International **emissions trading**

& Global **climate change**

Impacts on the Costs of Greenhouse Gas Mitigation

Prepared for the Pew Center on Global Climate Change

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Contents

Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

Several factors influence the costs of greenhouse gas mitigation. This report illustrates the importance of one such factor—international emissions trading—in reducing the costs of carbon control. The authors find that an international greenhouse gas emissions trading regime will significantly lower global mitigation costs. Specifically, the report finds:

- The costs of controlling carbon emissions would be significantly lower if trade is permitted than if each country is required to meet its obligations alone.

- Providing greater flexibility in trading mechanisms—for example, allowing trading among various greenhouse gases and across emissions sources, and allowing trades to occur over time—lowers the costs.

- Emissions trading reduces the potential for "leakage" of jobs, industry, and emissions compared to a control case with no trading because changes in world fuel prices would be moderated through the availability of trading.

- While broader participation in trading is likely to yield greater benefits, any amount of trading will lower the costs for those participating. If a climate policy regime is in place that allows emissions trading, all parties—with or without obligations—are better off trading than not.

- Issues of program design and institutional structure must be addressed carefully to realize the full economic potential of trading regimes.

- By making transparent the core structure and assumptions of economic models, the Pew Center hopes to provide policy-makers and consumers of economic information with tools to better understand the important assumptions driving the models' projections of costs.

This report is the first in a series designed to explore how economic models address the climate change issue. The first phase of this effort will make a direct and significant contribution to economic modeling in the following four areas: (1) review of existing models and identification of their key assumptions; (2) investigation of the models' theoretical frameworks; (3) encouraging best practices in modeling specific aspects of the climate change issue; and (4) integrating innovative modeling practices into a state-of-the-art assessment of the costs of climate change and the policies used to address it.

The second phase of the Pew Center's economics program will focus on how businesses react to climate change—and policies to ameliorate it—in the context of sound business strategy and practice. The Center is in a unique position to provide insight into the inner working of firms through the participation of our Business Environmental Leadership Council.

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Executive Summary

One of the earliest and most robust findings of economics is that, where relative costs of performing an activity differ among individuals, business firms, or regions, there are almost always potential gains from trade. In today's jargon, trade can always be win-win. Traditional approaches to addressing environmental problems have generally not taken advantage of this potential. Rather, command and control regulatory policy instruments have been the tools of choice. While these tools can be effective in reaching an environmental goal, they can also be expensive. Recently environmental policy-makers have begun to explore ways of obtaining more environmental benefits per dollar expended, and the use of emissions trading has been on the cutting edge of these efforts. Because climate change is an issue that requires a sustained policy commitment over the course of a century, attention to the cost of policy intervention is especially important. This paper explores the degree to which trade among parties to an international agreement can reduce the cost of greenhouse gas reductions.

International trade holds the potential of reducing costs of controlling world emissions of greenhouse gases (GHGs) because the nations of the world experience very different costs for achieving emissions reductions on their own. However, the potential gains from trade, like the costs of compliance themselves, may be very unevenly distributed across the world's participants. While all of the parties to an agreement stand to gain collectively under trade in emissions rights as compared with "independent compliance" (i.e., each country meeting its obligations alone), non-participants in the agreement may either benefit or not depending on their own particular circumstances. The detailed rules for trading affect how effective trading could be, as well as the level of gains that would be captured in practice. Details of the trading rules will influence both the total gains from trade and distribution of such gains. Key issues include definitions of the emissions rights to be traded, the rules for crediting carbon sinks, and regulations governing participation in the trading framework. In addition, there are economic uncertainties, such as the behavior of countries that have significant market power in supplying emissions credits, and the transaction costs associated with trading and enforcement. These effects could significantly increase the costs of mitigation compared to the most favorable case and could reduce the amount and benefits of trading.

A number of global economic models have been used to estimate the effects of emissions trading. Empirical results derived from these models can be summarized as follows:

- Costs of controlling carbon emissions would be significantly lower if trade in carbon emissions allowances were permitted than if each nation had to meet its emissions reduction responsibilities alone. The broader the trade possibilities, the lower the costs of control.

- All parties with GHG emissions mitigation obligations benefit from trade. Both permit buyers and permit sellers will benefit.

- Parties without obligations may be better or worse off under a trading regime relative to a regime that does not allow trading. However, given a regime that allows trading among parties with obligations, parties without obligations will be better off trading (i.e., selling emissions reductions) than not trading.

- Because the costs of fuels could be affected by emissions control and emissions trading, countries and regions may be affected whether or not they participate in emissions reduction and in emissions trading. Parties without obligations may be either better off or worse off after obligations are established for others. For example, if emissions trading is prohibited, the prices paid to fossil fuel producers are reduced, and the energy-exporting countries are worse off relative to a no-control case. Emissions trading mitigates this effect. Results for other non-participating regions are more ambiguous.

- Gains from trade are sensitive to the difference between the base case and target emissions and to the difference in marginal (incremental) abatement costs among countries. For any limit to emissions, the higher the future level of emissions is expected to be without intervention, the more difficult and costly mitigation is expected to be. Although the gains from trade depend on the differences between countries' marginal abatement costs, not their absolute level, the analysis in this paper shows that the gains from trade are larger for more ambitious emissions targets.

- The actual cost savings from trade in emissions are likely to be less than the theoretical savings shown in most analyses performed with integrated assessment models[1] because these models do not include the various measurement, verification, trading, and enforcement costs that would characterize any real trading system. Programs must be carefully designed to assure that the potential gains from trade are realized.

I. Introduction

One of the earliest and most robust findings of economics is that, where relative costs of performing an activity differ among individuals, business firms, or regions, there are almost always potential gains from trade. In the jargon of today, trade can always be win-win. Traditional approaches to addressing environmental problems have generally not taken advantage of this potential. Rather, command and control regulatory policy instruments have been the tools of choice. While these tools can be effective in reaching an environmental goal, they can also be expensive. Recently, environmental policymakers have begun to explore ways of obtaining more environmental benefits per dollar expended, and the use of emissions trading has been on the cutting edge of these efforts. Because climate change is an issue that requires a sustained policy commitment over the course of a century, attention to the cost of policy intervention is especially important. This paper explores the degree to which trade among parties to an international agreement can reduce the cost of obtaining greenhouse gas reductions.

The paper begins with a discussion of the principles of trade—the intellectual foundation upon which the concept of flexible instruments is based. The next section considers the evidence from modeling results pertaining to the magnitude of potential gains from emissions trading. The paper then discusses issues associated with rules of and mechanisms for trading. Finally, the effect of institutional arrangements on the results is discussed.

II. The Gains from Trade

The fact that trade produces gains is a powerful point that relates directly to the question of greenhouse gas control. Most greenhouse gases (GHGs) mix rapidly in the atmosphere, persist for decades or more, and are expected to affect climate. Because GHGs lead to global effects, it does not matter from where GHG reductions come. Thus the effect of trading on climate is neutral as long as global GHG emissions are the same with or without trading.

Countries and regions differ in their degree of dependence on production activities that emit GHGs, the efficiency with which they produce goods and services per ton of GHGs emitted, and the ease with which they can change their current dependency and efficiency (for example, their relative ease of access to coal and natural gas resources or combined cycle combustion technology). Therefore, it is only natural that they would experience different marginal (incremental) abatement costs when they attempt to limit their emissions of GHGs.

The principle of gains from trade states that whenever two or more organizations are obligated to produce a fixed amount of a good or service and their marginal costs of production differ, both can be made better off through trade. The gains can be realized if the entity with the higher marginal costs reduces production and pays the entity with the lower marginal costs to increase production. The principle depends on the difference between marginal costs, not the absolute level of costs. It is equally valid for two low-cost producers or two high-cost producers, so long as costs differ.[2] GHG emissions control would be less costly overall if those countries and organizations that have relatively high costs of emissions reductions were allowed to pay those with lower costs of emissions reduction to undertake more of the actual emissions reductions. These cost savings (i.e., the gains from trade) would be realized if markets could be established that allowed trading of "permits" or rights to emit GHGs. Nations with higher emissions control costs could then compensate lower-cost nations to undertake emissions control on behalf of the higher-cost nations. Of course, the principle is silent on the question of how the savings are actually shared (i.e., who pays whom how much). Nevertheless, the gains from trade are still potentially available to be shared regardless of how responsibility for mitigation is assigned.

There is a rapidly developing body of environmental practice among policy-makers in the United States and elsewhere that attempts to make use of the marketplace in this manner to achieve environmental goals. Examples from the United States include the sulfur dioxide permit trading system in the acid rain program, the Regional Clean Air Incentives Market (RECLAIM) in the Los Angeles Area, water quality permit trading, the emissions credit trading program for criteria air pollutants, and the U.S. phase-down of lead. Non-U.S. examples include the New Zealand Fisheries License Trading Program, the Framework Convention on Climate Change Pilot Program for Activities Implemented Jointly, and the Canadian trading program for ozone-depleting substances. Several authors have published reports on lessons learned from these programs.[3] The major advantage of a system of tradable permits is that both overall emissions control costs and individual net costs of compliance are lower than if each emitter undertook emissions control independently.

A. An Illustration

Let us begin with an example in which there are two countries emitting carbon and that an agreement to limit emissions exists. One country has higher domestic marginal costs of carbon control (the "high-cost" controller) and the other country has lower domestic marginal costs of carbon control (the "low-cost" controller). To make the example as clear and simple as possible, also suppose that both countries have full knowledge of each other's costs so that there is no controversy over where it is least costly to undertake emissions reduction; that both countries have full control over their own emissions and effective access to appropriate control technologies; that in both countries trading of environmental permits is considered an acceptable means of controlling emissions; and, finally, that it costs nothing to specify emissions, transact trades, and enforce compliance.[4] (The effects of some of the potential barriers to trading are discussed later in the paper.) Also, assume that emissions allowances cannot be used in any period other than the one in which they are issued.

It makes no difference for purposes of this example whether or not the low-cost controller has any actual obligation to control carbon.[5] Lower overall costs of carbon control would result if, rather than controlling emissions at its own high domestic marginal costs, the high-cost controller compensated the low-cost controller for undertaking emissions control that the low-cost controller was not otherwise obligated to perform. In a world where both countries had an initial stock of emissions permits corresponding to their annual emissions of carbon, this trade could take the form of the high-cost controller purchasing emissions permits from the low-cost controller.[6] So long as the payment for the permits is greater than the cost of control for the low-cost controller, the low-cost controller would benefit from this arrangement. So long as the payment is less than the costs of control for the high-cost controller, the high-cost controller benefits. So long as the costs of executing, monitoring, regulating, and enforcing trades do not absorb these cost savings, the overall costs of compliance are reduced. These cost savings are the so-called "gains from trade."

For example, assume that the low-cost controller can reduce emissions for $10 per ton of carbon, and the high-cost controller would face costs of $100 per ton for domestic control of carbon.[7] The difference in marginal control costs might occur because of the age and efficiency of industrial equipment, differences in the national endowments of fuels (i.e., coal vs. natural gas), or some other reason. Finally, assume that only the high-cost controller must reduce emissions by 1,000 tons. The cost of 1,000 tons of mitigation is $10,000 to the low-cost controller and $100,000 to the high-cost controller. If the low-cost controller can obtain a payment of more than $10,000 for the 1,000 tons, it can profit by undertaking the control of 1,000 tons of carbon. If the high-cost controller can pay less than $100,000, it is better off as well. Any agreement paying the low-cost controller more than $10,000 and costing the high-cost controller less than $100,000 is a win-win agreement.

Obviously, under these conditions the low-cost controller would always undertake all emissions mitigation and the high-cost controller would not undertake any because the low-cost controller is always the cheap supplier of mitigation. In the real world, marginal costs change as mitigation occurs. Every region has a long menu of potential emissions mitigation options. These opportunities range from the very inexpensive to the very expensive. Within a region, the cheap mitigation options would be expected to be undertaken before more expensive emissions control options; i.e., there is a schedule of control measures characterized by increasing marginal costs, also known as a "marginal abatement cost curve." If the cost of controlling the last unit of emissions is different between two regions, a potential gain can be shared between the parties by increasing mitigation in the region with the lower marginal cost and decreasing it in the region with the higher marginal cost.

In the real world, of course, significant departures from the idealized circumstances given above would reduce the gains from trade. Economic actors have problems in estimating costs, in accessing and acting upon technological information, in trading, and in enforcing the results of those trades. All of these factors increase the costs of trading and reduce the gains from trade. The impacts of these market imperfections and institutional issues are discussed in the later sections of the paper and in an upcoming Pew Center paper on the institutional issues of trading. However, for the purpose of explaining the principle of emissions trading, this section assumes that trading is costless.

