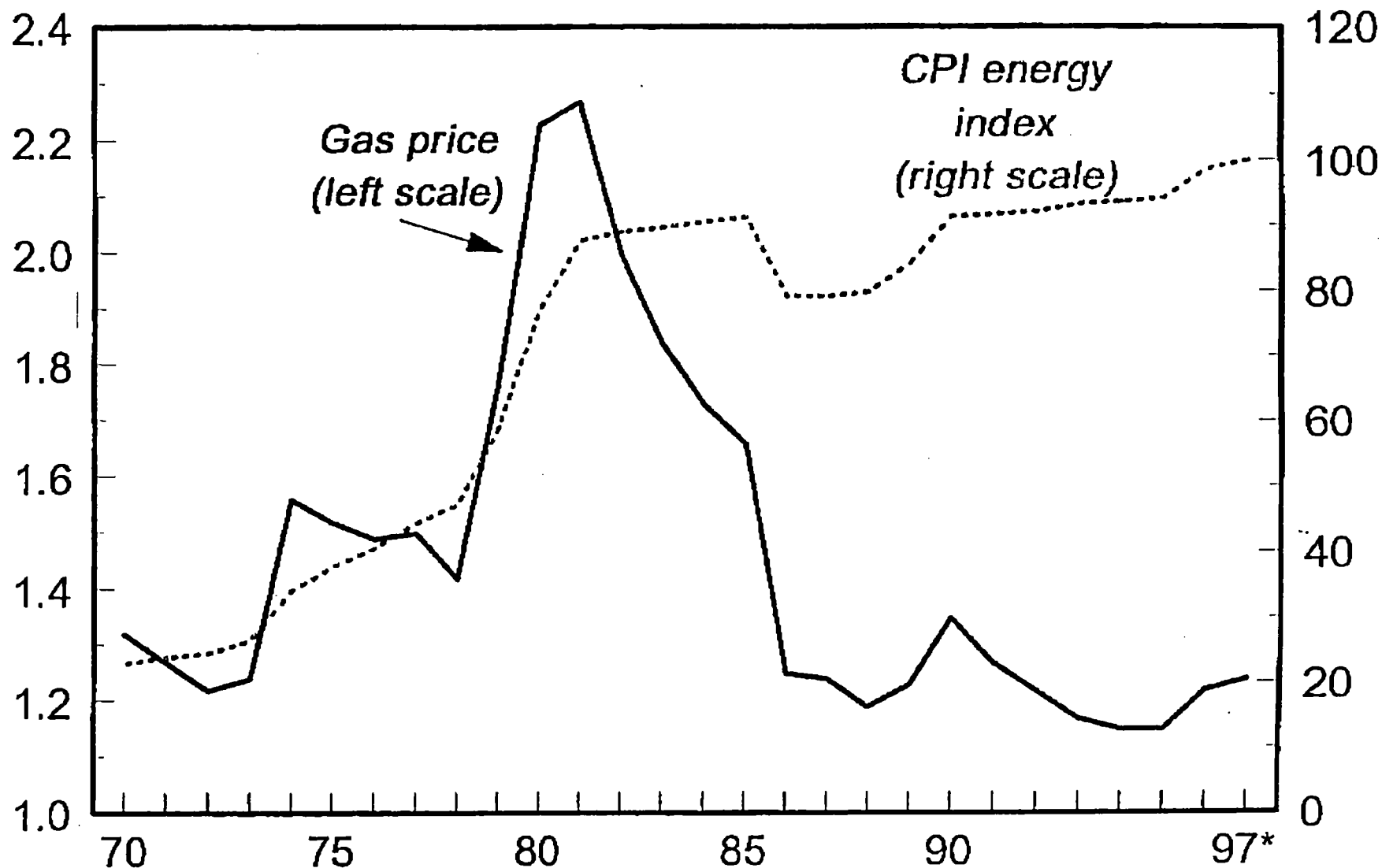
To What Extent can the Cost Savings from Electricity Deregulation Offset Price Increases Due to our Climate Change Plan?

- Electricity restructuring would reduce electricity prices by 0.5 to 1.1 cents per kw-hour; a carbon tax of \$30 to \$70 per ton would raise electricity prices by the same amount. This comparison is misleading, however, since the price reduction from electricity restructuring falls only on the electricity sector, while the price increase from a carbon tax would increase prices for other carbon-based fuels as well.
- Electricity restructuring is expected to save the average 4-person family about \$232-\$488 per year; a carbon tax of roughly \$15 to \$35 per ton would cost the average family about the same amount.

RETAIL ENERGY PRICES

97 dollars per gallon

Index, 97=100



* 1997 based on 7-month average

RETAIL PRICES OF GASOLINE AND TOTAL ENERGY

	Gasoline (1997 price per gallon)	Year-to-year change	Consumer energy price index (1997=100)	Percent Change
1970	1.32		22.911	
1971	1.27	-0.04	23.824	1.0
1972	1.22	-0.06	24.483	1.0
1973	1.24	0.02	26.453	1.1
1974	1.56	0.32	34.179	1.3
1975	1.52	-0.04	37.803	1.1
1976	1.49	-0.02	40.544	1.1
1977	1.50	0.01	44.385	1.1
1978	1.42	-0.08	47.207	1.1
1979	1.77	0.35	59.097	1.3
1980	2.23	0.46	77.321	1.3
1981	2.27	0.03	87.781	1.1
1982	2.00	-0.26	89.091	1.0
1983	1.84	-0.16	89.727	1.0
1984	1.73	-0.11	90.618	1.0
1985	1.66	-0.07	91.240	1.0
1986	1.25	-0.41	79.283	0.9
1987	1.24	-0.01	79.298	1.0
1988	1.19	-0.05	79.889	1.0
1989	1.23	0.04	84.419	1.1
1990	1.35	0.11	91.375	1.1
1991	1.27	-0.08	91.742	1.0
1992	1.22	-0.05	92.206	1.0
1993	1.17	-0.05	93.299	1.0
1994	1.15	-0.02	93.688	1.0
1995	1.15	0.01	94.227	1.0
1996	1.22	0.06	98.637	1.0
1997 (7-mo	1.24	0.02	100.000	1.0

	Standard Deviation	Average of Absol. Value of Yr/Yr Change	Standard Deviation	Average of Absol. Value of Yr/Yr Change
1970-97	0.32	0.11	26.80	1.06
1983-97	0.22	0.08	6.28	1.01
1985-97	0.13	0.08	6.74	1.01

DIRE PREDICTIONS THAT WERE PROVED WRONG

1. In 1972, The Club of Rome published in *The Limits of Growth* dire predictions that the world would run out of gold in 1981, mercury in 1985, tin by 1987, zinc by 1990, petroleum by 1992, and copper, lead, and natural gas by 1993. None of these predictions came true. Indeed the real prices of natural resources have been steadily dropping. For example, the price of crude petroleum in 1992 dollars, as measured by the composite of domestic and imported crude oil refiners acquisition costs, was \$10.69 per barrel in 1972, rose with the oil price shock in 1974 to \$23.56, and reached a high of \$53.47 in 1981 before more or less steadily declining to \$18.82 in 1996. (See reference A.)
2. On March 31, 1979, President Jimmy Carter predicted "There is a dwindling supply of energy sources. The prices are going to rise in the future no matter which party occupies the administration in Washington, no matter what we do." Subsequently, prices fell for 5 straight years from 1981 through 1986. (See reference B.)
3. Secretary of Energy Schlesinger was quoted by the *U.S. News and World Report* on July 10, 1978: "What we face in the middle 1980s is a notional worldwide shortage of about 5 million barrels of oil a day." Instead, there was a crude petroleum glut and price collapse. (See reference B.)
4. Kenneth Arrow, quoted in *Forbes* magazine on February 4, 1980, predicted that "We're heading into a world of considerably higher prices. There will be a major impact on housing by 1983, and I'd be surprised if gasoline is less than \$2 per gallon plus whatever inflation adds." Housing prices actually dropped in the late 1980s and during the 1990s. The actual price of a gallon gasoline was about \$1.16 in 1983 and has not reached \$2 plus inflation since. (See reference B.)
5. In 1979, the Annual Report to Congress (ARC) forecast for oil prices per barrel for 1990 ranged from \$39.47 to \$64.32 (in 1987 dollars). All were substantially above the actual oil price in 1990. 1980 projections by the Energy Information Administration (AEI) were also badly off the mark: their 1985 projection was 70.9 percent too high; their 1990 projection was 194 percent too high; and their 1995 projection was an astounding 385 percent too high. Its 1985 projections for 1990 and 1995 were a little better, 71.7 percent and 239 percent too high, respectively.

A.) Joseph Blast, Peter Hill, and Richard Rue, *Eco-Sanity*, 19xx.

B.) Malcom Shealy of decision Focus Inc., *A Review of Energy Forecasts: What Have We Learned?* February 16, 1989.

Version That was
"almost" agreed to last night

DRAFT**DRAFT**DRAFT**DRAFT

The Impact of Retail Restructuring and Federal Legislation on Carbon Emissions in 2010

An ad hoc agency staff group from DOE, EPA, and CEA considered the carbon reductions that are likely to occur in 2010 if DOE's proposed restructuring bill becomes law. Per discussion at the principals level, we attempt to separate the emissions effect of the explicit carbon friendly provisions of the DOE proposal from the effects of retail restructuring itself, which would be accelerated by, but is not entirely dependent on, Federal restructuring legislation. This memo reflects a quick-turnaround effort. Analyses are continuing at both agencies.

a. The Emissions Impact of Explicit "Carbon Friendly" Provisions of the DOE Proposal

There is agreement between DOE and EPA staff that the explicit "carbon friendly" provisions of the bill (Renewable Portfolio Standard, Public Benefits Fund, and Information Disclosure, the latter of which supports marketing of "green" power from renewable resources to interested customers. The estimated impact of these provisions is a carbon reduction of 13 to 36 million metric tons (MMT) of carbon in 2010 -- see summary table for components.

b. The Emissions Impact of Retail Restructuring Itself

Both DOE and EPA staff agree that substantial retail restructuring is likely to occur with or without Federal legislation. Indeed, major states such as California and Pennsylvania have already implemented retail competition, and other states are in various stages of developing such plans. The effect of retail competition on carbon emissions outside of the explicit "carbon friendly" provisions noted above is subject to considerable dispute, in part because the evolution of service offerings under incentives in the future competitive market are not presently known.

On the emissions-increasing side, retail competition should lower electricity prices, which will increase demand, and increase incentives for economically efficient dispatch, which could result in more use of existing coal plants in cases where capacity is available. Restructuring could also increase pressures for early retirements of nuclear power plants.

On the emissions-reducing side, retail competition will provide a financial incentive for generating plant owners to improve their heat rate, reducing the amount of fuel burned to generate each kilowatt-hour of electricity. In addition, competing retailers will likely increase value of their product to buyers by creating packages of electricity and efficiency services that take advantage of cost-effective efficiency opportunities (such as those identified in the recent "five lab" study), or by selling "green power" derived from renewable sources to environmentally-conscious consumers. Finally, some of the increased demand for electricity will reduce end-use consumption of primary fuels, reducing emissions outside the electric sector.

Given the number of factors involved, the ad hoc agency staff group settled on a range of estimates from an emissions reduction of 48 MMT to an emissions increase of 33 MMT in 2010 for all of the components discussed in the previous two paragraphs and included under headings "b1" and "b2" of the summary table. If, as EPA staff believes, no increase in efficiency services can be expected from differentiated product competition among competitive suppliers under any plausible circumstances (i.e. both the high and low estimate of this component are zero) then the range of estimates for emissions impacts due to restructuring are an emissions reduction of 25 MMT to an emissions increase of 33 MMT, as presented under heading "b1" of the summary table. In both cases, these emissions changes are "over and above" the reductions presented

"almost" agreed
p #2

above in section a of the memo and the summary table.

c. Caveats

There is considerable two-sided uncertainty regarding many of these estimates. For example, green power may be more attractive, heat rate improvements may be lower or greater than projected, and efficiency oriented marketing of electricity services may be greater or less than the range presented above. Notwithstanding these uncertainties, the ranges presented above reflect the best estimates of reasonable ranges of emissions impacts based on available information.

In addition, the distinction of "carbon friendly" provisions of the DOE bill and restructuring itself is somewhat fuzzy, given that the DOE bill is expected to speed the transition to retail competition. An indeterminate portion of the emissions impacts identified in Section (b) of this note are probably attributable to the DOE bill.

