Federal Reserve Bank of Dallas

Economic & Financial Policy Review

Volume 2, Number 1, 2003

Terms of Trade and OECD Policies to Mitigate Global Climate Change

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Previous economic research has identified two ways policy to mitigate global climate change could be implemented without minimizing world costs. Costs are boosted when agreements to reduce greenhouse gas emissions are limited to a subset of countries or deadlines for reducing emissions force the premature retirement of energy-using capital equipment. Stephen Brown and Hillard Huntington identify a third way global warming policy could prove more costly from a world perspective—by countries using criteria other than a fuel's greenhouse gas content when determining how to reduce their emissions.

According to the authors, an individual country can reduce its own cost of cutting emissions by more aggressively reducing its use of imported fuels than its exported fuels. Such a strategy would enable a country to obtain gains in the terms of trade at the expense of its trading partners. Although shifting costs this way benefits the individual country, it raises the world cost of reducing emissions. This potential for individual countries to shift costs could influence future international agreements on global warming policy.

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Suggested Citation

Brown, Stephen P. A., and Hillard G. Huntington (2003), "Terms of Trade and OECD Policies to Mitigate Global Climate Change," Federal Reserve Bank of Dallas *Economic and Financial Policy Review*, Vol. 2, No. 1, http://dallasfedreview.org/pdfs/v02_n01_a01.pdf.

International policy on global climate change is in flux. As of early 2003, only a few industrial countries had ratified the Kyoto Protocol—a pact negotiated in Kyoto, Japan, in 1997 to reduce greenhouse gas emissions. In 2001, the United States announced it would not abide by the protocol. Currently, there is no agreement about which countries will join an international accord, when they will act, what quantity of emissions they will curtail, or what policies they will use to curtail those emissions.

With future cooperation on the issue undecided, the economic inefficiencies that can occur in global warming policy are of particular interest. Such inefficiencies raise abatement costs, thereby affecting what policies are proposed and eventually adopted.

Many previous studies assume compliance with the targets set by the Kyoto Protocol and emphasize the "where" inefficiency that can arise in international agreements—that is, how limiting participation to a subset of countries would boost the cost of reducing global emissions.[1] Other studies (such as Reilly et al. 1999 and Manne and Richels 2000) examine the "when" inefficiency—that is, how setting target dates for reducing emissions can raise costs when energy-using capital equipment must be retired prematurely. These previous studies assume the abatement policies individual countries adopt depend solely on a fuel's carbon or greenhouse gas content. (See the box titled "The Kyoto Protocol and Inefficiencies in Global Warming Policy.")

The present study examines the policy implications of what we call the "how" inefficiency in the context of reducing emissions of carbon dioxide (CO_2)—the principal gas targeted by global warming policies. This inefficiency arises because individual countries have an incentive to reduce their emissions based on criteria that do not depend solely on the fuel's greenhouse gas content. An individual country can shift some of the costs of decreasing its CO_2 emissions by more aggressively reducing its use of imported fuels than its exported fuels. Such a strategy enables a country to obtain gains in the terms of trade at the expense of its trading partners. Although shifting costs this way is advantageous to the individual country, it raises the world cost of reducing emissions and may undermine international agreements to reduce greenhouse gas emissions or promote free trade.

Our focus on the "how" inefficiency represents a marked departure from previous policy studies. Numerous analyses incorporate the terms-of-trade effects in estimating the cost of meeting a particular target for reducing emissions but do not incorporate terms-of-trade effects into the policy decisions.[2] We reverse the process, considering a wide range of policy options and how these effects shape the policy decisions of individual countries.

Because including terms-of-trade effects complicates the analysis considerably, we take a relatively simple approach to modeling fuel use and greenhouse gas emissions. The reward is a more interesting and realistic assessment of policies countries might adopt. First, we present a simple graphical analysis that shows how changes in the terms of trade can affect the cost of reducing CO_2 emissions. Then we use a simulation model

[1] For examples, see the studies in Weyant (1999).

[2] For examples of this extensive literature, see Nordhaus (1994), Pezzey (1992a), Whalley and Wigle (1991), and the individual studies in Weyant (1999).

The Kyoto Protocol and Inefficiencies in Global Warming Policy

At the end of 1997, all parties to the United Nations Framework Convention on Climate Change agreed to a protocol that called for countries with a developed or transition economy to reduce their net greenhouse gas emissions by 5.2 percent below 1990 levels over 2008–12. Although the largest anticipated changes were in the emissions of carbon dioxide, the protocol was not confined to them. The accord was comprehensive in coverage, including both sources and sinks of five other gases: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Developing countries were not obligated to impose restrictions under the protocol.

The sixth session of the Conference of the Parties subsequently failed to resolve key disputes about implementation of the Kyoto Protocol, among them whether to include carbon sinks and how much emissions trading should be allowed. With the disputes unresolved, it seems likely the developed and transition countries will not ratify the protocol. The United States has already rejected the protocol's key provisions.

The effects of achieving the Kyoto targets have been extensively studied, including some recent analyses that look at some critical noncarbon gases like methane (for example, Reilly et al. 1999; Manne and Richels 2000). These studies have provided important insights into the cost of reaching the targets and the value of designing flexible policy. The Kyoto Protocol set relatively aggressive targets that must be met in a short time, prompting some analysts to note there may be a "when" inefficiency or inflexibility. Delaying achievement of the targets could reduce costs without seriously sacrificing the benefits from reduced climate change.

The protocol also would have created a "where" inefficiency, in that the developing countries were not obligated to reduce emissions even if their abatement costs were lower than in developed countries. However, some of the "where" inflexibility might have been reduced by programs such as the clean development mechanism, which would have allowed parties in developed countries to earn credits for emission reductions that result from projects in developing countries.

In theory, the Kyoto Protocol also could have led to a "how" inefficiency, which would have arisen from signatory countries seeking gains in the terms of trade and failing to reduce their greenhouse gas emissions in a way that would minimize world costs. Our estimates suggest the "how" inefficiency likely would have been of secondary importance under the targets set by the Kyoto accord. It is of much greater importance when considering how global warming policies might be developed in a post-Kyoto environment.

and welfare-theoretic framework that is consistent with previous analyses to develop supply curves for reducing emissions through energy conservation and fuel switching. In addition to the direct costs of abatement, some of the supply curves reflect gains in the terms of trade.

Using the supply curves, we examine emissions reductions, fuel mix, and abatement costs for countries participating in international agreements to reduce greenhouse gas emissions. We find that members of the Organization for Economic Cooperation and Development (OECD) have substantial incentives to reduce CO_2 emissions in a way that does not minimize world costs. These incentives can affect policy and ultimately how much emissions are cut.

