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The Economics of
The Kyoto Protocol

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ABSTRACT

The Kyoto Protocol to the Framework Convention on Climate Change (FCCC) was completed on the morning of December 11, 1997, following over two years of negotiations. The product of these deliberations is a complex and incomplete document knitting together the diversity of interests and perspectives represented by the more than 150 delegations. Because the document is complex, its implications are not immediately obvious. If it enters into force, the Kyoto Protocol will have far-reaching implications for all nations—both nations with obligations under the Protocol and those without obligations. National energy systems, and the world's energy system, could be forever changed.

In this paper we develop an assessment of the energy and economic implications of achieving the goals of the Kyoto Protocol. We find that many of the details of the Protocol that remain to be worked out introduce critical uncertainties affecting the cost of compliance. There are also a variety of uncertainties that further complicate the analysis. These include future non-CO_2 greenhouse gas emissions and the cost of their mitigation. Other uncertainties include the resolution of negotiations to establish rules for determining and allocating land-use emissions rights, mechanisms for Annex I trading, and participation by non-Annex I members in the Clean Development Mechanism. In addition, there are economic uncertainties, such as the behavior of Eastern Europe and the former Soviet Union in supplying emissions credits under Annex I trading. These uncertainties in turn could affect private sector investments in anticipation of the Protocol's entrance into force. The longer the nature of future obligations remains unclear, the less able decision makers will be to incorporate these rules into their investment decisions.

We find that the cost of implementing the Protocol in the United States can vary by more than an order of magnitude. The marginal cost could be as low as $26 per tonne of carbon if a global system of emissions mitigation could be quickly and effectively implemented. But it could also exceed $250 per tonne of carbon if the United States must meet its emissions limitations entirely through domestic actions, and if mitigation obligations are not adequately anticipated by decision-makers.

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INTRODUCTION

The Kyoto Protocol was completed on the morning of December 11, 1997, following more than two years of negotiations. The product of these deliberations is a complex and incomplete document knitting together the diversity of interests and perspectives represented by the more than 150 delegations. Because the document is complex, its implications are not immediately obvious. If it enters into force, the Kyoto Protocol could have far-reaching implications for both Annex I[1] and non-Annex I member states. National energy systems, and the world's energy system, could be forever changed.

In this paper we assess the energy and economic implications of achieving the goals of the Kyoto Protocol. We find that many of the details of the Protocol that remain to be worked out introduce critical uncertainties affecting the cost of compliance. There are also a variety of uncertainties that further complicate the analysis. These include future non-CO_2 greenhouse gas emissions and the cost of their mitigation. Other uncertainties include the resolution of negotiations to establish rules for determining and allocating land-use emissions rights, mechanisms for Annex I trading, and participation by non-Annex I members in the Clean Development Mechanism. In addition, there are economic uncertainties, such as the behavior of Eastern Europe and the former Soviet Union in supplying emissions credits under Annex I trading.

We begin by describing the major features of the Kyoto Protocol, the variety of policy issues remaining to be resolved, and our general approach to modeling those issues. We then review some of the necessary assumptions for this exercise, as well as the structure and calibration of the Second Generation Model (SGM). The SGM was used to simulate the impact of mitigation policies on the economies participating in the Kyoto Protocol. Finally, we discuss the results of our analysis in several areas, including the impacts of independent compliance, emissions permit trading, the Clean Development Mechanism, the inclusion of the six greenhouse gases, and land-use emissions. We focus on the impacts on regional energy systems and measures of compliance cost.

KEY FEATURES OF THE KYOTO PROTOCOL

Targets and Timetables

The most prominent feature of the Kyoto Protocol is the quantified emissions limitations and reduction commitments. Thirty-nine parties accepted quantified emissions limitations or reduction commitments. These are given in the Appendix to this paper, which lists emissions limitations and reduction commitments by SGM region.

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[1] The Kyoto Protocol actually prescribes emissions limitations for countries listed in Annex B to the Protocol. These countries are: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, 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 the United States of America. This list varies somewhat from the countries contained in Annex I to the FCCC. Several countries such as Slovakia, Slovenia, Liechtenstein, and Monaco have been added, while Belarus and Turkey are listed in Annex I of the FCCC but not Annex B of the Kyoto Protocol. In this analysis we refer only to Annex I, with Annex B obligations allocated appropriately as specified in Appendix A of this report.

We can summarize obligations as follows.

- Western European nations accepted an eight percent reduction relative to 1990 emissions, with the exception of Iceland and Norway which were allowed 110 and 101 percent of 1990 emissions respectively.
- Eastern European nations generally had the same obligation as Western European nations with some exceptions—Croatia was 95 percent, and Hungary and Poland were 94 percent of base year emissions. Note that the base year for the countries in this region need not be 1990.
- The Russian Federation and Ukraine were allowed 1990 emissions levels, while Latvia, Estonia and Lithuania agreed to eight-percent reductions.
- Japan and Canada agreed to a six percent reduction from 1990 emissions levels.
- The United States of America agreed to reduce emissions seven percent below 1990 levels. And,
- Australia was allowed to increase emissions eight percent above 1990 levels and New Zealand was allowed to emit up to 1990 levels.

The Six Gas Approach

Emissions are defined in terms of a basket of six gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexaflouride (SF_6). Gases are compared to each other using global warming potential (GWP) coefficients as developed by the IPCC. The use of GWPs allows for the aggregation of the six greenhouse gases specified in the Protocol into a singe value based on each gas' carbon equivalent. We will discuss the use of carbon equivalent emissions in this analysis later in the paper.

Land-Use Change Emissions Accounting

One of the most important and controversial features of the Kyoto Protocol is the treatment of emissions of greenhouse gases from land-use change. A very complicated set of rules was developed which addresses both political and scientific concerns. These rules are highly asymmetrical. They describe how nations compute their base year emissions, against which all future mitigation is measured. We provide further discussion of the rules under consideration and their impact on mitigation costs in a later section.

Emissions Trading

The principle of emissions trading was established in the Kyoto Protocol. However, several important issues are left unresolved. Emissions trading could occur within or between Annex I parties. Within a nation, domestic permit trading could take place among firms or other actors to which permits are allocated. Similarly, permit trading could take place among firms or governments of different nations in an international permit market. Specific arrangements under which trade would occur, however, are left to be worked out in the future. The Protocol also established the principle that, "trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction." Therefore, limits may be established in the use of emissions trading to satisfy a commitment.

The Clean Development Mechanism

The Protocol also established a Clean Development Mechanism (CDM). The CDM was created "to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their

quantified emission limitation and reduction commitments under Article 3." It allows emissions mitigation credits to be developed by non-Annex I parties beginning in the year 2000, as long as these activities are supplemental to activities that would have been undertaken in the normal course of events. It also identified a certification authority to insure that emissions mitigation activities were in fact real and supplemental. As with emissions trading, the rules are left to be developed in subsequent deliberations. Further, the degree to which this mechanism can capture emissions mitigation potential outside Annex I remains unclear.

Compliance

Unlike the Montreal Protocol, which established sanctions for non-compliance, the Kyoto Protocol establishes no such penalties.

Entry into Force

The Protocol is open to ratification beginning March 16, 1999. To enter into force, the protocol must be ratified by at least 55 Parties to the Convention, and ratifying parties must represent at least 55 percent of the total Annex I carbon dioxide emissions for 1990. This means that if parties representing more than 45 percent of Annex I emissions remain outside the Protocol, it cannot enter into force. It is particularly important whether or not the United States presents an instrument of ratification, acceptance, approval or accession. It alone represents nearly one-third of 1990 Annex I emissions. As of September 25, 1998, 55 countries had signed the Protocol. The United States had yet to sign the Protocol.

APPROACH

We examine the economic consequences of implementing the Kyoto agreement using the SGM. The SGM is a computable general equilibrium economic model that projects economic activity, energy consumption, and carbon emissions for twelve world regions. It is designed specifically to address issues associated with global change with special emphasis given toward performing the following types of analysis:

1. Provide estimates of future time paths of environmentally important emissions associated with economic activity.

2. Provide estimates of the economic cost of actions to reduce greenhouse gas emissions.

Sectors

The SGM has nine producing sectors and twelve inputs to production. The inputs are land, labor, capital, and the nine produced goods. Economic detail is maintained in the energy supply and transformation sectors that are important for greenhouse gas emissions projections, but aggregated elsewhere into one large "everything else" sector.

Five different fuels are used for producing electricity, resulting in at least five subsectors for the electric generating sector. A separate economic production function, of the constant elasticity of substitution (CES) functional form, is used for each sector or subsector. Capital investment decisions depend on an assumed lifetime of capital for each sector or subsector. Capital lifetimes range from 15 years in the oil, gas, and coal production sectors to 70 years for hydroelectric power. The relative size of each production sector and subsector for the United States is shown in Table 1.

Table 1. Producing Sectors in the SGM

	Producing Sector	Gross Output in 1985 (millions of 1985 $)
1	Agriculture	468,618
2	Everything Else	5,086,486
3	Oil Production	64,171
4	Gas Production	45,804
5	Coal Production	20,006
6	Uranium Processing	2,195
7	Electricity Generation	165,800
	a. oil	10,959
	b. gas	34,152
	c. coal	85,930
	d. nuclear	21,370
	e. hydro	13,389
8	Petroleum Refining	145,015
9	Gas Transmission and Distribution	105,330

Market Clearing

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 equilibrium. The set of prices in which the equilibrium holds is called the *market-clearing* price set. 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 the prices of oil, gas, and, at least indirectly, the prices of all markets in the economy.

Carbon permit prices are also solved for by the SGM as part of the market equilibrium. Specifically, the SGM finds the carbon price such that the amount of carbon emitted is just equal to the carbon constraint of the region or group of regions under a carbon emissions limitation constraint. The 12 SGM regions are listed in Table 2.

Table 2. Regions in the SGM

Annex I	Non-Annex I
United States	China
Canada	India
Western Europe	Mexico
Japan	South Korea
Australia	Rest of World[2]
former Soviet Union	
Eastern Europe	

[2] The Rest of World (ROW) includes Latin America, Africa, and other Asian countries.

Carbon Permit Fees and Revenue Recycling

The SGM uses a carbon permit fee within each region to provide an economic incentive for the economy to substitute away from carbon. We model this as a carbon tax placed on fossil fuels. The government collects the tax just as it would collect revenues from allocating the emissions permits. These revenues can be very large, and how the revenues are recycled, or redistributed to the economy, makes a difference in the final economic cost. For this exercise, we assume that all carbon fee revenues are recycled back to consumers through a lump-sum transfer.

For the cases where emissions rights are traded between countries, each SGM region is allocated an initial number of carbon emissions permits based on its commitments as defined in the Kyoto Protocol. Carbon permits can then be traded between countries at a price that clears the international market in these permits.

Modes of Operation

All of the SGM regions were initially developed as single-region models with a base year of 1985. Each regional model operates in five-year time steps and has been run with forecast horizons ranging up to the year 2100. Most of the single-region models were developed in collaboration with experts from that country. It is possible to run all of the regions individually or simultaneously in a global model with international trade. The three modes of operation for the SGM are:

1. Single Region
2. Global with Partial Market Clearing
3. Global with Full Market Clearing

Single-region Operation

For each SGM region, all produced goods are classified as being tradable, non-tradable, or traded at a fixed quantity. When SGM regions are operated independently, a fixed world price is assumed for certain tradable goods; regions may import or export as much of that good as desired at that fixed world price, subject to an overall balance of payments constraint. For all non-tradable goods, the quantity of trade is fixed in advance. The following assignments are used when a regional model is operated independently:

1.	Numeraire Sector:	Everything else (price always equals 1)
2.	Fixed World Price:	Crude oil
3.	Fixed Trade Quantities:	Agriculture, coal, nuclear fuel, refined petroleum, electricity
4.	Nontradables:	Distributed gas, land, labor

For each region, the large ‘everything else’ sector is the numeraire, with its price fixed at 1 for all time periods. The prices of the other sectors in the economy are reported relative to this fixed value. The ‘everything else’ good is a tradable good for all regions. An exogenous balance-of-payments constraint is specified in advance for each region. Most regions are assumed to move linearly from a historical trade balance in 1985 to balanced trade by 2005.