Summary Impacts of Restructuring and the DOE Bill on Carbon Emissions in 2010

Factor	Change in Carbon Emissions in 2010 (MMT)
a. Explicit "Carbon Friendly" Provisions, <i>including</i> :	-36 to -13
Renewable Portfolio Standard	-12 to -6
Public Benefits Fund	-11 to -4
Information Disclosure (supports "green marketing" — reflects ½ of total green power estimate)	-13 to -3
b1. Retail Restructuring, <i>including</i> :	-25 to +33
Electricity Demand Increase / Fuel Mix Change	+25 to +32
Nuclear Unit Retirement due to Retail Competition	+3 to 10
Green Pricing (½ of total "green power" estimate)	-13 to -3
Generation Efficiency (heat rate) improvements	-15 to -5
Demand Reduction for Direct Use of Primary Fuels	-2 to -1
b2. Efficiency Marketing by Energy Service Companies	-23 to 0
SUM OF COMPONENTS (a + b1 + b2)	-84 to +20

The Potential Benefit from Worldwide Trading

Lesser-Developed Countries (LDCs) and Economies in Transition (EITs) offer low-cost opportunities for reducing carbon emissions. Joint implementation and international trading mechanisms can help the world mitigate global warming in the most efficient manner.

Great Potential Benefits

There are three fundamental reasons why non-OECD countries offer the world such great opportunities for reducing carbon emissions:

Energy Efficiency. LDCs and particularly EITs are much less energy efficient than OECD countries. In many cases, these relative inefficiencies provide *negative cost* opportunities to reduce carbon emissions. For example:

- Chinese coal-fired boilers are only 2/3 as efficient as US boilers. Retro-fitting Chinese plants with US boilers saves more money than it costs.
- Retrofitting Khrushchev-era Russian apartments saves 30% of heat use and saves more money than it costs. Many other negative cost efficiency improvements have been identified for Russian industry, including the use of quality insulation around steam piping, improved energy control systems, and more efficient motors.

Overall, the possibilities from energy efficiency improvements provide large opportunities for carbon reduction. For example, a \$2 million study conducted by the World Bank and Chinese officials found that China could reduce its carbon emissions nearly 15% from its projected 2020 levels through zero and negative cost energy efficiency improvements.

- That is, we could reduce total emissions by roughly 333 MMT through these low or no cost improvements; this amounts to roughly the reduction required by the U.S. to reach 1990 levels in 2010. Approximately 2/3 to 3/4 of these improvements would come as a result of market oriented restructuring, while the remainder would come from specific, technical projects.

New Capacity. Due to their high growth rates, developing countries have an advantage over the OECD in their ability to meet their reduction targets by installing new, carbon-efficient plants rather than by retrofitting existing plants.

- Loosely speaking, OECD countries will have to balance the costs of building new, natural gas plants against simply continuing to operate existing coal plants -- large coal price adjustments will clearly be required to make building the new natural gas plant the preferable option. Developing countries, however, will balance the costs of installing new natural gas plants against the costs of installing new coal capacity. For these countries, little if any coal price adjustment would be required to make natural gas the economic choice.

Energy Subsidies. Recent World Bank estimates indicate that developing countries could reduce carbon emissions by 7 - 9% by eliminating energy subsidies.

For all of these reasons, the cost of carbon reductions is much lower in developing and transitional economies. For example, if the US, instead of reducing its own emissions to 1990 levels by 2010, transferred its reduction burden in entirety to China, China could accomplish these reductions at only 35% of the costs (this result comes from the mainstream SGM model).

Tapping the Potential: Current Success in JI Pilot Projects

Since its foundation in 1993, the US Initiative on Joint Implementation (USIJI) has accepted 25 project proposals which help US firms tap the potential outside the OECD for low-cost carbon reduction. Some of these projects have already begun to reduce carbon concentrations by implementing new, carbon-efficient power plants, improving energy efficiency, or through other methods such as planting new forests. For example:

- A project in the Czech Republic converted a district heating plant from coal to natural gas and built a cogeneration plant to provide both steam and electricity. This project is projected to reduce carbon emissions by 165,000 tons over 25 years.
- A project in Costa Rica has replaced fossil-fuel burning power sources with a 20 MW wind farm which is expected to reduce carbon emissions by 72,000 tons over 15 years.
- A project in Russia planted 506 hectares of trees and is expected to reduce carbon concentrations by 35,000 tons over 60 years.

Other projects, in various stages of implementation, include:

- A large forest management project in progress in Bolivia combines forest regeneration and protection with the promotion of sustainable forest-product enterprises to reduce atmospheric carbon by an estimated 14.5 million tons over 30 years.
- A project in Russia will improve heating efficiency in Zelenograd simply by installing new heat exchangers, pumps, and control equipment. This project can reduce carbon emissions by 440,000 tons over 30 years.

Joint Implementation, while very valuable in helping to efficiently reduce carbon emissions, can serve other useful purposes including: the opening of overseas markets, the wider dissemination of advanced technologies, and the creation of local health and environmental benefits.

Tapping the Potential: The Future

The success of JI pilot projects shows that they can work. Once countries face binding —

emissions limits -- and are allowed to acquire offsets from other countries -- JI and more general mechanisms for international cooperation will become essential in meeting common goals at the least cost. Many analysts believe that international permit trading and JI can reduce costs by 50% or more.

If LDCs and EITs sign on to binding agreements, international permit trading will allow the world to focus its carbon reduction efforts in the most efficient places. A portion of the easy reductions possible in developing and transitional economies stem from possible market oriented reforms and the elimination of energy subsidies. Reductions through these means will be of great benefit to other countries in an international permit trading regime, but will be difficult to tap in a project-oriented joint implementation setting. Insofar as developing countries and others choose to remain outside an international agreement -- so that they could not take part in a permit trading program -- JI will be relied on to play an important role.

The World Bank is exploring the possibility of a carbon investment fund to act as a market intermediary for JI projects. The fund, on behalf of its investors, would undertake JI type projects and sell the resulting carbon offsets to make a profit. Such a fund would improve on the efficiency of today's bilateral JI pilot projects by reducing transaction and search costs, providing efficient administration, and pooling risk. The Bank is continuing to investigate this and other mechanisms to help in international carbon offset trading.

October 21, 1997

MEMORANDUM FOR DEPUTY SECRETARY SUMMERS

FROM: Jonathan Gruber
Deputy Assistant Secretary (Economic Policy)

SUBJECT: Do we always overestimate environmental control costs?

In "Polluted Data: Overestimating Environmental Costs," (*The American Prospect*, Nov/Dec 97), Eban Goodstein and Hart Hodges argue that most pollution control programs turn out to be far less costly than had been estimated beforehand. They claim that "reducing pollution emissions at the source ... is almost certain to be (substantially) cheaper than we think it will be." But why, one might ask, are the experts always wrong -- and always in the same direction? "The reason, of course, is technology forcing," answer the authors. "When industry is required to lower pollution output, it usually doesn't just slap a new filter on an existing process; it often invents new technology."

The authors give a list of environmental programs in which, they claim, technical innovation came to the rescue and dramatically reduced costs, compared to initial estimates. Some of these examples lend credence to the authors' thesis, but many do not.

Convincing Examples:

Cotton dust. Actual costs were below estimated costs in part because estimates were based on models that did not include the effects of technical change in the industry. As the standards were introduced, the textile industry was about to replace its older capital stock with new machines that, among other things, markedly reduced the amount of cotton dust in the air. The standard accelerated this change.

Strip mining. The authors quote compliance cost estimates in the range of \$6 to \$12 per ton of coal, as against actual costs of 50 cents to \$1 per ton. Early costs estimates referred to reclamation at mines in operation at the time. In response to the law, however, producers expanded operations at sites where reclamation costs were lower, often on flatter terrain. Thus, these early "static" estimates overstated costs.

Vinyl chloride. The authors say that control cost estimates fell from about \$100 million per year to \$20 million per year. John Morrall of OIRA reports that the earlier estimates, which were based on static cost models, did turn out to be too high. We should note, however, that the authors also claim that the 1 ppm standard was met with a price increase of only about 6 percent. The US vinyl chloride market today is about \$1 billion, so 6 percent implies \$60 million annually

in direct control costs, undercutting their \$20 million estimate.

Problematic Examples

Asbestos. The paper says that one study by a consulting firm in the early 1970s estimated control costs that turned out to be too high by a factor of two. This refers only to the earliest estimates, done in support of OSHA's proposal in the early 1970s. Two later OSHA cost estimates, in the late 1980s and early 1990s, did not substantially overestimate control costs, according to John Morrall, now a branch chief at OIRA, who was responsible for reviewing all three sets of estimates.

Benzene. The paper cites a process that substituted other chemicals for benzene, "and virtually eliminated control costs." Benzene is one of the most widely used organic chemicals, with over \$2 billion in sales last year. The new process alluded to (using maleic anhydride) replaced benzene in only a small portion of its uses.

CFCs. The paper correctly quotes EPA's price estimates for reducing CFC production, which fell from \$3.55 per kg (1988) to \$2.45 per kg (1996); the latter price was for a more stringent standard. On the other hand, the well-publicized problem of CFC smuggling indicates that control costs at the margin, which is what counts, are much higher than these estimates. When the US ceased CFC production in January 1996, a CFC smuggling industry was already in place. CFC-12, the most common form, now has a street value of about \$50/kg. By one estimate, 10 thousand tons of CFCs are now smuggled into the US every year.

Coke ovens. The paper quotes a 1974 study that gave a range of \$200 million to more than \$1 billion, and says that a later study by the Council on Wage and Price Stability (COWPS) estimated the actual cost of the standard at \$160 million. The author of the COWPS estimate, John Morrall of OIRA, says that he did not make an independent estimate, but simply took the low end of the industry estimate that OSHA was using, on the grounds that industry had an incentive to overstate control costs. He also says that the authors' range (\$200 million to more than \$1 billion) appears to be the range in the industry study he used, with \$160 million rounded upward to \$200 million. Moreover, the OSHA standard was never met.

More General Critique

The authors are correct in their general claim that many cost estimates come from models that do not factor in technical innovation. But their argument is incomplete, and sometimes wrong.

First, analysts are often mistaken about the costs of environmental controls, but not just on the high side; this article has clearly selected its examples to illustrate its point, downplaying examples which cut the other way. For example:

- The National Ambient Air Quality Standards (NAAQS), set by the original Clean Air Act (CAA) of 1970, were estimated to be achievable in 7 years. Twenty-seven years later, we

still do not know how, when, or even if the original goals will ever be met. At the time EPA tightened the ozone NAAQs earlier this year, 75 areas did not even meet the standard then in place, which is looser than the original standard set a quarter century ago. These non-attainment areas contain 75 million people, and include most of the country's major cities: Los Angeles, Houston, Dallas, St. Louis, Chicago, Pittsburgh, Cleveland, Boston, New York, Philadelphia, Baltimore, Washington, and Atlanta.

- The Clean Air Act Amendments of 1990 established a program for "clean-fuel vehicles" in California, with a target of 150,000 vehicles to be purchased annually in model years 1996, 1997, and 1998, and 300,000 vehicles (about 25% of sales) in model years 1999 and after. The writers of this technology-forcing law seriously underestimated the cost of producing this vehicle. As of now, there appears to be no way to produce this car at a price consumers will accept, and EPA has, in effect, allowed the program to lapse.
- The authors make a false distinction between controlling pollution and the source, and treating soil and water after it has been contaminated. They concede that some programs, such as Superfund and the Clean Water Act, have been far more costly than anticipated. But they assert that this occurred because cleaning up existing contamination is not subject to the same forces of innovation as preventing pollution at the source. The authors offer no support for this claim.

Second, most ex-post cost estimates, including all those cited by the authors, include only direct compliance costs. Indirect costs, which are borne elsewhere in the economy, are harder to measure, but no less real. An often-cited 1990 study by Kopp and Hazilla of Resources for the Future estimates that indirect costs of environmental rules are roughly equal to direct compliance costs. In a 1993 study of the paper, oil refining, and steel industries, Gray and Shadbegian estimate that for every \$1 in compliance costs, total factor productivity is reduced by \$3 to \$4. In a series of papers this decade, Jorgenson and Wilcoxon calculated that environmental regulations have reduced the US capital stock by 4.3 percent, increased the cost of capital by 5.5 percent, and reduced real GDP by more than 3 percent annually, with indirect costs accounting for most of this burden.

Third, the authors do not support their claims about technology forcing. They quote Michael Porter, who has written that environmental regulations often yield "innovation offsets." But they try to prove their case with anecdotes. Anecdotes alone do not prove an assertion, because we have no guarantee that the speaker has not selected only those that support his position. Moreover, we have survey evidence that runs the other way. When the BEA conducted its surveys of environmental compliance costs, it asked about "product offsets," resulting from compliance with the regulation in question. In contrast to Porter's claims, only two percent of respondents identified any "product offsets."

Fifth, the same market forces that drive down compliance costs also drive down benefits. For example, several years ago OSHA estimated very large benefits for its new rules intended to control the spread of tuberculosis. But at the same time that OSHA's program was being put in

place, tuberculosis rates were falling, as the Centers for Disease Control (CDC) increased its focus on tuberculosis. This slowed the spread of the disease and reduced the benefits of OSHA's program. Similarly, OSHA's recent rules on blood-borne pathogens aimed to limit transmission of AIDS and, especially, hepatitis-B. The recent vaccine for hepatitis-B has considerably lowered the value of OSHA's rule.