COST OF REDUCING CO_2 EMISSIONS AND TERMS-OF-TRADE EFFECTS

Reducing a nation's energy consumption to decrease CO_2 emissions yields benefits, but it also imposes economic costs—the most direct of which are reductions in what economists call consumer surplus and pro-

Terms of Trade and the Cost of Conservation: Some Simple Analytics

The economic costs of energy conservation generally arise from two effects: change in consumer and producer surpluses and change in the terms of trade. We can take these effects into account by using a welfare-theoretic approach to derive formulas for the marginal cost of oil conservation. For any country (or country grouping), social welfare in the oil market is the sum of its consumer and producer surpluses:

B.1 $$W = \int_0^{Q_D} P_D(Q)dQ - P_W Q_D + P_W Q_S - \int_0^{Q_S} P_S(Q)dQ.$$

In the above equation, W denotes the welfare the country obtains from the market for a given source of energy, Q_D the quantity of oil demanded in the country, P_D the country demand price (the market's marginal valuation of consumption excluding externalities) at each quantity (Q), P_W the world price of oil, Q_S the quantity of oil production in the country, and P_S the country oil supply price (marginal cost of its oil production excluding externalities) at each quantity (Q).

The Cost of Gross Conservation

If the marginal cost of conserving a single energy source is defined as the welfare lost in the country by reducing its consumption, the negative of the first derivative of W with respect to Q_D yields the marginal cost of conservation:

B.2 $$MC = P_D - P_W + \frac{\partial P_W}{\partial Q_C} Q_M.$$

In the above equation, MC denotes the marginal cost of conservation, Q_C the quantity of conservation (where $\partial Q_C = -\partial Q_D$), and Q_M the quantity of the country's net imports of the energy source. As Equation B.2 shows, the gross marginal cost of conserving a given energy source is the difference between the domestic and world prices of the source ($P_D - P_W$) minus the transfer obtained by reducing the price of imported oil. ($\partial P_W / \partial Q_C$ is negative.)

ducer surplus. Combined, these surpluses are the difference between the value of output and the resources required to produce it.

In addition, an individual nation can experience gains or losses in well-being when the prices of energy commodities it imports or exports fall as a result of conservation. These gains or losses, known as terms-of-trade effects, are measured as the product of the change in the world price and the country's net trade in the commodity.[3] The terms-of-trade effects reduce the cost of conserving imported sources of energy and raise the cost of conserving exported sources of energy. (See the box titled "Terms of Trade and the Cost of Conservation: Some Simple Analytics.")

For an individual country, the reduction in consumer and producer surplus and the changes in the terms of trade are the principal costs of decreasing energy use to cut CO_2 emissions.[4] From a world perspective,

[3] Other sectors of the country's economy will experience terms-of-trade effects, but these sectors will be more diverse and have lower stakes in the policy. Consequently, the cost of organizing these separate groups into a coherent group is likely to prevent their participation in shaping policy.

[4] The cost of conservation may also be affected by market distortions that exist prior to the conservation effort. The costs will be higher if distortions have caused too little of an energy resource to be used and lower if distortions have caused too much of the resource to be used.

however, the cost of reduced fuel use is the sum of the resource costs imposed on all the affected countries. The gains in wealth obtained by one country through improved terms of trade will be lost by other countries, and these effects cancel out. Nonetheless, for a large country (such as the United States) or group of countries (such as the OECD), changes in the terms of trade can be an important cost of energy conservation and may affect conservation strategies.

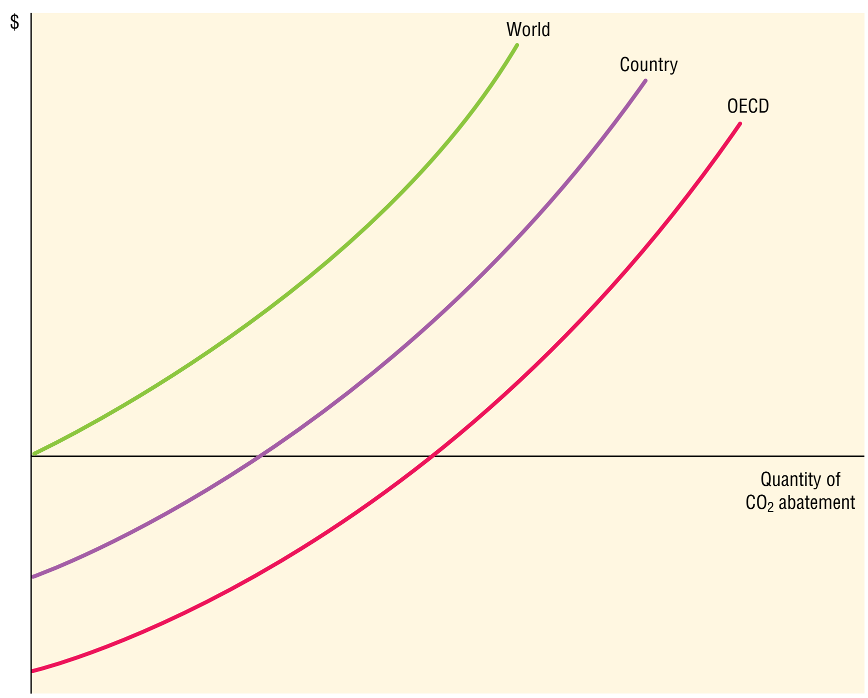
Cost of Conservation with One Fuel

Figure 1 shows how differently the world, the OECD, and an OECD member country might view the cost of that particular country's effort to conserve one energy resource, oil. The figure shows a country like the United States, which imports oil but less of it than the OECD as a whole. Because we are examining the cost of an individual country's conservation, the differences between the cost curves are strictly the result of differences in the terms of trade. At the world level, the terms-of-trade effects for individual countries are exactly offsetting. Therefore, the curve for the world's marginal cost of the country's oil conservation begins at the origin.[5]

The country's own cost curve lies below the world curve and starts below the origin because the country can improve its terms of trade by depressing the world oil price through oil conservation. The OECD curve shows how the country's oil conservation affects OECD costs (including those the country incurs). The OECD cost curve lies below the country curve because the OECD as a whole imports more oil than the individual country.

If the marginal benefit of oil conservation (the environmental damage avoided) is constant or declining, the country could find it advantageous to

Figure 1
The Cost of Oil Conservation to Reduce CO_2 Emissions



[5] For simplicity, Figure 1 does not represent the cost of OPEC restricting its oil production below free market levels.

conserve more oil than is optimal from a world perspective but less than the OECD as a whole would prefer.[6] We often see this line of reasoning in international discussions. Many OECD countries have been more adamant about the United States reducing its oil consumption than the United States has been. In addition, many oil-exporting nations have condemned oil-conservation strategies for imposing costs on them.