B. A Numerical Example of the Gains from Trade

To illustrate numerically the gains from trade in carbon emissions control, imagine three hypothetical countries (A, B, and C) in the situation illustrated in Table 1. In 1990, each country emits carbon as shown in the first row of the table. These emissions grow over time because of population and economic growth. At some designated year in the future—e.g., 2010—they have to reduce their collective emissions 10% below the 1990 level.

Table 1

Carbon Emissions and Carbon Control Obligations in Three Hypothetical Countries, 1990 and 2010 (million tons C)

	Country A	Country B	Country C	Total
1990	300	820	1,350	2,470
2010, Without Control	414	1,045	1,787	3,246
10% Below 1990	270	738	1,215	2,223
2010 Control Obligation	144	307	572	1,023

Box 1

Definitions of Cost

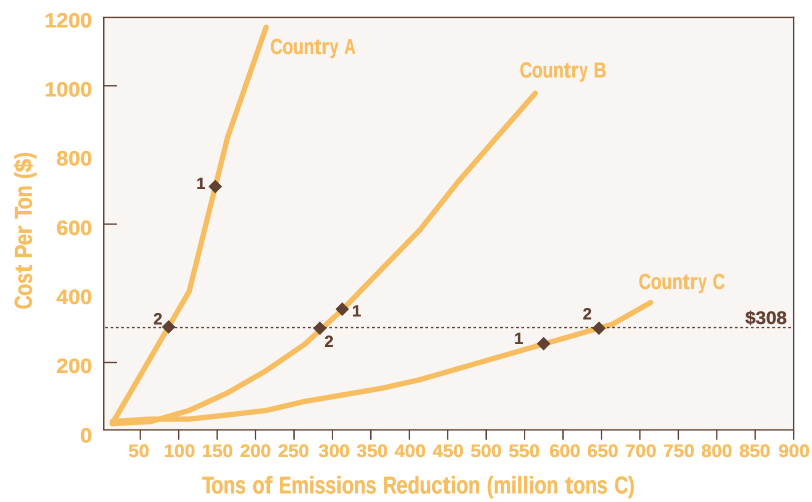
The gains from trade are related to the cost of meeting emissions limitation obligations. This paper uses four terms related to costs:

- Marginal Abatement Cost: The marginal abatement cost is the cost of the last ton of emissions mitigation. To minimize the cost of any level of abatement, low-cost control should be undertaken before higher-cost control. Thus marginal abatement costs rise as the level of abatement rises.
- Total Abatement Cost: The total abatement cost is the direct cost of emissions abatement. It is the sum of the costs for every unit of abatement. It does not take into account broader effects on the economy.
- Total Mitigation Obligation Cost: Under a trading regime, an emissions obligation can be satisfied through a combination of domestic abatement and the purchase of any emission permits from another party. Thus, the total mitigation obligation cost is the sum of the total abatement cost, plus the cost of purchasing any emissions permits, minus the value of any sales of emissions permits.
- Net Mitigation Cost: The net mitigation cost equals Gross Domestic Product costs plus permit purchases, minus the value of any emissions permit sales.

Figure 1 shows marginal abatement cost curves that depict the cost of abatement in the year 2010 for the three hypothetical countries (see Box 1 for definitions of cost used throughout this report). Each curve represents the marginal costs of reducing domestic carbon emissions in that country for different amounts of domestic emissions reduction. All costs in the figure and throughout the paper are shown in constant 1992 dollars. In the absence of the ability to trade, each nation must fulfill its abatement obligations from its own domestic sources—each country cuts emissions to an amount 10% below the 1990 level. As shown in Table 1, the obligation to control emissions at 10% below the 1990 level means a total of 1023 million tons of emissions (144+307+572) must be controlled in these three countries in the year 2010. The marginal abatement cost curves in Figure 1 show that for the three countries, the corresponding marginal abatement costs without trade range from $237 per ton in Country C, to $350 per ton in Country B, to $734 per ton in Country A. Total abatement costs (total costs of domestic emissions reduction) can be computed mathematically in each instance as the area under the marginal cost curve out to the amount of abatement. As shown in Figure 2, the corresponding total costs in the no-trade scenario are $48 billion in Country C, $39 billion in Country B, and $44 billion in Country A. The combined total costs of emissions reduction without trading would be $131 billion if each country reduced its emissions from its own domestic sources only.

Figure 1

Comparative Marginal Costs of Emissions Control



Country A

1 **Without Trade**
Emissions Reduction = 144 tons
Marginal Cost = $734/ton

2 **With Trade**
Emissions Reduction = 79 tons
Marginal Cost = $308/ton

Country B

1 **Without Trade**
Emissions Reduction = 307 tons
Marginal Cost = $350/ton

2 **With Trade**
Emissions Reduction = 286 tons
Marginal Cost = $308/ton

Country C

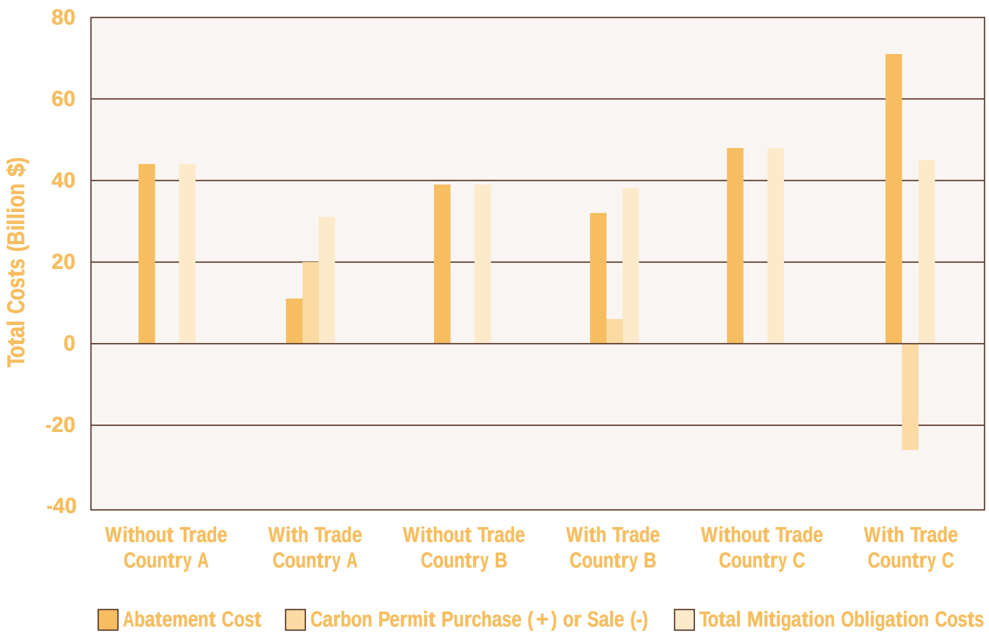
1 **Without Trade**
Emissions Reduction = 572 tons
Marginal Cost = $237/ton

2 **With Trade**
Emissions Reduction = 657 tons
Marginal Cost = $308/ton

In Figure 1, if it were possible to compensate other nations to undertake some additional emissions control, it would clearly be in the best interest of Countries A and B to compensate C to

Figure 2

Comparative Total Costs of Emissions Control



undertake extra emissions reduction because C's marginal abatement costs are so much lower. As shown in Figure 2, this approach would also reduce the overall costs of compliance for all three countries together. If emissions rights could be traded so that A and B undertook less emissions reductions, instead paying C to take on greater responsibility, for example:

- Country A could lower its emissions control to 79 million tons (total abatement cost $11 billion) and purchase 65 million tons of emissions (at a cost of $20 billion), for a total cost of $31 billion;

- Country B could lower its emissions control to 286 million tons (total abatement cost $32 billion) and purchase 21 million tons (at a cost of $6 billion), for a total cost of $38 billion; and

- Country C could increase its emissions control to 657 million tons (total abatement cost $71 billion) and sell 86 million tons of carbon permits (receipts of $26 billion), for a net total cost of $40 billion.

With trading, Country C could undertake an extra 86 million tons of emissions reductions and could "sell" these reductions to countries A and B at a price of $308 per ton, the common marginal abatement cost in all three countries. The overall total mitigation obligation cost (i.e., sum of the total abatement costs in each country) would then be $114 billion, a savings of $17 billion relative to the no-trade scenario. Although Country C faces higher total abatement costs, it is compensated for these costs through sales of credits to countries A and B. Total mitigation costs (i.e., abatement cost plus net purchases of emissions permits) are lower in all three countries when they trade than when they do not. The resulting savings in this case are about $17 billion.

There are two kinds of flexibility that can reduce the costs of carbon emissions control. The trading of emissions reductions among regions is what is commonly called "where" flexibility in the climate policy community. "Where" flexibility means that GHG emitters undertake emissions control in those locations where it is most cost-effective to do so. The other type of flexibility is "when" flexibility. Emitters having "when" flexibility undertake emissions control when it is most cost effective to do so. "When" flexibility may involve either acceleration or delay of emissions control, depending on the pace of technological development and the ability to trade emissions obligations over time. Unused permits may be held in reserve or "banked" until needed. Banking of unused emissions permits to be used in a later period is one way to achieve "when" flexibility. The extent of banking will affect the availability of permits for trading.

Section III amplifies the results in this section by discussing emissions trading in a more realistic policy experiment using a global economic model.

III. Modeling Analysis of Carbon Trading

The hypothetical example of emissions control in the previous section focused only on emissions control in isolation. It did not take into account the many ways in which the world's economies interact dynamically to determine the costs of carbon control and the benefits of emissions trading. To perform a more realistic analysis of the gains from carbon trading in the world's economies, it is necessary to analyze many of these interactions simultaneously, a task performed most conveniently with a computerized numerical model of the economy.

The modeling analysis of carbon trading in this paper is accomplished primarily with Pacific Northwest National Laboratory's Second Generation Model (SGM).[8] Similar to several other integrated assessment models, the SGM reflects the recent trend toward hybrid integrated computer models that incorporate features from both energy modeling approaches: the "top-down" approach (which describes economic behavior based on statistical and theoretical principles) and the "bottom-up" approach (which emphasizes technological and engineering data and principles). Economic detail is maintained in the energy supply and transformation sectors that are important for GHG emissions projections, but is aggregated elsewhere into one large "everything else" sector. The SGM, like most integrated assessment models, does a relatively good job of capturing long-run costs, but does not capture transition effects such as inflation rates, unemployment, GNP, and monetary aggregates.[9]

In an equilibrium model like the SGM, markets are linked to other markets through the market-clearing process. For example, a change in the demand for coal will have an effect not just on the price of coal, but also on the prices of oil, gas, and—at least indirectly—the prices of all markets in the economy. Thus, in the SGM, markets are said to clear when the model solves for the set of prices for all markets (or sectors) in the modeled economy so that demands and supplies of each market are in balance (equilibrium). The set of prices in which the equilibrium holds is called the market-clearing price set.

The SGM also solves for carbon permit prices as part of this market equilibrium. Specifically, the SGM finds the carbon price (i.e., marginal abatement cost) at which the amount of carbon abated

Table 2

Required Carbon Emissions Reductions in Selected Regions

	Base Case Emissions 1990 (Emissions in million tons C)	Projected Base Case Emissions (Emissions in million tons C)		Reduce Emissions to 1990 Level (Required emissions reduction in million tons C)		Reduce Emissions to 10% Below 1990 Level (Required emissions reduction in million tons C)	
Annex I Countries	**Year 1990**	**Year 2010**	**Year 2020**	**Year 2010**	**Year 2020**	**Year 2010**	**Year 2020**
United States	1348	1810	1974	462	626	597	761
Japan	272	367	371	95	99	122	126
Western Europe	904	1071	1223	167	319	257	409
Canada	117	168	179	51	62	63	74
Australia	62	87	95	25	33	31	39
Former Soviet Union	996	781	925	0	144	0	144
Eastern Europe	290	278	329	0	51	0	51
Subtotal	**3989**	**4562**	**5096**	**800**	**1334**	**1070**	**1604**
Non- Annex I	1481	2880	3759	0	0	0	0
Total	**5469**	**7442**	**8855**	**800**	**1334**	**1070**	**1604**

Target is for the Years 2010 and 2020, to Reduce Carbon Emissions to 1990 Levels or 10% Below 1990 Levels

just satisfies the carbon emissions limitation constraint of a region or group of regions. Thus, SGM provides a consistent way to examine alternative strategies for limiting CO_2 and other GHGs and to examine the impacts of energy prices on economic output.