More fundamentally, program costs can get wildly out of control when EPA takes a program with modest goals, and sweeps into it activities that were not intended to fall into its purview. Superfund is an example of this driftnet approach. Superfund began life as a program to clean up a few big sites on the order of Love Canal, but metamorphosed into "a behemoth, towering over American environmental policy, gobbling vast quantities of public and private cash and management time." [Francis Cairncross, environment editor of *The Economist*, in her book *Costing the Earth*]. On a smaller scale, EPA's rule on toxicity characteristics provided a way that a waste stream could be designated as hazardous. The agency estimated its cost in the low hundreds of millions of dollars per year. These estimates failed to anticipate that EPA would then insist on regulating many items posing low or negligible risk, including fluorescent light bulbs and telephone poles; as a result, the rule has been far more expensive than anticipated in these initial estimates.

BEHIND THE NUMBERS

EBAN GOODSTEIN AND HART HODGES

Polluted Data: Overestimating Environmental Costs

In July, Carol Browner, chief of the Environmental Protection Agency, issued new regulations reducing permissible levels of smog and particulate (fine soot) pollution. The political battle leading up to the decision was fierce, even within the administration. One staff member on the Council of Economic Advisers maintained that the regulations would cost a whopping \$60 billion—a figure quickly seized upon by industry opposition. The EPA's own cost estimate was much more modest, between \$6 billion and \$8 billion. In making her case for the new regulations, however, Browner publicly disavowed even her own agency's cost estimates. She argued that industry would find a way to do it cheaper.

Whom to believe? Confronted with conflicting estimates, most lay people either throw up their hands or choose sides ideologically. But history provides a basis for evaluating these estimates. Not only do industry lobbyists wildly overestimate the costs of proposed environmental regulations. More surprisingly, academic and government economists consistently do too—and for an equally surprising reason. When forecasting the costs of new environmental regulations, economic analysts routinely ignore a primary economic lesson: Markets cut

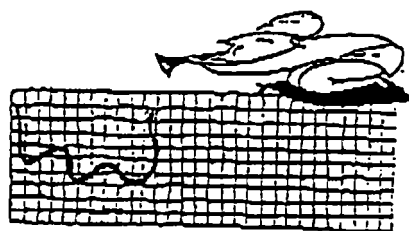
costs through innovation. And innovation can be promoted through regulation. This history is worth bearing in mind as we approach the most important environmental controversy to date—how to deal with the crisis of global warming.

THE ABCs OF OVERESTIMATION

In every case we have found where researchers have calculated actual regulatory costs and then compared them to *ex ante* estimates, the estimate exceeded the actual cost. We have uncovered a dozen such efforts, ranging from A (asbestos) to V (vinyl chloride). In all cases but one, the initial estimates were at least double the actual costs.

Asbestos. When the Occupational Safety and Health Administration (OSHA) instituted regulations covering exposure to asbestos in the early 1970s, they hired a consulting firm to estimate the cost of compliance. Two later studies found that the original prediction for the cost of compliance was more than double the actual cost, because of overly static assumptions.

Benzene. In the late 1970s, the chemical industry predicted that controlling benzene emissions would cost \$350,000 per plant. Shortly after these predic-



tions were made, however, the plants developed a process that substituted other chemicals for benzene and virtually eliminated control costs.

Chlorofluorocarbons (CFCs). In 1988, reducing CFC production by 50 percent within 10 years was estimated by the EPA to cost \$3.51 per kilogram. By 1993, the goal had become much more ambitious: complete elimination of CFC production, with the deadline moved up two years, to 1996. Nevertheless, the estimated cost of compliance fell more than 30 percent, to \$2.45 per kilogram. And where substitutes for certain CFCs had not been expected to be available for eight or nine years, industry was able to identify and adopt substitutes in as little as two years.

CFCs in automobile air conditioners. In 1993 car manufacturers estimated that the price of a new car would increase by \$650 to \$1,200 due to new regulations limiting the use of CFCs. In 1997 the actual cost was estimated to be \$40 to \$400 per car.

Coke ovens. The original OSHA estimate for the cost of complying with the 1976 coke

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oven standard was more than five times higher than estimates of actual costs. OSHA's contractor suggested that complying with the standard would cost from \$200 million to more than \$1 billion. However, a Council on Wage-Price Stability study later estimated the actual cost of the standard to be \$160 million.

The OSHA consultant estimated that three steel firms in their sample would spend \$93 million on capital equipment and \$34 million in annual operating costs to comply with the regulations. A later study by Arthur Andersen determined that the three firms actually spent between \$5 million and \$7 million in 1977 to comply with the standard, and only \$1 million to \$2 million on capital expenditures. Ultimately, firms were able to meet the standard without incurring all of the capital costs in the first year, and actual compliance costs were dramatically lower than originally predicted.

In the late 1980s, coke production again came under regulatory scrutiny, this time by the EPA. In 1987, the agency estimated that the cost of controlling hazardous air pollution from coke ovens would be roughly \$4 billion. By 1991 that estimate fell to between \$250 million and \$400 million.

Cotton dust. In 1976, OSHA proposed a maximum permissible exposure limit of 0.2 milligrams per cubic meter for cotton dust, and its consultant estimated that compliance costs would be approximately \$700 million per year. The standard promulgated in 1978 actually allowed for higher exposure levels in some sectors of the textile industry, but the small changes in the standard do not fully explain

the decrease in estimated compliance costs; in 1978 the estimate fell to \$205 million per year. Moreover, a new study conducted in 1982, after the Reagan administration called for a review of the standard, concluded that compliance costs were \$83 million per year.

Halons. In 1989 members of the United Nations Environment Program's Halons Technical Options Committee disagreed on whether direct halon replacements could be found and whether a phase-out was possible. However, in 1993 the committee concluded that a phase-out of halons, a substance found in fire extinguishers that destroys the ozone layer faster than chlorofluorocarbons, would be both technologically and economically feasible by 1994.

Strip mining. Prior to the passage of the 1973 Surface Mining Control and Reclamation Act, estimates for compliance costs ranged from \$6 to \$12 per ton of coal. Actual costs for eastern coal operations have been in the range of 30 cents to \$1 per ton. After the regulations were adopted, the market switched away from coal deposits with high reclamation costs. Ready substitutes included surface-minable coal in flatter areas (with lower reclamation costs), and underground deposits.

Vinyl chloride. OSHA's vinyl chloride standard, set in 1974, provides a final example of wildly excessive cost projections. The agency's consultant estimated that it would cost \$22 million per year to meet the permissible exposure limit of 2 to 5 parts per million (ppm) in the vinyl chloride monomer sector, and \$57 million per year to meet the 10 to 15 ppm

exposure limit in the polyvinyl chloride sector. In addition, the consultant argued that the 1 ppm permissible exposure limit simply could not be attained. The president of Firestone's plastics division said that a standard of 1 ppm "puts the vinyl plastics industry on a collision course with economic disaster."

In spite of these protests, OSHA did adopt the strict permissible exposure limit of 1 ppm. A study conducted several years later by researchers from the Wharton School of Business estimated that the total cost of compliance for both sectors had been about \$20 million per year. A 1976 congressional research paper also indicated that the actual cost of compliance was dramatically less than the original prediction. The early claims that the 1 ppm standard could not be met evaporated; instead, the regulatory action led to about a 6 percent rise in polyvinyl chloride prices.

While costs have been consistently overestimated for emission reduction, they have been underestimated for environmental cleanup. For example, when the Clean Water Act was enacted in 1972, the EPA estimated that \$12.6 billion was needed to provide secondary sewage treatment systems. According to the American Enterprise Institute, actual spending for sewage treatment between 1972 and 1981 exceeded \$160 billion.

Costs for the Superfund program have also mushroomed. When first launched, people expected the mandated cleanups to apply to a small handful of Love Canals. However, the pro-

gram has expanded dramatically, now covering far more than a thousand sites. In addition, cleanup has proved far more costly than predicted: The average cost overrun on cleanup expenditures at Superfund sites has been 44 percent.

The message from these cases is clear. On the one hand, treating already polluted water, cleaning dirty soil, and scrubbing oily rocks costs a lot of money, (much) more than expected. On the other, when it comes to reducing pollution emissions at the source, it is almost certain to be (substantially) cheaper than we think it will be. Updating *Poor Richard's Almanack*, an ounce of prevention is clearly worth a pound of cleanup.

Why were the estimated costs of reducing emissions at the source so inflated? The reason, of course, is "technology-forcing." When industry is required to lower pollution output, it usually doesn't just slap a new filter on an existing process; it often invents new technology. Frequently the new technology turns out to have higher productivity benefits, which help to offset the cost of the regulation. To see this, it is worth looking in detail at two high-profile cases where markets have responded to regulation by cutting costs.

COKE BREAK

Robert Hahn, a well-known environmental economist, is currently a resident scholar at the American Enterprise Institute and an adjunct research fellow at Harvard's Kennedy School of Government, and is a former

senior staff member of Bush's Council of Economic Advisers. In 1990 he and a co-author wrote a report for the U.S. Business Roundtable predicting the impact of the proposed Clean Air Act amendments on employment. These amendments had the dual purpose of cleaning up both acid rain and so-called "air toxics" from industrial plants.

The executive summary of Hahn's report leaves "no doubt that, across the Clean Air Act Amendments studied, there are a minimum of several hundred thousand jobs at various levels of severity of risk—even with the more moderate [Bush] Administration proposals." Hahn's absolute minimum prediction was 20,000 jobs directly lost, mostly from the closing of coke ovens in the steel industry. Hahn and his co-author viewed this as "truly a limiting, rock-bottom estimate" for several reasons. Important among them was that it considered only job losses arising from one portion of the bill—control of air toxics.

The amendments did pass later in 1990. The bill was in most respects more restrictive on air toxics than the one on which Hahn's study based its minimum job loss estimates. The legislation also authorized retraining funds of \$30 million per year for displaced workers, which gives a nice way to track job impacts.

In the almost seven years since passage of the legislation, fewer than 7,000 workers have received aid because their jobs were affected by the Clean Air Act amendments. And the vast majority of these have been eastern, high-sulfur-coal miners, who have been laid off due not to the air toxics

provision, but to the acid rain amendment. (The same legislation has in fact led to a boom in the western, low-sulfur-coal industry.) No workers from shut-down coke oven plants have received adjustment assistance. And between 1992 and 1995, production in the coke and (closely related) blast furnace industries actually increased, from \$1.74 billion to \$1.95 billion.

Hahn was consulting for industry here, so it is not surprising that his numbers were a bit on the high side. Corporate America, when faced with new regulations, has never been shy about claiming that the sky is falling. But Hahn is not a hired gun; he has very solid academic credentials. How could he have gotten it so wrong?

It turns out that Hahn's overestimation of regulatory impacts, while extreme, is not unusual. In fact, as we have seen in every case for which we have been able to track down data, academic and government economists have routinely overestimated the costs of reducing pollution emissions—by at least 30 percent, and generally by more than 100 percent.

THE ACID TEST

The EPA's acid rain program is another dramatic case in point. Since 1995, electrical utilities have been required to hold permits for each ton of sulfur dioxide they emit. These permits, in limited supply, are distributed to firms each year by the government. The innovative feature of the program is that the permits can then be bought and sold. Given this, permit prices roughly reflect per ton pollution control costs. This is true because a firm generally wouldn't buy an extra

permit if the cost of doing so exceeded the cost of reducing sulfur emissions by a ton.

When the tradable permits market was being designed in the early 1990s, credible industry estimates of permit prices (and thus control costs) were \$1,500 per ton; the EPA was predicting \$750. In 1997, permits were in fact selling for around \$100 a piece.

Part of the current low permit price is due to a higher than expected initial supply of permits, but real compliance costs have in fact been two to four times lower than the EPA expected, and four to eight times below industry estimates.

THE VIRTUE OF MARKETS

When environmental economists figure their cost estimates, one particular lapse is quite startling. Economists have tended to grossly underestimate a virtue of markets they readily preach elsewhere: flexibility. When pollution regulation makes a certain type of production more expensive, markets adjust—in fairly rapid order, uncovering substitute methods of production, and developing cheaper cleanup technologies. This fact, while not completely ignored by economists, is seldom factored into their cost estimates. Instead analysts tend to predict future costs statically, as if firms would continue to use existing practices and technologies.

So, for example, the much lower than expected costs for the acid rain program can be explained in retrospect by the increased flexibility that firms were given to achieve their mandated reductions in sulfur dioxide emissions. Rather than install

expensive scrubbers (or buy extra permits), many more firms than expected have met their sulfur dioxide targets by switching to low-sulfur coal, or developing new fuel-blending techniques. Railroad deregulation, along with economies of scale, led to an unexpected decline in low-sulfur-coal prices. And with the increased competition from coal, scrubber prices fell by half from 1990 to 1995.

All this is easy to see after the fact, but would have been very hard to predict. Hahn got his 20,000 lost jobs from air toxics regulation following this same practice—ignoring innovative market responses. While parenthetically noting that "technological improvements could reduce the direct economic impacts," the study explicitly ignores the possibility "because of the difficulties in predicting how technology will evolve." Because in the mid- to late 1980s, available control technologies for coke ovens seemed to be quite expensive, Hahn assumed that regulating air toxics would simply shut down much of the industry.

