Global Warming Policy: Some Economic Implications

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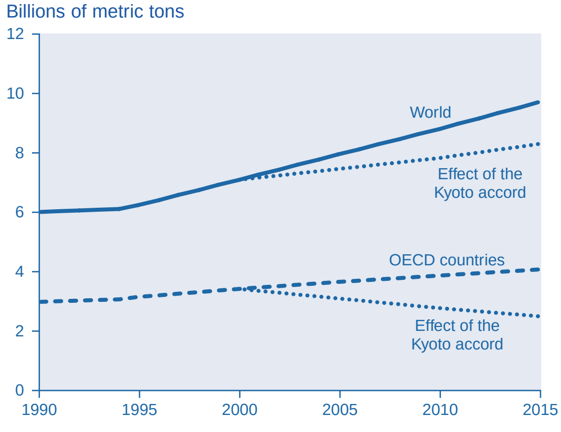
Compliance with the Kyoto accord would represent a sizable reduction in the use of fossil fuels.

Many analysts believe that adverse climate changes in the form of global warming are—or soon will be—under way as the result of anthropogenic emissions of greenhouse gases. (See the box entitled "What Is Global Warming?") The largest such source of these gases is carbon dioxide (CO_2) resulting from the growing consumption of fossil fuels (petroleum products, natural gas, and coal).[1] Consequently, the conservation of fossil fuels figures prominently in strategies to reduce CO_2 emissions.

Increasing concerns about the extent of global warming and its potential consequences culminated in a United Nations conference in Kyoto, Japan, in late 1997. Prior to the conference, President Clinton proposed that the United States join with other industrialized countries in setting a target for reducing CO_2 emissions in each country to 1990 levels by 2010. By the end of the conference, emissaries from the industrialized countries had agreed to a target 7 percent below 1990 levels by 2010 and to make further reductions in subsequent years. Developing countries would be expected to reduce their CO_2 emissions in future years as their incomes rise.

As shown in Figure 1, the U.S. Department of Energy has projected that CO_2 emissions from the consumption of fossil fuels in the industrialized countries will have increased about 30 percent from 1990 to 2010. Therefore, compliance with the Kyoto accord would represent a sizable reduction in the use of fossil fuels from what could otherwise be expected. My analysis indicates that the developing countries would consume nearly 12 percent of the amount of fossil fuels the industrialized countries must conserve to comply with the Kyoto accord. The net effect

Figure 1
Annual Carbon Emissions, 1990–2015



SOURCES: Energy Information Administration (1997); author's calculations.

What Is Global Warming?

Global warming is a scientific theory or scenario in which increased levels of atmospheric CO_2 are linked to generally rising temperatures around the world. To better understand global warming, start with the greenhouse effect. Sunlight heats the earth, but the earth would be far cooler if not for the presence of water vapor and greenhouse gases in the atmosphere. These gases let sunlight through to warm the earth but trap some of the heat escaping back into space in the form of infrared radiation. In this manner, the gases act like the glass walls and ceiling of a greenhouse.

Increasing the level of greenhouse gases in the atmosphere is like using thicker glass in the greenhouse: less heat escapes. Many scientists believe the CO_2 released by human activities is intensifying the greenhouse effect and contributing to an increase in the earth's overall temperature. This general increase in the earth's temperature is commonly known as global warming.

Many scientists and other people are concerned about global warming's potential effect on the environment. Among the predicted consequences are increased rainfall, melting polar ice caps, rising ocean levels, increased flooding, and widespread crop failure.

The evidence of global warming is inconclusive, but most scientists who study the issue think that it is occurring to some degree. Nevertheless, there is considerable uncertainty about the magnitude of the change, whether CO_2 is a contributing factor, and the environmental consequences.

would be to slow the growth of global CO_2 emissions from the projected 45 percent to 30 percent between 1990 and 2010.[2] Some worry that compliance with the Kyoto accord would impose drastic costs on the industrialized countries with little proven benefit. Others worry the Kyoto targets are too modest to prevent costly environmental problems.

These concerns raise several questions. What is the rationale for government intervention in markets to reduce CO_2 emissions? By how much does economic analysis suggest that the United States reduce its CO_2 emissions, and how do President Clinton's proposal and the Kyoto accord compare with what is optimal? The former question can be answered with simple economic theory. The latter question can be answered by combining estimates of the economic benefits of reducing CO_2 emissions with the opportunity costs of doing so.

CALL FOR GOVERNMENT POLICY

Although nature contributes its own CO_2 to the atmosphere, policy is more easily directed to the CO_2 contributed by human activity. The principal way people contribute to atmospheric CO_2 is through the consumption of carbon-based fuels. These fuels include petroleum products, natural gas, coal, and wood. Jointly, the first three are often identified as "fossil fuels."