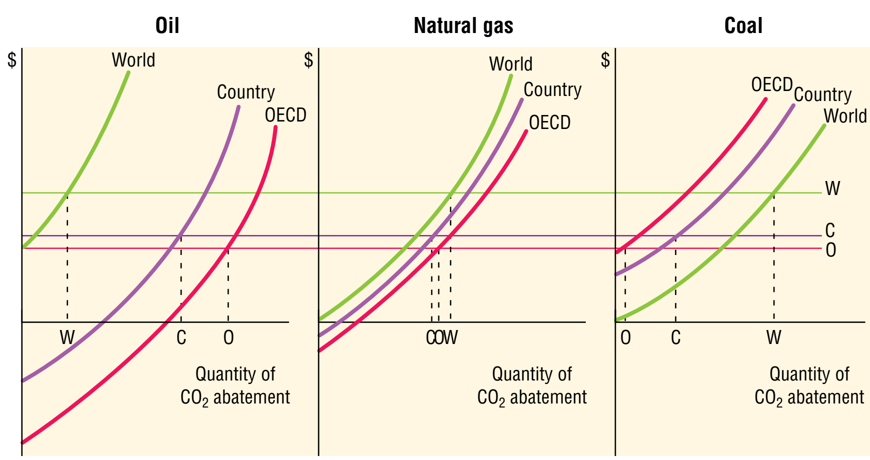
Cost of Conservation with Multiple Fuels

The analysis becomes much richer when we consider multiple fuels. Figure 2 presents cost curves for a particular country's CO_2 abatement through conservation of oil, natural gas, and coal. The labels "World," "Country," and "OECD" identify the cost of the country's abatement to each group. The differences in the curves represent differences in gains from terms of trade, as well as the cost of OPEC restricting its oil production below free market levels. The horizontal axis of each chart measures CO_2 abatement, while the vertical axis shows the cost of reducing CO_2 emissions by conserving the respective fuel.[7]

Our objective in using the figure is to find the lowest-cost method for the particular country to achieve a given reduction in CO_2 emissions as seen from the perspective of the world, the country itself, and the OECD. Holding the total reduction constant allows us to concentrate on the conflicts that can arise over energy conservation strategies even if the environmental benefits are equal under each of them.

First we examine what strategy the world would want the country to pursue. For a given conservation level, the world would want the country to conserve carbon-based fuels in a way that equalizes the marginal cost of CO_2 abatement across fuels for the world, as the horizontal line labeled "W" shows. Following these guidelines, the country would conserve the quantities of oil, natural gas, and coal that would reduce CO_2 emissions by

Figure 2
The Cost of One Country's Energy Conservation Efforts to Reduce CO_2 Emissions



[6] For a more thorough analysis of this issue, see Brown and Huntington (1998).

[7] For graphical analysis, we assume no interfuel substitution. Interfuel substitution complicates the analysis but does not alter the logic presented in Figure 2.

the quantities labeled "W" in each panel of Figure 2. The country's total reduction of these emissions is the sum of these quantities.

Next, we consider the strategy the country itself would prefer to pursue while achieving the same level of CO_2 abatement. To minimize its costs, the country selects a policy that equalizes the marginal cost of CO_2 abatement across fuels, as the horizontal line "C" shows. The country would conserve the quantities of oil, natural gas, and coal that would reduce CO_2 emissions by the quantities labeled "C" in each panel of Figure 2. The country's total reduction is the sum of these quantities and equals the total abatement obtained from the world's preferred policy. As the figure shows, the country would prefer to achieve the reduction with more oil conservation but less coal and natural gas conservation than would minimize world costs.[8] Pursuing this strategy improves the country's terms of trade.

Finally, we consider the strategy the OECD would prefer the country take. The OECD would prefer a policy that equalizes its marginal costs of CO_2 abatement across fuels, as the horizontal line "O" shows. The country would conserve the quantities of oil, natural gas, and coal that would reduce CO_2 emissions by the quantities labeled "O" in each panel of Figure 2. The total abatement is the same as in the other two cases.

Because the OECD imports more oil than the country, it prefers that the country conserve more oil than would minimize costs for either the country itself or the world. The OECD would also prefer that the country conserve less natural gas than would minimize world costs but more than would minimize the country's costs. Finally, the OECD would prefer that the country conserve less coal than would minimize either the country's or world's costs.

Without additional information about the underlying cost curves, it is impossible to predict how much an individual country's CO_2 abatement and energy strategy might conflict with the interests of other OECD nations or the rest of the world. The analysis suggests, however, that countries will not agree on the best CO_2 abatement strategies for any particular country to follow. After reaching an international agreement on how much abatement each country should achieve, individual countries have an incentive to implement policies that will not yield the lowest costs from either an international or OECD perspective. Instead, domestic political realities will encourage them to reduce consumption of the fuels where doing so will improve their terms of trade.

Terms-of-Trade Effects and U.S. Policymaking

The United States provides a ready example of the importance of the terms-of-trade effect in the development of a nation's energy conservation and greenhouse gas policies. The country exports coal and imports most of its oil and a small percentage of its natural gas. Several administrations have proposed strategies to reduce CO_2 emissions in a way that would fall disproportionately on imported energy sources.

In 1993, the Clinton administration proposed what was called a Btu tax to reduce CO_2 emissions. For the world, the least-cost approach for the United States most likely would have involved equal taxes on the carbon content of coal and natural gas and slightly lower taxes on crude oil.[9] As

[8] The effect on natural gas is an artifact of the way Figure 2 is constructed. Theoretically, the country could find it desirable to conserve more or less natural gas than is optimal from the world perspective.

[9] From the world perspective, the least-cost solution involves offsetting the effects of OPEC restricting its oil output.

Table 1 shows, however, the administration took a substantially different approach. The taxes are highest for the fuel with the largest import share (oil) and lowest for the fuel the United States exports (coal). The proposed tax on the carbon content of crude oil was 3.5 times that on the carbon content of coal. The proposed plan also would have placed a tax on the carbon content of natural gas that was about 70 percent higher than on the carbon content of coal.

Although the current Bush administration's energy plans would not impose additional taxes on energy use, its recommendations favor the development of domestic nuclear sources, hydrogen fuels, and clean-coal technology for combating growing concentrations of greenhouse gases. Development of these resources is likely to reduce oil imports.

Terms-of-Trade Effects and OECD Policy

As Table 2 shows, the energy consumption and production balances for the OECD countries reveal substantial incentive to seek gains in the terms of trade while conserving energy to reduce CO_2 emissions. In 2000, the OECD countries combined to import about 55 percent of their petroleum consumption, about 20 percent of their natural gas consumption, and about 10 percent of their coal consumption. OECD oil and natural gas imports are projected to grow by 2010, and the OECD is expected to become a net exporter of coal.

Table 1

U.S. Btu Tax Proposed in 1993

Fuel	Tax per standard unit	Tax per million Btu	Tax per metric ton carbon
Oil (crude)	$3.47 per bbl	$.599	$36.93
Natural gas	.26 per Mcf	.257	17.74
Coal	5.57 per short ton	.257	10.39

SOURCE: Columns 2 and 3 are authors' calculations.

Table 2

U.S. and OECD Energy Consumption, Production, and Imports, 2000

(in quadrillion Btu)

	Consumption	Production	Net imports
United States			
Petroleum	38.40	14.97	23.43
Natural gas	23.11	19.46	3.65
Coal	22.43	22.62	–.19
Nuclear	8.01	8.01	0
Other	6.81	6.54	.27
OECD			
Petroleum	96.05	42.66	53.39
Natural gas	49.31	39.37	9.94
Coal	44.44	39.88	4.56
Nuclear	25.66	22.17	3.49
Other	15.33	18.86	–3.53

SOURCE: Authors' calculations based on data from *International Energy Outlook*, Energy Information Administration.