However, as we saw above, the EPA's own estimates of control costs for coke ovens were plummeting even as Hahn was writing his report. By 1991, they were down by a factor of ten or more from the 1987 forecasts. Hahn may not have been aware of the EPA's work; instead he cites an industry source to justify his claim that "there is widespread agreement that coke ovens will be required to close down, with an estimated loss of 15,000 jobs."

A secondary reason for the overestimates is that in implemen-

tation, legislation is never as draconian as it appears on paper. In practice, timetables get stretched out, compliance dates get extended, and waivers are granted. Eventually the regulations begin to bite, but industry is usually given a fair amount of time to adjust. Most cost estimates assume high degrees of near-term compliance.

Pettering into the future is hard work. It is, in fact, close to impossible for economists to predict the specifics of how technology will evolve. This is especially true since much of the information about potential innovations consists of closely held trade secrets, which industry has little incentive to reveal. But basing cost predictions on scenarios that assume no technical evolution is guaranteed to produce gross overestimates. Innovation is indeed something at which markets are very good. When given a narrowly defined task—to produce commodity *x* emitting less of pollutant *y*—short-term substitutions and long-term shifts in technology guarantee large cost reductions over current practice.

INFLATING COSTS, IGNORING BENEFITS

In the late 1980s, when the international phase-out of ozone-destroying CFCs got underway, a company called Nortel began looking for substitutes. The company, which had used the chemicals as a cleaning agent, invested \$1 million to purchase and employ new hardware. Once the redesigned system was in place, however, Nortel found that it actually saved \$4 million in chemical waste-disposal costs and CFC purchases.

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The CFC regulatory compliance costs for Nortel clearly were \$1 million. But how do we figure in the \$4 million savings? Economists have long recognized that a dollar spent on environmental pollution control is not the "true" cost to society. Some have argued that the cost is in fact much higher, because environmental spending "diverts" capital investment from more productive uses.

In recent years, by contrast, Michael Porter of the Harvard Business School has been pointing to examples like Nortel to argue that environmental regulations, by forcing firms to rethink their production processes, can often lead to lower production costs and lead a competitive advantage.

More generally, much of the reported costs of environmental regulation occurs when firms invest in new capital equipment, thoroughly redesigned to be both cleaner and more productive. Many of these investments would have happened sooner or later anyway. So a primary effect of regulation is to speed up the investment process. This is costly to firms, since they must scrap old machinery that is not necessarily worn out. When this happens, however, much of measured compliance cost is in fact just early capital investments. This in turn implies that the compliance figures are much higher than the real costs.

Researchers at Resources for the Future recently conducted a study asking how much \$1 spent on environmental protection really costs an industry. For some industries, specifically steel, the answer was little more than \$1, due to the diversion effect. For others, notably plastics, the indus-

try actually saved money as productivity was boosted. On average, the study concluded, \$1 spent on environmental pollution control reflected a real expense of 13 cents. In general then, even when cost estimates are "correct," this new research suggests that the reported values often overstate the true costs to the firm, on average by a factor of seven.

THE ROAD TO KYOTO

The debate over compliance costs is now heating up for the mother of all pollution issues—global warming. International negotiators are at work on what are supposed to be binding carbon emission reduction requirements, to be announced in Kyoto in December. The European Union is pushing for a 15 percent cut below 1990 levels to be achieved by 2010; the members of the Alliance of Small Island States—whose very existence is at stake due to anticipated flooding—want a 20 percent cutback by 2005.

The United States, by far the world's biggest greenhouse polluter, is dragging its heels. President Clinton, when pressed to commit the U.S. to specifics, has promised only to convene a conference in the fall to try to achieve a consensus among American industry, labor, and other groups on the need for action. And Clinton will clearly face a tough sales job for ratification in the Republican-controlled Senate.

Academic economists have lined up behind a strong U.S. leadership role in Kyoto. Greenhouse "moderates" like Yale's William Nordhaus and Harvard's Dale Jorgenson headed up a list of more than 2,000 economists who

signed a letter arguing that a first round of carbon emission reductions could be achieved at relatively low cost. And in late July, to the dismay of U.S. industry, the Clinton economic team published its official cost estimates, confirming this general view.

There is a minority opinion among economists that reducing greenhouse gas emissions will be very, very cheap, and in the long run, even profitable. The reasons? Already existing energy efficiency technologies can help the United States break its addiction to cheap oil without too much pain. And within a decade or two, renewable fuel sources—coupled with efficiently redesigned technologies—will be cheaper than oil or coal are today. In this view, the sooner we redirect the market into a serious search for alternatives to fossil fuels, the richer we will be in the future.

There are, however, likely to be transitional costs, both for workers, particularly in fossil fuel industries, and for Third World countries. In the past, government has not done a very good job in equitably sharing the burdens of such transitions. This is no reason to reject a global warming accord, but it is a strong reason to be alert to the allocation of costs and benefits.

In the global warming debate, as when past environmental regulations have been proposed, there are the three compliance cost scenarios: apocalyptic (industry), doable but costly (academic and government), and profitable (a few visionaries). Our guess, based on the record of previous academic and government cost forecasts, is somewhere between doable and profitable.

EPI Review of DRI study of the Economic and Employment Impact of Climate Change Policies

On September 17, EPI released the results of its review of a study conducted by DRI on the economic and employment effects of climate change policy on the US economy. The results present a doom and gloom scenario largely because the model used by DRI is not appropriate for long term forecasting and because many of the assumptions tend to exacerbate the negative impacts.

WEFA has announced a study estimating the impacts of climate change policies. The only copy of their report that we have for review is methodologically bankrupt. However, the estimated permit price is similar to the EPI-DRI price and many of the results are of a similar magnitude. This attachment will focus on the EPI-DRI report because there is a detailed explanation of their methodology.

The model used in the DRI/McGraw-Hill study is a short-run forecasting model with an fixed coefficient, input-output-based structure. The shortcomings of this model for forecasting the impact of potential climate change policies are:

- Long-term climate policies are likely to alter significantly the structure of the economy and encourage fuel switching and capital-energy substitution. The model used by EPI-DRI fails to capture any of these changes because it relies on fixed, historical estimates and cannot adequately predict future production, investment, and labor supply/consumption decisions.
- This type of model tends to distort the adjustment behavior of the economy. As a result, errors due to the rigidity of the model are magnified as the time horizon of the forecast is lengthened. In other words, the forecasts for 2020 are less reliable than those for 2010, and the model is really only built to be able to produce reliable forecasts for two or three years in the future, in the present case the year 2000.
 - "[The DRI model] is highly inappropriate [for long-term predictions] and has some important limitations that are well-known to the community of economic forecasters. For example, the DRI long-term predictions are extremely sensitive to assumptions about energy prices." Jorgenson and Nordhaus from a memo to the IAT, April 24, 1997.
 - The DRI model used fixed proportions of inputs to outputs which fails to capture any energy conservation or carbon emissions reductions. Therefore, "it is clearly unrealistic for periods of a decade or more." Jorgenson and Nordhaus.

As noted above, this type of model is very sensitive to changes in the assumptions such as energy prices. In many cases, the EPI-DRI modelers choose assumptions that would exacerbate any negative economic and employment effects resulting from climate change policies. For example, the EPI-DRI review:

- Assumes that the permit prices will be between \$180 - \$190 per mmtC (1995 dollars) in 2010. This permit price is approximately twice as high as found by the Interagency Analytic Team on the Economic Effects of Global Climate Change Policies (IAT) which estimated permit prices between \$80 - \$100 for the same scenario. As a result, energy price increases are much greater in the EPI-DRI review. These higher prices are a result of two modeling decisions:
 - The EPI-DRI model assumes slightly lower baseline improvements in energy efficiency (1% versus 1.25%). This also has an effect on baseline carbon emissions growth.
 - The EPI-DRI model assumes smaller price and substitution elasticities than used by the IAT; again, this is a result of the limitations of the model which does not handle substitution and fuel switching well.
- Overstates the amount of carbon emission in 2010 and 2020. Baseline carbon emissions estimates are greater for 2010 and 2020 in the EPI-DRI scenario than in either the Energy Department's AEO97 baseline or the IAT report.
 - For example, in 2010 the EPI-DRI report baseline case predicts 1,746 million metric tons (mmt). The Energy Department predicts 1,722 mmt, and DRI in the IAT report predicts 1,693 mmt in the reference case.
 - In 2020, EPI-DRI predicts 1,894 mmt while DRI predicts only 1,805 in the IAT.
- Ignores international emissions trading and the role of JI or worldwide trading, which other models predict can lower permit prices by 50% or more.
- Exaggerates impact of climate change policies on international trade and the trade deficit, multiplying the unemployment figures.
 - The EPI-DRI model predicts substantial increases in the trade deficit from our climate change policy. This largely reflects poor modelling of the trade sector in the DRI model, which is not built to handle international trade. In fact, other models (such as the SGM model) which more appropriately reflect international trading suggest only minimal impacts on the trade deficit.
 - Two-thirds of all carbon emissions are from "non-tradable" sectors: residential and transportation.
 - On average, energy costs account for only about 2% of input costs for the industrial sector. In other words, 98% of production costs are non-energy related.
 - A recent CEA analysis states that the bottom line is that the evidence is

against the view that the exclusion of LDCs would have a substantial adverse effect on the overall US trade position.

- These increases in the trade deficit contribute substantially to the high unemployment numbers, since the DRI model simply multiplies the deficit to get trade-related unemployment.
- In 1992, EPI conducted a similar review of potential economic and employment estimates of the proposed NAFTA treaty. EPI stated that the available models were flawed and job losses would result from a NAFTA.
 - EPI highlighted the results of a 1991 Economic Strategies Institute study found that, as a result of increased Mexican imports to the US, there would be a net job loss of 900,000 by 1999.
 - EPI continues to assert that NAFTA has cost the US jobs. In two recent issue briefs, EPI states that NAFTA has resulted in a net loss of 394,835 jobs in the US in its first three years.
 - In fact, after taking in account storing US economic performance, Mexico's balance-of-payments crisis and 1995 recession, and US implementation of MFN tariff cuts mandated by the Uruguay Round, several studies, including ones from DRI and the Federal Reserve Bank of Dallas, generally conclude that NAFTA in isolation has had a modest positive effect on the US economy. The Administration has recently announced an increase of 311,000 jobs supported by exports to Canada (189,000) and Mexico (122,000) since 1993.

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Kyoto Protocol:
Article-by-Article Review

DRAFT

Preamble

- o The preamble is self-explanatory, containing nothing of particular interpretive significance.

Article 1 (Definitions)

- o The definitions are technical and not of policy significance.

Article 2 (Policies/Measures)

- o This Article obligates Annex I Parties, in achieving their target commitments, to implement policies and measures in accordance with their national circumstances.
- o The list of policies and measures in this Article (e.g., "enhancement of energy efficiency in relevant sectors of the national economy") is illustrative, not mandatory.
- o In order to avoid inconsistent national approaches in two areas where international coordination is desirable, the Article obligates Annex I Parties to pursue limitation or reduction of emissions from aviation and marine bunker fuels, working through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO). (It should be noted that, through a separate methodological decision, it is made clear that bunker fuels do not count against national emissions totals.)
- o In lieu of the G-77's unacceptable call for a compensation fund, the Article calls upon Annex I Parties, collectively rather than individually, to "strive" to implement policies and measures in such a way as to "minimize" adverse effects (both environmental and economic) on other Parties, including developing country Parties. The Conference of the Parties serving as the meeting of the Parties (hereinafter "COP/MOP") make take further action to implement this paragraph.

-- It should be noted that a similar provision appears in Article 3.14, discussed below.

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- It should be noted that COP 3 Decision L.9 requests the Subsidiary Body for Implementation, at its 8th session, to determine actions necessary to implement the corresponding provision in the Framework Convention (i.e., Article 4(8) and (9) relating to the specific needs of developing country Parties particularly affected by either climate change or by response measures to climate change) and further requests COP 4 to take a decision on actions.
- o Finally, the Article provides for the COP/MOP, if it decides it would be beneficial to coordinate any policies and measures (i.e., on a strictly voluntary basis), then it is to consider ways to elaborate such coordination.

Article 3 (Annex I Target)

- o Paragraph 1 contains two important features:
 - First, it sets forth the obligation of Annex I Parties to ensure that their emissions do not exceed their commitments, as set forth in Annex B (which contains the relevant percentage for each Party) and the rest of Article 3 (which contains time periods, base years, accounting rules, etc.). In order to make clear that the obligation, even though written in the plural ("The Parties included in Annex I shall..."), is not a collective obligation under which each Party would be responsible for another, the phrase "individually or jointly" was included.
 - Second, the end of the sentence containing the obligation states "with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012." There are three reasons why this phrase was written in non-legally binding terms:
 - o The point of the statement is more political than legal, i.e., it was considered that it more make it more palatable to have certain Annex I Parties increasing their emissions over 1990 levels (such as Australia) if it were pointed out that, as a group, the Annex I Parties will actually be reducing below 1990 levels.
 - o The figure of 5% below 1990 levels does not take account of the ability of Annex I Parties to increase their allowed emissions through the Clean Development Mechanism, described below. In other words, emissions trading and joint implementation among Annex I Parties would not change the 5% figure; however, additional emissions allowances through the CDM from outside of Annex I could theoretically even put the Annex I Parties over 1990 levels.