Given a trial set of prices, the SGM computes supply and demand for all producing sectors and primary factors of production. Markets for the non-tradable goods and goods traded at fixed quantities are brought into equilibrium by searching for a set of prices that equate supply and demand. Prices are adjusted until supply and demand are within 0.01 percent of each other.

Global Model with Partial Market Clearing

The global version of the SGM is used when there is at least one market that must clear globally. For the scenarios described in this paper, the market is the tradable carbon emission permit market. The model searches for a global permit price that clears the market for permits.

Each region is initially allocated a number of carbon permits and may trade those permits at the world permit price. Some regions will be sellers of permits and some will be buyers. After trading permits, all regions must hold permits equal to the domestic level of carbon emissions.

All regions are still subject to a period-by-period balance of payments constraint. The model does not allow borrowing to pay for carbon emissions permits. Imports of permits must be paid for with exports of some other good.

Global Model with Full Market Clearing

Under this mode of operation, there are no longer any markets with a fixed world price. A set of world prices is found that clears all world markets. Also, world markets can be created for goods that were traded in fixed quantities in the single-region model.

All of the scenarios described in this paper were run in the second mode, global with partial market clearing. This mode was chosen for two reasons. The first is that we chose to adopt a fixed time path of world oil prices for SGM model runs that were completed for the United States Government during the spring of 1997. This meant that the world oil market would not be allowed to clear in the model. The second reason is that model results are often easier to interpret when some variables in the model remain predetermined over time.

Data Requirements

Three types of data are used to construct and calibrate each region of the SGM:

1. Economic and Demographic Data
2. Energy Balances
3. Technology Descriptions

Economic data include input-output tables and supplemental information from the national income accounts. Population projections were obtained from the World Bank. Energy balance tables were obtained either from the International Energy Agency or from government agencies within a region.

Input-output tables describe, in value terms, the flow of goods between industries and consumers in an economy. However, a model concerned with quantities of carbon emissions must also be concerned with quantities of energy. An input-output table alone is not sufficient to determine the quantities of oil, gas, coal, electricity, and refined petroleum that are produced and consumed. Supplemental information on energy quantities is required to map currency units from an input-output table to energy units needed to calculate levels of carbon emissions. We combine economic input-output tables with energy balance tables to create a hybrid input-output table with units of joules for energy products and real dollars for all other products. Miller and Blair (1985) provide a general description of, and the motivation for using, hybrid input-output tables.

Individual energy technologies are characterized by the annualized cost of providing an energy service. Data needed to determine the annualized cost include capital cost, equipment lifetime, annual fuel requirements, the interest rate, and other annual maintenance and operating costs.

Measuring and Reporting Mitigation Costs

At least two measures of cost are available from the SGM and from other models as well. The first measure, which we call the *direct cost*, can be thought of as either a deadweight loss or the integral under the marginal cost curve for carbon. Using either approach, direct cost is approximately equal to one-half of the carbon tax (or permit price) times the reduction in carbon emissions. For the permit trading cases, direct costs are then adjusted by the value of transfer payments required to purchase or sell permits. This measure of net cost is simple to construct and is comparable across models. We discuss the measurement of costs in more detail later in the paper.

REFERENCE CASE AND CALIBRATION

The cost of reducing greenhouse gas emissions is dependent on the reference case. The higher the growth rates of emissions in the reference case the greater the cost of meeting the Kyoto commitments. Therefore, much effort is expended to create an acceptable reference case before running any of the mitigation scenarios.

Results for this study are reported for the years 1990 through 2020. The United States reference case was closely calibrated to the Annual Energy Outlook 1998 (AEO98). For the other global regions, economic and energy consumption growth rates were roughly calibrated to regional projections from the World Energy Outlook 1996 (WEO96) or the International Energy Outlook 1998 (IEO98). Population projections for all regions with the exception of the United States were set exogenously based on the World Population Projections 1994-1995, published by the World Bank. The United States population projection was set according to AEO98 projections. The international crude oil price trajectory was also taken from the AEO98. Prices for all other fuels and goods in the model were determined endogenously. Projections of carbon emissions, population, gross domestic product (GDP), energy consumption, and electricity generation for the Annex I regions are described below.

The general calibration procedure was to first match GDP growth by adjusting parameters that control total factor productivity in the ‘everything else’ sector. Then energy consumption by fuel was calibrated by adjusting input-specific technical change parameters. Carbon emissions are an output of the model derived directly from primary energy consumption by applying fuel-specific emission factors.

Gross Domestic Product

Table 3 shows average annual growth rates for the seven Annex I regions for GDP, CO_2 emissions, carbon equivalent emissions, and primary energy consumption. The negative growth rates shown for the former Soviet Union and Eastern Europe reflect the economic downturn that occurred in those regions between 1990 and 1995.

Table 3. Projected Average Annual Growth in GDP, CO_2 Emissions, Carbon Equivalent Emissions and Primary Energy Consumption from 1990 to 2010 in the SGM Reference Case

			Carbon	

Region	GDP	CO_2 Emissions	Equivalent Emissions	Primary Energy Consumption
Canada	2.6%	1.8%	1.8%	1.4%
former Soviet Union	-1.1%	-1.2%	-1.1%	-0.9%
Japan	1.9%	1.5%	1.7%	1.5%
United States	2.2%	1.5%	1.4%	1.5%
Western Europe	2.3%	0.8%	0.4%	1.2%
Australia	2.8%	1.8%	1.6%	1.7%
Eastern Europe	2.3%	-0.2%	-0.3%	-0.2%

Carbon Equivalent Emissions

For the purpose of this analysis, we generated non-CO_2 greenhouse gas emissions trajectories for each Annex I region based on values provided by the Working Group on Public Health and Fossil Fuel Combustion (1997). We used these trajectories, measured in million metric tons (tonnes) of carbon equivalent, in conjunction with our carbon dioxide emissions trajectories, to adequately represent the basket of six gases called for in the Protocol. As a result, the baseline trajectories and required commitments in this analysis are expressed in terms of carbon equivalent rather than carbon or carbon dioxide.

Figure 1 shows emissions paths for the reference case in million metric tonnes of carbon equivalent (MMTCe) by region.[3] The reference case assumes that no emissions mitigation policies are undertaken to control emissions of greenhouse gases to the atmosphere. In 1990, total carbon equivalent emissions in the Annex I regions were 4,913 MMTCe. Model results show that total Annex I emissions actually drop from 1990 to 1995 as the decline in Eastern Europe and the former Soviet Union overwhelms emissions growth in the other Annex I regions. After 1995, Annex I emissions rise as those two regions begin their recovery and as fossil fuel consumption increases in all regions. By 2010, Annex I emissions reach 5,479 million tonnes, or a 12 percent increase in total emissions over the 1990 level at an average emissions growth rate of 0.55 percent per year.

Eastern Europe and former Soviet Union Permit Allocations

While carbon equivalent emissions in most regions are anticipated to continually increase beyond commitment levels over time, this is not the case for the Eastern Europe and former Soviet Union regions. Emissions in these regions have declined since 1990. Their reference case emissions trajectories reflect this decline from 1990 to 1995 and then increase slowly from 1995 onward. Economic growth and the nature of restructuring will play an important role in determining the potential supply of emissions permits originating from these two regions. Because the Russian Federation and Ukraine are allocated emissions rights equal to their 1990 emissions levels, they have potentially greater emissions rights in excess of their quantified emissions limitation than Eastern European nations as a group.

[3] We use the following regional abbreviations in several figures: "CAN" for Canada, "FSU" for former Soviet Union, "JPN" for Japan, "US" for United States, "WEU" for Western Europe, "AUS" for Australia, and "EEUR" for Eastern Europe.

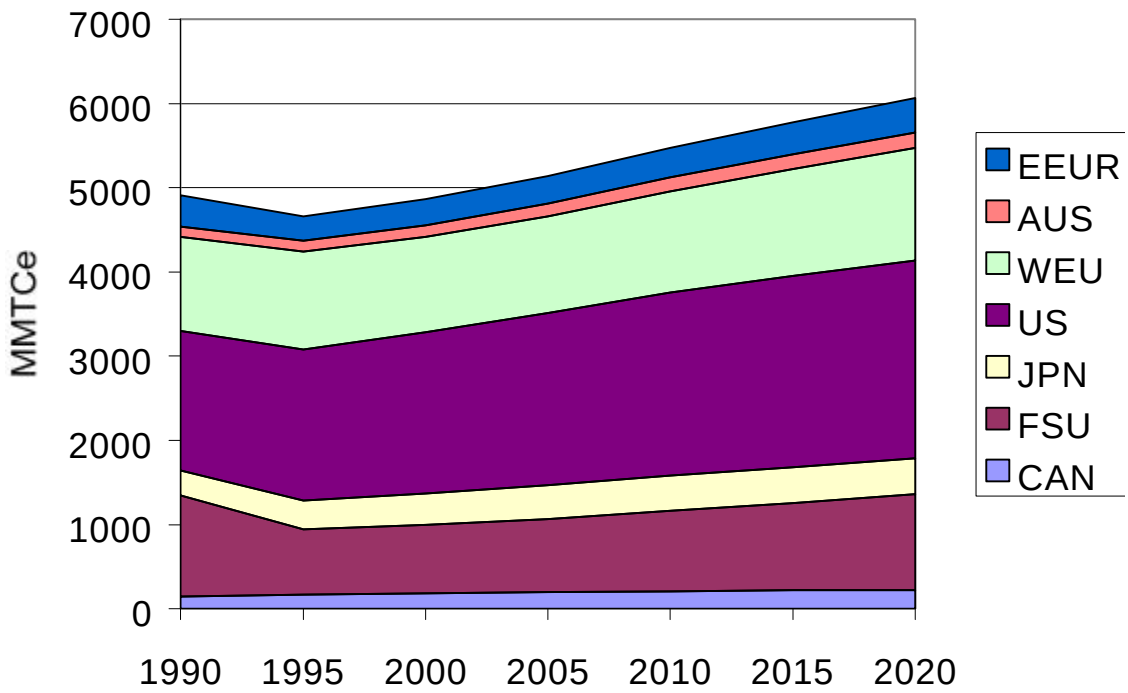

Figure 1. Baseline Carbon Equivalent Emissions for Annex I

As noted earlier, Eastern European parties to the Kyoto Protocol have different quantified emissions limitations than the Russian Federation and Ukraine, Table 4. We allocate the former Soviet Union region rights to emit up to its 1990 emissions levels as the Russian Federation and Ukraine represent over three-quarters of the region's 1990 emissions. Given the national limitations, Eastern Europe as a region must reduce emissions 7 percent below base year levels. Article 4, paragraph 6, of the Framework Convention on Climate Change, however, allows for "a certain degree of flexibility" for countries undergoing the transition to a market economy. Under this provision, four countries in Eastern Europe (Bulgaria, Hungary, Poland, and Romania) have been permitted to select base years other than 1990 for the determination of their quantified emissions limitation. Emissions in their chosen non-standard base years are higher than 1990 emissions, thereby increasing the quantified emissions limitation for the Eastern Europe region as a whole (Victor, et al. 1998). The resulting target for Eastern Europe is 6 percent above 1990 levels, which is not constraining on the region's emissions in 2010.

To the extent that compliance period reference case emissions are lower than in 1990 in the former Soviet Union and Eastern Europe, emissions permits will be greater than reference level emissions. This excess is sometimes referred to as "paper credits" or "hot air" and is equal to the difference between the lower post-1990 emissions and the target established under the Protocol. We shall refer to these permits as "base mitigation credits." For example, the former Soviet Union's reference emissions level in 2010 is 953 MMTCe, significantly lower than its 1990 emissions of 1,200 MMTCe. Under the Kyoto Protocol it would therefore receive 247 MMTCe worth of permits more in 2010 than its projected emissions, giving it 247 MMTCe worth of permits to sell without incurring any emissions reductions of its own.