Deforestation is another way people contribute to increased levels of atmospheric CO_2. Scientists estimate that the world's forests remove about one-third of the current CO_2 emissions from fossil fuels. Thus, large reductions in the world's forests could significantly affect the atmospheric levels of CO_2. Nevertheless, recent changes in the earth's forests have had little effect on atmospheric CO_2 in comparison with the effects from fossil fuel consumption.

At the pragmatic level, the call for government action on global warming comes from the concern that rising consumption of carbon-based fuels will increase levels of atmospheric CO_2, which will lead to warmer temperatures that could harm the environment. At a more analytical level, however, when consumers act individually they lack an incentive to consider the global side effects resulting from their consumption of carbon-based fuels. Taken collectively, individual actions could be contributing to greater emissions of CO_2 than are desirable from the perspective of economic efficiency.

To some extent, the divergence between individual and global interests can be seen in the debates that occurred at the UN conference on global warming. The representatives of each country jockeyed for advantage and criticized each other for not doing enough. At the international level, debate has been exacerbated by the fact that reducing energy consumption on a global scale yields gains in the terms of trade for energy-importing countries.

EVALUATING GLOBAL WARMING POLICY: A COST–BENEFIT APPROACH

Economics offers two approaches for evaluating how much effort should be put forth to reduce global warming. One approach is to set an appropriate tax on carbon-based fuels. Another is to use cost–benefit analysis.

The cost–benefit approach offers two advantages. It allows us to consider more directly the uncertainty about the benefits of reducing CO_2 emissions. It also allows representation of the wide range of debate about global warming policy. Under this approach, a reduction in environmental harm is the benefit of reducing CO_2 emissions. The foregone economic opportunities from using less fossil fuel are the cost.

Benefits of Reducing CO_2 Emissions

The benefits of reducing CO_2 emissions are the environmental damages that are avoided by preventing rising concentrations of atmospheric CO_2 that intensify the greenhouse effect and boost global temperatures. Potential environmental damage from global warming includes a variety of effects, from the impact on

Table 1
Reference Case Quantities, Prices, and Elasticities

	Quantity (10^{15} Btu)	Price elasticity of fuel at left with respect to price of: Oil	Natural gas	Coal	Other
United States					
Consumption					
Oil	42.5	–.72	.25	.03	.06
Natural gas	29.2	.25	–.72	.10	.06
Coal	22.8	.12	.63	–.96	.06
Other	14.2	.05	.05	.10	–.50
Production					
Oil	17.9	.51			
Natural gas	24.9		.51		
Coal	25.2			1.86	
Other	14.2				1.00
Other OECD					
Consumption					
Oil	58.8	–.72	.25	.03	.10
Natural gas	34.2	.25	–.72	.10	.10
Coal	18.1	.12	.63	–.96	.10
Other	29.1	.05	.05	.10	–.50
Production					
Oil	25.7	.43			
Natural gas	24.2		.43		
Coal	18.3			1.86	
Other	29.1				1.00
C/EE/FSU					
Consumption					
Oil	17.8	–.225	.075	.01	.05
Natural gas	33.2	.075	–.225	.04	.05
Coal	13.1	.04	.20	–.31	.05
Other	6.5	.02	.04	.04	–.25
Production					
Oil	20.4	.30			
Natural gas	43.3		.30		
Coal	14.3			1.24	
Other	6.5				1.00
OPEC					
Consumption					
Oil	11.3	–.72	.25	.00	.01
Natural gas	5.6	.25	–.72	.00	.01
Coal	.3	.12	.63	–.96	.10
Other	.4	.05	.10	.10	–.50
Production					
Oil	72.6	*			
Natural gas	5.6		.40		
Coal	.3			1.65	
Other	.4				1.00
Other LDCs					
Consumption					
Oil	64.5	–.45	.15	.02	.08
Natural gas	26.8	.15	–.45	.10	.08
Coal	68.5	.08	.40	–.61	.08
Other	17.0	.04	.08	.08	–.50
Production					
Oil	58.3	.43			
Natural gas	31.0		.43		
Coal	64.7			1.86	
Other	17.0				1.00

World reference prices	$\$/10^6$ Btu†	\$/standard unit†
Oil	\$3.519	\$20.41 per barrel
Natural gas	\$1.9553	\$2.01 per Mcf
Coal	\$ .7924	\$16.919 per short ton

* OPEC adjusts its production to maintain a constant share of the oil market.
† Prices are in 1995 dollars.

agriculture and forests to the costs of coping with more severe weather, flooding of coastal property, and increased disease.

An emerging literature attempts to evaluate the economic costs associated with the potential environmental damage caused by CO_2 emissions. (For examples, see Fankhauser 1994; Hope and Maul 1996; Nordhaus 1991a, 1991b, 1992, 1993; and Peck and Teisberg 1993a, 1993b.) Analysts and researchers working in the field must contend with several uncertainties: the extent to which these emissions will affect global warming, the environmental harm caused by global warming, and the economic costs of those environmental effects.