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- o If legally binding, the provision might imply a collective responsibility to meet the group target, which would not have been acceptable to us.
- o It should also be noted, with respect to paragraph 1, that there has been a lack of clarity under the Convention as to which emissions count against a Party. In part to address this issue, and in part to address the U.S. national security issue, COP 3 adopted Decision L.5, which provides, inter alia:
 - that emissions based upon fuel sold to ships or aircraft engaged in international transport are not included in national totals; and
 - that emissions resulting from multilateral operations pursuant to the UN Charter are not included in national totals; and
 - that other emissions related to the operations noted above (such as from training in a foreign country) are to be included in the national totals of one or more of the Parties involved, but it leaves to those Parties to figure out which. (In this way, it allows Parties to reallocate emissions without going through emissions trading.)
- o Paragraph 2, in order to respond to calls for an obligation before the 2008-2012 commitment period, calls for each Annex I Party to have made "demonstrable progress" in achieving its commitments. The U.S. took the position that, for example, having in place the necessary implementing legislation would fulfill this obligation.
- o Paragraph 3 relates to sinks, specifically their treatment during the commitment period. (One must look to paragraph 7 of this Article to see that sinks are not included in the baseline.) The significant features include:
 - that net changes in the specified categories are to be used in meeting the target commitment; in other words, a Party does not get to count only the positive.
 - that the net changes in the specified categories must be counted; in other words, counting sinks is not optional.
 - that the categories are currently limited to afforestation, reforestation, and deforestation, and, further, that these activities only count since 1990; in other words, the net changes in emissions from trees planted before 1990 would not count.

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- o Paragraph 4 contains two elements:
 - First, each Annex I Party is to provide data to SBSTA to establish its level of carbon stocks in 1990.
 - Second, the COP/MOP is authorized to decide upon the rules for how sink activities are to be counted, as well as for which additional activities are to be counted. (In order to avoid a situation where the addition of a new activity would make it more difficult for a Party to reach its target, any additions apply automatically only to subsequent commitment periods; a Party may, however, take advantage of an additional activity by opting to count it for purposes of the first commitment period.)
 - o (Pursuant to COP 3 Decision L.7, this issue is on the agenda for COP 4.)
- o Paragraphs 5 and 6 deal with countries with economies in transition. They provide:
 - that the countries whose base years were decided under the Convention (e.g., 1987 for Russia) are to use those base years;
 - other countries with economies in transition may use a base year other than 1990, provided the COP/MOP approves such base year; and
 - the COP/MOP is to provide countries with economies in transition "a certain degree of flexibility" in the implementation of obligations under the Protocol other than under Article 3, i.e., such countries may not be accorded flexibility with respect to any other aspect of the target obligation other than the base year.
- o Paragraph 7 defines the initial "assigned amount" for the first commitment period of 2008-2012, i.e., the amount that may be emitted during that period.
 - It is derived from taking a Party's emissions of the six gases listed in Annex A in 1990 (except that economies in transition may be using a different base year and that Parties may elect 1995 for three of the gases, see below), multiplying that number by the percentage inscribed in Annex B (i.e., 93% for the United States), and multiplying that total by 5 (the number of years in the commitment period).

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- To accommodate Australia, this paragraph also provides that Parties for whom land use change and forestry constituted a net source of emissions in 1990 are to include the net change amount in their assigned amount.
- o Paragraph 8 allows a Party to elect to use 1995 as its base year for HFCs, PFCs, and SF6.
- o Paragraph 9 provides that commitments for subsequent commitment periods are to be established through amendment of Annex B. The amendment procedure that would apply would require affirmative ratification, approval, etc., i.e., the quicker opt-out procedure that might otherwise apply to annex amendments would not apply.
- o Paragraphs 10, 11, 12 are accounting paragraphs. They provide for assigned amounts to be increased or decreased based on amounts received or transferred under emissions trading, joint implementation, or the Clean Development Mechanism.
- o Paragraph 13 incorporates the U.S. "banking" proposal, namely it allows a Party that emits less than its assigned amount during a commitment period to add that amount to a subsequent commitment period's assigned amount.
- o As noted above, paragraph 4 is similar to paragraph 3 of Article 2, except that:
 - it applies to each Annex I Party, rather to Annex I Parties collectively; and
 - it specifically notes that the COP/MOP is to consider the establishment of funding, insurance, and transfer of technology.

Article 4 ("Bubble")

- o This Article allows Annex I Parties to prospectively reallocate their emissions targets, provided their total emissions do not exceed their combined assigned amounts.
 - If the Parties failed to achieve the total level of emissions reductions, each Party would be responsible for its own level of emissions set out in the reallocation agreement.
- o Any reallocation agreement must be notified upon ratification and remains in operation for the commitment period in question. In other words, it may not be changed for that commitment period.

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- o If a regional economic integration organization (such as the EU) is involved, any change in the composition of the organization after adoption does not affect existing commitments. In other words, if an Eastern European country were to join the EU next week, it could not join the EU bubble; that country would only be part of the bubble for purposes of subsequent commitments.

Article 5 (Measurement)

- o Under this Article, each Annex I Party must have in place, no later than 2007, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of greenhouse gases.
- o Guidelines for national measurement systems are to be decided by the COP/MOP and are to incorporate the IPCC methodologies, which were agreed upon at COP 3.
- o Where a Party does not use the accepted methodologies, appropriate adjustments (e.g., discounting) are to be applied according to methodologies agreed by the COP/MOP.
- o The COP/MOP is to regularly review methodologies and revise them as needed; importantly, revisions would only apply prospectively to subsequent commitments.
- o This Article also provides that the global warming potentials (GWPs) used to calculate carbon dioxide equivalence (note that the target commitment is written in terms of carbon dioxide equivalence) are those accepted by the IPCC and agreed by COP 3. As with methodologies, the COP/MOP may revise GWPs; however, any revisions would only apply to subsequent commitments.

Article 6 (JI with Annex I)

- o This Article is largely the joint implementation provision that the U.S. sought, except limited to Annex I Parties.
- o The key elements include:
 - Unlike under emissions trading (see Article 16 bis below) and the Clean Development Mechanism (see Article 12 below), the COP/MOP is not commanded to set rules; rather, it is authorized ("may") to further elaborate guidelines. This implies that JI could go forward without further COP/MOP action. (It should be noted, however, that the elaboration of guidelines is on the COP 4 agenda.)

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- JI applies to emission reduction units resulting not only from mitigation projects, but also from projects "enhancing anthropogenic removals by sinks."
- Projects must have the approval of the Parties involved.
- A project must provide a reduction that is "additional" to any that would otherwise occur.
- A Party cannot acquire units if it is not in compliance with its measurement/reporting obligations; if a compliance issue is raised, units can continue to be exchanged; however, units may not be used to meet the target until any compliance issue is resolved.
- As under emissions trading (see Article 16 bis below), JI is to be "supplemental" to domestic actions for meeting the target.
- Parties may authorize legal entities (which could include the private sector) to participate.

Article 7 (Reporting)

- o Under this Article, each Annex I Party must incorporate in its annual inventory of emissions/removals and its national communication under the Convention the additional information that is necessary to ensure compliance with the target obligation.
- o The COP/MOP is to adopt guidelines for the submission of such additional information.

Article 8 (Review)

- o This Article provides that the information submitted by Annex I Parties under the previous Article is to be reviewed by expert teams, which are to be coordinated by the Secretariat and to be composed of experts selected from those nominated by Parties and, as appropriate, by intergovernmental organizations.
- o Expert teams are to prepare a report to the COP/MOP assessing implementation of all commitments (not just the target), including identifying potential problems in fulfilling commitments.

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- o The COP/MOP is to consider:
 - information submitted under Article 7;
 - the reports prepared by the expert teams; and
 - any questions of implementation raised by the reports, as well as any questions raised by Parties;
- and take decisions.

Article 9 (Review of Protocol)

- o This Article provides for the COP/MOP to review the Protocol periodically, in coordination with relevant reviews under the Convention; the first review is to take place at the second session of the COP/MOP.
- o Significantly, the review under this Article is not (as had been proposed by some) limited to reviewing the commitments of Annex I Parties

Article 10 (Advancing Implementation of Commitments)

- o Pursuant to the Berlin Mandate, this Article advances the implementation of existing commitments under Article 4.1 of the Convention.
- o It applies to all Parties.
- o With various qualifiers, it calls upon Parties to:
 - formulate cost-effective programs to improve the quality of local emission factors;
 - implement programs containing measures to mitigate climate change and facilitate adaptation to climate change;
 - cooperate in promoting effective modalities for development, application, diffusion, and transfer of environmentally sound technologies pertinent to climate change; (significantly, the provision refers to the creation of an "enabling environment for the private sector");
 - cooperate in scientific and technical research and promote systematic observation systems; and
 - cooperate in development and implementation of education and training programs.

Article 11 (Financial Resources)

- o This Article essentially restates the financial provisions of the Convention; it does not create new financial obligations.
- o First, it provides that the operating entity of the financial mechanism of the Convention (i.e., the GEF) shall apply.
- o Second, under the Convention, developed country Parties are obligated to provide new and additional financial resources to meet:
 - the agreed full costs incurred by developing country Parties in meeting certain commitments, such as reporting; and
 - the agreed full incremental costs of meeting "other commitments."

This Article makes clear which provisions of the previous Article (which advances the implementation of existing commitments under the Convention) qualify for full cost funding and which qualify for incremental cost funding.

Article 12 (Clean Development Mechanism)

- o This Article provides for the functional equivalent of joint implementation with developing countries.
- o It provides for Annex I Parties to be able to get credit towards "part" of their target (to be defined by the COP/MOP) for emissions reductions from project activities in non-Annex I countries.
- o Emission reductions are to be certified by operational entities to be designated by the COP/MOP, based on:
 - voluntary participation by each involved Party;
 - real, measurable, and long-term benefits related to mitigation of climate change (which would appear to include sink projects);
 - reductions in emissions that are "additional" to any that would occur in the absence of the activity.
- o The COP/MOP is to ensure that a share of proceeds from certified activities is used to cover administrative expenses, as well as assist developing country Parties (such as small island states) to adapt to climate change.

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- o As in Article 6 on JI, it is clear that the private sector may participate; participation may involve either investing in project activities that yield emission reductions or acquiring certified emission reductions without such an investment.
- o Significantly, the Article provides for early credit in that certified reductions obtained from 2000 up to 2008 can be used to meet the target.
 - COP 3 Decision L.7 calls for COP 4 to analyze the implications of this provision.

Article 13 (COP/MOP)

- o As a compromise between those wanting the Convention's Conference of the Parties (COP) to be the institution for the Protocol and those seeking a new, separate institution, Article 13 provides that the Convention COP will serve as the "meeting of the Parties" to the Protocol. While leaving ambiguous whether the COP/MOP is a new institution, the Article does make clear that decisions under the Protocol may only be taken by those that are Parties to the Protocol.
- o The COP/MOP has basically the same functions with respect to the Protocol that the COP has with respect to the Convention.
- o Significantly, the Article provides that the Convention's rules of procedure and financial rules will apply under the Protocol, except as otherwise decided by consensus by the COP/MOP. The implications of this provision are:
 - that, in the absence of agreed rules of procedure under the Convention (the current situation), the default decision-making rule under the Protocol would be consensus; and
 - the Convention's rules of procedure now need to be approached from the point of view that, absent consensus to the contrary, they will also apply to the Protocol.

Article 14 (Secretariat)

- o This Article provides for the Convention Secretariat to serve as the Protocol Secretariat.

Article 15 (Subsidiary Bodies)

- o This Article provides for the Convention's subsidiary bodies, namely the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation, to serve as the subsidiary bodies under the Protocol.

Article 16 (Multilateral Consultative Process)

- o Article 13 of the Convention provides for the COP to
"consider the establishment of a multilateral consultative process, available to Parties on their request, for the resolution of questions regarding the implementation of the Convention."
- o The intent was to create a forum for implementation questions that, in contrast to traditional dispute-settlement, was: multilateral; friendly; and able to take up issues that were necessarily alleged treaty violations.
- o Numerous, inconclusive discussions have taken place under the Convention concerning the establishment of such a process.
- o This Article of the Protocol presupposes the existence of a process under the Convention. It provides for the COP/MOP to consider the application to the Protocol of such a process, making modifications as appropriate.

Article 16 bis (Emissions Trading)

- o This Article establishes emissions trading for purposes of meeting target commitments.
- o Its significant features include:
 - It provides for the COP (as opposed to the COP/MOP, so that decisions can be made in advance of the Protocol's entry into force) to define the relevant rules for trading. (The rules are on the agenda for COP 4.)
 - There is a free-standing sentence providing for the ability to participate in emissions trading; unlike the penultimate version of the text, it is not explicitly preconditioned on the establishment of rules.