Table 4. Quantified Emissions Limitations for Eastern Europe and the former Soviet Union (Percent of 1990 Carbon Equivalent Emissions)

SGM REGION	CONVENTION PARTY	QUANTIFIED EMISSIONS LIMITATIONS
Eastern Europe	Bulgaria	92[a]
Eastern Europe	Croatia	95
Eastern Europe	Czech Republic	92
Eastern Europe	Finland	92
Eastern Europe	Hungary	94[a]
Eastern Europe	Poland	94[a]
Eastern Europe	Romania	92[a]
Eastern Europe	Slovakia	92
Eastern Europe	Slovenia	92
former Soviet Union	Estonia	92
former Soviet Union	Latvia	92
former Soviet Union	Lithuania	92
former Soviet Union	Russian Federation	100
former Soviet Union	Ukraine	100

[a] Country using base year other than 1990.

Energy Consumption

The SGM projects Annex I primary energy consumption to grow at an average annual rate of 0.77 percent between 1990 and 2010. Eighty four percent of that growth is in the form of fossil fuels, and nearly 63 percent is supplied by natural gas alone. Figure 2 shows the percentage of total primary energy consumption supplied by fossil fuels by region in 2010. The total percentage and the composition of that fossil fuel consumption have a significant impact on the costs of mitigating carbon equivalent emissions.

Petroleum remains the major source of energy through 2010, but its share of total consumption declines over time, giving way to natural gas and, to a lesser extent, renewable energy sources. Coal is the third largest source of energy, and its consumption remains steady at slightly more than 20 percent of total consumption. Nuclear energy's contribution to energy consumption also remains steady with declines in the United States roughly matched by increases in Western Europe.

Electricity Generation

Figure 3 shows electricity generation by fuel in 2010 for the Annex I regions. The composition varies greatly from region to region. The United States, Australia, and Eastern Europe, for example, rely heavily on coal while Canada generates almost 60 percent of its electricity from hydroelectric sources. Eastern Europe has the most balanced composition with no one fuel supplying more than one-third of the total generation.

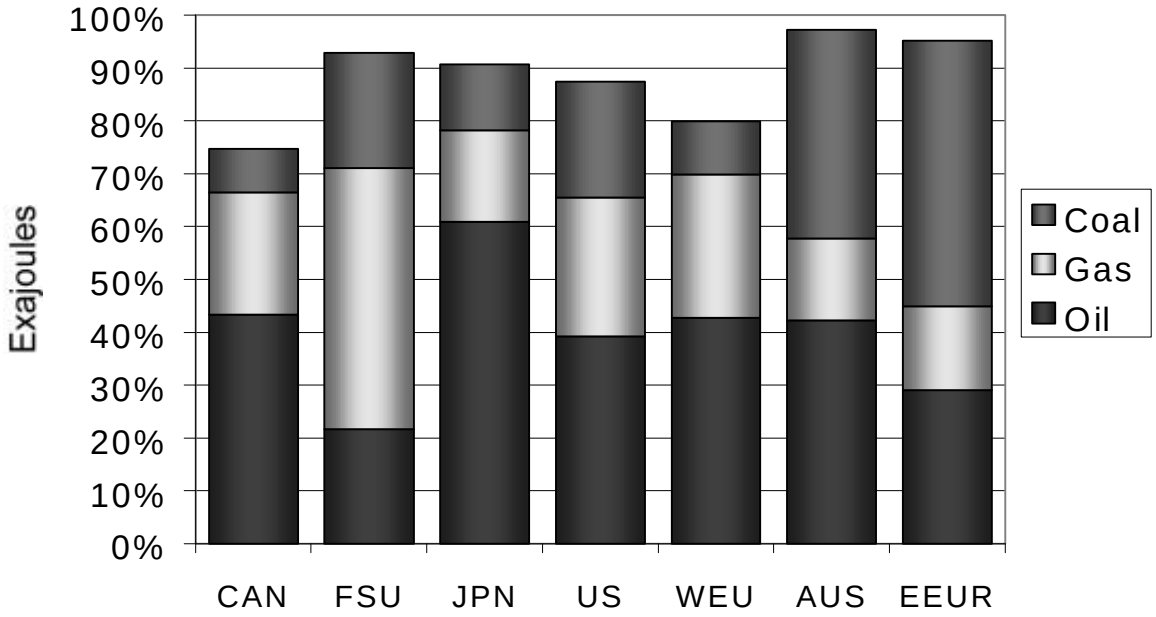

Figure 2. Percentage of Total Primary Energy Consumption Supplied by Fossil Fuels in 2010

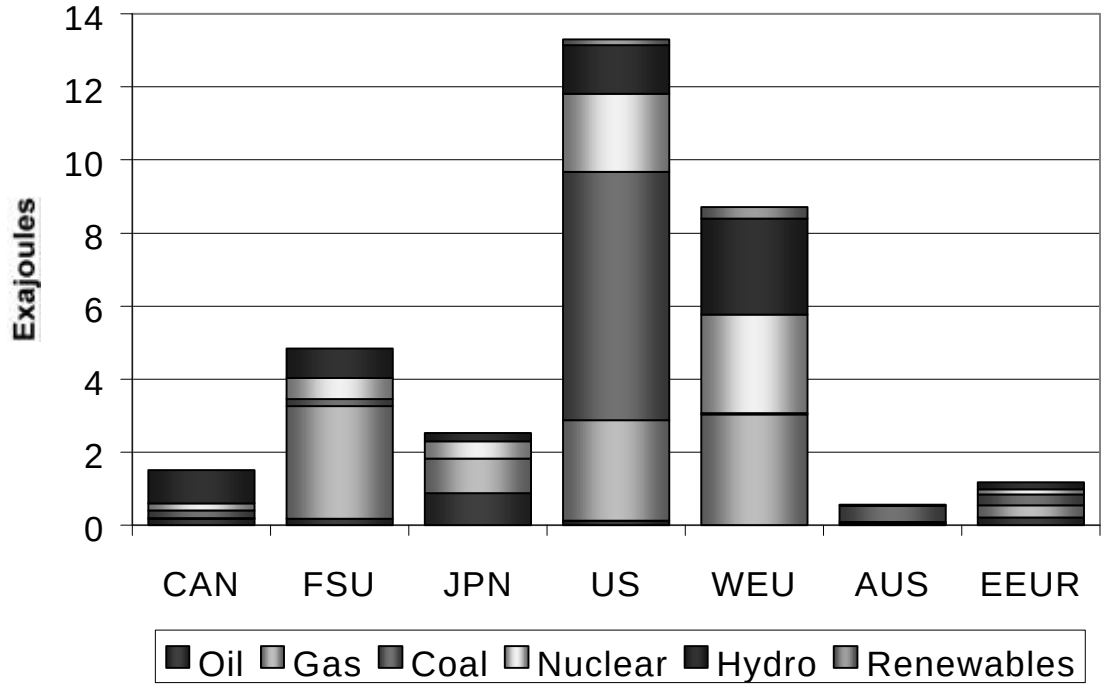

Figure 3. Total Electricity Generation by Fuel in 2010

COMPLIANCE

In the following sections, we systematically address the question of compliance cost for the Kyoto Protocol. In each mitigation scenario, allowable emissions are reduced linearly from the reference level in 2000 to the emissions target in 2010. Because the SGM operates with 5-year time steps, we treat the year 2010 as a typical year within the 2008 to 2012 budget period and assume that average cost experienced in the budget years before and after are on average the same as for the year 2010. We address five different issues:

1. The impacts of independent compliance,
2. The impacts of joint compliance with Annex I trading,
3. The impacts of joint compliance with Annex I trading with an operational Clean Development Mechanism,
4. The effect of non-CO_2 greenhouse gases on compliance costs, and
5. The effect of carbon sinks on compliance costs.

Independent Compliance

In the independent mitigation case, each Annex I region must individually meet its quantified emissions limitations without any trading of permits across regions. A time series of carbon taxes is determined for each region to reduce emissions to be equal to its allocated emissions rights. In our examination of independent compliance we assume that non-CO_2 greenhouse gases grow at exogenously specified rates in the reference case. Because we are ignorant about the mitigation cost functions for these other gases, we assume that their aggregate mitigation cost functions are similar to fossil fuel carbon. Thus, we compute non-CO_2 greenhouse gas mitigation cost as a proportion of fossil fuel carbon mitigation cost. In other words, the same percentage of total non-CO_2 emissions is abated for a given tax as the percentage of carbon dioxide emissions abated for that same tax. In a later portion of this paper we will investigate the implications of relaxing this assumption. Similarly, we apply ad hoc assumptions regarding land-use emissions mitigation. Although most of the Annex I regions had net sequestration in 1990, we assume for this analysis that regions receive no credits for this sequestration in the compliance period.[4] As with the mitigation cost assumptions, this assumption about credits for emissions sequestration will be relaxed in analysis discussed later in the paper.

Several issues arise in the analysis of independent compliance. Successful compliance will change the regional and world energy systems. The individual energy circumstances characteristic of each region will shape the nature and cost of compliance. For example, the electric power sector plays an important role in shaping the cost of compliance. In the United States the substitution of natural gas for coal plays an important role whereas in Western Europe the role of nuclear power is increased substantially.

Some technology options have significant lead times to their deployment. For example, it takes time to build the gas pipeline infrastructure needed to re-power coal fired electricity generating facilities, to build and deploy gas turbines, and to build and license new nuclear power plants. Sub-optimal investment decisions may result from uncertainty regarding whether or not and under what conditions the Protocol will ever enter into force as well as national implementation policies.

[4] The exception to this is Australia. Because Australia was a net land-use emitter in 1990, its land-use emissions are included in its Kyoto target. Australia is also projected to be a net emitter in the compliance period in this analysis and these emissions are added to the carbon equivalent emissions to generate its emissions in 2010.

Costs of Independent Compliance

We first compute the permit fees required to bring each region into compliance independently on the assumption that independent compliance is fully anticipated by all public and private sector investment decisions taken after the year 2000. These results are shown in Table 5. Values are included for 2020 to show what the potential compliance costs would be if the requirements of the Kyoto Protocol were to be extended beyond the 2008 to 2012 budget period.

Table 5. Emissions Mitigation Relative to Reference and Emissions Taxes Required to Meet Kyoto Quantified Emissions Limitations and Reduction Commitments (MMTCe/year and 1992 US$ per Tonne of Carbon Equivalent)

	Emissions Mitigation Relative to Reference to Meet Kyoto Quantified Emissions Limitations And Reduction Commitments (MMTCe/yr.)		Carbon Permit Price or Tax Needed to Achieve Independent Compliance (1992 US $/tonne Ce)	
Region	**2010**	**2020**	**2010**	**2020**
Canada	72	86	350	387
former Soviet Union	- 247	- 65	--	--
Japan	137	150	458	430
United States	634	805	168	199
Western Europe	176	314	130[a] 144[b]	208 [a] 247[b]
Australia	34	44	117	141
Eastern Europe	- 42	22	--	41

[a] Allows new nuclear power capacity to be built. [b] No new nuclear power capacity allowed.

Permit fees of this magnitude change domestic and international energy systems. The changes in national energy systems vary greatly from region to region. Different growth rates in the Annex I regions result in varying amounts of mitigation required to comply with the Kyoto Annex I emissions limitations. Figure 4 shows the percent reduction in emissions from 2010 required by each region to meet its emissions goal. As mentioned earlier in the discussion of the construction of the regional reference cases, emissions growth rates, by affecting the emissions projection in 2010, significantly affect the cost of mitigation. Within the OECD regions, permit prices under independent mitigation are lowest in Australia, where it requires $117 per tonne of carbon equivalent to comply with the Protocol in 2010, and highest in Japan, where the price rises to $458 per tonne.

Energy Sector Adjustments in the United States

In the absence of emissions trading, the Kyoto quantified emissions limitations and reduction commitments anchor a nation's energy system to 1990. There are a limited number of ways to meet this target. Nations can either

- Capture and sequester carbon—in the time frame of the first commitment period this is limited to afforestation and reforestation;

- Undertake Fuel Switching—either expanding the production of non-carbon emitting energy sources such as hydro, nuclear, and solar power or biomass, or shifting from fuels with high carbon-to-energy ratios (such as coal) to fossil fuels with low carbon-to-energy ratios (such as natural gas);
- Conserve Energy—increasing the amount of services provided by a fixed energy input, or a reduction in the provision of energy services.