TERMS-OF-TRADE EFFECTS AND POLICY FOR CO_2 ABATEMENT

The effects of an OECD CO_2 abatement policy depend on the objectives the individual countries pursue in implementing it. One possibility is that each country could reduce emissions in a way that is most efficient from the world perspective.[10] Another possibility is that each country could reduce emissions in a way that minimizes its own costs by taking into account gains in the terms of trade for the fuels it imports and exports.[11] Yet another possibility is that the OECD countries could act cooperatively to enhance the gains in trade.

To more thoroughly examine how terms-of-trade effects might shape policy to reduce greenhouse gas emissions, we combine a welfare-theoretic framework with a simulation model of world energy markets (described in the appendix). Using this framework and model, we estimate the cost of reducing CO_2 emissions in 2010 under three different policy scenarios and for implementation rates that range from business as usual to beyond full compliance with the Kyoto Protocol.[12] The scenarios include one in which the OECD minimizes world costs, one in which the OECD acts cooperatively to minimize its own costs, and one in which two groups of OECD countries act noncooperatively to minimize their own costs. The cost estimates depend on the specific model used, but the principles they demonstrate do not.

Cost of Various OECD Policies for CO_2 Abatement

Figure 3 presents the costs to the world, the OECD, and the United States under the three policy scenarios.[13] (This figure and Figure 4 show the policies in terms of the percentage compliance with the reduction in OECD CO_2 emissions required to achieve 1990 emission levels.[14]) Full compliance with the Kyoto accord would require 110 to 125 percent of these reductions, depending on offsets and credits.

Although we developed estimates for reductions in CO_2 emissions beyond full compliance with Kyoto, we have truncated the figures at 100 percent compliance. Analysis using cost estimates from our model and benefit estimates drawn from the literature shows the optimal reduction in OECD CO_2 emissions is likely to be substantially lower than that required

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[10] Under this approach, each nation might use fees based on the carbon content of each fuel. Most studies of carbon policies assume countries follow this path.

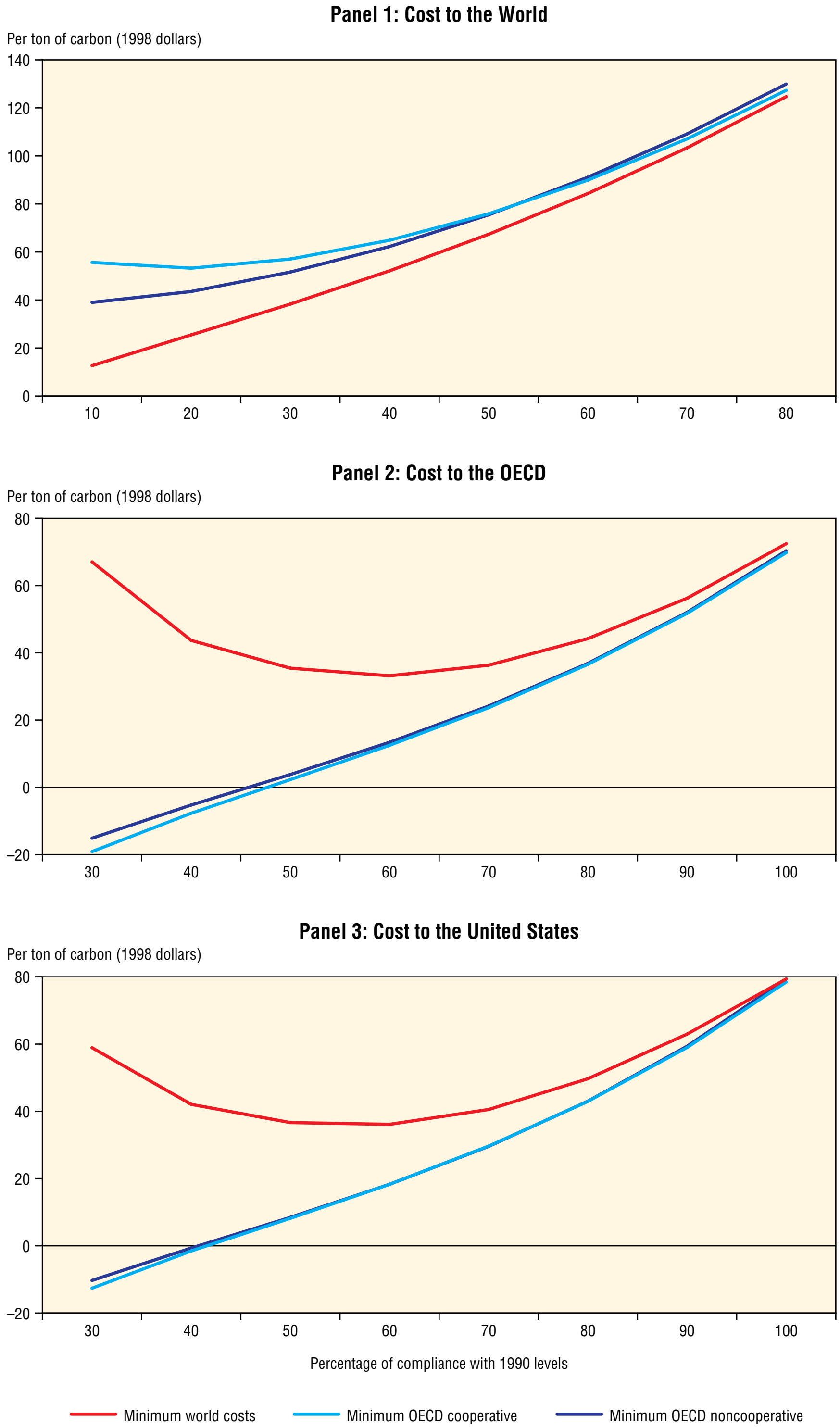
[11] To pursue such a strategy, the nation would reduce its carbon emissions by discouraging the use of its imported fuels more heavily than its exported fuels.

[12] A typical approach to reporting the cost of CO_2 abatement is as the tax per metric ton of carbon at the margin required to achieve a given reduction. Such taxes incorporate the direct costs but exclude any terms-of-trade transfers. As explained in the box titled "Terms of Trade and the Cost of Conservation: Some Simple Analytics," our approach requires that the cost measure incorporate terms-of-trade gains or losses in addition to the tax wedge.

[13] The estimated cost curves would rise more steeply with compliance if the price elasticities of supply and demand for each fuel in the simulation model were lower. The cross-price elasticities of fuel demand also have an important role. Lower cross-price elasticities would allow countries to better separate fuels and target them for conservation, which would increase the divergence in costs between the cases.

[14] Reducing OECD CO_2 emissions in 2010 to those of 1990 would require an emissions reduction of 883 million metric tons of carbon below the baseline projection we use.

Figure 3
Estimated Cost of Reducing CO_2 Emissions



under Kyoto—about 15 to 65 percent of that required to reach 1990 levels.[15] (See the box titled "The Range of Policy Interest.")