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- In contrast to proposals to put a percentage limit on the amount of the target that Party could satisfy through trading (either through a number or by providing that domestic actions had to be the "main" means of meeting the target), the Article simply provides that trading is to be "supplemental" to domestic actions.
- Unlike other provisions in Article 3, which refer to Parties "included in Annex I," this Article provides for trading among "Parties included in Annex B." This is a result of a technical fix that was made when Article 10 (voluntary opt-in) was still in the text; that Article provided that, if a developing country took on a target, it would be inscribed in Annex B. In order to make clear that such countries could then trade, the emissions trading article then had to say that trading was possible among "Annex B" Parties. Even in the absence of Article 10, this Article can be read to allow trading among Parties, provided they are listed with a target in Annex B. As such, a developing country could presumably propose an amendment to Annex B with its target; if it were adopted and entered into force, it would seem to be able to trade.

Article 17 (Non-Compliance)

- o This Article provides for the COP/MOP to approve appropriate and effective procedures and mechanisms to determine and address cases of non-compliance. Pursuant to a U.S. proposal, the task includes development of an indicative list of consequences for non-compliance, taking into account the cause, type, degree and frequency of non-compliance.
- o It also provides that any binding consequences need to be adopted through an amendment.
- This provision was a compromise between two views. Some considered that the COP/MOP ought to be authorized to establish binding penalties through decision. Our view was that binding consequences of non-compliance should be spelled out in the Protocol itself (such as our borrowing proposal) and that it was not appropriate (or likely to be acceptable to the Senate) to establish binding penalties through decisions. The compromise provides for the option of binding penalties, but makes clear that they would need to go through the normal amendment procedure.

Article 18 (Dispute Settlement)

- o This Article incorporates by reference the Convention's provisions on dispute settlement. Technically, this Article was not necessary, given that Article 14 of the Convention provides that

"the provisions of this Article shall apply to any related legal instrument which the Conference of the Parties may adopt, unless the instrument provides otherwise."

- o Article 14 of the Convention (and this Article, by reference) provides for Parties to settle disputes through negotiation or other peaceful means. Parties may further opt to settle disputes through binding arbitration and/or the International Court of Justice. In the case of Parties that have not settled a dispute and have not opted for other settlement means, the dispute is to be submitted to non-binding conciliation.

Article 19 (Amendments)

- o Amendments may be adopted by a three-fourths majority of Parties present and voting and enter into force for those Parties having accepted it ninety days after instruments of acceptance have been received from at least three-fourths of the Parties.

Article 20 (Annexes)

- o Consistent with numerous other international agreements, this Article provides for a special, quicker procedure for adding/amending annexes. In sum, in exchange for being restricted to material that is "scientific, technical, procedural or administrative," such annexes may be added/amended without going through ratification; a Party that does not want to be bound simply "opts out."
- o The original Annexes to the Protocol (Annex A on gases and Annex B on targets) are not, however, scientific, technical, etc. They are extremely substantive. Thus, this Article makes clear that the simplified procedure does not apply to them. Any amendment to these Annexes would need to go through the normal amendment procedure under Article 19.

Article 21 (Voting)

- o This Article reflects the standard voting provision -- each Party has one vote, except that regional economic integration organizations (such as the EU) do not get an extra vote.

Article 22 (Depositary)

- o The UN Secretary-General will be the Depositary.

Article 23 (Signature)

- o The Protocol will be open for signature at UN Headquarters in New York from March 16, 1998, to March 15, 1999. It is only open for signature and ratification by States and regional economic integration organizations that are Parties to the Convention.

Article 24 (Entry into Force)

- o This Article provides that there are two requirements for entry into force:
 - at least 55 Parties to the Convention must have submitted their instruments of ratification, acceptance, etc.; and
 - those having ratified, etc., must include Annex I Parties that accounted in total for at least 55% of total CO2 emissions for 1990 of Annex I Parties (to be determined in accordance with the first national communications of such Parties submitted under the Convention).

Article 25 (Reservations)

- o This Article provides that no reservations may be made to the Protocol. The United States opposed this Article, but did not prevail.

Article 26 (Withdrawal)

- o A Party may withdraw three years after the Protocol entered into force for it; such withdrawal becomes effective one year after notification of withdrawal.

Article 27 (Languages)

- o The six official UN languages are equally authentic.

Annex A (Gases)

- o This Annex (which is referred to in Article 3 in describing the target obligation) contains the six major greenhouse gases, as well as the sectors/source categories that are covered.

-15-

Annex B (Target Commitments)

- o This Annex lists Parties with target commitments, as well as the percentage of the base year to which they have committed.
- o Initially, the list contains only Annex I Parties (minus Turkey), but could be amended to include Parties that are not Annex I Parties.

To: Janet Yellen
Jeff Frankel

From: Adele Morris

Date: June 1, 1998

Subject: Seller vs. Buyer Liability

Introduction:

As we prepare for negotiations on international trading rules later this year, CEA should be very involved in the decisions regarding the treatment of transferred permits of Parties that over-emit -- the so-called "liability" question. The attached paper was written by several of us and sent to the Umbrella countries by the State Dept last Friday. It provides an introduction to the issues without taking a position.

So far, all the economic analysis has implicitly assumed that every permit is fully valid for one ton of emissions, and that all countries comply with their treaty obligations. The liability decisions could produce a sharp departure from that world:

- In a buyer liability system, the permits we buy from other Parties would be devalued in the event that they don't retain enough to cover their own emissions. Thus the price of a Party's tons would be discounted according to their risk of over-emission.

The biggest problems:

- The risk connected to purchasing permits could seriously impede the startup of the trading system.
- The price discount may not compensate buyers for the information and transactions costs, as well as precautionary permit purchases.
- U.S. tons could trade at a discount if other buyers think we own too many risky permits. Thus, U.S. selling sectors could be affected by the behavior of U.S. buying sectors.
- Buyer liability is a very blunt instrument to get at the behavior of the one or two countries that people are worried about (Russia and Ukraine).

Argument for buyer liability:

Others argue that compliance tools are extremely limited, and even if you have second period penalties, the treaty doesn't offer enough disincentives for rogue nations to sell excessively. Only by introducing a price incentive for them to demonstrate compliance can you ensure that they participate responsibly.

What everyone else thinks:

State: Victoria Greenfield largely agrees with me. She thinks that market power exertion by the Russians may prevent them from selling too much, irrespective of noncompliance penalties. [Monopoly power raises another whole set of issues for the development of the trading rules.] The diplomatic side of State (e.g. Jonathan Pershing) seems to care most about process, and views compromise, or at least dialogue, on liability as a way to make progress in other areas.

Mike Toman is even more worried about buyer liability than I am. He thinks it could be a disaster. He suggests we concentrate on borrowing from second period budgets with a penalty as the main means to encourage compliance in the first period.

Treasury: So far David Wilcox and Jon Gruber don't like buyer liability, but view seller liability as something we can give away in negotiations to get something more important. While I agree that there are more important rules than liability, such as caps on trading, I view caps that won't bind as definitely preferable to buyer liability.

DOE: Abe Haspel's shop supports a version of buyer liability that discounts by date of first transfer, with the last permits sold as the first devalued. So far, we haven't heard much from Mark Mazur.

EPA: David Doniger supports a hybrid approach in which a small initial set of permits are sold at full value (with proceeds dedicated to real reductions and building monitoring and reporting infrastructure) and later permits are sold as buyer liable.

Allocation of Risk under International Emissions Trading

Introduction

- To comply with the Protocol, each Annex I Party has the obligation to hold enough tonnes of carbon dioxide equivalent at the end of the first commitment period to cover its net emissions during that period.
- Rules under Article 17 should indicate clearly from the outset what will happen to tonnes that a Party has previously transferred if it has excess emissions at the end of the commitment period. (This paper focuses on excess emissions; however, failure to comply with measurement and reporting obligations also needs to be addressed.)
- Different approaches to the allocation of risk as between the selling and buying Parties could produce substantially different prospective incentives for selling and buying Parties and other entities (e.g., private sector firms) involved in international emissions trading.
- Because those incentives have potentially large implications for the economic and environmental consequences of the trading system, careful consideration must be given to the various advantages and disadvantages created by the different approaches before one is chosen.
- This paper briefly outlines possible approaches, but much more analytical work is necessary to explore the options.
- In addition, consultations with potential private sector participants could help us understand the effects of the risks and uncertainties associated with different approaches, as well as the extent to which they may impede the development of the trading system.

Basic Options

- The rules could provide that previously transferred tonnes are unaffected, placing total responsibility for the excess emissions on the selling Party.
- Under this option, a selling Party could be required to make up its shortfall, by acquiring tonnes from others or by deducting its excess emissions, with a penalty, from its assigned amount for the second commitment period.
- Alternatively, the rules could provide that previously sold tonnes will be applied to cover the selling Party's excess emissions, effectively shifting non-compliance risks to the buying Party of those tonnes.

- Hybrid approaches could be possible.

Discussion

1. Selling Party Bears Risk

- As noted above, under such an approach, the rules would provide that any tonnes transferred by a party may be used (or re-transferred) by the acquiring Party at their full value (i.e., a tonne is always equal to a tonne), regardless of whether the originating Party had retained enough tonnes to cover its own net emissions at the end of the commitment period.
- The selling Party would be solely responsible for its excess emissions.
- While further sales of tonnes could be prohibited once the selling Party's emissions had used up its entire assigned amount after adjustments for trading, past sales would be unaffected.
- Consequences for the selling Party would depend upon the trading rules and the more general non-compliance rules. The rules could require the selling Party to make up the excess emissions -- by acquiring that number of tonnes from others within a specified period of time after the end of the commitment period, by deducting that number of tonnes (with a penalty) from its assigned amount for the following commitment period, or by some other means. They could also preclude the Party from participating in trading in the subsequent commitment period.

Implications

- Likely to be the simplest system, providing relative certainty for buyers.
- Buying Parties (and their entities) could acquire and use tonnes from any Annex B Party at face value and treat them as completely interchangeable. Buyers would bear no added costs to evaluate or purchase additional tonnes to protect against the possibility of the selling Party's non-compliance.
- To the extent that a selling Party with market power oversells, thereby reducing the price of tons, the market itself would provide an incentive for that Party to comply.
- Unless trading or non-compliance rules create consequences for a Party that oversells, this approach may not provide sufficient incentive for a selling Party to retain enough tonnes to cover its own emissions.
- As such, there could be negative environmental consequences.
- Others?

2. Buying Party Bears Risk

- Under such an approach, the rules would provide that if a selling Party does not possess enough tonnes to cover its emissions at the end of the commitment period, tonnes that the Party had previously sold would be applied to cover the shortfall.
- In other words, tonnes sold abroad would be applied to the excess emissions of the selling Party rather than the buying Party.
- There are several approaches to how (and which) tonnes could be devalued (reclaimed) to cover the excess emissions, for example, all tonnes could be devalued by an equal share or tonnes could be devalued on the basis of their transfer date.
- To the extent that buyers may not be able to apply their tonnes purchased from a non-complying Party, the tonnes from different Parties would potentially trade at different prices, reflecting buyers' assessment of the risk of the originating Party's non-compliance.

Implications

- Selling Parties would have a price incentive to demonstrate compliance, because buyers would pay more for tonnes from Parties with solid compliance assurances (although the magnitude of the price incentive is uncertain).
- Would create risks for buyers, who would not know whether the tonnes they acquired are fully valid until the end of (or perhaps after) the commitment period.
- However, buyers might manage risk in numerous ways, such as: creating portfolios of tonnes from different Parties, trading through contracts that are contingent on the performance of the selling Party, using the services of risk-raters (akin to Moody's bond ratings), etc.
- Such an approach could impede development of the trading system by: overburdening a fledgling market with excess risk; raising transaction costs (e.g., to get risk information); potentially requiring buyers to buy extra tonnes to guard against a shortfall.
- Even if the selling Party gets only a discounted price, it might still have an incentive to oversell.
- The approach creates complex interdependencies, under which market prices for a Party's *own* tonnes may be weakened if it holds large numbers of tonnes from risky sellers.
- Private sellers could be adversely affected by the purchasing decisions of private buyers in the same country. In other words, a buyer of tonnes from Party A, in deciding how much to pay for tonnes from Party B, would need to take into account whether Party B was likely to comply. To the extent that Party B (including through its private sector) had acquired

tonnes from Party C (a compliance risk), tonnes from Party B could be devalued.

- Others?

3. Hybrid Options

- Hybrid options could be possible.
- There appear to be at least three ways in which a hybrid approach might work:
 - The mixed allocation could be decided up front.
 - A pure buyer or seller allocation could apply initially, but could later switch under certain circumstances (such as under a "yellow light" scheme).
 - A selling Party could be given the option to choose, including up front: 1) to make up its excess emissions by either acquiring tonnes or deducting them from the next commitment period (in which case previously transferred tonnes would retain their full value); or not to make up its excess emissions (in which case the risk would switch to the buying Party).
- Further consideration would need to be given to ensure that hybrid options were designed to mitigate concerns raised by pure buyer/seller options.