Table 2 shows the reductions in carbon emissions that are necessary to return emissions to 1990 levels, or to 10% below 1990 levels, from a base case or "no control" case. It is immediately obvious that, because emissions in each country or region grow over time in the base case due to economic and population growth, the fixed obligation of a return to 1990 emissions levels (or fixed levels below 1990 levels) implies that annual emissions reductions requirements would be greater:

- the faster the rate of economic and population growth,
- the more stringent the level of mitigation that must be reached, and
- the further out in time the emissions controls are implemented.

This paper describes analyses of various levels of emissions stabilization, ranging from 1990 levels to 10% below 1990 levels. As a point of reference, the Kyoto Protocol[10] targets for Annex I countries (i.e., the Organization for Economic Cooperation and Development (OECD), Eastern Europe, and the countries that formerly were part of the Soviet Union)[11] range from 10% above to 8% below 1990 levels. The focus of this paper is not the Kyoto Protocol, but rather the implications of trading for a range of emissions targets.

The effects of GHG emissions trading on emissions and costs are shown for the years 2010 and 2020. Three control cases are examined in this section. The cases are related to the Kyoto Protocol, under which the so-called Annex I countries have set targets for emissions reductions to be completed during the years of 2008 to 2012. The aim of these cases is not to highlight the costs of implementing Kyoto, but rather to show the magnitude of the costs savings that may occur from international emissions trading.

- *No Trade Scenario.* Each nation is responsible for its own emissions reductions and bears its own abatement costs.
- *Annex I Trading.* Annex I countries are assumed to trade permits among themselves to reduce compliance costs. It is assumed that permits are supplied in competitive markets and that no restrictions exist on the supply or use of permits. (Restrictions on availability and use are discussed in Section V).
- *World Trading.* This case is introduced to demonstrate the potential gains from trade that could be achieved by having the entire world participate in achieving the Annex I emissions obligation. In this case, the global emissions mitigation limitation remains the same as in the other cases. What changes is the extent to which parties other than those with explicit emissions limitations can participate in the process. This analysis is agnostic about the mechanism by which this extension is accomplished.[12] This case treats non-Annex I countries as if they agreed to distribute permits equal to their annual base case emissions and allowed these permits to be traded internationally. Some would argue that this case corresponds to very broad utilization of the CDM and perhaps that the inherent limitations of credit trading in general, and of the CDM specifically, would not allow such broad utilization.

Several basic results that emerge from the analyses conducted with the SGM are listed below.

- Mitigation of carbon emissions will cost less overall (generally, much less) if trade in carbon emissions is allowed than if each nation must meet its emissions reduction targets on its own. The broader the trade possibilities, the less the overall costs of control.
- Carbon permit buyers generally will benefit from emissions trading as a method to meet reduction goals. The permit buyers can gain from lower-cost emissions mitigation.
- Given that trading is allowed, potential permit sellers can gain by selling permits whose value exceeds the extra cost of their emissions mitigation. If trading is not allowed, some potential non-Annex I permit sellers could still be better off because Annex I's emissions mitigation efforts will lower the price of remaining energy supplies on the world market.

- Independent compliance by Annex I countries lowers international fossil fuel prices and increases the costs of energy-intensive activities in the Annex I countries. Thus energy-intensive countries could benefit if: (a) they are potential permit sellers, (b) they compete with Annex I countries, and (c) their export product markets are not too tied to Annex I countries.

- Because the costs of fuels could be affected by emissions control and emissions trading, countries and regions may be affected whether or not they participate in emissions reduction. For example, if emissions trading is forbidden, then relative to the base case: (a) fossil fuel prices fall because the requirement to control carbon reduces fossil fuel demand in Annex I countries as inputs to production; and (b) Annex I economies import relatively more energy-intensive goods (which can be produced less expensively in regions with no mitigation obligations) but (c) overall Annex I demand for goods and services falls. The first two effects are positive for non-Annex I countries, but the third is not. The final result depends on which of these effects is the most important within each region. By allowing Annex I countries to reduce their carbon emissions while consuming more energy than they would in the no-trading case, trading leaves world oil prices higher, and therefore reduces both the positive and negative effects on non-participants.

A. No Trade Scenario

Each region's marginal abatement cost is different. Table 3 gives estimates of the effects of reducing emissions to 1990 levels in 2010 for the No Trade scenario, the carbon reduction required in each region, the marginal costs of abatement, and total costs (which in this case equals total abatement costs). Generally, the model predicts that Japan will have the highest marginal abatement costs, followed by Canada and Australia, but the United States bears the largest total costs because of the large amount of carbon reduction that it must accomplish.

Only Annex I countries are shown in Table 3 because no country outside of Annex I has to undertake emissions reductions in the No Trade case. Non-participating countries can benefit from "leakage," in which carbon-emitting activity that is constrained in the OECD migrates to other countries that are not constrained.[13] In effect, the Annex I countries face an economic penalty for using fossil fuels, while non-Annex I countries face no such penalty (a marginal cost of GHG emissions of zero). Relative to the base case, Annex I fossil fuel-intensive economic activity becomes less profitable and declines, reducing Annex I demand for fossil fuels, putting downward pressure on world fossil fuel prices (especially prices for oil and coal), and shifting some fossil fuel-intensive economic activity to non-Annex I countries where it is relatively more profitable. Although non-Annex I countries could absorb some of the residual supplies in the world energy market, most models show some net decline in world fossil fuel prices. As a result of lower world fossil fuel prices and the reduced economic output in the OECD countries, the energy exporting countries (who face reduced prices for their major exports) also show lower economic output relative to the base case. Those non-Annex I nations that are the OECD's principal trading partners (who face declining markets) could also show lower output relative to the base case.

Relative to the base case, the principal economic beneficiaries in the No Trade case are those countries that use large quantities of fossil fuels and that do not rely extensively on OECD markets. However, the direction and level of economic impact on a given country depends on how much international fossil fuel prices are affected by carbon mitigation. Table 4 demonstrates the sensitivity of economic production in Annex I and non-Annex I countries by region for the No Trade carbon abatement regime under three different scenarios: (1) a base case in which oil prices are unaffected by carbon abatement; (2) a case in which world oil prices fall by 10% relative to their base value as a result of carbon mitigation's negative impact on the world demand for fossil fuels; and (3) a case in which they fall 20% relative to their base value. Table 4 shows that there is relatively little variation in impact on the OECD countries from the differences among oil prices in the three cases. National Gross Domestic

Table 3

Carbon Reduction and Costs Under No Emissions Trading by Region (1992$)

	2010			2020		
	Carbon Reduction (million tons C)	**Marginal Abatement Cost ($/ ton C)**	**Total Abatement Cost ($ billion)**	**Carbon Reduction (million tons C)**	**Marginal Abatement Cost ($/ ton C)**	**Total Abatement Cost ($ billion)**
Region						
United States	462	$139	$27.6	626	$170	$42.8
Japan	95	304	11.8	99	324	13.2
Western Europe	167	154	11.4	319	273	36.0
Canada	51	249	5.2	62	320	7.1
Australia	25	147	1.5	33	169	2.3
Former Soviet Union	0	0	0	144	75	4.7
Eastern Europe	0	0	0	51	223	5.5
Total Reductions	800	—	$57.5	1,334	—	$111.6

The model solves for returning carbon emissions to 1990 levels in the years 2010 and 2020. All reductions are differences in domestic emissions relative to the "base case"; i.e., the level that would have been achieved in the year shown with no abatement. Base case emissions in the year 2010 are below 1990 levels in the Former Soviet Union (FSU) (996 million tons) and Eastern Europe (290 million tons). Base case emissions remain below the 1990 level in the FSU in 2020. Both the FSU and Eastern Europe are treated as though 2010 instead of 1990 were the base year for purposes of emissions reduction requirements and no -10% requirement is imposed. This ensures that there is no difference between aggregate Annex I emissions in the trade and no trade cases (see discussion in the text). No abatement is required from non-Annex I countries.

Source: SGM

Products (GDPs) are lower because of the cost of carbon mitigation to these economies. The offsetting effect of lower world oil prices is relatively modest in these countries because end users only see the higher domestic fuel prices that include the embedded marginal cost of carbon reduction (e.g., world oil price plus a domestic carbon tax). If the world oil price were lowered substantially by carbon mitigation in Annex I countries, however, several of the non-Annex I countries stand to benefit from leakage of energy-intensive economic activity and from lower oil prices. Thus, Korea and India, for example, show higher GDPs as a result of lower oil prices. The effect on China and Mexico would be more modest, as China restricts oil imports and Mexico is an oil exporting country. Because world oil prices are likely to be higher in a regime with carbon reduction and trading than in a regime with carbon reduction and no trading, leakage would be less with trading than without it. Thus, while higher prices would result in lower world carbon emissions and could benefit some non-participants through lower energy prices, they would not benefit other non-participants.

B. Annex I Trading

Trade significantly reduces compliance cost for controlling carbon emissions. Table 5 shows the impact of Annex I trading in the year 2010.[14] The economic gains from trade are substantial (i.e., about $20 billion). The effect on carbon permit prices is substantial as

Table 4

Carbon Control to 1990 Levels with No Carbon Trading: Sensitivity of Economic Activity to the Effects of Carbon Abatement on World Oil Prices

	Percent Change in GDP with Base Case Oil Prices		Percent Change in GDP with Oil Prices 10% Below Base		Percent Change in GDP with Oil Prices 20% Below Base	
Region	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
United States	-0.24%	-0.29%	-0.24%	-0.28%	-0.24%	-0.28%
Japan	-1.12	-1.41	-1.10	-1.36	-1.07	-1.32
Western Europe	-0.80	-1.41	-0.76	-1.33	-0.72	-1.26
Canada	-1.88	-2.89	-1.86	-2.89	-1.84	-2.89
Australia	-0.73	-0.77	-0.73	-0.76	-0.73	-0.76
Former Soviet Union	0.00	-0.33	0.00	-0.33	0.00	-0.33
Eastern Europe	0.00	-0.99	0.00	-1.00	-0.01	-1.00
China	0.00	0.00	0.02	0.02	0.03	0.03
India	0.00	0.00	0.08	0.08	0.17	0.16
South Korea	0.00	0.00	0.12	0.22	0.23	0.43
Mexico	0.00	0.00	0.04	0.09	0.07	0.12
Rest of World	0.00	0.00	0.04	0.07	0.08	0.14

All figures shown in the table are percentage changes in Gross Domestic Product (GDP) relative to a no-control case. In the base case, oil prices are the same as when no carbon abatement is attempted: prices are 10% and 20% lower in the other two cases. Non-Annex I countries have a zero percent change in GDP with Base Case oil prices due to energy prices in SGM being determined exogenously.

Source: SGM

well. For example, the market-clearing price of permits (the price that makes quantity demanded equal to quantity supplied and also equalizes marginal abatement costs among regions) is about $106/ton, compared with marginal abatement costs ranging from $0/ton in the Former Soviet Union to $304/ton in Japan without trade. The United States net permit purchases are 75 million tons of carbon. Thus, it satisfies its 462 million ton obligation in the following manner: 84% from domestic sources (386 million tons) and 16% with purchased permits (75 million tons). The corresponding domestic abatement and purchased permit percentages in Western Europe are 77% and 23% and in Japan, 48% and 52%, respectively.[15] Total costs now not only include the amount spent on domestic emissions control, but also the amount (positive or negative, depending on whether a region is a buyer or seller of permits) spent on purchasing permits as a substitute for domestic emissions control. As explained in Box 1, these costs of abatement plus permit purchases are called mitigation obligation costs.

The gains from trading permits among the regions in this set of scenarios are about $20 billion (1992$) worldwide in the year 2010. This reduction in direct cost is 30% of the cost that would have been incurred by the Annex I countries in the absence of an ability to trade permits internationally. The cost of returning emissions to 1990 levels is met entirely within the Annex I countries in this case; there is no obligation on the part of the rest of the world to reduce GHG emissions.