As the three panels of Figure 3 show, the estimated cost of reducing CO_2 emissions to the world, OECD, and United States vary considerably across the scenarios. Most significantly, the policy that is the lowest cost for the world is the highest cost for the OECD and United States. Conversely, the OECD can reduce its own costs by deviating from the policy that minimizes world costs. This finding demonstrates that the "how" inefficiency arises from countries pursuing gains in the terms of trade for the fuels it is conserving.

The costs converge, however, as the OECD's compliance rate moves toward 1990 emissions levels. The cost differences between the policy scenarios are substantially reduced beyond 100 percent compliance. As CO_2 emissions are cut, the terms-of-trade effects diminish and the direct costs of reducing emissions increase.[16] At sufficiently high levels of abatement, the direct costs dominate, and the incentive for the OECD to seek additional gains in the terms of trade is diminished.[17]

For compliance rates of less than 80 percent, the OECD nations find it substantially more expensive to adopt the world's best policy than to adopt one that favors their own interests. Even at 70 percent compliance, the marginal cost of being good world citizens is $10 per metric ton higher. The OECD is better served by adopting a more selfish policy.

At the lowest compliance rates shown in Figure 3, the OECD can find a policy mix that produces net benefits (negative costs) for itself. These benefits differ fundamentally from the usual "no regrets" policy because pursuing this policy raises world costs, as the top panel of the figure

[15] Benefits are the environmental damages that are avoided by preventing rising concentrations of atmospheric CO_2, which would enhance the greenhouse effect and boost global temperatures. Potential environmental damage from global warming includes a variety of effects from the impact on agriculture and forests to the cost of coping with more severe weather, flooding of coastal property, and increased disease. See Brown (1998).

Estimates adapted from Brown and Huntington (1998) put the marginal benefit of reducing CO_2 emissions in 2010 in a likely range of about $6 to $60 per metric ton, though possible estimates range from $0 to $300 per metric ton. Previous analysis suggests a flat marginal benefit curve. Marginal benefits are essentially unaffected by the emissions levels in a given decade because temperature change depends on gas concentration, which is not greatly affected by emissions levels in the decade.

[16] The terms-of-trade effect is a generalization of the oil import premium examined in earlier literature, where a large importing nation has a strong incentive to reduce its oil imports. The incentive decreases as conservation proceeds (and imports are reduced) because the gains are diminished as the country imports less of the commodity. At some point a country achieves its maximum welfare gain, after which gains in the terms of trade are more than offset by the direct welfare losses of using less of the commodity. Numerous authors have applied this concept to the oil market, for example, Karp and Newbery (1991).

[17] Although the difference in estimated costs and their convergence depends on the specific model used, the presence of terms-of-trade effects and the gradual dominance of direct effects as CO_2 abatement increases do not.

Clearly, the assumed growth in baseline fuel consumption and CO_2 emissions prior to the implementation of policy is important to the estimates. If there are unexpected opportunities to reduce fossil fuel consumption below the levels of our baseline case prior to any policy action, the cost of achieving a given compliance rate would be less. Moreover, the terms-of-trade effects that distinguish one strategy from another would remain important at higher compliance rates than is shown in our figures.

The Range of Policy Interest

Most industrialized countries have not adopted the Kyoto accord, apparently because they view it as too costly. Consequently, we compare costs and benefits to suggest the future range of policy analysis. The figure below presents the marginal costs to the world of reducing CO_2 emissions under three policy scenarios. These estimates are derived from the model described in the body of the article and appendix.

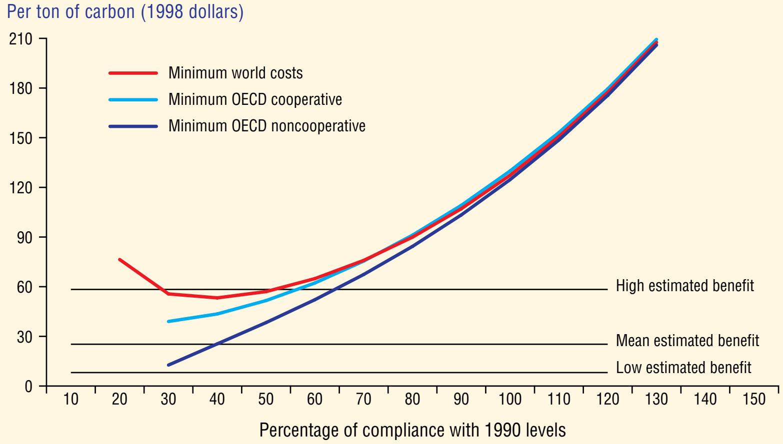
The figure also presents marginal benefit curves of reducing CO_2 emissions. These benefits are the environmental damages avoided by preventing rising concentrations of atmospheric CO_2 that enhance the greenhouse effect and boost global temperatures. Potential environmental damages from global warming include a variety of effects from the impact on agriculture and forests to the costs of coping with more severe weather, flooding of coastal property, and increased disease. An emerging literature provides estimates of these costs. (For examples, see Fankhauser 1994; Hope and Maul 1996; Nordhaus 1991a, 1991b, 1992 and 1993; and Peck and Teisberg 1993a and 1993b.)

This literature suggests the plausible range of marginal benefits is $0 to $300 per metric ton, but the likely range is roughly $6 to $60, which is shown in the figure.[1] Given the estimates of the marginal benefits and costs of reducing CO_2 emissions, the optimal reduction in OECD CO_2 emissions is likely to be substantially lower than that required under Kyoto—from about 15 to 65 percent of that required to reduce emissions to 1990 levels. This finding suggests that in the absence of new information about the costs or benefits of reducing emissions, future policies to lower them may be substantially less ambitious than the Kyoto accord.

NOTE

1 These estimated benefits of reducing CO_2 emissions are adapted from Brown and Huntington (1998). Previous analysis suggests that the benefit curve is nearly flat. The marginal benefits are relatively unaffected by the emissions levels in any given decade because temperature change depends on gas concentration, which is not greatly affected by emissions levels in the same decade. See Brown (1998).

World Benefits and Costs of Alternative OECD Strategies



shows. No-regrets policy is based on market failures in the purchase of energy-efficient technologies, which are not part of the present analysis.[18]

As might be expected, the noncooperative strategy results in somewhat higher OECD costs than the cooperative strategy. Acting independently, each of the two OECD groups fails to take into account the terms-of-trade gains for the other group. We find the estimated difference in cost between the noncooperative and cooperative strategies to be relatively small, but this could change if we disaggregated the OECD into smaller groups.

As the top panel of the figure shows, the OECD's pursuit of gains in the terms of trade reduces its costs at the expense of the rest of the world. Both the cooperative and noncooperative strategies push world costs above the policy that seeks to minimize world costs (a carbon tax adjusted for OPEC's monopolistic power). The difference in world cost between the OECD noncooperative and cooperative cases demonstrates that enhanced cooperation among the OECD countries shifts more of the costs to the rest of the world and increases total world costs.

Whether acting cooperatively or noncooperatively, the OECD can reduce its own costs at the rest of the world's expense. It can do so by taxing the carbon content of its imported fuels more heavily than its exported fuels. For the OECD, this action extracts income through lower import prices that more than offset the increase in direct resource costs.