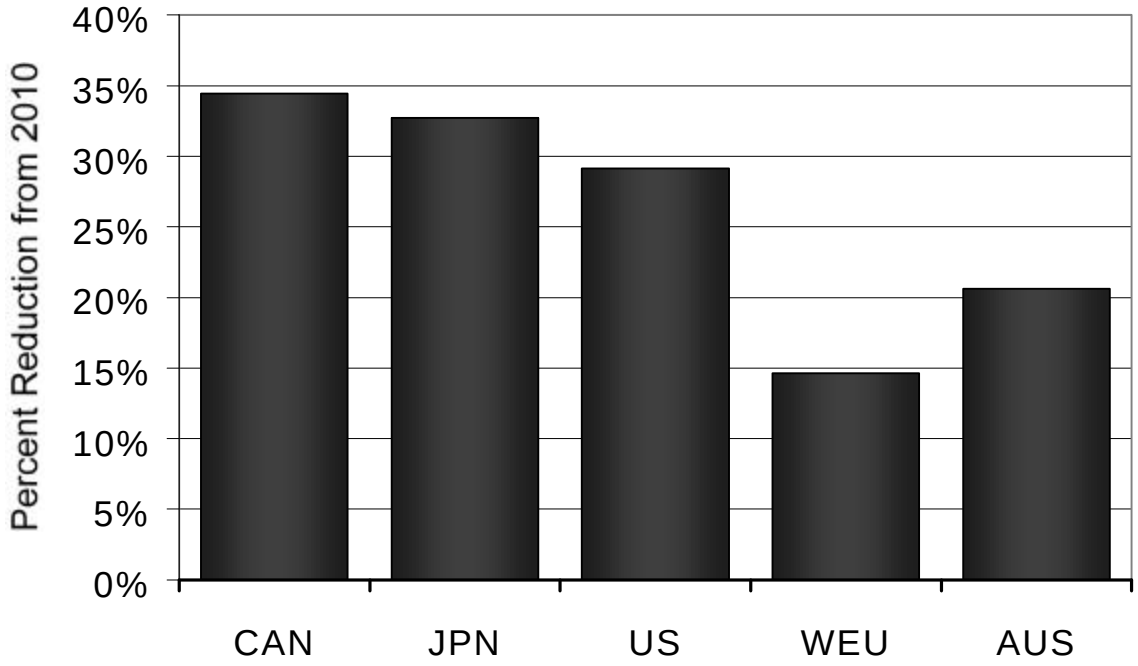

Figure 4. Percentage Reduction in Emissions Required to Meet Kyoto Constraint

One of the notable responses in the United States is the substitution of natural gas for coal in the production of electric power. Fuel switching from coal to natural gas and renewable fuels in the United States electricity generation sector accounts for roughly 40 percent of the reduction in total emissions. Energy conservation makes up the remaining 60 percent of the reduction in 2010.

The domestic carbon tax of $168 in 2010 in the independent compliance case results in a reduction of total energy consumption by 20 percent relative to the reference case. Consumption of coal drops by three-quarters while consumption of petroleum drops by 13 percent. Consumption of natural gas, however, increases by 3 percent due to fuel switching. Figure 5 shows the change in energy consumption by fuel in the year 2010 under the independent compliance regime relative to the 2010 baseline value.[5] Although we do not account for carbon capture and sequestration in this analysis, the figure does show indications of fuel switching and conservation. In the United States, the carbon tax leads to a slight increase in total gas consumption and a significant amount of conservation. Meeting the commitment in Western Europe leads to significantly less conservation but a much greater degree of fuel switching from fossil fuels to nuclear

[5] Eastern Europe and the former Soviet Union are not included because their 2010 emissions are not constrained by the quantified emissions limitation.

power. Note that even though emissions are drawn below 1990 levels, the scale of the total energy system remains above 1990 levels for all regions but Japan and Canada. The fuel switching mentioned above allows the emissions targets to be met without reducing total consumption by the same percentage as the required reduction in emissions.

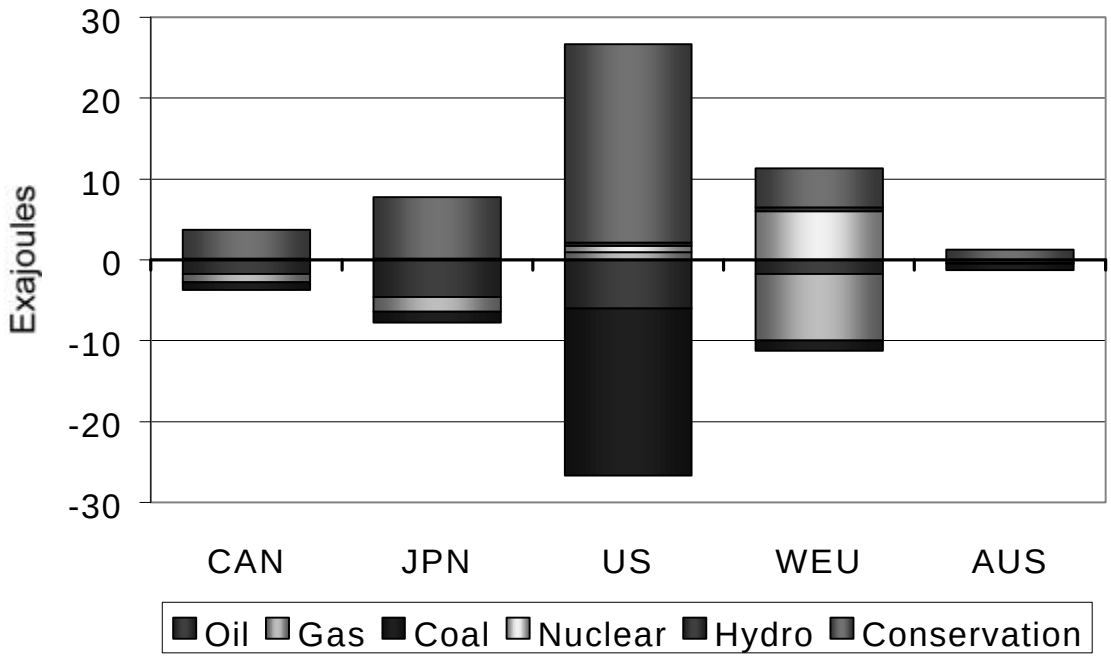

Figure 5. Change in 2010 Energy Consumption from Baseline by Region and Fuel

Total electricity generation in the United States drops by 24 percent as a result of the emissions constraint. The permit fee results in the share of electricity generated from coal dropping from 51 percent in the reference case to 11 percent in the independent compliance case. The reduction in electricity generation from coal is partially compensated for by fuel switching to natural gas. The share of electricity generation from natural gas more than doubles from 21 percent in the reference case to 48 percent in the independent compliance case. Even so, conservation accounts for 70 percent of the drop in total generation from reference levels. Figure 6 shows how the utility sector in the United States switches from coal-fired to gas-fired electricity generation technologies given a range of permit fees.

The imposition of permit fees has a depressing effect on the price of coal. Gas prices under the independent compliance regime increase nearly 20 percent in response to increased demand from the utilities sector. But interestingly, it has relatively little effect on the overall consumption of natural gas. The increased demand for gas to replace coal in power generation is roughly offset by a decrease in the demand for natural gas for end-use applications resulting from the higher price, leaving total consumption relatively stable.[6]

[6] Other models have shown substitution of gas into the non-utility end-use sectors (e.g. Manne and Richels, 1998). This increase in demand could drive up gas prices even further, possibly limiting the extent to which utilities would increase their consumption as a substitute for coal. Such a result could increase the permit fee necessary for the economy to comply with the required emissions reductions.

Certain caveats apply to the discussion above concerning the substitution of natural gas-fired electricity generation capacity for existing coal-fired capacity. The analysis requires that the emissions targets be in place indefinitely. If the targets are believed to be only temporary, the optimal degree of substitution is diminished and the permit fee required for Protocol compliance raised. The permit fees required for mitigation also depend on the cost of altering the existing infrastructure necessary to supply natural gas to potential new users. Extending pipelines to particular areas, for example, might increase the cost of gas enough so as to discourage switching from coal-fired plants in those areas.

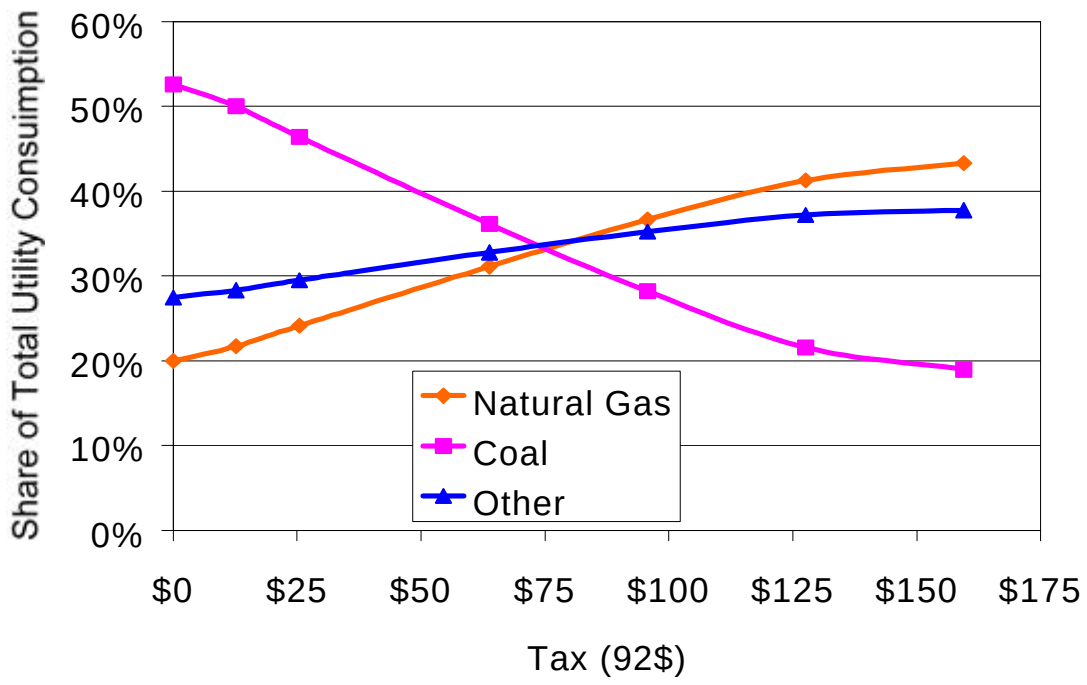

Figure 6: The Relationship Between Carbon Tax and Coal Utilization in the SGM

Energy Sector Adjustments in Australia

The energy system in Australia reflects a relative abundance of coal and scarcity of domestic natural gas supply. It has the lowest cost of independent compliance among OECD regions primarily because it has the highest allowable percentage emissions growth relative to 1990, eight percent. Independent compliance with the Kyoto Protocol is accomplished primarily by reducing coal usage and secondarily with reductions in oil consumption.

Energy Sector Adjustments in Western Europe

The energy system in Western Europe is very different from that of the United States. Whereas relatively low energy tax rates and high dependence on coal for electric power generation characterize the United States, Western Europe is characterized by relatively high energy-tax rates and only modest use of coal for power generation. As Figure 5 shows, the model responds to a constraint on carbon emissions by shifting to non-carbon power generating technologies—in particular, nuclear power. This is a case that may be either politically or technically impossible to realize. Outside of France few nations would allow a

significant expansion of nuclear power. Furthermore, given the lead time required to build and deploy a new nuclear facility, even in France, this option will be available for only a brief period if it is to impact emissions by the beginning of the budget period. If it takes ten years to bring a new facility on line, that process must commence in 1998 to have an influence on the first compliance year, 2008.

When no new nuclear power generation capacity is allowed, the cost of compliance rises from $130 per tonne of carbon equivalent in 2010 to $144. Without a nuclear option more of the Western European mitigation must come from conservation.