Table 5

Carbon Reduction and Costs Under Annex I Trading by Region in Year 2010 (1992$)

Region	Domestic Carbon Reduction (million tons C)	Permit Purchases or Sales (million tons C) (negative = sales)	Domestic Total Abatement Cost ($ billion)	Total Direct Mitigation Obligation Cost ($ billion)	Total Direct Mitigation Obligation Cost, No Trade ($ billion)	Gains from Trade ($ billion)
United States	386	75	$18.2	$26.2	$27.6	$1.5
Japan	46	49	2.2	7.4	11.8	4.4
Western Europe	129	38	6.1	10.2	11.4	1.2
Canada	28	23	1.3	3.7	5.2	1.5
Australia	20	5	0.9	1.4	1.5	0.1
Former Soviet Union	162	-162	7.2	-10.0	0	10.0
Eastern Europe	28	-28	1.5	- 1.5	0	1.5
Total	800	—	$37.5	$37.5	$57.5	$20.0

Note: Marginal cost = $106/ton C in all regions

The model solves for a return to 1990 emissions with competitive permit supply. All values in the table except marginal abatement cost are relative to a business-as-usual no control case. Total direct mitigation cost equals domestic abatement cost plus cost of permits purchased, minus revenues from permits sold. The analysis assumes no restrictions on permit supply or demand; see text for a discussion of such restrictions. Both the FSU and Eastern Europe are treated as though 2010 instead of 1990 were the base year for purposes of emissions reduction requirements, so there are no "base mitigation credits" available, and only the distribution of emissions reduction and total cost, and not the total amount of emissions reduction, is influenced by the availability of trading. Note: Columns may not add to total due to rounding errors.

Source: SGM

Although not shown in Table 5, the U.S. mitigation cost for a reduction in emissions to 10% below the 1990 level is $52.4 billion. The gains from trade for the United States are $2.9 billion. The corresponding world gains from trade are $43.4 billion, illustrating the increased importance of trade for meeting more ambitious targets.

C. World Trading

The gains from trade are potentially much greater if the group of nations undertaking reductions could be expanded to include the non-Annex I countries as well as the Annex I countries. Although under the Kyoto Protocol non-Annex I countries currently have no obligation to control GHG emissions, this hypothetical case treats non-Annex I countries as if they agreed to create permits equal to their annual base case emissions and allowed these permits to be traded internationally.[16] (See Table 2 for base case emissions. Permits would be needed domestically to accommodate economic growth). The non-Annex I countries are expected to grow quite rapidly economically and are expected to burn a considerable amount of fossil fuel (especially coal in China and India) with relatively inefficient technology. Table 6 shows low marginal carbon control costs ($24/ton, in contrast to $106/ton with Annex I trading or $139/ton to $304/ton with no trading). The decline in overall cost is the result of engaging the world economy in the search for emissions abatement opportunities. Despite the fact that non-Annex I nations have no emissions mitigation obligation, in this case they can search for low-cost abatement opportunities, create an excess in emissions permits relative to their emissions, and sell the excess permits at the world price. This reduces the pressure to prematurely retire existing capital stock in the developed world, and allows a greater share of emissions abatement to come from altering the character of new investments at the lowest marginal cost.

In Table 6, the broader trading possibilities mean that the marginal abatement cost (and the permit price) is much lower than it otherwise would be with more limited trading opportunities ($24 with world trading vs. $106 with Annex I trading). A larger number of regions now participate in GHG mitigation. The overall gains from trade are $49 billion with world trading, an improvement of $29 billion relative to Annex I trading. The broader trading regime takes advantage of the more abundant

Table 6

Carbon Reduction and Cost Under World Trading by Region in the Year 2010 (1992$)

Region	Domestic Carbon Reduction (million tons C)	Permit Purchases or Sales (million tons C) (negative = sales)	Total Domestic Abatement Cost ($ billion)	Total Net Mitigation Cost ($ billion)	Total Net Mitigation Cost, No Trade ($ billion)	Gains from Trade ($ billion)
United States	110	352	$1.4	$10.0	$27.6	$17.6
Japan	13	82	0.2	2.2	11.8	9.7
Western Europe	38	129	0.4	3.6	11.4	7.8
Canada	8	43	0.1	1.1	5.2	4.1
Australia	6	19	0.1	0.5	1.5	1.0
Former Soviet Union	53	-53	0.6	-0.7	0	0.7
Eastern Europe	7	-7	0.1	-0.1	0	0.1
China	289	-291	3.1	-4.0	0	4.0
India	191	-191	1.7	-3.0	0	3.0
South Korea	4	-4	0.1	-0.0	0	0.1
Mexico	22	-22	0.2	-0.3	0	0.3
Rest of World	57	-58	0.7	-0.7	0	0.7
Total Reductions	800	—	$8.6	$8.6	$57.5	$49.0

Note: Marginal Abatement Cost =$24/ton C in all regions

Table represents a return to 1990 emissions and competitive carbon permit supply. All figures in the table except marginal abatement cost are relative to a business-as-usual no control case. Details may not add to totals due to rounding error.

Source: SGM

abatement opportunities and greater disparity of marginal abatement costs among the Annex I and non-Annex I countries to achieve greater cost savings. The United States, for example, satisfies 24% of its obligation of 462 million tons from domestic sources (110 million tons) and 76% of its obligation with purchased permits (352 million tons). In Western Europe, the domestic abatement and purchased permit percentages are 23% and 77%, respectively; in Japan, 14% and 86%. The permit buyers like the United States and other OECD countries "win" because they achieve their emissions obligations at much lower total direct cost than if they had to achieve all of their abatement domestically, or even if they could only trade emissions permits with other Annex I countries. The Annex I countries benefit because, as a group, the direct cost of fulfilling their carbon obligations is reduced by $41 billion relative to the No Trade case. The Former Soviet Union and Eastern Europe would still benefit from world trading; however, they are not as well off as they would be under Annex I trading, when they were the only net suppliers of permits. Their gains from trade are much smaller in Table 6 ($0.7 billion and $0.1 billion, respectively) than in Table 5 ($10 billion and $1.5 billion). In effect, they lose out to less expensive competition. Non-Annex I regions (which include China and the countries listed below it on Table 6) on balance benefit relative to the No Trade case from undertaking emissions reductions and then selling their permits to the Annex I countries (total sales of $13.8 billion, minus mitigation costs of $5.7 billion, for net gain of about $8.1 billion).

These calculations estimate the potential value of extending participation to the entire world. Real world gains from trade will likely be smaller. Costs of monitoring and compliance will certainly increase as trade expands from the narrow domain of Annex I nations with extensive monitoring and verification capabilities to encompass the entire world. If, as in the case of the Kyoto Protocol, non-Annex I nations have no formal emissions limitation obligation, mechanisms such as the CDM will have to be used to approximate the case modeled here. With a second-best policy instrument such as the CDM, either the supply of credits and/or the actual environmental benefit (i.e., actual net national emissions abatement, as opposed to emissions abatement that may be achieved for particular projects) will be smaller than what is estimated for a perfect world.

IV. Comparison Among Models of Carbon Trading

Several modeling groups have undertaken empirical analyses to estimate the impact of carbon trading on emissions and costs of GHG abatement, and all have projected substantial economic benefits. The findings described in Section III are not unique to the SGM. While there are quantitative differences among models due to reasonable differences in assumptions and differences in the details of model structure, there is very broad agreement in recent modeling analyses conducted around the world that emissions trading could substantially reduce the costs of accomplishing any given level of carbon emissions reduction. Many of these analyses were either performed in anticipation of the international agreement reached in Kyoto, Japan in 1997 or they were performed after the fact in an attempt to understand the implications of that agreement. If it enters into force, the agreement would require specific cuts in emissions of six GHGs. Annex I signatories agreed to adopt national policies to return anthropogenic emissions of GHGs to levels averaging approximately 5.2% below 1990 levels during the years 2008 to 2012, with average OECD emissions reduced approximately 7%. Thus, the cuts in emissions and the trading benefits that are shown in this literature are somewhat different than those analyzed in Section III. This section examines the benefits of emissions trading using recent analyses of the Kyoto Protocol as examples. The summaries of the analyses shown in this section are not intended to re-examine the costs or benefits of the Kyoto Protocol, but to examine and evaluate those factors that would cause the gains from trade to be larger or smaller under any emissions trading scheme for real-world trading.

Some important complications arise in analyzing the real Kyoto Protocol that did not arise in analyzing the hypothetical trading regime of Section III. The most important of these arises as a consequence of the allocation of emissions to the FSU and Eastern Europe. In 2010, allowed emissions in these two regions may be greater than reference case emissions. Emissions permits are distributed based on 1990 emissions. Therefore, total Annex I emissions abatement without trade could be greater than the abatement with trade in the first compliance period (2008-2012). In the results reported in this section, under the Kyoto Protocol, cost reductions occur for two reasons: (1) "where" flexibility (as in the hypothetical protocol in Section III), and (2) a reduction in the required net Annex I abatement in the first compliance period. Results reported below do not distinguish between these two causes of gains to trade.

In the long term, of course, cumulative emissions would be the same with and without trading. In a "no trade" case, the excess of allowable emissions over reference emissions in the Former Soviet Union's first budget period would be banked and utilized in subsequent budget periods. Thus, a trading case would have lower emissions in the future relative to a "no trade" case. From the perspective of the environment, the difference between the two profiles is that the "no trade" case has a slightly lower near-term GHG concentration and a slightly higher long-term GHG concentration.

A. Models Used

The comparative analyses in this section uses the results from eight models. The models include the Pacific Northwest National Laboratory's SGM;[17] the Massachusetts Institute of Technology's Emissions Prediction and Policy Assessment (EPPA) Model;[18] the MERGE model of the Electric Power Research Institute (EPRI);[19] the National Energy Modeling System (NEMS) of the U.S. Energy Information Administration (which looked only at U.S. domestic costs);[20] Charles River Associates' International Impact Assessment Model (IIAM);[21] the OECD GREEN model from the OECD Development Center in Paris;[22] the Global Trade and Environment Model (GTEM) of the ABARE modeling group in Australia;[23] and the G-Cubed model by McKibbin, Shackelton and Wilcoxen.[24] Descriptions of the models are presented in Box 2.

There are many similarities between the models used in this comparison. Except for the NEMS analysis, all of the projections in this section came from multiregional economic models that feature international trade in goods and services. These projections allow for examination of the effects of actions taken in one region on the economies in other regions. These models are hybrid computer models of the economy and energy sector that belong to a class of models known as computable general equilibrium models.[25]

While the analyses reported here have many quantitative differences, they confirm the main qualitative findings of the previous section of this report. The main apparent differences occur here

Box 2

Some Key Characteristics of Models Compared

	Models							
Feature	NEMS	EPPA	MERGE	SGM	OECD-GREEN	G-Cubed	IIAM	GTEM
Production	Energy Technology Vintage Detail	Energy Technology Vintage Detail	Aggregate Production/ Cost Functions	Energy Technology Vintage Detail	Energy Technology Vintage Detail	Energy Technology General Production function	Energy Technology General Production function	Energy Technology General Production function
Number of Sectors	14	10	11	9	4	12	6	16
Number of Fuels	8	7	8	7	8	5	4	4
Regions	1	12	9	12	12	8	5	9
Foresight	No	None	Perfect	Limited	None	Limited	Perfect	Limited
International Capital Flows and Financial Effects	No	No	No	No	No	Yes	No	No

On the supply side, all of the models employ a "bottom-up" representation of the energy system. The models include detailed technical descriptions of energy technologies (e.g., availability dates, heat rates, carbon coefficients). The suite of energy technologies includes both existing sources and new options that are likely to become available. Cost and performance constraints vary by region and also improve with time (assumed technological change). For the balance of the economy, a more "top-down" perspective is taken, with macroeconomic production functions that provide for substitution between capital, labor, and energy inputs. All of the models except for NEMS, which solves for each year, solve for every 5 years. Over these longer time steps, short-term macroeconomic adjustment effects such as business cycles, inflation, and unemployment are expected to be less important than the final configuration of the economy after the 5 years have passed. Full employment is assumed in the other models.

There are also significant structural differences between the models that account for some of the differences in estimated costs of particular policies. Some of these differences include:

- the resources and technologies available and the marginal costs of those resources and technologies;
- the sensitivity of energy demand to changes in prices of fuels;
- the degree of foresight that decision-makers are assumed to have (in particular, their ability to react to expected price changes);
- the ability of regional economies to shift into industries of greater or less energy intensity as energy prices change;
- the degree and speed of substitution between factors of production (i.e., labor, capital, materials, energy) when relative prices change;
- the representation of technology, especially energy equipment.

For example, NEMS, EPPA, MERGE, SGM, and OECD GREEN all have detailed representations of energy technology wherein energy equipment is tracked by vintage and only retired as the economics of operating it dictate. IIAM and GTEM have more general production functions. The models vary considerably in the number of industries (4 industries in OECD GREEN, 16 in GTEM) and the number of fuels. Population dynamics vary in complexity from OECD GREEN, which simply uses United Nations demographic projections, to GTEM, which has a highly detailed demographic structure that responds to economic incentives. Foresight ranges from perfect foresight (knowledge of future prices and available technologies) (MERGE) to contemporaneous and backward-looking only (GREEN, EPPA). In general, those models with a high degree of technological detail and foresight can adjust more quickly to carbon price increases, as can those that are relatively optimistic about technological change in general.