As the bottom panel of Figure 3 shows, the United States has a similar perspective on policy as the OECD as a whole. Cooperative behavior slightly reduces U.S. costs because the country gains trade benefits through the import reductions carried out by other OECD members in addition to those from its own import reductions. This finding suggests that the two OECD groups in our analysis are more similar to each other in their imports and exports of energy than they are to the rest of the world.

Effects on Fuel Use

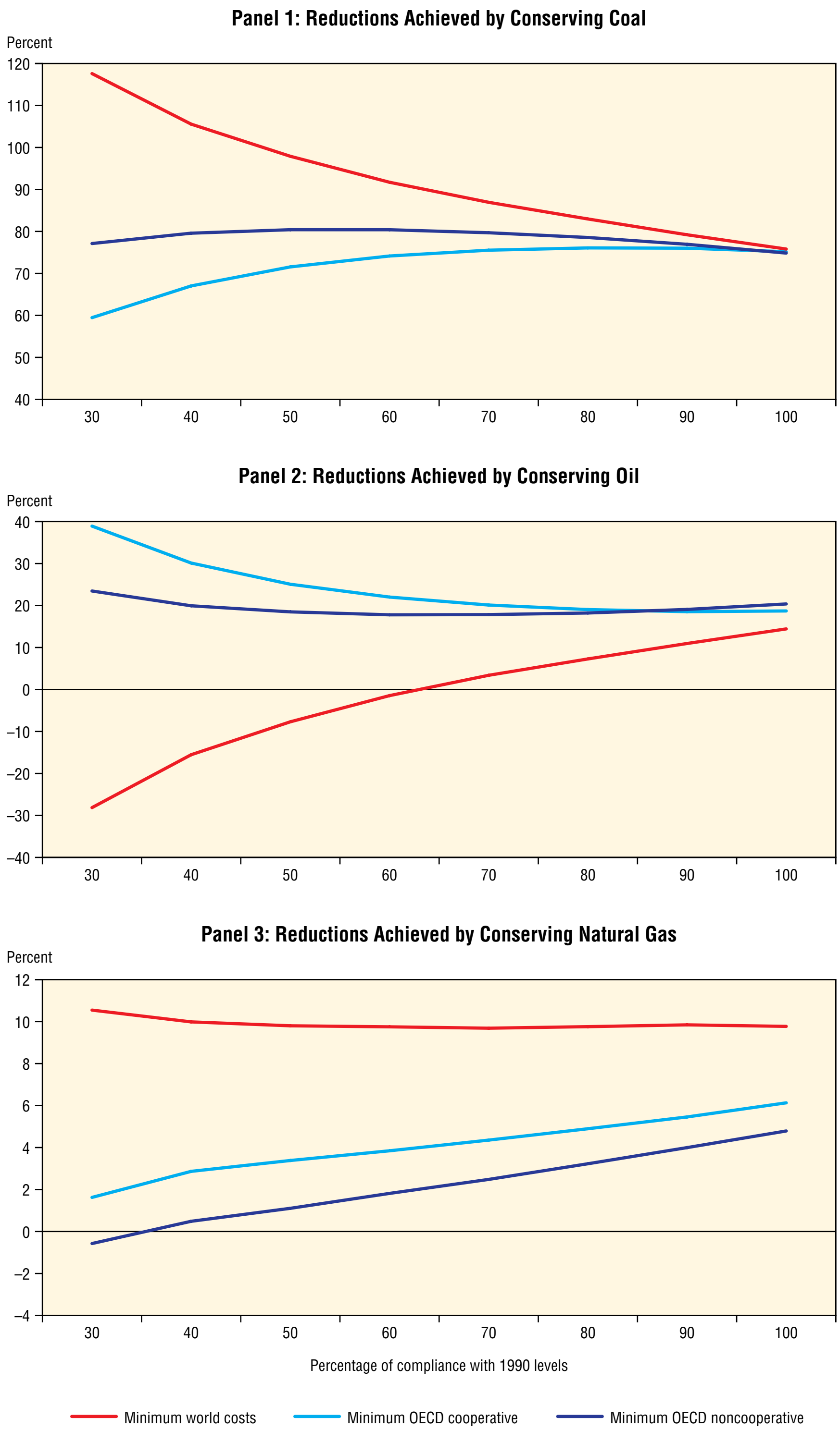
As might be expected, the three policies have very different effects on the consumption of coal, oil, and natural gas. Figure 4 shows that the greatest differences between fuels conserved under the policy are found at the lowest compliance rates. As compliance rises toward 100 percent, the differences are reduced.

Coal conservation figures prominently in all three policy scenarios. Coal has the highest carbon content per Btu, and its production is very responsive to price. Coal has its most prominent role in the world-cost-minimizing policy scenario. In fact, for compliance rates of less than 40 percent, this scenario calls for more than 100 percent of U.S. carbon reduction to be achieved through reduced coal use.

Coal is most prominent in the world-cost-minimizing scenario because oil is underproduced in the baseline case. As a result of the OPEC cartel, oil-importing countries face an oil price that exceeds marginal production costs. Thus, expanding OPEC production would reduce overall energy costs from the perspective of the world. At low compliance

[18] For ease of presentation, our analysis does not incorporate the market failures that result in no-regrets policies. If these failures were distributed evenly across all fossil fuels, our cost curves would shift rightward and converge at higher implementation rates. To fully incorporate such market failures, we would need to know the size of these effects in each fuel market and how quickly these cost-free opportunities would disappear in the absence of policy change.

Figure 4
Reducing U.S. CO_2 Emissions



rates, minimizing world costs calls for expanded oil use and offsetting reductions in coal consumption that take the reductions in its emissions beyond 100 percent of the total reductions in carbon emissions. Such a policy can be achieved by modifying the carbon tax to put relatively less burden on oil.[19]

In contrast, coal accounts for a much smaller percentage of the reduced CO_2 emissions under the OECD cooperative and noncooperative policy scenarios. These smaller shares reflect coal's export position in the United States and the rest of the OECD and the ability of these countries to obtain gains in the terms of trade by reducing oil consumption. The smaller reductions in coal usage are also the result of policy not being directed toward offsetting the underproduction of oil that occurs in the baseline case. As the middle panel of Figure 4 shows, oil accounts for a much larger percentage of reduced CO_2 emissions under the cooperative and noncooperative scenarios.

All three scenarios show natural gas making modest contributions to reducing CO_2 emissions. This minor role reflects the fact that all the policies tax coal and oil more heavily than natural gas. Natural gas has a lower carbon content per Btu and does not figure prominently in OECD imports. Although raising natural gas taxes reduces its use, higher taxes on the other fuels also encourage a substitution toward natural gas. The net effect is relatively small adjustments in its use. Natural gas use is reduced somewhat more in the world-cost-minimizing case because boosting OPEC oil production helps keep consumers on oil.