The model shows relatively little energy conservation in Western Europe relative to the other Annex I regions. This reflects the fact that existing energy prices are already high, and whereas a $100 per tonne carbon equivalent tax raises the price of end-use fuels by between 20 and 25 percent in the United States, this is not the case in Western Europe. As a consequence of the relatively smaller price signal in Western Europe than in the United States, there is a relatively smaller conservation response.

Energy Sector Adjustments in Canada and Japan

The energy systems in Canada and Japan are quite different from each other. The Canadian energy system obtains a high fraction of electric power from hydroelectric facilities, while oil and gas dominate the Japanese system. Canada is a nation with low population density, with a transportation system reflecting a greater need to transport people greater distances. In contrast Japan has relatively high population density and a transportation sector geared appropriately. However, these two systems are similar in that both systems have relatively little coal use and have high percentage emissions mitigation requirements—more than 30%—relative to the reference case emissions in the year 2010. The minimal domestic coal consumption available for replacement by alternative fuels leaves these nations with the two highest marginal independent-compliance costs in our analysis.

Imperfect Energy Transitions

In the preceding analysis we have assumed that investment decisions begin to be altered starting in the year 2000. This assumption implies a smooth compliance transition, which need not be the case. We have run excursions to explore the implication of a less than perfect transition under independent compliance in the United States in the year 2010. In one exercise, we systematically reduced the mitigation potential available outside the electric utility sector. As the ability of the non-utility sectors to reduce emissions is diminished, the burden borne by the electric power sector increases—implying higher marginal abatement costs. The relationship between the burden borne by the utility sector and marginal abatement cost is shown in Figure 7.

At a marginal cost of approximately $100 per tonne carbon equivalent utilities provide approximately 45 percent of the mitigation in the year 2010 by substituting gas plants for coal plants. But the marginal cost must reach $255 per tonne carbon equivalent before the mitigation reaches 70 percent of the 2010 requirement. If the non-utility sectors have difficulty in reducing emissions, either because technical options are unavailable or because emissions mitigation requirements were not anticipated in investment planning during the decade prior to the first compliance year, 2008, then the marginal cost could exceed $250 per tonne of carbon equivalent emission.

Relaxing the assumption that utilities begin anticipating implementation of the Kyoto Protocol in investment decisions from the year 2000 onward has a similar effect on the marginal cost of mitigation. In the case of perfect foresight, utilities replace existing coal-fired capacity with gas turbines. This implies

building new gas transmission and distribution lines as well as the turbines. When no anticipatory actions are undertaken, utilities are left with the option of either paying for the carbon emissions and continuing to operate the plant, or shutting down. Utilities that are forced to shut down lose the value of the capital stock and cease to generate power but reduce emissions by the full amount of the plant's capacity.

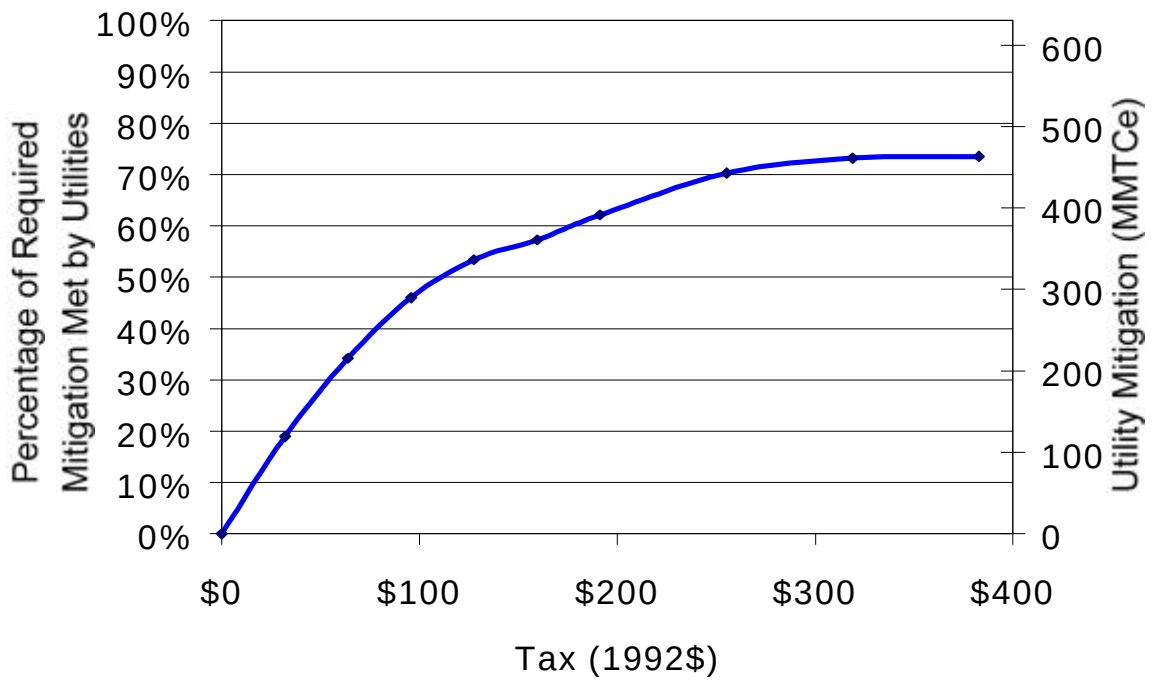

Figure 7: The Relationship between Utility Emissions Mitigation and Marginal Cost in the United States in the Year 2010.

Sensitivity of Results to Economic Growth in the United States

The reference case shows United States GDP growing at an average rate of 2.1 percent per year from 2000 to 2010. Because the future rate of economic growth is uncertain, we performed two additional analyses to determine the sensitivity of marginal costs to the United States to changes in its GDP growth rate. To conduct this experiment we adjusted the total factor productivity in the 'everything else' sector to increase or decrease the average rate of growth by 1 percent per year relative to the 2.1 percent reference level while holding the carbon equivalent-to-GDP ratio at reference case levels in 2010.

Changes in the expected rate of economic growth in the United States could have significant impacts on the costs of compliance with the Protocol. A decrease in the average annual rate of GDP growth from the reference level of 2.1 percent to 1.1 percent per year results in a marginal cost of mitigation for independent compliance of $85 in 2010, just over half of the $168 per tonne cost required under reference case growth assumptions. The high growth case of 3.1 percent per year, or 1.0 percent above reference level growth rates, results in a cost of $301 per tonne, nearly 80 percent higher than under reference assumptions.

Annex I Trading

In an Annex I trading regime, regions may only emit more carbon than their allocated emissions rights allow if another Annex I region is willing to sell a corresponding number of its permits, thereby forcing the seller region to reduce its domestic emissions beyond the required target. This is modeled as if a common carbon tax were applied to all Annex I regions to meet the overall Annex I emissions target. Since the overall Annex I target is met with equality, excess emissions in permit buying regions are exactly matched by emissions credits in permit selling regions. The permit price is inferred to be the common Annex I tax rate and is used to compute the value of sales and purchases.

Allowing trade among Annex I parties raises a number of additional, important issues. These include:

1. Reference emissions in Annex I nations: Of particular interest is the degree and nature of recovery of Eastern Europe and the former Soviet Union. These countries are the largest block of potential suppliers of emissions credits to the market. The number of credits available will have an important influence on the international price of credits, and the incentive to mitigate domestically.
2. Trade behavior: Since the number of sellers could be small, there is potential for monopolistic behavior. Thus a smaller number of permits could be placed on the market than are potentially available. The monopolistic selling position of a few nations could imply a floor on the price of mitigation credits.
3. Trade Rules: Rules may be written which restrict trade.
4. Incomplete markets: Market formation may be incomplete. Trade may occur among a subset of regions. For example, the European Union could form one trading regime and the other Annex I nations could form another. This is sometimes referred to as the "double bubble."

"Base mitigation credits" in Eastern Europe and the former Soviet Union

It has been argued that the excess permits granted to the former Soviet Union and Eastern Europe should not be tradable because they would lead to lower environmental benefits than if the emissions could not be traded. The argument is that if each region meets its commitments independently, then total Annex I emissions will be lower than the quantitative emissions limitation. If trade is allowed, then Annex I emissions will be exactly equal to the quantified emissions limitation. The difference is the amount of extra emissions that go into the atmosphere due to trade in the budget period. The problem with this argument is that it is static. It presumes that there is only one budget period. But if there is only one budget period and no subsequent mitigation commitment, then it is hard to see why any party would ever undertake a Kyoto commitment.

But, if there were multiple budget periods, and no trade, the excess permits would be banked by the former Soviet Union and Eastern European parties for use in subsequent periods when 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 trade in "base mitigation credits" is allowed. And to the extent that there is any difference to the environment, the long-term, year 2050, concentration is somewhat lower if emissions are released earlier in the century rather than later. The carbon cycle has a bit longer in that case to remove carbon from the atmosphere.

The Cost of Compliance with Annex I Trading

Trading regimes are inherently more complicated than non-trading regimes, particularly when the rules for trade have not been established. But even if the rules were known, the circumstance could exist in which the number of buyers and/or sellers is small, raising the issue of market power. We examine four cases:

1. Competitive permit supply
2. Monopolistic permit supply
3. Trade limitation
4. The "Double Bubble"

Competitive Permit Supply

Under a competitive permit supply model, suppliers of permits are numerous and no single permit vender can affect the price received by withholding permits from the market. This situation would be the case if all permits were distributed within nations to numerous private parties. The competitive prices of Annex I permits in comparison to independent compliance prices are shown in Table 6.

Permit prices are lower with Annex I trading than with independent compliance, Table 6. In the independent emissions mitigation case, greenhouse gas emitters in the United States may undertake emissions mitigation options available only within the United States. In the Annex I joint case, however, regions are included that have mitigation options with significantly lower costs, thereby lowering the marginal cost to the emissions permit market of meeting the desired emissions targets. This flexibility in meeting emissions targets has a significant impact on permit prices and costs, especially in the case in which "base mitigation credits" are available on the market at no cost to the supplier.

Table 6. Emissions Taxes/Permit Prices Required to Meet Policy Goal (1992 US$ per Tonne of Carbon Equivalent)

	Independent Compliance		Annex I Trading	
	2010	**2020**	**2010**	**2020**
Canada	350	387	73	118
former Soviet Union	--	--		
Japan	458	430		
United States	168	199		
Western Europe	130	208		
Australia	117	141		
Eastern Europe	--	41		

A fixed emissions level and an increasing reference case emissions level imply both a rising percentage emissions reduction and a rising price of meeting the fixed emissions target over time. Increasing population in the United States, and the economic growth that accompanies it, put upward pressure on emissions that in turn forces larger shifts away from coal toward natural gas and renewable energy sources.

As the permit prices decrease across trading regimes, the United States purchases increasing quantities of permits from abroad, thereby enabling it to emit more than its allocated permits alone would allow. Figure 8 shows total emissions in 2010 for each region disaggregated into emissions allowable under the Kyoto commitment, or the level allowed under independent compliance, and additional emissions granted by the purchase of permits. Under independent compliance, the United States is limited to emitting only what it is allocated under the Kyoto Protocol. With Annex I trading, however, the United States purchases 248 MMTCe worth of permits in 2010 from two sellers, the former Soviet Union and Eastern Europe.