The emerging literature provides estimates of the benefits of reducing CO_2 emissions. This literature suggests the worldwide marginal benefit from a reduction in CO_2 emissions occurring in 2010 plausibly ranges from \$0 to \$33.75 (in 1995 dollars) per barrel of oil equivalent. (In this case, barrel of oil equivalent refers to the CO_2 emissions resulting from the consumption of a barrel of oil.) The literature also suggests that the most likely range for worldwide benefits is about \$.92 to \$6.61 per barrel of oil equivalent, as is shown in Figure 2. The mean estimate is \$2.86 per barrel of oil equivalent.[3]

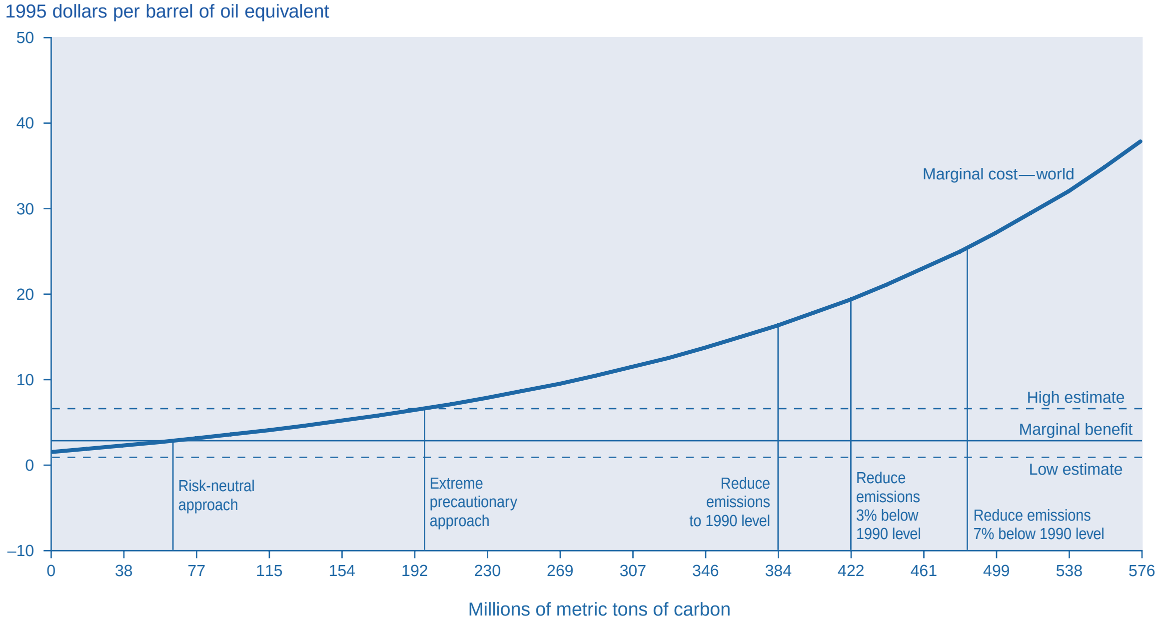
Given the considerable uncertainty about the benefits of reducing CO_2 emissions, some analysts have suggested that making the reductions is similar to insurance in one important respect: the costs of reducing emissions are fairly well known, but the benefits cannot be known with any certainty.

Estimating the Costs of Reducing CO_2 Emissions

Completing the cost–benefit analysis requires estimates of the costs of reducing CO_2 emissions through conservation of fossil fuels. Following several previous studies, marginal cost estimates are obtained by using a welfare-theoretic framework built on top of a simulation model of world energy markets.[4] Many analysts use U.S. Department of Energy (DOE) projections as a reference standard for analysis, and the simulation model is calibrated to reproduce the DOE's 1997 projections for world energy market conditions in 2010, as shown in Table 1. The data in the table represent one of many possible world energy outlooks for 2010.[5]

Table 1 also summarizes representative estimates of the long-run supply and demand responses to prices for the major regional areas in the analysis. These estimates are derived from a variety of sources. The oil price elasticities of supply and demand are based on an Energy

Figure 2
Estimated Costs and Benefits of CO_2 Abatement



Modeling Forum study (1991) that compares ten major world oil market models.[6] Elasticities for other fuels are calibrated to estimates adapted from Bohi (1981) and Brown and Yücel (1995).