CONCLUSIONS

In addition to "where" and "when" inefficiencies in global carbon abatement policy, there appears to be a "how" inefficiency. If countries in a global agreement to reduce CO_2 emissions seek to minimize their own costs rather than world costs, they are likely to choose substantially different policies than most studies assume. Rather than simply abating emissions on the basis of carbon content, the country could consider which fuels it exports and imports and lower its own costs at the expense of its trading partners.

By taking into account the sources of its fuels, a country can reduce its own costs for meeting specific abatement targets. For an imported fuel, curtailed use lowers the world price and yields the importing country a gain in the terms of trade. For an exported fuel, curtailed use yields the exporting country a loss in the terms of trade. These effects vary across countries by the amount of each fuel imported and exported. From a world perspective, however, the effects exactly cancel.

Consequently, emissions reduction strategies that would minimize costs for the United States or other OECD countries can differ substantially from those that would minimize world costs. Furthermore, our simulations indicate that the OECD can lower its own costs of reducing CO_2 emissions by deviating from a policy of minimizing world costs. The incentive to pursue such a policy creates the "how" inefficiency.

Given its sizable oil imports, the OECD has an incentive to deviate from policies that would minimize world costs. By reducing oil consump-

[19] OPEC's monopoly power is unimportant for the existence of the terms-of-trade effects, but it affects fuel choice and alters the economic efficiency of a pure carbon tax.

tion, the OECD can reduce the world oil price and achieve a gain in the terms of trade at the expense of its trading partners. This ability gives the OECD an incentive to reduce oil consumption by more than is optimal from the world perspective. At the same time, the OECD would reduce natural gas and coal consumption by less than is optimal from the world perspective.

At relatively low levels, the direct costs of CO_2 abatement are low and total costs depend primarily on the terms-of-trade effects. At these low levels, the OECD's marginal cost of reducing CO_2 emissions through oil conservation will be negative because the OECD imports oil and will obtain sizable gains in the terms of trade by reducing its usage. Consequently, at CO_2 abatement levels that are lower than thought to be required for compliance with the Kyoto accord, terms-of-trade effects can give the OECD a substantial incentive to deviate from policies that would minimize world costs.

In contrast, our estimates indicate that for the relatively high CO_2 abatement that is thought to be required for compliance with the accord, the terms-of-trade effects are much less important to a country's costs than direct welfare losses. As a result, the OECD will have less incentive to deviate from policies that minimize world costs. Consequently, for studies that focus solely on how to implement the Kyoto targets and assume a baseline similar to that used in our analysis, the "how" inefficiency is less important and may not require as much attention.

Nonetheless, given the lack of ratification of the Kyoto Protocol, terms-of-trade effects may gain importance in international agreements to reduce greenhouse gases. Countries could take a more gradual approach to reducing emissions than the accord proposes, or technological change could reduce the baseline emissions more than anticipated. The possibility that countries will pursue self-interest in determining their emissions policies adds to the issues that merit consideration in seeking the cooperation needed to forge such agreements.

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Appendix
Estimating the Cost of CO_2 Abatement

To estimate the cost curves for reducing CO_2 emissions under each of the three policy scenarios for 2010, we combine a relatively simple simulation model of world energy markets with a welfare-theoretic framework. The model divides the world into five regions: the United States; other OECD countries; China, Eastern Europe, and the former Soviet Union (C/EE/FSU); OPEC members; and other developing nations. Each region consumes and produces coal, oil, natural gas, and other energy (including nuclear power and renewables). International trade in the three fossil fuels depends on world prices and region-specific emissions policies. Nuclear and renewable energy are not traded but are provided within a region at a domestically determined price.[1]

The welfare-theoretic framework we use follows Felder and Rutherford (1993), Brown and Huntington (1994, 1998), and Brown (1998). Combined with the simulation model, the framework yields estimates of the marginal cost of reducing CO_2 emissions under the various scenarios and a range of implementation rates. The resulting cost estimates take into account the direct welfare costs of a country's mitigation efforts, the transfers from changes in the terms of trade, and the effect lower world energy prices would have on energy consumption in nonparticipating countries. The estimates also reflect the economic cost of OPEC cartelization.

Because lower world prices for fossil energy stimulate the consumption of these fuels in nonparticipating countries, CO_2 emissions in these countries will rise, creating what is sometimes known as the leakage effect. The result is a smaller net reduction in world CO_2 emissions and a higher marginal cost. The leakage effect is also incorporated into the cost estimates.

World Energy Market Model and Policy Implementation

Each policy scenario is developed from the same baseline case, with price, production, and consumption estimates from a recent *International Energy Outlook*, produced by the U.S. Energy Information Administration (EIA). Table A.1 provides the 2010 values for each energy source and region. Under the baseline, U.S. energy consumption in 2010 is projected to result in 384 million metric tons more carbon emissions than it did in 1990, while total OECD energy consumption will result in 883 million metric tons more. The EIA's outlooks assume no new policy initiatives and are widely available, well documented, frequently compared with other major energy outlooks, and often evaluated for their ability to track the historical record.

Policy that calls for a reduction in CO_2 emissions is represented as a departure from these baseline conditions. Each policy case specifies emissions targets for the United States and other OECD countries and an assumption about whose costs are minimized. As the model adjusts to policy implementation, world energy prices adjust to restore market-clearing conditions in each energy market. Analytically, policy is implemented through the use of six separate taxes—one for each of the three fossil fuels in the two OECD regions.[2]

For these internationally traded fuels, the taxes create a gap between the price paid by consumers in the two OECD regions and the prices energy suppliers receive. Within the OECD, a tax on fuel increases its price and domestic use falls. To restore market-clearing conditions, the world price falls, which deters production and stimulates consumption in nonparticipating countries. Interfuel substitution is also important and complicates the analysis. For example, an increase in domestic coal prices could push OECD consumers toward natural gas, putting upward pressure on world natural gas prices.

We simulate new market conditions (production, consumption, and prices) with log-linear supply and demand functions for each region, using price elasticities based on an extensive set of past econometric studies.[3] Table A.1 summarizes these

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elasticities. The elasticities represent long-run responses, which means market participants today and in each year until 2010 expect to see that price in 2010 and fully adjust to it.[4]

Econometric studies (Griffin 1985; Dahl and Yücel 1991) suggest that OPEC acts like an imperfect cartel during some periods but not others. In contrast, formal models of cartel behavior have been unable to predict OPEC behavior. In our simulation model, OPEC acts to maintain a constant market share, which approximates an imperfect cartel response.[5]

The Policy Simulations

We consider three of many possible OECD strategies for reducing CO_2 emissions: world-cost minimizing, cooperative, and noncooperative. The world-cost-minimizing strategy assumes the OECD adopts policies to reduce its CO_2 emissions in a way that keeps world costs as low as possible. Essentially, the OECD imposes a carbon tax on member countries, with appropriate adjustments to account for OPEC's restricted oil production.

The cooperative strategy assumes that OECD members adopt policies to minimize OECD's total cost of achieving each level of CO_2 abatement. The noncooperative strategy divides OECD countries into two groups: the United States and all other OECD countries. Under this strategy, the United States and the other group act independently of each other to minimize their own costs, while taking the behavior of the other group as given. Equilibrium values are established through a Nash–Cournot solution.