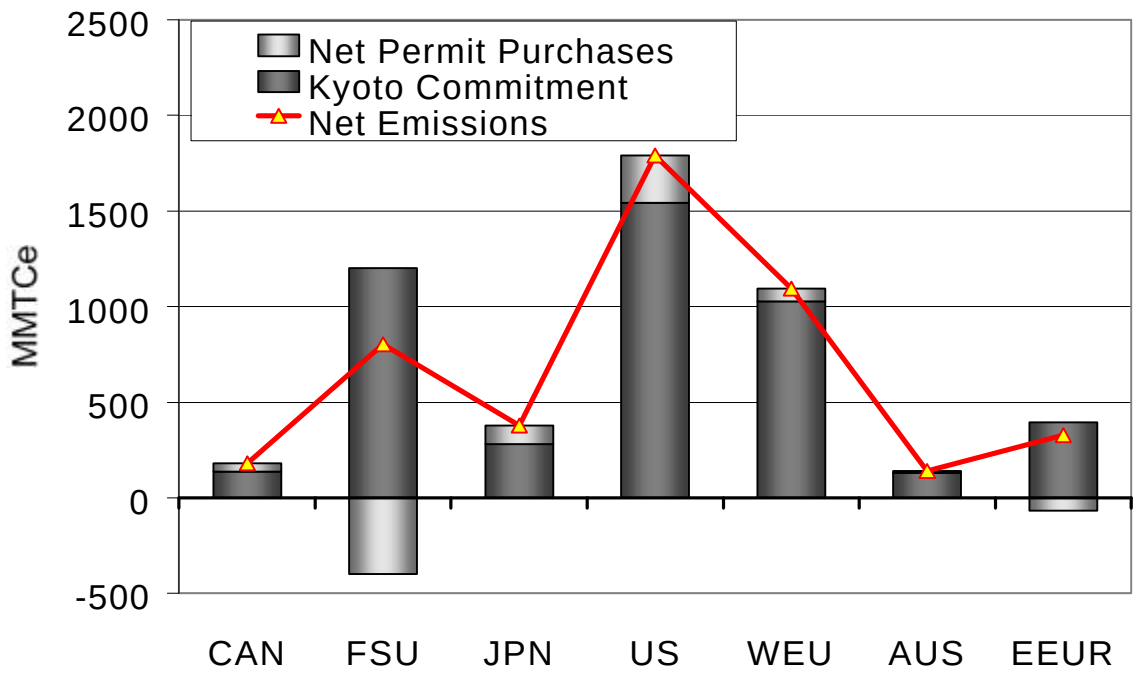

Figure 8. Annex I Emissions by Region – Kyoto Protocol

Cost calculations for the emissions trading cases are different than in the independent case. Costs for the trading case must take into account the value of permits traded. For a buyer of permits, such as the United States, net cost therefore includes the direct cost of domestic mitigation plus expenditures on carbon permits. A breakdown of these two cost components is shown for the Annex I trading case with competitive permit supply in Figure 9. The direct costs of domestic mitigation range from 15 to 55 percent of the net cost for Annex I regions. The remaining cost, the difference between the 'direct cost' and 'net cost' lines in Figure 9, is the value of emissions permits that would be purchased from other Annex I countries.

Increased growth in the regional energy systems is allowed by the purchase of permits. Figure 10 shows the percent change in primary energy consumption in 2010 relative to 1990 baseline consumption for permit buyers for three cases: the baseline, independent compliance, and Annex I permit trading. Annex I permit trading restores a portion of the growth in the regional energy systems lost under independent compliance. The impacts of permit trading are especially evident in Japan and Canada. Trading under an Annex I permit trading regime allows Japanese and Canadian energy consumption to expand to approximately two-thirds of reference case emissions growth.

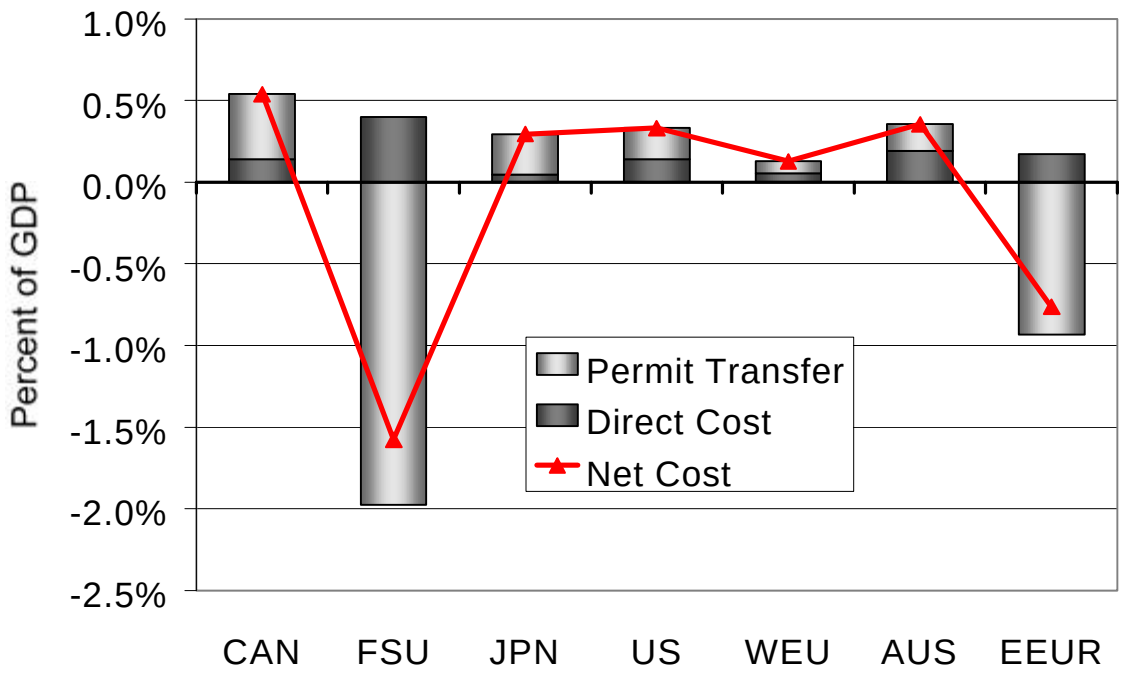

Figure 9. Breakdown of Costs by Region – Kyoto Protocol

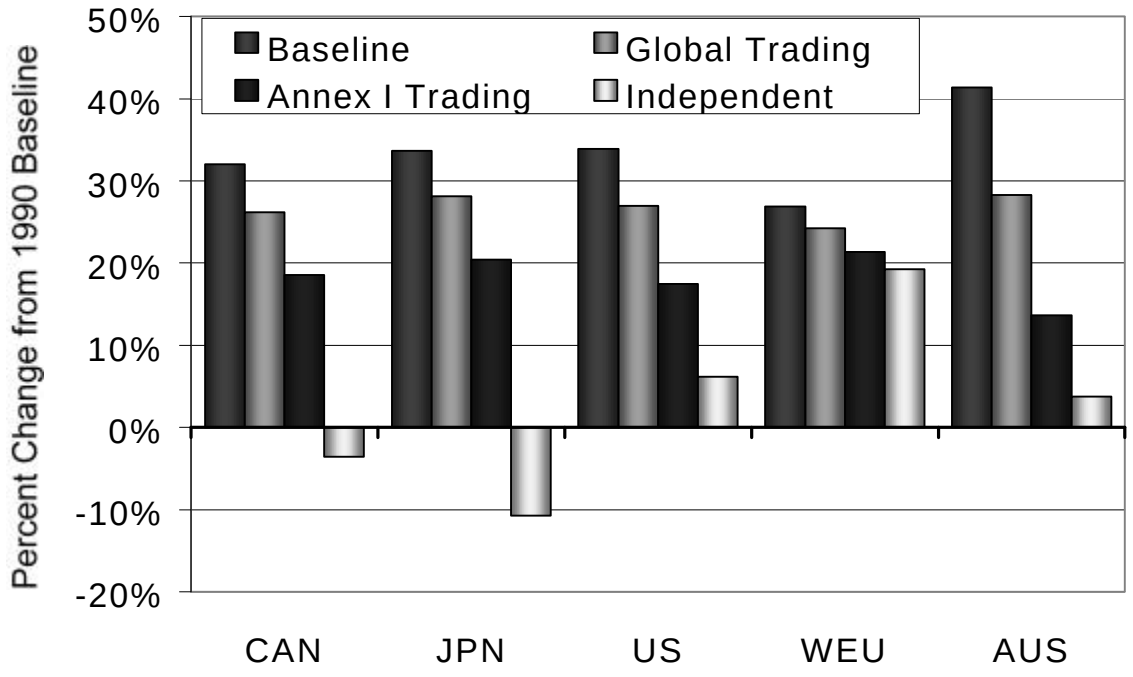

Figure 10. Percentage Change in Energy Consumption to 2010 from 1990 Baseline – Three Permit Trading Scenarios

The former Soviet Union and Eastern Europe regions, the permit sellers under Annex I trading, face no reductions in energy growth under independent compliance but undertake large reductions in a permit trading regime to generate more marketable permits. The heavy dependence on coal in Eastern Europe and the multiplicity of conservation opportunities in the former Soviet Union provide inexpensive mitigation credits. These reductions are predicated on a competitive model of economic behavior. The conditions necessary for such a model may be unrealized, however. We further note that we assume no problems with measurement or verification of emissions mitigation. Such real-world problems could limit market performance.

Sensitivity of Results to Mitigation Supply

In the following two sections, we discuss the impacts on Annex I permit prices of the former Soviet Union and Eastern Europe limiting, either by choice or as required by the final treaty, sales of permits to other Annex I regions. In both cases, the available quantity of "base mitigation credits" in the two regions plays a significant role in determining the supply of permits to the market. Because the quantities of "base mitigation credits" available to the former Soviet Union and Eastern Europe are highly uncertain, we first examine the sensitivity of the Annex I permit price to the supply of these permits.

Several factors might contribute to a change in the amount of "base mitigation credits" available for sale to the Annex I permit market relative to the reference case. These factors could include, among other things, changes in the economic growth rate of the former Soviet Union and Eastern Europe, choices in the fuel mix as these economies recover, and methods of accounting for land-use change under the final Protocol. For the purpose of this analysis, we do not specify which of the many possible contributing factors or combinations of factors might lead to a change in the number of these permits.

Table 7 shows the impact on Annex I permit prices of altering the number of "base mitigation credits" that the former Soviet Union and Eastern Europe have available to sell in the permit market. We vary the availability of these credits from 0 percent of reference level permits, or no "base mitigation credits" at all, to double the reference level supply. With no "base mitigation credits" available to the Annex I market, permit prices to the Annex I regions rise by nearly 55 percent. If an Annex I permit trading regime is to develop, therefore, future developments in the former Soviet Union and Eastern Europe are likely to impact compliance costs both domestically and throughout Annex I.

Table 7. Sensitivity of Annex I Permit Prices in 2010 to Mitigation Supply (1992 US$ per Tonne of Carbon Equivalent)

Percentage of Reference Case "base mitigation credits"	Annex I Permit Price (1992 US$)
0%	$113
50%	$92
100% (Reference)	$73
150%	$56
200%	$41

Monopolistic Permit Supply

If the Russian Federation and Ukraine were the dominant sellers of emissions mitigation credits, these governments could control the supply of permits centrally. From a national perspective, it is never optimal to sell permits beyond the point at which total revenues begin to fall. Since from the perspective of a monopolist adding permits to the market always lowers the price, the trick is to never add permits beyond the point at which the price declines faster than permits are being added to the market. If revenues can be maximized without exhausting the supply of "base mitigation credits," then supply cost is zero and no more sophisticated model is required for a single period analysis. Of course, adding multiple periods or non-zero costs of permit creation to the problem creates situations in which still fewer permits might be introduced for sale in the first budget period.

If a seller anticipates that the price of a permit will rise faster than the rate of interest, then it pays to hold the permit for sale in a later period. If, on the other hand, the seller anticipates that the permit price will rise less rapidly than the rate of interest, it pays to cash the permit and invest the proceeds. Note that the price of permits rose at a rate less than three percent per year in the competitive case.

For the purpose of this analysis, we combine the former Soviet Union and Eastern Europe regions and treat them as a single monopolist. The monopolist maximizes its profits, or the difference between its revenues from permit trading and its costs of domestic mitigation, in each time period without respect to the potential value of the permits in later periods. The potential supply of permits available to the permit buying regions includes any excess in emissions rights above reference emissions, "base mitigation credits" which might exist in both regions, and any permits created by domestic mitigation undertaken within the seller regions. The monopolist controls the supply of permits and sells the permits at the resulting market price.

In the year 2010 a revenue-maximizing monopolist would withhold permits to the point at which the price rose to $105 per tonne of carbon equivalent.[7] This market price is 44 percent higher than the competitive market price. The sellers restrict the supply of permits to 62 percent of the permits available in the competitive case. As a result, the combined sellers generate 10 percent more profits under a monopolistic supply regime than under the competitive supply regime. Note, however, that even the monopolistic permit price under the Annex I permit trading regime is less than the permit prices faced by the regions under independent compliance.