The various models also differ from each other in how they define regions and in the base cases used for the analysis. For example, the EPPA model breaks the OECD into the U.S., Japan, the European Economic Community, and "other" OECD regions (which include Canada, Australia, and New Zealand) while SGM shows Canada, Australia, and Western Europe separately, but not the European Economic Community. NEMS has only one economic region (the U.S.), while EPPA, OECD GREEN and SGM have 12 regions, G-Cubed has 8, GTEM has 19, and IIAM uses 5 geopolitical regions which it disaggregates into 87 individual countries.

because of the various baselines assumed by the different modelers. For example, the modelers disagree on such assumptions as the elasticity (i.e., responsiveness) of energy demand and supply technologies to fossil fuel prices and future economic growth rates in specific regions (e.g., whether Eastern Europe needs to undertake emissions reductions before 2010 due to economic growth). The EPPA modelers, for example, appear to be sanguine about Eastern Europe's future economic growth prospects, so EPPA projects that reductions would be required in Eastern Europe in 2010, while the other models do not.

While different modelers have assumed slightly different levels of economic activity, in general most of the analyses are close enough to provide a useful source of comparison. While the results differ in detail, the main empirical findings in Section III hold up. In addition, the analyses indicate that, under the Trading scenario relative to the No Trade scenario:

- Permit buyers benefit from lower compliance costs and permit sellers benefit from being paid more for permits than their additional mitigation costs. If trading is allowed, potential permit sellers will be better off if they trade than if they do not.
- Oil exporters benefit from trade in permits because oil prices are generally higher (i.e., are depressed less) than if each nation independently met its own mitigation obligations. This occurs both because trade shifts emissions abatement away from oil and toward coal, and because allowing trade raises Annex I total emissions in the first budget period.[26]
- Results for other non-participants are mixed. Lower costs for Annex I nations mean that Annex I parties are richer than they would be without trade, and their increased income enhances the general demand for imports of goods and services from non-participants. On the other hand, individual countries may be more affected by specific changes in relative competitiveness in specific industries and by individual fuel price changes.

B. Gains from Trade by Buyers and Sellers of Permits

Because the underlying assumptions and model structures differ, so do the marginal abatement costs, net mitigation costs (i.e., GDP costs plus purchases of permits minus permit sales) and effects on GDP. However, all of the models show substantial savings from trade. Marginal abatement costs are generally about 18% to 50% lower than without trade, net costs 15% to 75% lower, and GDP losses 0% to 2.2% lower.

Table 7

Costs in the United States of Achieving Carbon Emissions 7% Below 1990 Levels (1992$)

		No Trade			Annex I Trading		
Model and Year		Marginal Abatement Cost ($/ ton)	Net Abatement Cost ($ billion)	Percent Change in GDP	Marginal Abatement Cost ($/ ton)	Net Mitigation Cost ($ billion)	Percent Change in GDP
EPPA	2010	243	NA	-1.5	160	NA	-1.5
	2020	134	NA	-1.5	109	NA	-1.5
MERGE	2010	256	67	-1.0	104	16	-0.5
	2020	229	74	-1.0	172	67	-1.0
IIAM	2010	269	75	-2.1	100	42	-1.3
	2020	288	101	-2.4	160	75	-1.7
NEMS	2010	317	86	-4.2	149	57	-2.0
	2020	278	94	-0.8	129	60	-0.6
SGM	2010	201	59	-0.4	91	50	-0.2
	2020	261	100	-0.4	129	93	-0.2

Net Abatement Cost, Net Mitigation Cost, and GDP are changes relative to a no control case. Net Mitigation Cost is the loss of GDP, plus the cost of permits purchased, minus the value of permits sold.

Source: EIA

The first set of results, shown in Table 7, was provided by the U.S. Energy Information Administration (EIA).[27] This analysis ignores effects on countries other than the United States, but it is useful in that it compares the results for six domestic U.S. analyses for the years 2010 and 2020.

Table 8 shows the effect of Annex I emissions trading on marginal abatement cost of reducing carbon emissions to 5.2% below 1990 levels for selected world regions in five different models.[28] The marginal cost varies considerably among the models and among the regions, with Japan generally the highest, followed by Western Europe and then the United States.[29] Table 9 shows the corresponding impact on each region's domestic carbon emissions reductions and Table 10 shows the corresponding impact on GDP for three out of the five models (EPPA and GREEN did not report GDP effects). Generally, the models show that the permit-buying regions (USA, Japan, and Western Europe) benefit from facing lower marginal abatement costs, lower domestic carbon emissions reductions, and smaller negative impacts on gross domestic output.[30] Again the details of the analyses vary because of differences in model structure and base case assumptions; however, the impact of trading remains significant. Both models that report GDP results for the Former Soviet Union also show that the impact of emissions reduction in the Former Soviet Union is to reduce domestic product in this permit-exporting region. However, the Former Soviet Union reaps substantial gains from trade, selling millions of tons of permits whose aggregate value on the open market is roughly twice what it costs the Former Soviet Union to reduce carbon emissions, which should have a positive effect on national income even if domestic production declines.[31]

Table 8

Comparison of the Effect of Annex I Emissions Trading on Marginal Abatement Cost Required to Reduce Annex I Carbon Emissions 5.2% Below 1990 Level in 2010 (1992$/ton C)

	SGM		EPPA		GTEM		G-Cubed		OECD GREEN	
Region	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading
United States	$168	$73	$186	$162	$346	$114	$ 59	$34	$145	$65
Japan	458	73	584	162	693	114	234	34	75	65
Western Europe	144	73	273	162	714	114	155	34	192	65
Former Soviet Union	0	73	0	162	0	114	0	34	13	65

The experiments reported here differ from those reported in Table 7 (taken from EIA, 1998) due to differences in original sources and reference cases.

Table 9

Comparison of the Effect of Annex I Emissions Trading on Domestic Carbon Reduction (% Change in Carbon Emissions Relative to No Control)

	SGM		EPPA		GTEM		G-Cubed		OECD GREEN	
Region	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading
United States	-29%	-18%	-31%	-25%	-28%	-10%	-29%	-18%	-29%	-21%
Japan	-33%	-8%	-34%	-12%	-22%	-6%	-29%	-5%	-24%	-13%
Western Europe	-15%	-9%	-29%	-19%	-25%	-6%	-25%	-6%	-27%	-14%
Former Soviet Union	0%	-16%	0%	-31%	+2%	-41%	NA	NA	-7%	-34%

The model solves for Annex I carbon emissions 5.2% below 1990 level in 2010.

Table 10

Effect of Annex I Emissions Trading on Changes in Real GDP Required to Reduce Annex I Carbon Emissions 5.2% Below 1990 Level (% of GDP Relative to No Control)

	SGM		GTEM		G-Cubed	
Region	No Trade	Annex I Trading	No Trade	Annex I Trading	No Trade	Annex I Trading
United States	-0.4%	-0.2%	-2.0%	-0.4%	+0.1%	-0.1%
Japan	-2.2%	-0.3%	-0.7%	0.0%	-1.6%	-0.5%
Western Europe	-0.8%	-0.4%	-0.9%	-0.1%	-1.5%	-0.5%
Former Soviet Union	0.0%	-0.5%	0.0%	-1.9%	NA	NA

The experiments reported here differ from those reported in Table 7 (taken from EIA, 1998) due to differences in original sources and reference cases.

C. Effects on Non-Participants and Leakage

Emissions trading could also significantly affect the prices of fossil fuels and trade in both these fuels and in other goods, which in turn affects the economies of non-participants. Key effects on non-participants have been examined in many of the models reporting international results. One significant consequence of carbon control is that carbon-intensive economic activity migrates from Annex I countries (where it is penalized) to non-Annex I countries (where it may actually become more profitable). For example, the EPPA model reports that without trade in permits, this "leakage" of carbon-intensive economic activity from meeting the Kyoto requirements increases non-Annex I emissions by about 62 million tons, an offset of about 3%.[32] Without trade in permits in the EPPA model, domestic use of coal plummets by about 50% to 65% in the Kyoto-constrained regions.[33] The EPPA model also reports a worldwide fall in oil prices (by 10%) and natural gas prices (by 17%) which negatively affects the revenues of the regions that export these commodities.[34] These fuels are traded extensively internationally. Use of gas and oil by the Annex I countries falls by between 3% and 25%, depending on the region, but other regions that are not constrained by the Kyoto Protocol take up most of this consumption. Thus, the main effect on energy-exporting countries is through the decline in energy prices. Output of energy-intensive goods declines in the Kyoto-constrained regions (-$159 billion in 1992 dollars), but expands significantly in the rest of the world (+$116 billion in 1992 dollars). The analysis does not include effects on overall GDP or other broader economic measurements.

The EPPA model also provides some additional information on the effects of carbon permit trading on carbon leakage and non-participant economies.[35] With Annex I trading, the domestic price of coal in non-participant nations falls relative to the base case in those regions where it is used, but the decrease is only about half as large as it is under the No Trade scenario. In contrast to the No Trade case, the international prices of oil and natural gas are virtually unaffected under Annex I trading relative to the base case. They decrease by less than 1% and 4% respectively, and use of these fuels in the Annex I countries falls by less than 1%. Thus, energy-exporting countries see a much smaller decline in their revenues than when trade is not permitted. With trading, there is also a much smaller decline in the production of energy-intensive goods in the Annex I countries than when trade in permits is prohibited (only -$4 billion vs. -$159 billion in 1992 dollars). The rest of the world (mainly China and India) then shows a decline in the production of energy-intensive goods (-$12 billion in 1992 dollars) rather than the major increase shown in the No Trade case. Again, however, the overall effect cannot be easily characterized.

An analysis of carbon leakage from the Annex I to the non-Annex I world by Charles River Associates (CRA) in January 1997[36] did not deal with trade of emissions permits, but did point out that without trade, the effects on the non-Annex I world could be significant even though they were not involved in controlling carbon emissions. Generally speaking, non-Annex I countries are affected in one of three ways in the CRA's analysis:

- Trading affects the prices of fossil fuels. In the No Trade case, international oil prices fall substantially relative to the base case. This generally harms the economies of oil exporting countries (e.g., many of the OPEC members). The shift from No Trade to Trade moderates the negative impact on oil prices and oil exporting countries. This occurs both because: (1) emissions trading shifts emissions abatement away from oil and toward coal; and (2) allowing emissions trading raises the Annex I total emissions in the first budget period. Energy-importing non-Annex I countries generally benefit from lower fossil fuel prices, so they would be harmed by emissions trading relative to the No Trade case.

- Non-Annex I countries that are energy-intensive (especially if they are also energy importers) generally benefit from the lower fossil fuel prices and from the increase in demand for energy-intensive goods by Annex I nations.

- Non-Annex I countries that trade mainly with other non-Annex I countries generally would see expanding markets for their products, but would generally see shrinking markets among participant countries. Trade in permits tends to moderate this effect.

Thus, if Annex I permit trading is not allowed, non-Annex I energy-intensive, energy-importing countries that traded mostly with non-Annex I countries would benefit financially from carbon mitigation. Those countries that benefit from permit trading tend to have the opposite characteristics. CRA's extensive analysis of non-Annex I countries in the year 2030 shows that a comparative handful of non-Annex I countries benefit from non-participation in the No Trade case, ranging from Jamaica with 1.5% gain in year 2030 GDP, to Ghana at about 0.1% gain. Losses range from small (Poland, -0.1%) to significant (United Arab Emirates, -3.3%). Because carbon trading reduces the energy price effects of carbon control, trade would reduce both gains and losses, but would not necessarily change losers to winners.