Following Brown and Huntington (1998), the responses for the region that encompasses China, Eastern Europe, and the former Soviet Union (C/EE/FSU) are judgmental. The production and consumption decisions in these countries are more likely to be influenced by the forces of economic transition than by changes in world energy prices. In fact, if the supply and demand responses for the C/EE/FSU were made comparable to responses for other country groups, the conservation scenarios considered here would reduce world energy prices enough that the model would predict these economies would import significant quantities of energy. The author considers such a result untenable and therefore assumes a smaller response to price than for other countries. To the extent that these countries are more sensitive in their response to price, the estimated costs of achieving various world conservation targets without cooperation from these countries would be larger than reported here, but the thrust of the current analysis would be unchanged.

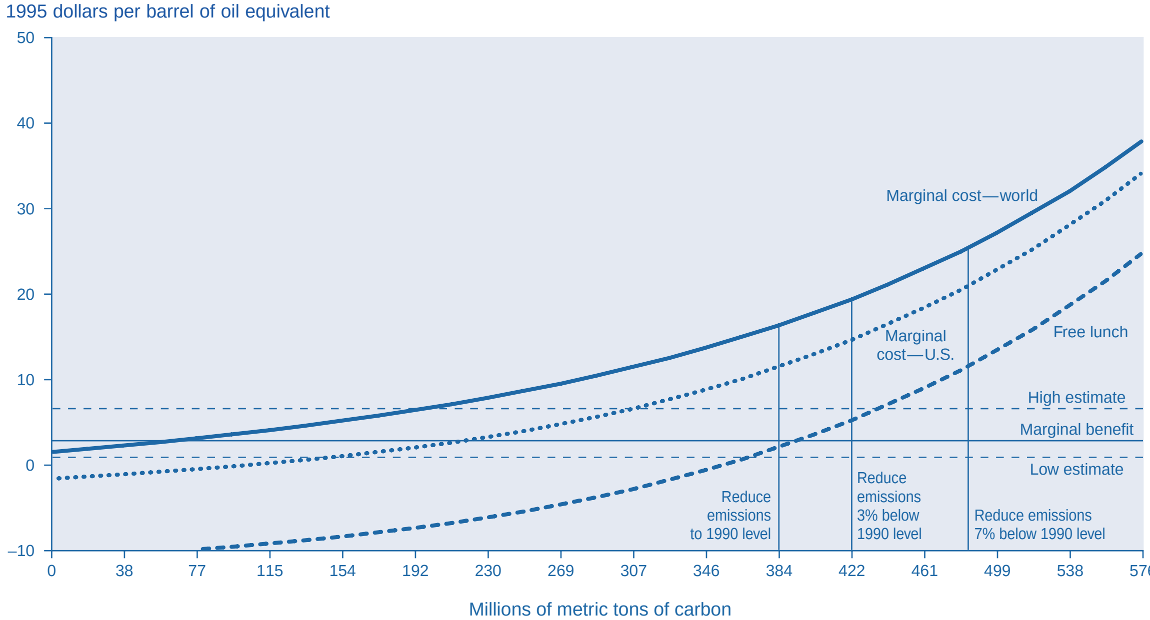
The response of oil producers within OPEC is highly uncertain. To date, formal modeling of OPEC decisions has been far from reliable. OPEC appears to operate like an imperfect cartel at some times but not at others. The OPEC countries appear to be about as uncomfortable with a rapidly increasing market share (such as accompanied the relatively low prices of the 1960s) as they are with a rapidly decreasing market share (such as occurred in the aftermath of the price hikes of the late 1970s and early 1980s). The analysis presented here assumes that OPEC acts to maintain a constant market share.[7]

Cost estimates are obtained by computing the welfare costs of policies under which the United States works in concert with other countries in the Organization for Economic Cooperation and Development (OECD) to reduce global CO_2 emissions through fossil fuel conservation. The modeling framework allows world energy prices to adjust to the conservation of fossil energy to restore a balance between supply and demand conditions in each market. Analytically, carbon taxes are used to reduce the consumption of fossil fuels in the two country groups. The tax approach assumes that conservation measures are applied across all end uses.

Values from these simulations are used with equations in the appendix to construct marginal cost curves for U.S. abatement of CO_2 emissions. This methodology follows the welfare-theoretic approach previously employed by Brown and Huntington (1994a, 1994b, 1998) and Felder and Rutherford (1993). The resulting cost curves take into account a number of factors, including the direct welfare costs of U.S. conservation efforts, transfers of wealth

Figure 3

Estimated Costs and Benefits of CO_2 Abatement



between countries, the effect lower energy prices would have in stimulating energy consumption in nonparticipating countries, and the economic cost of OPEC cartelization.[8]

Costs of Reducing CO_2 Emissions

The first marginal cost curve, which is labeled "Marginal cost—world," is shown in Figure 2. This curve represents the marginal costs to the world of the U.S. fossil fuel conservation necessary to reduce CO_2 emissions. Economic well-being is maximized at the level of CO_2 abatement where the marginal cost equals the marginal benefit. The risk-neutral approach would be to equate marginal cost to the mean estimate of marginal benefit. As shown in Figure 2, estimated marginal cost equals the mean estimate of marginal benefit at 65 metric tons of CO_2 abatement.