As one might expect given the level of the permit price, monopolistic permit pricing restricts the regional energy systems by more than competitive Annex I trading but by less than the independent compliance regime. Energy consumption in Japan, for example, increases by 16 percent from 1990 to 2010 under monopolistic pricing, near to the 20 percent achieved under competitive pricing and well above the drastic reductions undertaken in an independent compliance regime. Growth in the United States is reduced from 17 percent in the competitive case to 12 percent in the monopolistic case.

[7] We also ran a case in which the former Soviet Union acted as a monopolist without collaboration by Eastern Europe. The resulting permit fee for Annex I permit trading, including the sale of some permits by Eastern Europe, is $99 per tonne of carbon equivalent. Total profits for the former Soviet Union are 3 percent lower than in the case in which the monopoly includes Eastern Europe.

Limited Trading

Limits may be placed on the fraction of a party's quantified emissions limitation and reduction commitment that may be satisfied with allowances originating outside of that party's boundaries. Such limits may be non-binding. That is, they may be set at levels at which regions' behavior would not be constrained. If they are set at binding levels, then the marginal cost of mitigation for a party is simply that cost of the final mitigation action necessary to satisfy the domestic requirement. In a competitive permit supply market the marginal cost of international permits would be set by the interplay of supply and demand among parties for whom the constraint is non-binding.

At the June meeting of the Framework Convention on Climate Change's subsidiary bodies in Bonn, Germany, two proposals were presented regarding Annex I permit trading and limits on that trading. The United States and seven other industrialized nations, including the Russian Federation and Japan, proposed that Annex I trading of all six greenhouse gases considered under the Kyoto Protocol be permitted without limiting the number of permits bought and sold by a particular region. This proposal describes the trading system that we have used thus far in this analysis. Less than a week later, however, the European Union, Switzerland, and seven Eastern European nations proposed an as yet unspecified ceiling on the number of permits a nation could purchase from the international market. Their proposal also required that Annex I permit sales be limited so that net permit transfers from a country could not exceed the amount of emissions mitigated domestically. This condition would effectively limit the portion of "base mitigation credits" that the former Soviet Union and Eastern Europe could sell to the amount of domestic reductions that each region undertakes. Such a rule would ensure that the total Annex I reductions under a permit trading regime would be at least as great as the total reductions required under independent mitigation. Such proposals are difficult to implement. The degree of realized mitigation is impossible to calculate. There is only one history that will ever be recorded, and therefore no unambiguous reference case will ever exist against which to compare the realized historical emission.

This is not a problem from the perspective of a model, however. We consider here a ceiling on permit purchases from the international market set at 10 percent of each region's allowable emissions under independent mitigation as defined in the Kyoto Protocol. For example, because the United States has an emissions cap of 1,542 MMTCe in 2010, it would be limited to purchasing a maximum of 154 MMTCe in permits from the international market to meet its obligation. As suggested in the European proposal discussed above, we also limit sales of "base mitigation credits" permits from the former Soviet Union and Eastern Europe to the number of tonnes of carbon equivalent mitigated domestically. For the former Soviet Union to sell all 247 MMTCe of permits, therefore, it would need to undertake at least 247 MMTCe of domestic mitigation.

A ceiling on permit purchases implies that each region will face a distinct marginal cost for its domestic mitigation activities and another cost for the permits it purchases from the international permit market. The domestic price, as in the independent mitigation case discussed above, will be a function of each particular region's marginal cost curve and the ceiling placed on permit trading. The marginal cost for each region is reported in Table 8.

The entire market for permits under this regime can be satisfied with sellers providing permits to the market at price of $64 per tonne of carbon equivalent in Eastern Europe and the former Soviet Union.
But there is no unique market clearing price under this particular set of rules. The domestic price of mitigation within potentially buying regions and the cost of mitigation supply in potentially selling regions bound the range of prices.

Table 8. Permit Prices in 2010 Under Limited Permit Trading Case (1992 US$ per Tonne of Carbon Equivalent)

	Permit Price (1992 US$)	
	Domestic Marginal Cost in Buying Regions	Domestic Marginal Cost in Supplying Regions
Canada	197	
former Soviet Union		64
Japan	304	
United States	100	
Western Europe	47	
Australia	60	
Eastern Europe		64

The "Double Bubble"

As mentioned earlier, permit trading may occur among only a subset of the Annex I regions. In the "Double Bubble" case, the Western Europe region is removed from the Annex I trading bloc, leaving it to meet its obligations independently. For Western Europe, the necessary carbon taxes and energy impacts are the same as under its independent compliance case. But for the remaining regions in the permit market, the departure of Western Europe results in a 2010 permit price that is lower than in full Annex I competitive trading--$64 per tonne as compared to $73 under full Annex I trading.

The Clean Development Mechanism

The Clean Development Mechanism (CDM) was created as a vehicle which would allow non-Annex I nations to continue to pursue economic growth while at the same time have access to additional resources for the purpose of reducing greenhouse gas emissions. In the words of the Protocol:

> *The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.*

The CDM provides a mechanism in which certified emission reductions can be created on a project by project basis. Annex I parties can use these certified emission reductions to contribute to compliance with part of their quantified emission limitation. The CDM is to be subject to the authority of the Conference of the Parties and will be supervised by an executive board. Participation in the CDM is voluntary.

Certified emission reduction credits can be created by projects as long as these projects:

1. Lead to real, measurable, and long-term benefits related to the mitigation of climate change, and
2. Undertake reductions in emissions that are in addition to any that would occur in the absence of the certified project activity.

Interestingly, the CDM can create certified emission reduction credits beginning in the year 2000, and these credits can be applied to the budget period.

At the writing of this paper the rules for creating certified emission reduction credits have not been written. Therefore, we can not directly simulate the impact of the CDM on permit prices and costs of mitigation. However, full global trading of emissions rights provides a lower bound on permit prices and mitigation costs. The CDM should provide a cost of mitigation that lies between the cost of Annex I trading and full global trading.

Full Global Permit Trading

In the global trading case, emissions rights are allocated to Annex I regions at the same levels as in the Annex I trading case. Under global trading, however, the Annex I regions are allowed to purchase permits from each other as well as from non-Annex I regions so long as the global emissions constraint is met. The global constraint in each period is composed of the Annex I constraint and the sum of the non-Annex I regions' reference level emissions in that period. The SGM is used to determine a global permit price just large enough to meet the global emissions target.

Non-Annex I regions are not required to constrain their emissions in the global trading scenario. Under this hypothesized global trading regime, non-Annex I regions participate in the market for emissions permits only when it is to their economic benefit to do so. These regions are allocated permits equal to their projected reference emissions, so they only reduce their emissions by an amount equal to the number of permits they wish to sell.

Expanding the supply of emissions mitigation through global permit trading results in significantly lower permit prices than those achieved under the Annex I permit trading scenarios. Table 9 shows the 2010 permit price under global trading as compared to the independent compliance and Annex I trading regimes.

Table 9. Emissions Taxes/Permit Prices Required to Meet Policy Goal in 2010
(1992 US$ per Tonne of Carbon Equivalent)

	Independent Compliance	Annex I Trading		Global Trading
		Monopolistic	Competitive	
Canada	350	105	73	26
former Soviet Union	--			
Japan	458			
United States	168			
Western Europe	130			
Australia	117			
Eastern Europe	--			

Table 10 shows the composition of the permit market in the global trading case. As mentioned above, permits sold by the non-Annex I regions are generated by equivalent emissions reductions in those regions. The 308 MMTCe of permits sold by the former Soviet Union, however, include 247 MMTCe of "base mitigation credits."

The additional permits supplied by China account for most of the difference in permit prices between the Annex I permit trading and global trading cases. To sell such a large number of permits, China reduces its

energy consumption by nearly 24 percent in 2010 relative to the baseline consumption, with over 85 percent of that reduction coming from reduced coal consumption. The mitigation activities in China and the other non-Annex I regions are undertaken at significantly less cost than in the Annex I regions, however, thereby allowing the permit buying regions to emit more than in the Annex I trading or independent mitigation cases for less cost. And although the non-Annex I permit sellers achieve mitigation primarily through conservation, their energy consumption and carbon equivalent emissions continue to grow.

Table 10. Composition of the Emissions Permit Market in the Global Trading Case (Million Tonnes of Carbon Equivalent)

	Permits Traded (MMTCe)	
	Purchased	Sold
Canada	61	
former Soviet Union		308
Japan	121	
United States	470	
Western Europe	134	
Australia	25	
Eastern Europe		49
China		341
India		37
Korea		3
Mexico		19
Rest of the World		54
Total	811	811

Costs as a percentage of GDP are consequently the lowest for the Annex I regions under the global trading case, although Eastern Europe and the former Soviet Union lose some of their gains from trade to the non-Annex I permit sellers. Figure 11 shows the total costs as a percent of GDP to all regions separated into the direct cost and net permit trading revenues components for the global trading case.

The lower permit price induces only minor changes in the Annex I regions' energy systems relative to the reference case. Energy consumption in the United States in 2010 increases by 26 percent over 1990 levels, as compared to an increase of only 17 percent under Annex I competitive permit trading, as shown in Figure 10. The remaining Annex I permit buyers experience similar impacts, with energy growth under global trading falling about halfway between that in Annex I trading and the baseline case.

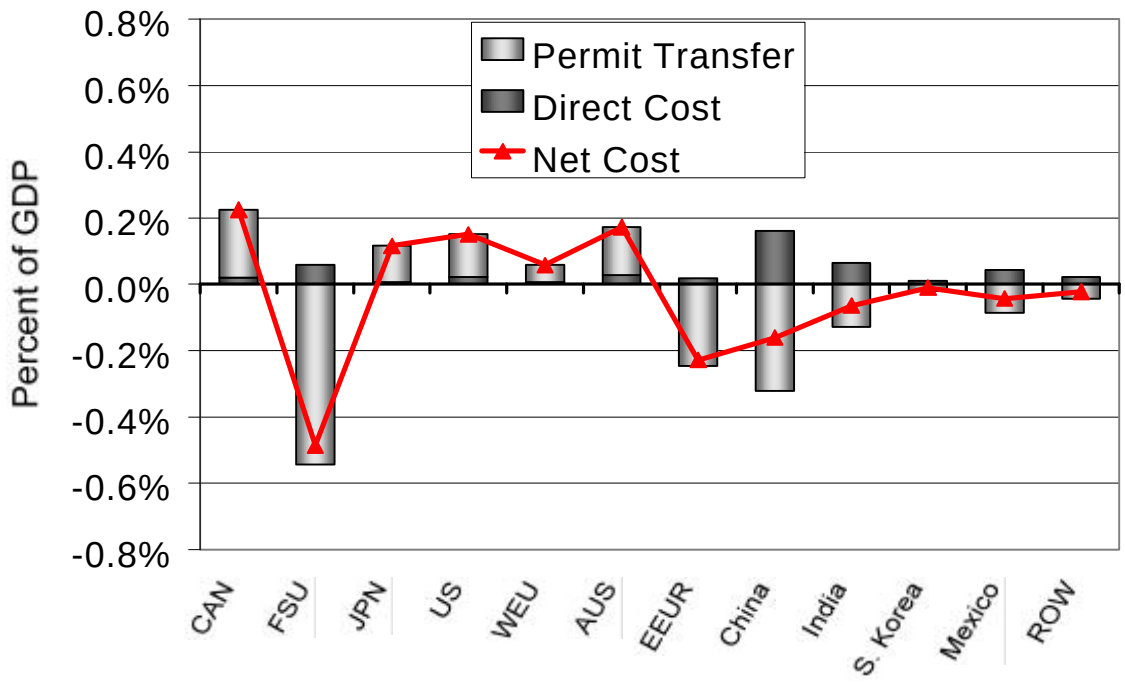

Figure 11. Cost by Component and Region in 2010 in Percentage of GDP - Global Trading

SUMMARY OF PARTICIPATION AND BEHAVIOR ANALYSIS

Where and under what circumstances emissions mitigation can be undertaken has a significant impact on the potential costs or benefits of participation in the Kyoto Protocol. Figure 12 shows the range of permit prices that the United States could face depending on which of the above permit trading frameworks is accepted as part of the final Protocol. Note that the other Annex I regions face the same range of permit prices as those shown in the figure except that the independent compliance values differ from region to region. Note also that in the case of Annex I Trading with EU Limits, the permit value is indeterminate. We therefore present a range; while the lower end of the range is determined by the conditions in the permit supplying regions, the upper end of the range is always region specific.