Relationship Between CO2 Concentration Ceilings, Maximum Emissions, and the Subsequent rate of Emissions Decline

Steady State Concentration	350 ppmv	450 ppmv	550 ppmv	650 ppmv	750 ppmv
Deflection Date IS92a (Tech +)	2001	2007	2013	2018	2023
Deflection Date IS92Aa (1990 Tech)	2001	2006	2007	2007	2007
Growth Rate to Maximum Date	0.3%	0.3%	0.5%	0.5%	0.4%
IS 92a (Tech +) Growth Rate	1.8%	1.4%	1.1%	0.9%	0.7%
IS92a (1990 Tech) Growth Rate	1.6%	3.3%	2.8%	2.6%	2.6%
Maximum Date	2005	2011	2033	2049	2062
Maximum Emission	6	8	9.7	11.4	12.5
Rate of Decline	-	1.1%	0.8%	0.6%	0.5%

Deflection Date: Year in which emissions first fall below IS92a emissions by more than 0.1 Pg/yr

Growth Rate to Maximum Date: Average annual rate of growth (%/yr) of fossil fuel carbon emissions between deflection date and maximum date

IS 92a Growth Rate: The rate of growth (%/yr) of fossil fuel carbon emissions between the deflection date and the maximum date

Maximum Date: Date of peak emissions prior to decline

Maximum Emission: Pg/yr fossil fuel carbon emissions on the date of maximum total anthropogenic carbon emissions

Rate of Decline: Rate of decline in fossil fuel carbon emissions in percent per year, over the first 75 years following the date of maximum emissions

CC: SA
 JF
 ARE orig

CL PL
JF
AM ← orig

NUCLEAR ENERGY PLANT OPTIMIZATION

Background

Modern U.S. nuclear power plants are the only proven energy source in large-scale use today that provide large amounts of reliable baseload electrical generating capacity without contributing to regional air pollution or global greenhouse gas emissions. The continued safe and economic operation of the Nation's 105 nuclear power plants provide security and diversity to the electrical supply system during a period of immense change in the electrical utility industry. These power plants provide over 20 percent of the Nation's electricity and nearly one-half of the 50 states receive more than 25 percent of their electricity from nuclear power.

In the next two decades, greater than 85% of the currently operating nuclear plants will be retired due to economics or expired operating licenses.

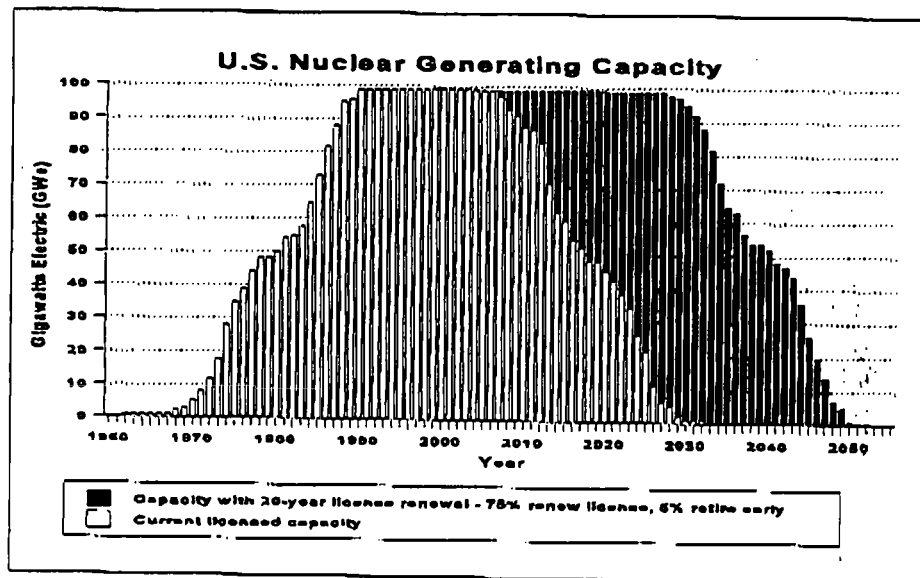
projected to retire prior to expiration of their operating licenses due to plant economics and aging degradation of plant components. In addition, EIA projects another 65 units (51% of nuclear generating capacity) will shutdown at the end of their 40 year operating license period between 1996 and 2020, with 60% of these retirements occurring between 2010 and 2020. The Department believes that technologies proposed to be developed in this initiative can have a significant impact on EIA's projections and demonstrate nuclear plant license renewal is an effective strategy to continue operation of existing nuclear plants.

In November, 1997 the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST) recommended that

"DOE work with its laboratories and the utility industry to develop a program to address the problems that may prevent continued operation of current plants."

The Department of Energy (DOE) has responded to that recommendation and has proposed the *Nuclear Energy Plant Optimization (NEPO)* program in

coordination with the Electric Power Research Institute (EPRI). The Department and EPRI have developed the *Joint DOE-EPRI Strategic*



If no action is taken, according to the Energy Information Agency's (EIA) 1998 *Annual Energy Outlook*, 24 nuclear plants are

Research and Development Plan to Sustain Operation of Current Nuclear Plants to identify and prioritize the essential R&D needs of the commercial nuclear industry for the next seven years. This plan specifies the government and industry roles for this public-private cooperation and the R&D technology collaboration needed to address the critical issues associated with the continued operation of current nuclear plants, and provide a foundation from which U.S. nuclear electric utility companies can move forward with confidence to renew their operating licenses. This R&D plan identifies the specific R&D activities for long term cost effective management of plant aging and material degradation, demonstration of the license renewal regulatory process and optimization of nuclear plant generation.

The Department is also collaborating with other federal government and international research agencies to coordinate nuclear plant research and leverage limited resources. Specifically, the Department is its research activities with the Nuclear Regulatory Commission (NRC) to assure the R&D activities of the respective agencies are consistent with their mission and purpose with no duplication of effort.

The Department has established the following goals for the Nuclear Energy Plant Optimization program:

Technologies to Optimize and Extend Plant Service

- Manage the long-term effects of nuclear plant component aging:
 - Steam generators;
 - Key reactor components;

- Reactor internals
- electrical cables;
- Structures
- Establish a viable license renewal process through a cooperative demonstration program with industry.

Generation Optimization Through Efficiency and Capacity Improvements

- Improve nuclear power plant capacity factors (hours of operation per year) by 9%.
- Optimize nuclear power plant electricity generation through new advanced technologies in digital instrumentation, sensor, diagnostic capability and information management.

FY 1999 Planned Accomplishments:

- Identify at least one new technology to reduce stress corrosion cracking in current operating nuclear plants
- Select pilot plants for cooperative demonstration of the NRC license renewal process.
- Demonstrate new technology to non-destructively inspect and measure circumferential cracking in nuclear steam generator tubes.
- Demonstrate NRC-licensable digital reactor protection system instrumentation replacement technology.
- Complete prototype testing of advanced on-line monitoring and diagnostic system that uses artificial intelligence.

Program Budget Request: \$10 million

Nuclear Energy Research Initiative

Background

In January, 1997 the President tasked his Committee of Advisors on Science and Technology (PCAST) to evaluate the current national energy R&D portfolio and provide a strategy to ensure the U.S. has a program to address the nation's energy and environmental needs for the next century.

In its November 1997 report, the PCAST Panel on Federal Energy R&D determined that establishing nuclear energy as a viable and expandable option was important and that a properly focused R&D effort to address the problems of nuclear waste, proliferation, safety and economics was appropriate.

The PCAST panel further recommended that the Department of Energy reinvigorate its nuclear energy research and development activities in a focused R&D effort to address these problems with a new nuclear energy research initiative based on competitive selection of research proposals from the national laboratories, universities and

industry to "address the key issues affecting the future of fission energy including proliferation-resistant reactors or fuel cycles; new reactor designs with higher efficiency, lower-cost, and improved safety to compete in the global market; lower output reactors for use where large reactors are not attractive; and new techniques for on-site and surface storage and for permanent disposal of nuclear waste".

In response, the Department is proposing the Nuclear Energy Research Initiative (NERI) to address the key issues affecting the future of nuclear energy and to preserve our nation's nuclear science and technology leadership. To achieve this long range goal, the following objectives have been established:

- Development of advanced concepts and scientific breakthroughs in nuclear fission and reactor technology that will further enhance nuclear energy as a safe, environmentally sound, and cost-effective global energy source;



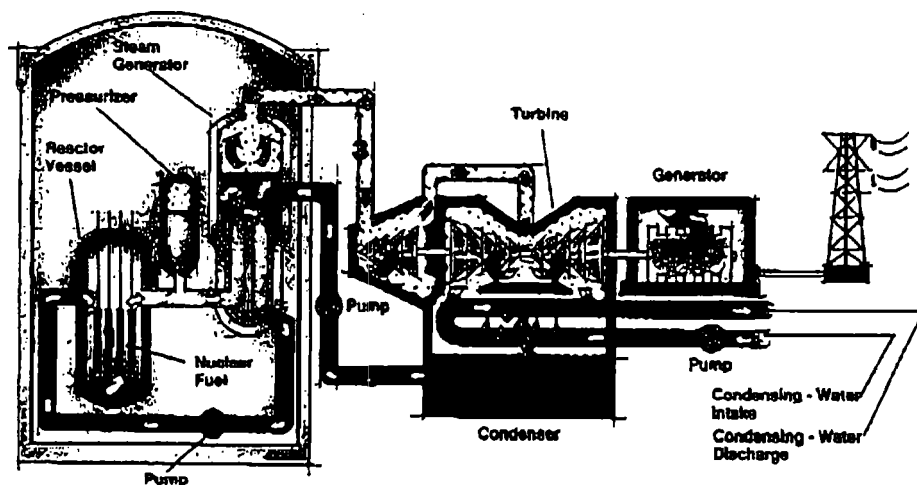
- Focus the university and laboratory scientific R&D infrastructure on the nuclear energy issues, and foster collaborative basic and mission oriented research and development to leverage resources;
- Facilitate the transfer of basic fission energy research from defense and other research areas to the mission directed nuclear energy and science challenges in the civilian sector;
- Encourage international cooperation in the development of advanced nuclear technologies.

The proposed program will feature a competitive, peer reviewed R&D selection process to fund researcher initiated R&D proposals from universities, national laboratories and industry. In

FY 1998, the Department plans to establish an independent Nuclear Energy Research Advisory Committee to provide advice and recommendations to assist the Department on the direction and focus of nuclear energy R&D.

FY 1999 Accomplishments:

- Completion of initial R&D procurement by soliciting research proposals, conducting proposal peer-review and award first research grant and contracts by January 1999;
- Initiate, as a minimum, research projects in the following areas: high efficiency nuclear fuel, proliferation resistant reactor and fuel technologies and high efficiency reactor concepts.

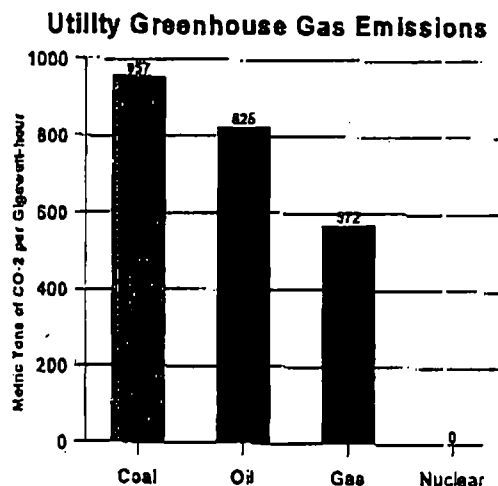


Program Budget request

\$24 Million

Nuclear Energy Fact Sheet

- In 1996, nuclear energy generated over 675 billion kilowatt-hours of electricity, the equivalent 20% of the total domestic electricity supply, second only to coal. Nearly half of the 50 states obtain more than 25% of their electricity needs from nuclear power.
- The U.S. nuclear industry generates highly skilled and professional jobs employing approximately 400,000 people in nuclear-related jobs.
- The nuclear industry supports a strong economy pumping more than \$90 billion into the economy in goods and services in 1995 and contributing more than \$17 billion in federal, state and local taxes.
- EIA projects 65 nuclear units, representing 51% (52 gigawatts) of the current nuclear generating capacity, will retire between 1996 and 2020 due to expiration of their operating licenses. By 2020, 173 new fossil plants (300 megawatt each) will be required as replacements contributing an additional 90 million tons of carbon emissions annually.
- Nuclear power plants release no greenhouse gas or other harmful air pollutants such as sulfur dioxide and nitrous oxide.
- Nuclear energy's environmental benefits are being felt worldwide. Only 12 countries including the U.S. reduced their carbon emissions between 1973 and 1990, and nine of those cases can be attributed to nuclear energy.
- Nuclear energy accounts for almost 90% of all CO₂ emissions avoided by the utility industry since 1973.
- Nuclear energy has supplied almost half of all U.S. electricity demand growth since 1973 while avoiding 2 billion tons of carbon emissions. Continued operation of existing nuclear plants will displace over 620 million tons carbon dioxide annually.
- Nuclear plants are achieving record capacity levels achieving an industry wide average capacity factor of 79% in 1995 (76% in 1996) with industry targets of 85% by 2010.
- Efficiency improvements at nuclear plants over the past six years added the equivalent of 11 new 1,000 megawatt power plants to the electricity supply system, while avoiding an additional 12.5 million tons of carbon emissions.
- Improved nuclear plant performance is being achieved while maintaining productions costs competitive with coal. In 1996 nuclear power cost 1.92 cents per kilowatt-hour in comparison to 1.82 cents for coal and 2.8 cents for natural gas.