Models that include a more sophisticated treatment of international financial flows, such as G-Cubed, show additional effects. In such models, carbon mitigation in the No Trade case has a negative impact on rates of return on capital in the Annex I countries relative to the non-Annex I countries. This causes capital outflows to the non-Annex I world. This effect in turn leads to exchange rate appreciation of these countries' currencies relative to the dollar, yen, and other Annex I country currencies. This strongly limits the non-Annex I countries' advantage in exports of carbon-intensive goods. However, the exchange rate appreciation has two other beneficial effects that are not reflected in their GDP on the inhabitants of the non-Annex I countries. First, exchange rate appreciation means that non-Annex I dollar-denominated international debt is now less expensive, improving their net international investment position. Second, their imports of goods and services from the Annex I countries are also less expensive. Both effects increase domestic wealth in the non-OECD countries. Trade in permits moderates, but does not eliminate, these effects.[37]

D. The Initial Allocation of Permits

In several of the models, the initial allocation of emissions permits under the Kyoto Protocol means that the countries encompassing Eastern Europe and the Former Soviet Union will have emissions which are below their emissions limitation in 2010 without any explicit abatement efforts. This is due both to their current and expected poor economic performance and to economic restructuring away from energy-intensive industry. As a consequence, these regions are not expected to regain their 1990 emissions levels by 2010. Poor economic performance and economic restructuring are potentially important sources of emissions abatement within Annex I countries.

The resulting emissions allowances, which could be sold on the open market, are a potentially important export for the Former Soviet Union and Eastern Europe. But, even if the initial allocation of permits limited the Former Soviet Union to the level of its anticipated reference case, the Former Soviet Union's gains from trade would still be $10 billion in the year 2010 as shown in Table 5.[38]

Concern that emissions trading under the Kyoto Protocol would lead to higher Annex I emissions in the first budget period than "no trade" has led to the view in some quarters that permits granted to the Former Soviet Union and Eastern Europe should not be tradable. This would prevent environmental benefits from declining under permit trading relative to the no-trade case. The problem with this argument is that it is static. It presumes that there is only one budget period, the period 2008-2012.

On the other hand, if permits could be applied to multiple budget periods and the Former Soviet Union and Eastern Europe were not allowed to trade, they could "bank" excess permits from the period 2008-2012, then use them in subsequent periods when their national emissions exceeded the quantified emissions limitation. These parties' emissions would therefore simply be moved into the future. Over time, cumulative Annex I emissions would therefore be the same whether or not the Former Soviet Union and Eastern Europe were allowed to trade. And to the extent that there is any difference to the environment, the long-term, year 2050 concentration would be somewhat lower if emissions are released earlier in the century rather than later, because the natural removal processes will have had longer to work. The carbon cycle would have a bit longer in that case to remove carbon from the atmosphere.[39]

E. Other Key Sensitivities

Estimation of the gains from trade discussed in this section is sensitive to a number of key assumptions. These include the effects of non-CO_2 trace gases and carbon sinks on compliance costs.

Non-CO_2 Trace Gases. Non-CO_2 GHGs include methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexaflouride (SF_6). Emissions of all non-CO_2 trace gases are projected to grow substantially unless they are controlled. Multi-gas control (of CO_2 and non-CO_2 trace gases) has been explicitly examined in both the SGM and EPPA models. Edmonds et al. 1998 (see endnote 8) looked at three sensitivity cases to bound the effects of non-CO_2 trace gases on direct costs:

- Costs of controlling non-CO_2 trace gases are proportional to the costs of controlling CO_2.
- Non-CO_2 trace gases can be controlled at zero marginal cost, so control of all GHGs costs only as much as controlling CO_2 alone. This places a lower bound on the cost of multiple-gas control.
- Control of non-CO_2 trace gases has an infinite marginal cost, so all commitments must be met from CO_2 alone. The effective CO_2 control target becomes more stringent and places an upper bound on the cost of multiple-gas control.

Table 11

Sensitivities of Total Cost of Control for Non-CO_2 Trace Gases Under the Kyoto Protocol with No Permit Trading (1992$ billion)

	SGM (Edmonds et al. 1998)			EPPA (Reilly et al. 1999)[a]		
Region	**Infinite Marginal Cost**	**Proportional Cost**	**$0 Cost**	**Infinite Marginal Cost (Multi-gas Target, CO_2 Control)**	**Multi-gas Target and Control**	**CO_2 Target and Control Only**
United States	$79	$53	$25	$58	$35	$48
Canada plus Australia	22	15	4	23	10	20
Japan	37	31	17	54	39	43
Western Europe	14	11	1	56	30	38
Eastern Europe	0	0	0	15	12	11
Total	$152	$111	$47	$206	$127	$160

[a]Includes contributions of terrestrial carbon sinks.

Costs shown are total direct costs for control of Annex I GHG emissions to about 5.2% below the 1990 level. The column titles for SGM refer to the marginal abatement costs for non-CO_2 trace gases (e.g., the marginal cost of control is infinite for these gases). EPPA column titles are self-explanatory. There is no case in the EPPA analysis for which marginal cost of controlling non-CO_2 trace gases is zero. Details may not sum to totals due to independent rounding.

The EPPA analysis looked at the infinite cost case, but also explicitly examined control of non-CO_2 trace gases using a marginal cost relationship for each gas in each region. Table 11 reports some of these cost sensitivities. If the marginal costs of control for non-CO_2 trace gases are less than those for CO_2, meeting the requirements of the Kyoto Protocol for non-CO_2 trace gases would be less expensive without trade, and trading less attractive for these gases than for CO_2. No explicit analysis was found of the cost effects of trading permits for emissions of these gases.[40]

It is important to note that the inclusion of non-CO_2 trace gases brings with it additional obligations to reduce emissions, not simply low-cost alternatives to CO_2 control (for example, Reilly et al. (1999) show total required emissions reductions of 650 million tons carbon equivalent with all gases, of which CO_2 comprises 571 million tons). Even so, the Reilly et al. (1999) analysis in Table 11 shows that fully accounting for multiple gases' sources and sinks appears to reduce the overall costs of compliance.[41] The Edmonds et al. (1998) SGM analysis shown in the table does not allow for sinks, which they separately calculate would reduce the independent marginal cost of compliance in the U.S. from $168 to under $120 per ton; it equates the cost of controlling non-CO_2 gases to the cost of controlling only CO_2. Therefore, the SGM appears to show that controlling all gases might be more expensive than controlling CO_2 alone, whereas this might not be the case.

Sinks. Atmospheric GHG concentrations change not only because of emissions due to fossil fuels but also because of changes in terrestrial sources and sinks from changes in land use or agriculture and forestry practices. The Kyoto Protocol provides credit for new "direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990"—that is, terrestrial carbon sinks established after 1990 (Article 3.3). Sequestration in soils and other reservoirs is not yet considered. Strict interpretation of Article 3.3 leaves little room for counting sinks toward emissions mitigation in Annex I nations, with the exception of Australia, which has net land-use emissions in 1990. A strict interpretation of Article 3.3 removes an important potential source of net GHG emissions from the accounts. A full accounting of all net emissions from land use changes could have a significant impact on both marginal and total costs in those cases where a country has significant terrestrial capacity available. In the case of Canada, for example, full allowance for terrestrial carbon sinks could provide a credit equivalent to 80 million tons of carbon emissions, enough to more than satisfy Canada's Kyoto obligations.[42] In the case of the Former Soviet Union and Eastern Europe, sinks offer up to 213 million tons of additional potential baseline credits that could be sold. Overall, Edmonds et al. conclude that full allowance for terrestrial carbon sinks could reduce the Annex I joint trading permit price from $73 to $23 for meeting the goal of emissions 5.2% below 1990 levels.[43] Entering their emissions estimates into the MIT Integrated Global Systems Model (IGSM), which takes account of climate and ecosystem effects as well as natural sources and sinks, Reilly et al. conclude that achieving the same reduction in warming in the year 2100 by control of only fossil fuel-based CO_2 costs 60% more than if other GHGs and terrestrial sinks are considered.[44] The impacts of credits and sinks presumably would be larger still if credit could be taken for non-Annex I carbon sinks.

V. Some Institutional Issues in Carbon Trading

Numerous issues concerning carbon trading regimes have yet to be worked out, but could significantly affect the various parties involved in trading. These issues include:

- whether countries' control regimes will be compatible with trading;
- the effect of restrictions on permit availability or demand;
- impacts of international transfer payments;
- measurement and reporting of emissions, sinks, and costs; and
- accountability and enforceability.

Many of these issues are examined in much greater depth in an upcoming Pew Center paper on institutional issues and trading. They are of concern here because of their impacts on the effectiveness and cost of trading and on the volume of permits traded.

A key implication of this discussion of institutional issues is:

The actual cost savings from trade in emissions will likely be less than the theoretical savings shown in most analyses performed with integrated assessment models because these models do not include the various measurement, verification, trading, and enforcement costs that would be characteristic of any real trading system. On the other hand, the gains from trade could be greater than the models predict since the models may not anticipate all the control options trade would encourage.

A. Compatibility of Control Regimes with Trading

Just because governments have rights that can be traded among themselves does not mean that actual control will take place via tradable allowances allocated to individual carbon emitters such as power plants or companies that supply fossil fuels. The United Nations Conference on Trade and Development's (UNCTAD's) Greenhouse Gas Emissions Trading Project determined as one of its three basic assumptions that any global GHG trading system would leave each country free to choose its own domestic policy mix for controlling GHG emissions.[45] Domestic controls could take one of three forms: (1) taxes on GHGs, carbon, energy, fossil fuels or fossil-energy-related activities (either supply or consumption of fuels); (2) command-and-control regulations that directly limit emissions or prescribe certain technologies or activities (e.g., regulating automobile fuel efficiency); or (3) allocating emissions allowances that can then be traded among emitting entities. Hahn and Stavins have shown the importance of compatibility between domestic and international policy instruments in a recent paper.[46] They show that the full gains to trade cannot be realized unless all of the parties engaged in international trade also employ a domestic marketable tradable permit system. When parties employ taxes or regulatory instruments as their domestic emissions control mechanism, international permit trade is less efficient in reducing aggregate costs than it is when all parties employ domestic marketable tradable emissions control mechanisms.

B. Restrictions on Permit Availability and Permit Demand

Restrictions on permit availability or demand due to regulation or monopolistic market behavior could reduce the gains from trade that are actually achieved. All of the analysis thus far has assumed that the market for emissions permits functions smoothly and without restrictions. The Ellerman et al. (1998) analysis notes that if usable world permit supply is low relative to its potential, then the world permit price required to meet Kyoto obligations rises from $31/ton of carbon (1992 dollars) with unconstrained world trading, to $55/ton with 50% availability and to $230/ton with only 5% availability.[47] Edmonds et al. (1998) examined this issue in the context of Annex I trading only and showed that the permit price rises from $73/ton with unconstrained Annex I trading to $113/ton if no permits were available from the FSU and Eastern Europe.[48] (For example, these countries might "bank" their permits for their own future use). Thus, the ability to make permits available for trade is critical to the success of any trading program. Some regions' governments could utilize their position to gain monopoly power in the permit marketplace to limit the supply of permits and increase their price. In the context of Annex I trading, a monopolist (for illustration's sake, the FSU) could charge about $105-$137/ton for permits.[49] In the context of world trading, an efficient monopolist could charge about $80/ton.[50]

It is also possible that the kinds of sources that actually participate in emissions reduction and trading could be limited for reasons of administrative convenience, political expediency or limited technological options, thereby reducing the potential supply of permits. The allocation of permits is extremely important in determining the cost of monitoring and compliance within the system. It is one thing to allocate permits "upstream"—that is, where carbon enters the economy at the point of extraction or import/export—and another to try to allocate permits at the point of combustion. The former has far fewer parties involved in a program of universal coverage than the latter. Systems that try to balance the emissions abatement budget on the backs of a subset of downstream economic activities can be very expensive. To illustrate the cost of narrowly focusing the emissions reduction burden, Edmonds et al. showed that electric utilities' marginal cost of emissions mitigation in the United States would rise to more than 250% of the No Trade case as the utility mitigation burden was arbitrarily raised to 70% of the total.[51] Although trading would help reduce the impact of such exemptions and technology limitations, the widest possible pool of potential permit suppliers would clearly be advantageous for reducing costs.