An extreme precautionary approach to avoiding the risk of global warming suggests using the upper bound estimate of the likely range as the measure of marginal benefit. As shown in Figure 2, marginal cost equals this upper bound at just under 200 metric tons of CO_2 abatement.

In comparison, President Clinton's proposal to reduce U.S. emissions to 1990 levels by 2010 implies 384 metric tons of CO_2 abatement, a figure substantially higher than what is optimal under either measure of marginal benefit. At this level of CO_2 abatement, the marginal cost is more than \$16 per barrel of oil equivalent, substantially more than the mean estimate of marginal benefit of \$2.86 per barrel of oil equivalent or the likely upper bound estimate of \$6.61 per barrel of oil equivalent.

Compliance with the Kyoto accord would seem to imply 478 metric tons of CO_2 abatement in 2010 from fossil fuel conservation, at a marginal cost of nearly \$25 per barrel of oil equivalent. U.S. officials expect to use offsets and other credits, however, to reduce the burden from conservation of fossil fuels to 3 percent below 1990 levels. That implies 424 metric tons of CO_2 abatement from the conservation of fossil fuels, at a marginal cost of just under \$20 per barrel of oil equivalent.

Improved Terms of Trade

Because the United States imports oil and natural gas, it can improve its terms of trade by conserving those fuels. The improved terms of trade mean that the United States incurs lower costs for its actions to reduce CO_2 emissions than the world incurs from the U.S. actions. As shown by the curve labeled "Marginal cost—U.S." in Figure 3, the lower marginal cost implies that a greater reduction in CO_2 emissions is optimal.

Such a conclusion is flawed, however. Optimality cannot be found by equating the marginal benefit to the world to the marginal cost to the United States. Sound analysis requires consistency in defining the incidence of costs and benefits.

Free Lunch: There Is No Such Thing

A number of energy analysts argue that the United States can cut its energy consumption by 25 percent and achieve a cost savings at the same time. As shown by the curve labeled "Free lunch" in Figure 3, President Clinton's target for reducing CO_2 emissions would be very close to optimal if the free-lunch cost curve represented reality. In fact, some analysts who consider this cost curve accurate and also favor the extreme precautionary approach to reducing CO_2 emissions have criticized the president's target as too conservative. As shown in Figure 3, achieving the target of reducing CO_2 emissions from fossil fuels 3 percent below 1990 levels would have a marginal cost that is above the mean estimate of marginal benefit but below the likely upper bound.

Analysts who believe in the free lunch use conceptually flawed studies to support their claims. What these analysts are unable to explain is why a free market would leave such cost savings on the table. Instead, they offer vague explanations of market barriers, including inappropriate lifestyle choices, and demand government regulation to reduce what they see as wasteful use of energy (see Brown 1996).

Hidden Costs of Policy

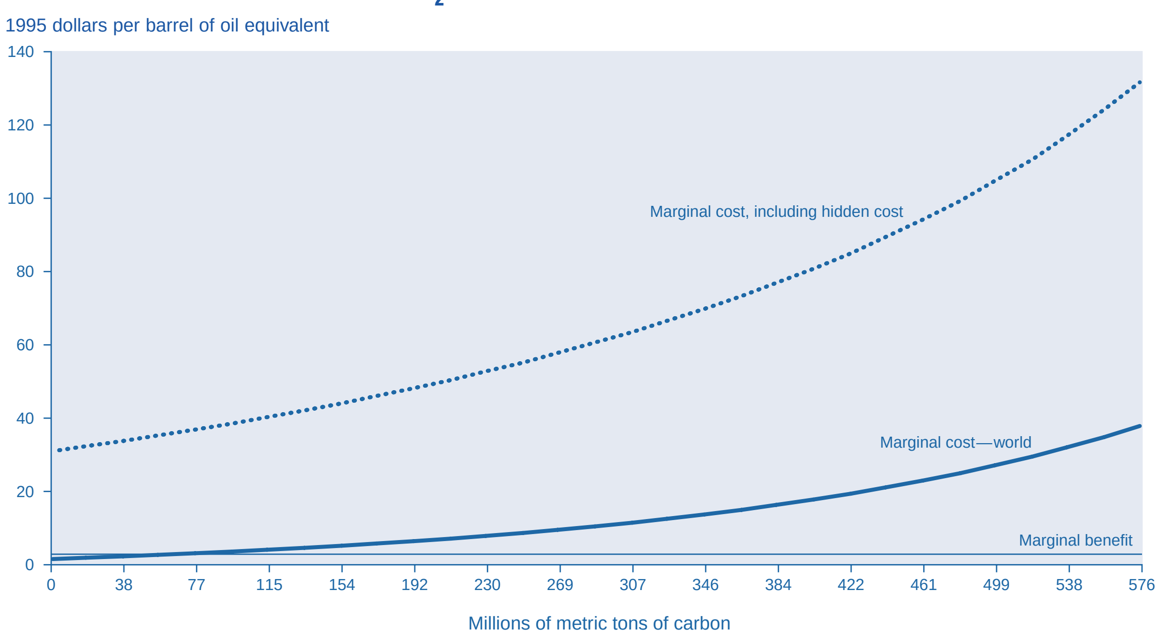
Economic policy often carries with it hidden costs that are not captured by traditional welfare-theoretic measures. Regulatory inefficiency is one way in which costs can escalate. When regulation is used instead of broad market incentives, such as taxes, the lowest cost methods of energy conservation can be ignored.