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MEMORANDUM

TO: Jeff Frankel, Council of Economic Advisers
FROM: Rob Stavins *RA*
DATE: August 25, 1998
RE: *Fossil Fuel Use Without CO₂ Emissions*

I thought you'd find of interest the paper on carbon removal strategies I mentioned at the Snowmass workshop. A revised version is forthcoming in *Science*.

Enclosure

*W: JY
JA
SP
QF
Cing.*

FOSSIL FUELS WITHOUT CO₂ EMISSIONS

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Abstract: 81 words
Main text: 2,067 words
References: 412 words

Version 6.4, August 6, 1998

Forthcoming in *Science*

(still to be copy-edited)

ABSTRACT

Recent work in carbon management (CM)— the separation and sequestration of carbon from fossil-fuel combustion to reduce atmospheric CO₂ emissions —has raised estimates of sequestration capacities and lowered estimates of costs, such that CM may offer substantial abatement possibilities more cheaply than non-fossil energy. CM's seeming technological and economic attractiveness has major implications for the political economy of abatement and the design of abatement policies. CM also carries novel environmental risks and raises serious inter-generational equity issues, which urgently require assessment.

One way to reduce the climatic impact of fossil energy is to separate the resulting carbon and sequester it away from the atmosphere (1). Recent work in carbon management (CM) – the linked processes of separating and collecting carbon, and sequestering it in the ocean or underground – has shown substantial progress in developing the necessary technologies and understanding sequestration potential (2–4). One large-scale project sequestering CO₂ to avoid atmospheric emissions is operational; several others are planned. CM's technical progress is outpacing consideration of its limitations and potential risks. We sketch recent technical developments in CM, and discuss its implications for the policy and politics of global climate change.

Technical Status and Prospects

A diverse and expanding array of technical options now exists for both separation and sequestration of carbon. Carbon can be separated from fossil fuels by separating CO₂ from products of combustion in air or in pre-separated oxygen, or by steam reforming of the fuel to yield a hydrogen-enriched fuel stream and a carbon-enriched stream for use or sequestration. In electrical generating stations, post-combustion amine solvent separation (a mature technology) imposes an energy penalty of ~20%, equivalent to a cost of 70–140 \$/tC depending on the base plant (4,5). Various approaches promise large cost improvements. Recent studies combining existing commercial components (for example, oxygen plants, gasifiers, combined cycle systems) in integrated plant designs predict energy penalties under 15% and net plant efficiencies of ~50% (6). Advanced separation technologies such as improved solvents, membranes, and low-pressure formation of CO₂ hydrates, promise energy penalties under 10%.

Because of economies of scale in CO₂ collection, CM in the transport sector would require shifting from petroleum to a non-fossil secondary energy carrier, either electricity or hydrogen. Large-scale thermochemical production of hydrogen from fossil fuel, and its long-range transport, are mature technologies in the petrochemical industry (3). If hydrogen were used as the energy carrier – which would require further commercialization of automotive fuel cells – CM would benefit from the efficiency advantages of this thermochemical process over electrolysis (5,8).

Carbon can be sequestered in the ocean or in geological reservoirs. While Marchetti first proposed ocean CO₂ injection two decades ago (1), recent research has clarified the fate of the injected CO₂, its biological effects and its legal status (2–4). The sequestration capacity of the deep oceans is ~10³–10⁴ gigatons of carbon (GtC), much larger than current anthropogenic emissions of 6–8 GtC per year. When carbon is emitted to the atmosphere, ~80% is transferred to the oceans on a time-scale of ~300 years, with the remainder removed much more slowly (9). Injecting CO₂ in the deep ocean speeds this equilibration, reducing peak atmospheric concentrations. Depending on the injection site, however, ~20% of the injected carbon returns to the atmosphere on the ~300-year time-scale.

The most promising sites for geological sequestration are depleted oil and gas reservoirs (global capacity ~200–500 GtC), deep coal beds (~100–300 GtC), and deep saline aquifers (~10²–10³ GtC) (3,4,8,10). Injection of supercritical CO₂ into oil and gas reservoirs, and its long-range pipeline transport, have long been practiced for enhanced oil recovery (EOR). Adding

separated CO₂ to current sources and depleted reservoirs to current injection sites would accomplish sequestration with little change to current practice. The long-term stability of such reservoirs, however, is uncertain.

Deep coal beds contain methane adsorbed on coal surfaces, in quantities of the same order as global conventional gas reserves. Injected CO₂ can displace adsorbed CH₄ in a molar ratio of ~2:1, allowing the coal beds to serve as both a natural gas source and a highly stable CO₂ repository. Synergies between gas production and CO₂ sequestration are expected to yield low net costs of sequestration. A pilot-scale project in Alberta, Canada aims to develop a zero-emission electric plant that exploits these possibilities (11).

The first large projects disposing of CO₂ to avoid emissions use widely occurring deep saline aquifers as sequestration sites. Responding to Norway's carbon tax of \$170/tC, Statoil currently separates 300 ktC/yr of CO₂ from a natural gas field and injects it into an aquifer under the North Sea. A similar project under development in Indonesia will inject 30 MtC/year, roughly 0.5% of present global emissions. Norway's tax has also elicited a vigorous industry response in developing projects to generate electricity from North Sea gas and sequester the resultant emissions.

Comparing Abatement Costs

Despite evident uncertainties, current understanding allows some confidence in comparing costs of CM with alternative forms of abatement. Certain low-cost CM applications may be competitive with current energy sources. In addition to coal-bed methane production, these may include zero-emission plants burning waste fuels available at negative cost (7). Absent such synergies, CM currently costs more than other options for small levels of abatement. Typical U.S. abatement studies find reductions of 10-20% from 2010 emissions – probably insufficient to meet the Kyoto targets – available at marginal costs below \$50/tC, primarily through efficiency improvements and switching to natural gas (12,13)

Stabilizing atmospheric CO₂ concentrations at currently proposed targets (350 - 750 ppm) will require much larger reductions, implying major new sources of emission-free energy (14, 15). Most estimates show that reductions beyond 10% from 1990 emissions have sharply increasing marginal abatement cost, well over \$100/tC, based on large-scale use of solar or nuclear energy (13,16). In this range, CM can substantially expand the abatement attainable at moderate marginal cost. In electric plants, even present CM technology can reduce emissions by more than 80% with increases of only 30-60% in total cost per kWh, a penalty similar to nuclear power and substantially less than present solar power (5). Current levels of interest and private funding for CM suggest the possibility of near-term cost declines, while such non-cost factors as regulatory and political obstacles to nuclear, and solar's siting and dispatch limitations, further increase CM's relative attractiveness. CM's costs will be lowest at large point sources, where the cost of separation dominates. With distributed sources CM costs also include collection, which will be large for such highly decentralized sources as vehicles, home furnaces, or small distributed electrical generators.

To meet stringent abatement goals, however, the transport sector must participate. In contrast to the electric sector, the required reorganization of the transport system would preclude incremental adoption of CM. Its costs are consequently much more uncertain, and may be dominated by transitional costs. Most non-fossil routes to steep transport abatement would require similarly difficult system reorganizations. Among alternative low-emission transport systems, the high efficiency of thermochemical fossil hydrogen production will likely give a fossil/CM system a substantial cost advantage over hydrogen derived from non-fossil electricity. (5,8).

Implications for Policy

Adoption of CM beyond synergistic applications will require modest policy-generated incentives to offset its cost penalty over current fossil energy, likely of the ~ \$50 – 100 /tC range widely proposed to meet the Kyoto targets. Both CM's rapid recent development, and continuing uncertainty over what share it can or should contribute to future abatement, underscore the value of generating such incentives through policies that allow flexibility in the means of abatement, such as taxes or tradable permits targeted on emissions. Industry's response to Norway's carbon tax vividly demonstrates the power of such policies when they apply substantial incentives to marginal emissions.

Because emissions are so heterogeneous and spatially distributed, however, broad-based taxes or permits applied at the point of emission are widely considered infeasible. Instead, approximations are proposed such as permits or taxes applied upstream, at the point of fuel extraction. Because CM changes relationships between emissions and upstream activities that have been strongly correlated, it requires modifying such policies to include credit granted at the point of sequestration – a tax rebate, or generation of additional permits – as proposed for petrochemical feedstocks.

CM will impose related requirements on emission-accounting procedures, such as the national inventories required by the Framework Convention. The international inventory methodology and most national inventories disregard or treat inadequately the CO₂ that is already actively managed (17). CO₂ currently separated at wellheads or refineries may be re-injected for EOR, sold for emissive uses, or vented. International CO₂ trade for EOR already occurs. Expanded CM will require emission inventories to account accurately for such CO₂ flows, transformations, and sequestration. Ocean injection will pose particularly acute emission-accounting challenges, associated with access to injection sites, the legal status of injection, and the uncertain, site-specific rates at which sequestered CO₂ returns to the atmosphere.

Because low-cost CM is only available in new capital, its largest near-term opportunities lie in the energy-sector growth underway in rapidly industrializing nations. Here, in addition to policies targeting marginal emissions, CM may also require international financial aid or technology transfer to offset aggregate cost penalties. The Kyoto Protocol provides several mechanisms for such international cooperation. CM projects may be particularly suitable for the Protocol's Clean Development Mechanism (CDM), which grants transferable credits for emissions avoided by individual investment projects in states without national emission targets. Defining a credible project baseline from which to grant credit has been considered a serious

challenge to the CDM. CM projects, which sequester an observable quantity of emissions through a discrete technological choice, may allow an uncontroversial calculation of abatement credit and so be more suitable for the CDM than other forms of energy investment.

CM in transport would pose much more extreme policy challenges. The required system transformation would call for a focused national effort and pose substantial economic, technological, and safety risks. Network externalities risk locking in inferior early technical choices, whether made as intentional policy choice or through decentralized market decisions. Such a system transformation may be more feasible in a rapidly industrializing country such as China, which is expanding its transport infrastructure and arguably not yet locked into a petroleum-based system. China may now have a one-time opportunity to develop an alternative transport system using domestic coal for primary energy, hydrogen fuel cells for motive power, and CM to abate climatic effects (8).

CM's most important novelty may be its potential to transform the political economy of abatement policy. By weakening the link between continued use of fossil energy and atmospheric CO₂ emissions, CM makes it more feasible to consider a fossil-based global economy through the next century, even in a greenhouse-constrained world. By consequently reducing the severity of the threat that emission reduction poses to fossil industries and fossil-rich nations, CM may ease current deadlocks in both domestic and international abatement policy.

The abatement required to stabilize CO₂ concentrations is immense, and will require revolutionary changes in global energy infrastructure. No clear path to such a transformation is evident. A serious effort to limit climate change will require pursuing multiple technological paths, and aggressively exploiting the potential for early learning-by-doing. In the context of such an effort, CM's near-term potential is at least as great as that of non-fossil energy.

CM carries novel and potentially serious environmental impacts and risks. Many of these will be associated with particular sequestration sites, such as impacts on ocean chemistry and benthic ecosystems, and the re-release, rapidly or slowly, of injected emissions. Geological sites capable of sudden release would pose acute local risks. Sites subject to slow release would still reduce near-term peak atmospheric concentrations, even if all the injected CO₂ eventually returned – if a viable longer-term strategy to reduce global emissions were in place. Use of such sites would pose serious questions of equitable inter-generational distribution of risk, particularly because CM's energy penalty requires that more fossil fuel be used per unit delivered energy, and more CO₂ sequestered, than with conventional fossil combustion. Consequently, CM could reduce atmospheric CO₂ concentrations in the near term but increase them in the long term.

Moreover, CM occupies an ambiguous place in the conventional *abate – adapt – geoengineer* taxonomy of responses, bearing some resemblance both to conventional abatement and to geoengineering (18). This ambiguity, and CM's character as an "end of pipe" technological solution, foretell intense – and proper – controversy over the appropriate extent of intentional human intervention in global systems, as well as over CM's specific benefits and risks. In view of its apparent technological and economic attractions, and its serious implications, CM has received inadequate attention in climate assessments and policy debates. Continued rapid technical progress in CM, and continued slow progress on abatement, pose the risk of large-scale

adoption of CM without adequate reflection its implications. Large-scale adoption of carbon management would represent a major social and technological choice, which would be difficult to reverse, and which urgently requires explicit assessment and policy debate.

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