Costs would also rise if there were rules that imposed significant restrictions on the extent to which imported permits may be used to satisfy mitigation obligations, thereby limiting demand for permits, reducing their market price, and increasing costs of compliance.[52] As the allowed permit import percentage falls from unlimited to a limit of 25%, Ellerman et al. (1998) calculated that the price of permits in the world trading case (where the permit buyers satisfied their commitments 71% with imports) would fall from \$31 to \$4, while total world cost would rise from \$14 billion to \$70 billion.[53]

C. International Transfer Payments

While the pattern of trade in emissions depends on the initial allocation of permits, it is likely that there could be substantial transfers of wealth between some countries and regions associated with the trade in permits. The initial allocation and the rules of trade will decide not only the number of permits traded but also whether a given country or region is a net seller or net purchaser of permits.[54] For example, under Kyoto rules, neither the countries with economies in transition (the Former Soviet Union and Eastern Europe, who are predicted by many models to be emitting less carbon in the year 2010 than in 1990) nor the non-Annex I countries (who have no obligation under Kyoto) would have to reduce carbon emissions in the year 2010. They might not have permits to sell, and they might not be willing to sell in any case. If trade in carbon were confined only to the Annex I countries (i.e., excluding economies in transition and the non-Annex I countries), most modeling groups show that the United States would be a net seller of permits to Japan and Europe. However, if the economies in transition and (especially) the non-Annex I countries were allowed to trade carbon permits, the United States would be a net purchaser. One of the consequences, for example, of the United States' desire to purchase large numbers of permits from Eastern Europe and the FSU would be substantial capital flows into those countries from the United States. On the one hand, these flows would provide hard currency reserves necessary to rebuild these economies. On the other hand, the flows probably would strengthen the local currency against the dollar. This would help solidify the local standard of living and make importing easier, but would also make their exports less competitive.

These potential large-scale financial impacts of changes in trade are not treated well in many of the current economic/emissions models. The financial flows involved could be substantial and could require careful handling, particularly for economies such as the FSU, where their magnitude is large compared to other financial flows. For example, to return the United States to 1990 emissions levels, Tables 5 and 6 imply the United States would send about $8-$8.5 billion dollars abroad in the year 2010 to pay for emissions permits. While small relative to the total U.S. trade and capital accounts, these amounts still represent a net change in the trade deficit roughly equivalent to a purchase of 1 million barrels a day of crude oil at the price of $20 per barrel. On the selling side, under Annex I trading, the FSU would receive $17 billion in 2010, equivalent to 75% of Russia's trade surplus in 1997, or all U.S. lending to Russia between 1990 and 1996.[55] Under world trading, the FSU would receive only about $1 billion, but China would receive $7 billion (about 18% of its current trade surplus), and India, over $4 billion (about half the size of its current trade deficit).[56]

D. Monitoring, Reporting, and Certification Costs

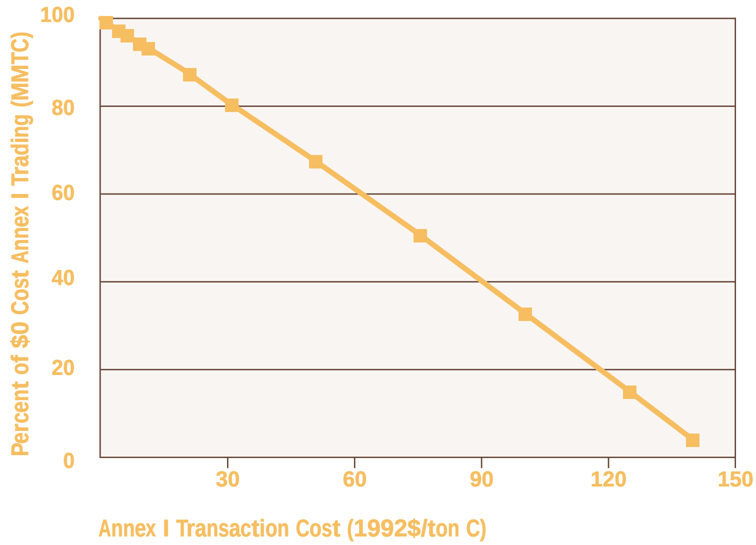
Transaction costs for monitoring, reporting, and certification could also limit the gains from trade from emissions trading. A structure for emissions monitoring, reporting, and certification must be specified as part of any carbon control system, with or without trading. Each Party included in Annex I (those with responsibility to reduce emissions) must establish a national system for estimation of sources and removals of GHGs. The following are some of the major institutional issues.[57] Emissions can be monitored either directly using monitoring devices or indirectly using predictive methods (e.g., an emissions factor multiplied times fuel used). There is a trade-off between accuracy and cost. For example, continuous stack monitoring provides more accurate measurements but is more costly than occasional air sampling or emissions estimates. Self-reporting and certification by countries may take place at the national level, while actual emissions reductions and sequestration will occur at the project or company level. Thus, both the quality of the monitoring and certification program within a given country's borders and the accuracy and veracity of its reporting must be considered. Two approaches to the uncertainty created by less-than-perfect monitoring systems are to limit emissions control and trading only to those gases and sources that can be readily and reliably monitored, or to adjust measured emissions using techniques such as presumptive emissions factors. The "presumptive permits" could then be traded. If emissions control and trading are limited to only those gases that can be measured accurately, the potential gains from trade will also be limited. If a presumptive permits system is used, the actual effectiveness of the system may be compromised. One reason that emissions control and trading under the U.S. acid rain program has been successful is that verifying emissions is comparatively easy and accurate.

At the other end of the spectrum, the United States Initiative on Joint Implementation (USIJI), a pilot program that may enable future domestic credit for carbon emissions reduction and sequestration from projects outside of the United States, frequently deals with indirect estimation of the emissions prevented or carbon sequestered. Experience with this program indicates that in indirect approaches, determining and certifying emissions reduction credits are particularly difficult.[58] The presence of uncertainty suggests that emissions permit supply curves for CO_2 from stationary sources within Annex I countries would require the addition of relatively minor incremental transaction costs. The supply curves for other sources, for other GHGs, for carbon sinks, and for other countries might have prices that contain a substantial premium beyond actual marginal abatement cost.

The effects of transaction cost premiums on the volume of trade in permits are illustrated in Figure 3. This figure begins with the volume of emissions permits that would be bought and sold in the year 2010 under an Annex I trading scheme, as in Table 5 (i.e., a total of 190 million tons traded; the U.S. would purchase 75 million tons worth of carbon permits), when transactions costs are zero. The figure then shows how, as transaction costs per ton of carbon increase, the volume of permits decreases as a percentage of the volume under the $0 transaction cost case. For example, as transaction costs increase from $0 to $20/ton of carbon (and the effective permit price rises from $106/ton to $126/ton), the volume of trade declines to about 88%, and so on. The volume of trades that can reduce abatement costs is itself reduced as the difference between the marginal cost of abatement and the cost of purchasing or selling a permit increases due to transaction costs. As is apparent from the figure, any significant level of transaction costs will significantly limit the benefits of a trading program.

Figure 3

Transaction Cost v. Permit Trading



E. Liability, Accountability, and Enforceability

Accountability and enforceability would also be a problem should information concerning permit validity prove inaccurate. Accountability and enforceability are problems that must be solved in all emissions control systems. In the context of trading emissions permits, there is a specific question concerning whether the buyer or the seller is partly responsible (and legally liable) for the integrity or validity of the permit.[59] While trading provides some incentive to obtain accurate information concerning permit validity, the burden of diligence tends to fall most heavily on the party liable for permit validity. The UNCTAD analysis notes that strict seller liability is preferable because it enhances the standardization and therefore the tradability of permits.[60] If compliance mechanisms are strong and it is easy to rectify any excess emissions—e.g., by frequent settling of accounts (i.e., many short commitment periods), subtracting emissions allocations in the following period, and adding a penalty—strict seller liability might be all that would be needed. However, with one long commitment period as under the current Kyoto Protocol, there is no way to penalize buyers who buy from suspect sources. Partial or total buyer liability would discourage purchasers from buying permits from suspect sources, but this feature also means that buyers would also discount deeply or not trade emissions because of the market risks involved with buying a permit that was later found to be unallowable. Viewed in terms of Section III, strict seller liability would probably reduce the world supply of permits at any given price, while buyer liability would reduce demand. Both would reduce the potential gains from trade discussed in Section III. Governments and private parties can provide a useful role as independent verifiers, but such services are neither foolproof nor costless.

VI. Conclusions

Any scheme to mitigate global greenhouse gas emissions will be less expensive overall if the actual emissions reductions are undertaken at the sources that are the least costly to mitigate. However, the nations with responsibility for reductions almost certainly will be those with the most costly reduction options. Thus, independent mitigation could be quite costly. For example, this paper shows that if no trading is allowed, returning carbon emissions in the Annex I countries to 1990 levels has been projected to cost about $58 billion per year by 2010, rising to $112 billion by 2020.

Trading emissions permits among nations offers substantial gains from trade because the marginal cost of mitigation differs substantially among the Annex I countries. Costs could be reduced about one-third by trading among the Annex I countries in this case, with more gains from trade to be had, the more severe the emissions target. The differences in costs are even larger between Annex I and the non-Annex I countries. Thus, worldwide emissions trading could reduce the costs of mitigation even more.

Additional effects worth noting include the impact on the economies of non-participants in trading schemes. Some models show that if independent mitigation is undertaken, then prices of fossil fuels will likely be reduced by up to several percent relative to the no control case. This will adversely affect the economies of energy exporting countries. What happens to other countries' economies is ambiguous. The net effect will depend on: (a) the change in world energy prices and energy intensity of each country's production; (b) the effect of the increases in Annex I countries' demand for imported energy-intensive products; and (c) the overall reduction in demand brought about by reductions in Annex I countries' GDPs. Most models also show substantial financial wealth transfers from countries that are buyers of permits to those that are sellers, and some models show substantial changes in the terms of trade and in costs of externally held debt that at once add to seller wealth, reduce their costs of imports, and discourage their exports. Relative to independent mitigation, emissions trading moderates the reduction in fossil fuel prices, reduces incentives for carbon leakage, provides net financial flows to the non-Annex I countries, and—because GDPs will be higher—reduces the negative impact on trade.

The paper also notes that there are several critical design issues regarding emissions trading that could substantially reduce the potential gains from trade. Some issues can be resolved with good program design while others appear to be endemic and more difficult to resolve.

In summary, the ability to trade emissions permits offers significant gains from trade. However, various institutional questions, unresolved technical questions of measurement, and the very real costs of transactions and enforcement could substantially limit the extent of trading and the benefits of trade. Thus, policy-makers will have to pay careful attention to actual program design to realize these potential gains.

Endnotes

1. "Integrated assessment models" take into account some of the critical features of GHG emissions, the climate system, effects on natural and human systems, and the economy.

2. Because the differences in marginal cost can persist or even emerge as new technology is developed and adopted, trading should be viewed as a permanent option, not as a bridging strategy to be used only until new technologies are available.

3. For example, see Grubb, M., A. Michaelowa, B. Swift, T. Tietenberg, Zhong Xiang Zhang, *Greenhouse Gas Emissions trading: Defining the Principles, Modalities, Rules, and Guidelines for Verification, Reporting, and Accountability,* United Nations Conference on Trade and Development (UNCTAD), Geneva, Switzerland, 1998; Organization for Economic Cooperation and Development, Environment Policy Committee, *Lessons from Existing Trading Systems for International Greenhouse Gas Emissions Trading,* Annex I Expert Group on the United Nations Framework Convention on Climate Change Information Paper. ENV/EPOC(98) 13/REV1, Organization for Economic Cooperation and Development, Paris, France, 1997; Stavins, R.N., *Market-Based Environmental Policies*. Discussion Paper 98-26. Resources for the Future, Washington, D.C., 1998.

4. The authors note the limiting nature of these assumptions. All of the issues enumerated entail costs, and these costs reduce the gains from trade. Their inclusion does not reverse the findings of the simpler case but does affect the magnitude of the gains from trade.

5. Society is accustomed to the situation in which an emissions limitation obligation comes with a set of associated emissions allowances. This need not be the case. Gains to trade occur regardless of the initial allocation of obligations and allowances. Of course, the distribution of emissions and allowances has profound economic implications for the participants.

6. The trade also works if only the high-cost controller initially has permits and the low-cost controller has no obligation to control and therefore, has no permits to sell. The trade could take the form of a purchase of carbon credits, wherein the low-cost controller undertakes an emissions reduction on behalf of the high-cost controller, and the high-cost controller gets a credit for this reduction that functions like a permit. There are important institutional differences between permits and credits.

7. In discussing this issue, most authors adopt the metric ton (2,204.6 lbs. or 1,000 kilograms) rather than the short ton of 2,000 lbs. This paper uses the metric ton.

8. The Second Generation Model (SGM) is described in Edmonds, J., H.M. Pitcher, D. Barns, R. Baron, and M.A. Wise. 1995. “Modeling Future Greenhouse Gas Emissions: The Second Generation Model Description,” in *Modelling Global Change.* United Nations University Press, Tokyo, Japan, October 1995. More recent updates may be found in Edmonds, J.A., S.H. Kim, C.N. MacCracken, R.D. Sands, and M.A. Wise, *Return to 1990: the Cost of Mitigating United States Carbon Emissions in the Post-2000 Period*, PNNL-11819, Pacific Northwest National Laboratory, Richland Washington, 1997; Edmonds, J.A., C.N. MacCracken, R.D. Sands, and S.H. Kim, *Unfinished Business: The Economics of the Kyoto Protocol*, PNNL-12021, Pacific Northwest National Laboratory, Richland, Washington, 1998. The model’s strengths include considerable detail on fuel choice and technology options and decision-making in the energy sector

(especially electricity). Because it assumes full employment and does not include a financial or monetary sector, it does not deal with business-cycle issues such as unemployment, inflation, and consequences of international financial capital flows.