Welfare Analytics of the Cost of CO_2 Abatement

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:

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

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, and 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} is 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).

The Cost of Gross CO_2 Abatement

Welfare losses in the energy markets are the most direct way to measure the cost of reducing CO_2 emissions by altering energy consumption. Assuming no other distortions in domestic energy markets and no significant international trade in noncarbon energy, we sum over the marginal effects of the emissions-reduction policy on each carbon energy source to obtain the marginal cost of compliance for country i:

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

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} is the world price of energy source j, Q_{Cij} the quantity of energy source j that is conserved (where

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Appendix *(continued)*

Estimating the Cost of CO_2 Abatement

$\partial Q_{Cij} = -\partial Q_{Dij}$), Q_{Mij} country i's imports of energy source j, and E_i is the reduction in country i 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 by 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.

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

A.3
$$\frac{\partial E_W}{\partial E_i} = 1 - \sum_{j=1}^{n} E_j \frac{\partial Q_{DXj}}{\partial P_{Wj}} \cdot \frac{\partial P_{Wj}}{\partial E_i}.$$

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 (1994, 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 emissions for country i by the net change in world emissions resulting from country i reducing its emissions yields:

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

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

The World Perspective

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

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Appendix *(continued)*
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Accounting for the offsetting transfers, as well as the distortion in world oil markets resulting from OPEC restraining its oil production below free market levels, we alter Equation A.4 to obtain:

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

In the above equation, MC_W denotes the net marginal cost to the world of country i's emissions reduction, 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.

Comparability With Other Analyses

Because examination of energy supply and demand conditions yields a wide range of supply and demand elasticities and such examinations differ from each other, there is considerable uncertainty about the key responses in an analysis like ours. Stronger price responses, due to a greater ease of fuel substitution or a greater capital malleability and higher turnover, will reduce the costs of meeting the targets (Weyant and Hill 1999).

To provide a perspective on our estimates, we consider a case in which the United States and the rest of the OECD hold their 2010 carbon emissions at the 1990 level. We estimate that marginal U.S. direct costs in 2010 would be $212 per million metric ton. These costs fall in the middle of the range of other estimates for compliance with Kyoto with no emissions trading, which Weyant and Hill (1999, xxii–xxiii) and Weyant (2000, 32–36) show as being approximately $80 to $400 per million metric ton in 1990 dollars. Among the various estimates reported in these two sources, directs costs of about $200 per million metric ton are similar to those found with the Second Generation Model (SGM) and the MIT–EPPA model.

Our estimate is not strictly comparable with these estimates because we use a different baseline scenario and examine a less extreme reduction in CO_2 emissions than the 5.2 percent reduction below 1990 emissions levels required by the Kyoto Protocol. On the other hand, our estimates do not allow any credit for carbon sinks or reductions in other greenhouse gases, which might have caused the Kyoto carbon targets to be less binding than the 5.2 percent reduction. Keeping these differences in mind, our estimates of the direct costs of this policy appear similar to those found by other researchers examining compliance with the Kyoto Protocol without emissions trading.

Our estimates of the carbon-leakage effect also appear comparable to those in other studies as well. In our world-optimizing case, unilateral OECD action that reduces 2010 emissions to the 1990 level will stimulate a 1.2 percent increase in carbon emissions outside the OECD for each 10 percent reduction in carbon emissions within the OECD. This 12 percent leakage is consistent with the 14 percent estimate that Polidano et al. (2000) obtain (with GTEM, a highly detailed computable generation equilibrium model) for compliance with Kyoto without emissions trading.

Notes

[1] The model has a parsimonious structure that allows it to be simulated numerous times for extensive searching for the lowest-cost policies of various approaches and at varying implementation rates over multiple policy options and different fuel combinations. To maintain parsimony, we confine our analysis to estimating the cost of reducing CO_2 emissions through energy conservation and fuel switching for the three major fossil fuels and other energy sources. In doing so, we exclude carbon sinks, nonfuel carbon sources, and the clean development mechanism. Under the latter, industrialized countries can claim credit for projects that reduce emissions in developing countries. The necessity for parsimony also excluded the use

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Appendix *(continued)*
Estimating the Cost of CO_2 Abatement

of a large computable general equilibrium model with detailed sectors, such as GTEM, developed by Tulpule et al. (1999). Such a model would take into account secondary effects in nonenergy sectors of the economy, which the present analysis does not consider.

[2] This approach assumes that energy conservation is achieved efficiently across all end uses of a particular fuel. The tax approach is typically thought to understate the cost of implementing policy. The country could decide to restrict some high-valued energy uses by adopting non-market mechanisms or by excluding some consumers from the policy. The tax approach also could overstate the cost of compliance because it excludes from consideration the possibility that market imperfections might lead to higher energy use than is optimal (Pezzey 1992b).

[3] Sources include surveys by Bohi (1981), Dahl (1986, 1993, 1994a, 1994b), Dahl and Sterner (1991), Hawdon (1992), Barker et al. (1995), and Atkinson and Manning (1995). Additional sources include the Energy Modeling Forum (1991a, 1991b) and Huntington (1992, 1993) for oil price elasticities, Brown and Yücel (1995) for price elasticities for other fuels, and Pesaran et al. (1998) for price elasticities in developing countries.

[4] Given the quality of data and availability of published studies, the price elasticities better reflect those of the industrialized nations. Studies by Dahl (1993, 1994a, 1994b), Pesaran et al. (1998), and Gately and Huntington (2002) suggest that elasticities are lower in developing countries, and that is incorporated in the analysis. The elasticities for C/EE/FSU are judgmental and reflect our assessment that these countries are unlikely to be able to change their import-export positions very dramatically given their current constraints.

[5] The OPEC countries appear to be about equally uncomfortable with a rapidly increasing or decreasing market share. A sensitivity analysis using alternative assumptions that allow modest adjustments in OPEC's market share confirms the thrust of our analysis. In the extreme, OPEC could maintain a given price and accept a substantial loss in market share in the face of reduced demand. Under these conditions, the United States and other OECD countries would not obtain wealth gains from terms-of-trade effects in oil.

Table A.1
Reference Case Quantities, Prices, and Elasticities

	Quantity (10^{15} Btu)	Price elasticity of fuel on 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	0	.01
Natural gas	5.6	.25	–.72	0	.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

(continued)

* China, Eastern Europe, and the former Soviet Union.
† OPEC adjusts its production to maintain a constant share of the oil market. See text.
‡ Prices are in 1995 dollars.

Table A.1 *(continued)*

Reference Case Quantities, Prices, and Elasticities

	Quantity (10^{15} Btu)	Price elasticity of fuel on left with respect to price of: Oil	Natural gas	Coal	Other
Other Nations					
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 bbl
Natural gas	1.9553	2.01 per Mcf
Coal	.7924	16.919 per short ton

* China, Eastern Europe, and the former Soviet Union.

† OPEC adjusts its production to maintain a constant share of the oil market. See text.

‡ Prices are in 1995 dollars.