Interference in free trade is another way policies to reduce CO_2 emissions can have hidden costs. Broad programs of energy conservation permit energy-importing countries to improve their terms of trade with energy-exporting countries—a fact that has not been lost on OPEC. The countries that are the most dependent on imported energy have been the most aggressive in promoting global cooperation to reduce CO_2 emissions. More self-sufficient countries, such as the United States, have been more reluctant to participate. Within the United States, energy conservation has a decided tilt toward the conservation of oil, the fuel for which we are most import-dependent.

Rent-seeking behavior is another way in which policy can have hidden costs. Changes in policy create winners and losers. Both groups have an incentive to expend real resources to achieve their objectives by influencing the political process, which can add sizable costs to policy.

Using an approach first suggested by Tullock (1967), the author estimates the potential hidden costs of policy. As shown in Figure 4, these costs can be sizable. With the hidden costs incorporated, the marginal cost of reducing U.S. CO_2 emissions is more than \$30 per barrel of oil equivalent at zero abatement and more than \$80 at full compliance with the Kyoto

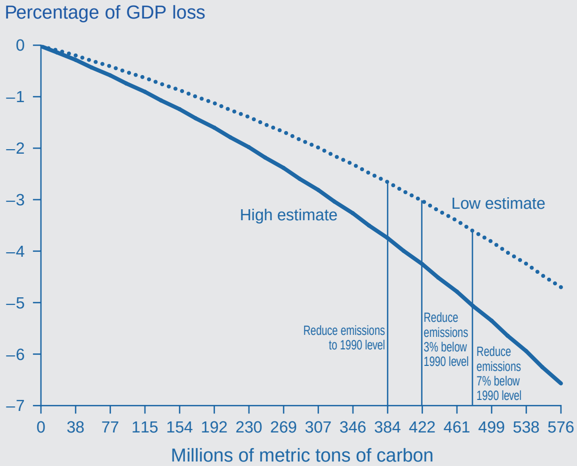
Figure 4
Estimated Costs and Benefits of CO_2 Abatement



Aggregate Economic Consequences for the United States

Figure B.1

U.S. CO_2 Abatement and GDP Losses



In terms of foregone economic opportunities, the energy conservation associated with CO_2 abatement can be seen as equivalent to increasing the price of energy, which carries with it the expectation of slower economic growth. Most economists agree that GDP is a poor way to measure economic well-being, particularly when evaluating environmental policy. Nevertheless, slower economic growth can result in significant political pressure on fiscal and monetary authorities to offset the slowdown. Yielding to that pressure could lead to higher inflation.

As shown in Figure B.1, the effect on aggregate economic activity depends on the amount of CO_2 abatement. The amount of energy conservation required to reduce 2010 CO_2 emissions to the 1990 level would imply that U.S. GDP would be 2.7 to 3.7 percent lower in 2010 than it would otherwise be.* Assuming the United States could use offsets and credits, compliance with the Kyoto accord would imply that U.S. GDP would be 3 to 4.3 percent lower in 2010. These estimates imply that if the United States embarked on a ten-year program to achieve compliance with the Kyoto accord, U.S. GDP growth would be 0.3 to 0.4 percent lower per year.

* GDP loss estimates are obtained through elasticities that relate energy prices to aggregate economic activity. The elasticities were chosen to represent the range of estimates from a number of prominent economic studies.

accord. If the potential for hidden costs were taken seriously, the cost of reducing CO_2 emissions would greatly outweigh its benefits.

CONCLUSIONS

Global warming is a theory partially supported by the facts. More evidence is needed to definitively conclude that the rising atmospheric level of CO_2 resulting from the use of carbon-based fuels is causing global warming. Nevertheless, most scientists who study the issue think that the use of fossil fuels is contributing at least some of the global warming that appears to be occurring. Despite this seeming consensus, there is considerable uncertainty about both the magnitude and the environmental consequences of global warming.