9. For discussion of the limitations of the SGM, see P.M. Bernstein and W.D. Montgomery, "How Much Could Kyoto Really Cost? A Reconstruction and Reconciliation of Administration Estimates," p. 4 (1998) and Interagency Analytical Team, "Economic Effects of Global Climate Change Policies," pp. 2, 3 (Draft, 1997). The inherent limitations of the SGM grow out of its computable general equilibrium structure. Other models of this class therefore share these limitations. It is worth noting that the SGM produced the median estimate of marginal control costs for the United States in the year 2010 under conditions of independent compliance with the Kyoto Protocol in the recent EMF-16 exercise (Weyant, J.P. and J.N. Hill. 1999. "Introduction and Overview," *The Costs of the Kyoto Protocol: A Multi-Model Evaluation. The Energy Journal, Special Issue*:*vii-xliv*.).

10. The Kyoto Protocol is a supplement to the United Nations Framework Convention on Climate Change. The Framework was first proposed in Rio de Janeiro in 1992 and has since been signed by most of the world's nations, including the United States. The Kyoto Protocol, which proposes specific emissions goals for the Annex I countries, makes provision for trading emissions permits and credits, and outlines many of the general principles for trade, has not yet gone into effect.

11. The Annex I countries are Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, the European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Turkey and Belarus are Annex I nations that have not ratified the Convention and did not commit to quantifiable emissions targets. Some of the analyses in Section IV of this report were actually done on the so-called Annex B countries. Annex B is the same list of nations as Annex I, excluding Turkey and Belarus.

12. In the real world, many problems confront the extension of participation from those with explicit emissions limitations to those without such limitations. This paper estimates the potential benefit of a successful extension to non-obligated parties' emissions. The Kyoto Protocol includes a Clean Development Mechanism (CDM) that allows non-Annex I parties to create "certified emissions reductions" which may be used by Annex I parties to "contribute to compliance with part of their quantified emission limitation and reduction commitments." This paper uses the term "credits" to refer to "certified emissions reductions." The essential difference between permits and credits is that permits are obligations to reduce emissions under an established cap in total emissions (relatively easy to verify and enforce), but credits are allowances for emissions without an established cap on total emissions (more difficult to verify and enforce). Because credit baselines must be established on a case-by-case basis, they result in higher transaction costs. Full worldwide permit trading is not yet an option since non-Annex I countries are not currently obligated to reduce emissions. This paper uses the term "permits" in a way that has become common in the context of international climate negotiations. In other contexts, the term "permit" refers to a specific legal right to emit pollution. The U.S. acid rain trading program uses the term "allowance" to describe the concept that we are calling "permit" here.

13. Leakage is measured as the difference between Annex I emissions reductions and global emissions reductions.

14. The Former Soviet Union was projected to produce lower carbon emissions in 2010 than in 1990 even without control in the No Trade case, so no control was required in this region. FSU emissions control in the Annex I Trading case is undertaken only on behalf of OECD trading partners. In reality, the countries comprising this region might not make carbon permits available, or might choose to exercise some degree of monopoly power. If so, the gains from trade could be smaller than shown.

15. See Section V for a discussion of limits on the supplies and uses of traded permits.

16. This is not necessarily the same thing as a CDM credit, which is created by the Kyoto Protocol. In a perfect world, the CDM and tradable emissions permit might be made to be the same. In the real world, there will be differences that may be large or small depending on a wide array of factors. Depending on how they are created, CDM credits may be either greater or smaller in magnitude than the emissions credits modeled here, and may represent either less or more emissions abatement.

17. Edmonds et al. 1997; Edmonds et al. 1998.

18. Yang, Z. et al., *The MIT Emission Prediction and Policy Analysis Model*, Program Report 6, MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology, Cambridge, Massachusetts, 1996; Ellerman, A.D. and A. Decaux, *Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves*. Program Report 40, MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology, Cambridge, Massachusetts, 1998; Ellerman, A.D., H.D. Jacoby, and A. Decaux, *The Effects on Developing Countries of the Kyoto Protocol and CO_2 Emissions Trading*. Program Report 41, MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology, Cambridge, Massachusetts, 1998; Reilly, J., R.G. Prinn, J. Harnisch, J. Fitzmaurice, H.D. Jacoby, D. Kicklighter, P.H. Stone, A.P. Sokolov, and C. Wang, *Multi-Gas Assessment of the Kyoto Protocol*. Program Report 45, MIT Joint Program on the Science and Policy of Global Change. Massachusetts Institute of Technology, Cambridge, Massachusetts, 1999.

19. Manne, A.S., and R.G. Richels, "On Stabilizing CO_2 Concentrations: Cost-effective Emissions Reduction Strategies," *Energy Journal*, 18(3) 31-58, 1997.

20. U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*. SR/OIAF/98-03, Energy Information Administration, U.S. Department of Energy, Washington, D.C., October 1998.

21. Bernstein, P. M., W. D. Montgomery, and T. F. Rutherford, *World Economic Impacts of U.S. Commitments to Medium Term Carbon Emissions Limits*, Charles River Associates, Boston, Massachusetts, January 1997.

22. Van der Mensbrugghe, D. *A (Preliminary) Analysis of the Kyoto Protocol: Using the OECD GREEN Model*, OECD Development Centre, Paris, France, March 1, 1998.

23. Tulpulé, V., S. Brown, J. Lim, C. Polidano, H. Pant, and B. S. Fisher, *An Economic Assessment of the Kyoto Protocol Using the Global Trade and Environment Model*, ABARE, Canberra, Australia, September 1998.

24. McKibbin, W. J., R. Shackleton, and P. J. Wilcoxen, *The Potential Effects of International Carbon Emissions Permit Trading Under the Kyoto Protocol*, The Brookings Institution, Washington, D.C., November 2, 1998.

25. Computable general equilibrium models use a computerized solution algorithm to numerically solve a set of simultaneous equations that represent all of the sectors of the economy of each region. In all markets for energy and non-energy goods and services, quantities and prices adjust so that markets "clear" (supply equals demand) in every sector.

26. Results from the hypothetical protocol discussed in the previous section support this result even in the absence of an increase in allowable emissions under trade.

27. U.S. Energy Information Administration, 1998.

28. The results reported in Table 8 differ from those reported in Table 7 (taken from EIA, 1998) due to differences in original sources and reference cases. The individual reductions approximate the Kyoto requirements for the Annex I countries that amount to an approximate 5.2% reduction in emissions below 1990 levels over the compliance period between 2008 to 2010.

29. G–Cubed initially shows Japan as the highest-cost region; but then clean backstop fuels rapidly penetrate the Japanese market, reducing the required carbon tax. OECD GREEN's marginal abatement cost for Japan in the table appears is unusually low. According to the OECD modelers, in the year 2005, the carbon price spikes very high in Japan (about $285/ton C). However, by 2010 in Japan the tax level decreases substantially, "as clean backstops are able to compete successfully due to the high price of energy in Japan. The backstops are not able to penetrate to any significant extent in the other OECD regions...".

30. In the G-Cubed model, international financial flows play a much larger role than in the other models. The United States shows a slight increase in GDP in the No Trade case because it has much lower marginal costs of abating than Japan and Europe. Thus, rates of return in investment fall less in the United States, investment portfolios are shifted toward the United States, and the United States enjoys higher investment, leading to higher GDP.

31. In the case of OECD GREEN, results were shown only for real income rather than GDP (which was not reported). In percentage terms, the principal difference is that income includes international payments such as payments for emissions permits, while the latter does not. The OECD GREEN analysis shows that the Former Soviet Union loses 1% of base case real income in the No Trade case because, as a major energy exporter, the region suffers from a decline in the price of internationally traded fuels. In contrast, it obtains a 3% gain in income in the Annex I case due to sales of permits and the higher export price of energy.

32. That is, in the No Trade case, the EPPA model shows that together, the FSU (whose emissions are not constrained because they are still below 1990 levels) and the non-Annex I countries emit 62 million more tons of carbon than they would if the OECD countries did not undertake emissions reduction. This offsets about 3% of the OECD carbon mitigation effort in 2010. See Ellerman and Decaux 1998.

33. Ellerman et al. 1998.

34. Results on oil and gas prices vary among models and also vary according to how the experiments were done. The articles reviewed for this report did not generally show the effects on oil and natural gas prices; therefore, a more comprehensive assessment was not possible.

35. Ellerman et al. 1998.

36. Bernstein et al. 1997.

37. McKibbin et al. 1998.

38. While it is also true that the FSU's GDP could be reduced relative to the No Trade case (as shown for the Kyoto commitment in Table 10, for example), the international payments received by the FSU for permits are not reflected in the GDP figures. When these are added in, the FSU is better off.

39. From the perspective of long-term concentrations, it is actually better to have emissions occur early rather than late as long as cumulative emissions are the same, because shifting emissions toward the present takes maximum advantage of atmospheric removal mechanisms. That is, even if cumulative emissions are the same in two cases over the same period of time, the final period concentrations will be lower for the case in which the larger proportion of emissions were released earlier. But early emissions also imply higher near-term concentrations and therefore higher near-term rates of climate change. Since the impacts of climate change depend both on the concentration and the path to the concentration, shifting emissions toward the present may also change climate impacts making it impossible to indicate that one emissions path is unambiguously preferable to another.

40. Reilly et al. 1999 do report that they performed an analysis of Annex I trading with multiple gases and concluded that the number of base mitigation permits in the FSU and Eastern Europe are reduced and that the value of

trading is reduced, relative to controlling CO_2 alone. In this case, the U.S. marginal cost with trading of multiple gases was almost the same as with CO_2 alone.

41. This was also the conclusion reached in an overview of the models surveyed by the Energy Modeling Forum-16. See Weyant, J. P. et al. 1999.

42. Edmonds et al. 1998. The analysis was based on estimated land use emissions credit supplied by the U.S. Council of Economic Advisors. The point here is not whether this figure is the "correct" one; rather, the point is that how rules are written regarding countries' ability to trade and take credit for terrestrial sinks could strongly affect compliance costs.

43. Edmonds et al. 1998. Note that the $73 in Table 8 is per ton of carbon equivalent for a 5.2% reduction below 1990 levels of all six gases by all Annex I parties. In Table 5 the marginal cost is $106 per ton for stabilization at 1990 levels, but for CO_2 alone. The base case is also slightly different between the two tables.

44. Reilly et al. 1999.

45. Joshua, F.T., Greenhouse Gas Emissions Trading After Kyoto: Insights from UNCTAD's Research & Development Project, 1998. <http://www.ecouncil.ac.cr/rio/focus/report/english/Unctad.html>.

46. Hahn, R.W. and R.N. Stavins. "What Has Kyoto Wrought? The Real Architecture of International Tradable Permit Markets," *EPRI Global Climate Change Research Seminar*, Columbus, OH, September 27-29, 1999.

47. Ellerman et al. 1998.

48. Edmonds et al. 1998.

49. Edmonds et al. 1998; Ellerman et al. 1998.

50. Ellerman et al. 1998.

51. Edmonds et al. 1998.

52. For example, the European Union has proposed that there be a trading rule that establishes, by mathematical formula, a limit on the amount of credits any Annex I nation could sell. The Kyoto Protocol specifies in Article 6 that "acquisition of emissions reduction units shall be supplemental to domestic actions," but does not spell out what "supplemental" actually means.

53. Ellerman et al. 1998.

54. Edmonds et al. 1998; Ellerman et al. 1998.

55. Trade and lending figures from U.S. Central Intelligence Agency, *World Factbook 1998*.

56. CIA *World Factbook 1998.*

57. Grubb et al. 1998.

58. Lile, R., M. Powell, and M. Toman, *Implementing the Clean Development Mechanism: Lessons Learned from U.S. Private-Sector Participation in Activities Implemented Jointly*. Discussion Paper 99-08. Resources for the Future, Washington D.C., 1998.

59. For example, it is inherently more difficult to trade emissions credits (which are open-ended and difficult to verify) than to trade permits that represent GHGs measured against a known emissions commitment.

60. Grubb et al. 1998.

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