Given these uncertainties, reducing CO_2 emissions is like insurance against global warming and its possible environmental consequences. Under most current proposals, the developed nations would buy all or most of the insurance. Developing nations would be asked to contribute once they attain higher levels of income. Cost–benefit analysis suggests that reducing U.S. emissions of CO_2 to comply with the Kyoto accord or to reach the more modest target proposed by President Clinton represents too much insurance. Analysis for the other OECD countries yields a similar result. It is not surprising, therefore, that little headway has been made in ratifying the accord.

NOTES

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1 For a comprehensive treatment of emissions other than CO_2, see Hall (1990, 1992).

2 The Department of Energy projection that world CO_2 emissions from fossil fuels would increase about 45 percent from 1990 to 2010 owes greatly to expectations of accelerating growth and industrialization in developing areas of the world.

3 These estimates of damage are adapted from Brown and Huntington (1998). Previous analysis suggests a flat marginal damage curve. Summarizing the previous literature, Peck and Teisberg (1992) explain that marginal damage costs are essentially unaffected by the emissions levels in any given decade. This conclusion rests on the finding that temperature change depends on gas concentration, which is not greatly affected by emissions levels in any given decade. I follow this characterization by assuming horizontal damage curves that depict a constant level of benefits for any level of CO_2 abatement.

4 The author developed the analytical framework with Hillard G. Huntington of Stanford University.

5 The projected energy-demand conditions depend on a variety of assumptions about economic growth and the extent of energy-saving technological change in the absence of price change. The supply conditions other than OPEC oil production incorporate assumptions about the resource base, engineering constraints on developing resources, and producer-country taxes and policies. In these projections, OPEC members satisfy the excess demand but adjust the next period's price in response to market tightness.

6 See Huntington (1992, 1993).

7 Griffin (1985) and Dahl and Yücel (1991) provide empirical estimates of OPEC behavior that are broadly consistent with this view.

8 My analysis abstracts from a number of considerations featured in other studies of energy conservation. Hoel (1991a) and Newberry (1992) consider the effects of other taxes and redistributive policies. Bohm (1993); Brown and Huntington (1994b); Eyckmans, Proost, and Schokkaert (1993); Hoel (1991b and 1994); Manne

and Rutherford (1994); Welsch (1995); and Whalley and Wigle (1991) consider alternative policies for distributing conservation goals across countries and gains from cooperation. Felder and Rutherford (1993) and Pezzey (1992) allow for different types of goods.

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Appendix
Some Analytics of CO_2 Abatement

A welfare-theoretic approach can be used to derive formulas for the marginal cost of CO_2 abatement achieved through the conservation of carbon-based energy. For any country (or country grouping), the economic welfare obtained from the market for a particular source of energy is the sum of consumer and producer surpluses:

$$\text{(A.1)} \qquad W_{ij} = \int_0^{Q_{Dij}} P_{Dij}(Q_j)dQ_j - P_{ij}Q_{Dij} + P_{ij}Q_{Sij} - \int_0^{Q_{Sij}} P_{Sij}(Q_j)dQ_j.$$

In the above equation, W_{ij} denotes the economic welfare country i obtains from the market for energy source j, Q_{Dij} the quantity of primary energy j demanded in country i, P_{Dij} country i's demand price for energy source j (the market's marginal valuation of consumption excluding externalities) at each quantity (Q_j), P_{ij} the market price of energy source j in country i, Q_{Sij} the quantity of energy j produced in country i, and P_{Sij} the domestic supply price of energy source j in country i (marginal cost of its oil production excluding externalities) at each quantity (Q_j).

Cost of Gross CO_2 Abatement

The most direct measure of the cost of reducing CO_2 emissions is the welfare losses occurring in the energy markets that result from altering energy consumption to reduce emissions. Assuming no other distortions in domestic energy markets and no significant international trade in nonfossil energy, summing over the marginal effects of the emissions reduction policy on each fossil energy source yields the marginal cost of compliance for country i:

$$\text{(A.2)} \qquad MC_i = \sum_{j=1}^{n}\left[(P_{Dij} - P_{Wj})\frac{\partial Q_{Cij}}{\partial E_i} + Q_{Mij}\frac{\partial P_{Wj}}{\partial E_i}\right].$$

In the above equation, MC_i denotes the gross marginal cost of reducing CO_2 emissions through the conservation of carbon energy sources, P_{Wj} the world price of energy source j, Q_{Cij} the quantity of energy source j that is conserved (where $\partial Q_{Cij} = -\partial Q_{Dij}$), Q_{Mij} country i's imports of energy source j, and E_i is the reduction in country i's emissions under the policy whose costs are being estimated. As Equation A.2 shows, the gross marginal cost of reducing emissions is the difference between the domestic and world prices of each carbon energy source ($P_{Dij} - P_{ij}$) weighted by the shares of each fuel conserved for a one-unit reduction in CO_2 emissions, minus (plus) the transfers obtained (lost) by reducing the price of imported (exported) carbon energy, noting that $\partial P_{Wj}/\partial E_i$ is negative.

Cost of Net CO_2 Abatement

The net effect of the CO_2 abatement actions taken by a country or group of countries is the quantity of their abatement minus the induced

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Some Analytics of CO_2 Abatement

(*continued*)

change in CO_2 emissions in the rest of the world. The change in CO_2 emissions in nonparticipating countries depends on how their consumption of fossil energy is affected by a change in world energy prices and how the conservation actions in the participating countries affect the world oil price. Therefore, the relationship between a change in participant CO_2 emissions and the net change in world CO_2 emissions can be expressed as

$$\text{(A.3)} \qquad \frac{\partial E_W}{\partial E_i} = 1 - \sum_{j=1}^{n} E_j \frac{\partial Q_{DXj}}{\partial P_{Wj}} \bullet \frac{\partial P_{Wj}}{\partial E_i}.$$

In the above equation, E_W denotes the amount by which world CO_2 emissions are reduced, E_j the CO_2 emissions associated with consuming one unit of carbon energy j, and Q_{DXj} the quantity of carbon energy j consumed by nonparticipating countries.

Following Felder and Rutherford (1993) and Brown and Huntington (1994a, 1998), Equations A.2 and A.3 can be combined to express the marginal cost of the net world reduction in CO_2 emissions for country (or country grouping) i. Specifically, multiplying the marginal cost of the gross reduction in CO_2 emissions for country i by the net change in world CO_2 emissions resulting from country i reducing its CO_2 emissions yields

$$\text{(A.4)} \qquad MC_{Wi} = \sum_{j=1}^{n}\left[(P_{Dij} - P_{Wj})\frac{\partial Q_{Cij}}{\partial E_i} + Q_{Mi}\frac{\partial P_{Wj}}{\partial E_i}\right] \bullet \left(1 - \sum_{j=1}^{n} E_j \frac{\partial Q_{DXj}}{\partial P_{Wj}} \bullet \frac{\partial P_{Wj}}{\partial E_i}\right).$$

In the above equation, MC_{Wi} denotes the net marginal cost to country i of its actions to reduce world CO_2 emissions.

As Equation A.4 shows, the effect fossil energy conservation has on the cost of energy imports and on nonparticipant consumption of carbon energy are related through the effect conservation has on the world prices for these fuels. As cooperative conservation lowers the world prices of fossil energy, it reduces the cost of country i's energy imports and increases nonparticipant fossil energy consumption. If conservation has no effect on world energy prices, however, the energy-importing countries will not obtain terms-of-trade advantages, and fossil energy consumption will not be stimulated in nonparticipating countries.

World Perspective

From the world perspective, the cost of reducing CO_2 emissions through fossil energy conservation is the sum of costs borne by each country. From this perspective, net transfers cancel to zero. For every country or group of countries that obtains transfers from reduced prices for carbon energy, another country or group of countries yields an offsetting transfer, and $M_{ij}(\partial P_{Wj}/\partial E_i)$ is exactly offset.

Accounting for the offsetting transfers, as well as the distortion in world oil markets resulting from OPEC holding its oil production below free market levels, alters Equation A.4 to yield

$$\text{(A.5)} \qquad MC_{Wi} = \left[\sum_{j=1}^{n}\left((P_{Dij} - P_{Wj})\frac{\partial Q_{Cij}}{\partial E_i}\right) + \frac{\partial Q_{Ci1}}{\partial E_i} S_{O1}(P_{W1} - C_{O1})\right] \bullet \left(\frac{\partial E_W}{\partial E_i}\right)^{-1}.$$

In the above equation, MC_{Wi} denotes the net marginal cost to the world of country i's actions to reduce emissions, Q_{Ci1} the amount of oil conserved, S_{O1} OPEC's share of world oil production, and C_{O1} OPEC's cost of oil production.

Hidden Costs

Tullock (1967) argues that economic agents have the incentive to expend real resources to influence economic policy up to the total value of the transfers that might result from the policy. In doing so they would dissipate the total value of the potential transfers as costs. Incorporating these hidden costs into the analysis alters Equation A.5 to yield

$$\text{(A.6)} \qquad MC_{Hi} = \left[\sum_{j=1}^{n}\left(Q_{Dij}\frac{\partial (P_{Dij} - P_{Wj})}{\partial E_i}\right) + \frac{\partial Q_{Ci1}}{\partial E_i} S_{O1}(P_{W1} - C_{O1})\right] \bullet \left(\frac{\partial E_W}{\partial E_i}\right)^{-1}.$$

In the above equation, MC_{Hi} denotes the net marginal cost to the world, inclusive of hidden costs, of country i's actions to reduce emissions. Note that Q_{Dij} is the consumption of fuel j in country i.