NON-CO2 GREENHOUSE GASES

The complexity of the Kyoto Protocol is not limited to issues concerning the characteristics of the permit trading mechanism. The protocol is also framed in terms of a suite of six gases and contains provisions for the inclusion of credits for terrestrial carbon sinks. This section will discuss the role of non-CO_2 greenhouse gases in determining costs and the following section will address the importance of land-use change emissions.

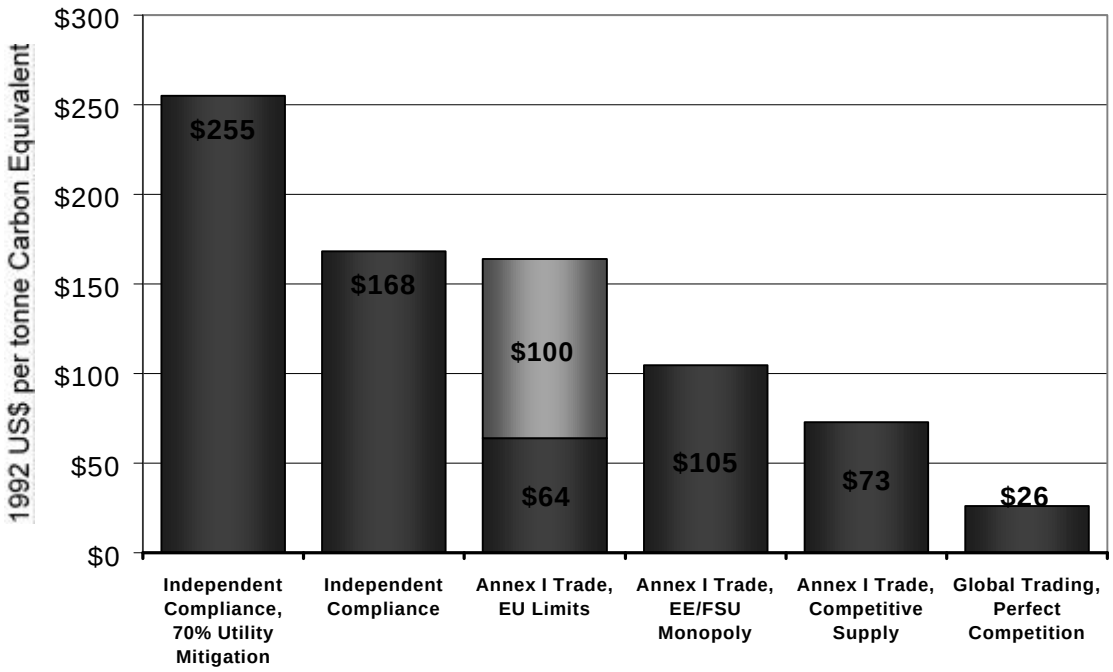

Figure 12. Range of Permit Prices for US

The contribution of non-CO_2 greenhouse gases to total carbon equivalent emissions in 1990 ranges from 10 percent in Japan to over 24 percent in Australia and Eastern Europe among the Annex I regions. Figure 13 shows the composition of total carbon equivalent emissions in 1990 and 2010 for the Annex I regions. The figure also shows the emissions target by region as specified in the Kyoto Protocol (see Appendix A). The former Soviet Union and Eastern Europe face targets that are above their 2010 baseline emissions levels, resulting in the "base mitigation credits" discussed in previous sections. Australia is allocated an 8 percent increase in emissions from 1990 to 2010, so its target as shown in Figure 13 is greater than the sum of its 1990 greenhouse gas emissions.

The results until now have assumed that the mitigation costs of the non-CO_2 greenhouse gases are proportionate to the cost of mitigating emissions of fossil fuel carbon. We refer to this case as the "Proportional Cost" case. In an attempt to bound the compliance costs with respect to these other gases, we modeled two additional mitigation cost cases. In the first case, the "$0 Cost" case, we assume that all of the non-CO_2 greenhouse gases can be mitigated in 2010 at zero marginal cost, thereby reducing the total commitment level by the 2010 emissions of these gases. In the second case, the "Infinite Cost" case, we assume exactly the opposite – that the non-CO_2 gases are impossible to mitigate at any cost. The "Infinite Cost" case therefore assumes that the Kyoto commitment must be met using reductions in carbon dioxide only. All of these scenarios share the same assumptions about land-use emissions as the previous cases.

Figure 14 shows the impacts on the marginal cost of independent compliance for the Annex I regions of the two non-CO_2 greenhouse gas mitigation cost cases and the original "Proportional Cost" case. Total Annex I emissions fall under the target in the "$0 Cost" case because of the reduced mitigation

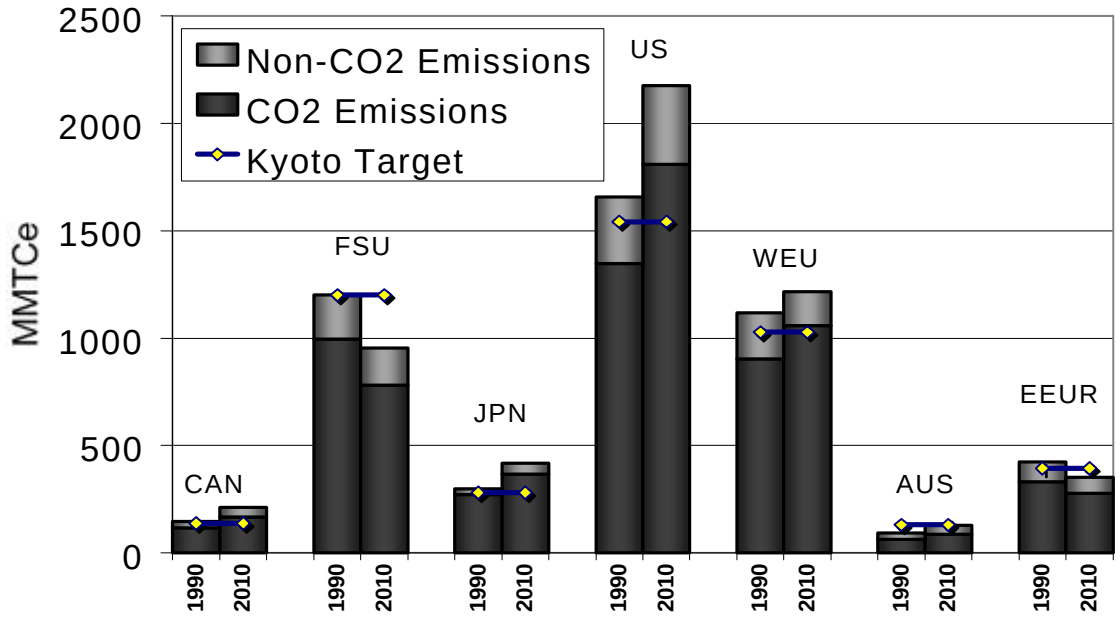

Figure 13. Breakdown of Kyoto Target by CO_2 and Non-CO_2 Emissions

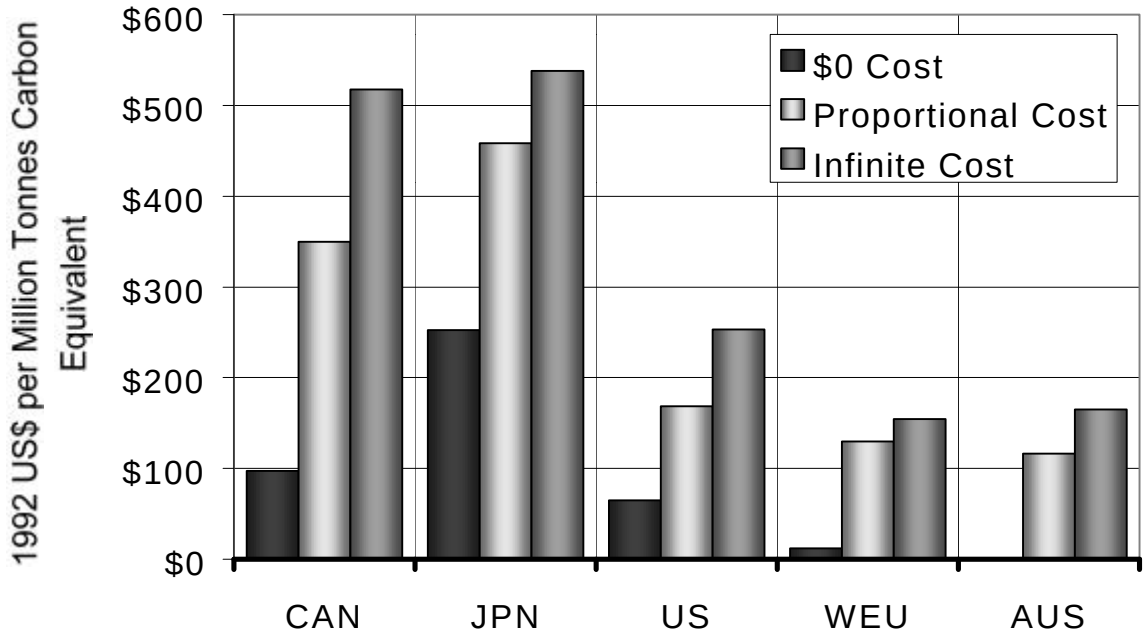

Figure 14. Permit Prices in 2010 Under 3 Non-CO_2 Gas Mitigation Cost Options – Independent Compliance

requirements in each country and the additional “base mitigation credits” available to the former Soviet Union and Eastern Europe from their non-CO_2 gas credits. The permit price in a competitive Annex I market with no constraint is zero. On the other hand, the Annex I competitive permit price under the “Infinite Cost” case increases from $73 under the “Proportional Cost” case to $93, causing total costs to increase as well.

LAND-USE EMISSIONS

In the preceding analysis we have ignored the potential of terrestrial carbon sinks on net carbon emissions under the Protocol. But the Protocol makes provision for land-use change emissions and sinks and, while net land-use emissions are small relative to fossil fuel carbon emissions, their treatment can have a major impact on the initial cost of achieving any emissions mitigation objective. Land-use emissions are presently treated as a flow in determining the base year (1990) emission rate. Most Annex I nations are in the process of reforesting, and therefore have net accumulation of carbon. This accumulation reduces net anthropogenic emissions.

Although this approach is appropriate for a global accounting of carbon flux, it may not be desirable as a methodology for setting 1990 base year emissions. The implication of this treatment is that if a nation were reforesting in 1990 and were committed to maintaining 1990 emissions rates under the Protocol, it could not reduce the rate of reforestation rate without lowering fossil fuel carbon emissions to below 1990 levels. Thus reforesting is not enough. The rate must be maintained. For nations that were deforesting, this method would create a base year emission target that is the sum of deforestation plus fossil fuel emissions which would in turn implicitly grant those nations a perpetual right to deforest. If the deforestation rate is ever reduced, for example as a consequence of destroying all forested areas, then fossil fuel emissions could be higher than 1990 levels by the 1990 rate of deforestation.

The delegates at Kyoto agreed that if a country in the base year had net land-use accumulation of carbon—negative land-use change emissions—the base year emissions for determining emissions limits would be determined by industrial emissions only. This method was termed the "gross" approach to accounting, a term which is anything but self-explanatory. The idea is that the country would note its stock of terrestrial carbon, not the change in stock. In other words, land-use emissions are ignored in computing the base emissions rate.

On the other hand, if a country were had net land-use carbon release, then it could count both industrial and land-use change emissions in determining its base year emission inventory. This accounting method became known as the “net” approach.

In the budget period, 2008 to 2012, all countries include both industrial and net land-use emissions in their emissions inventory. For those countries with net emissions from land-use change in the base year, the accounting method was then the "net-net" approach in that net emissions flows are used in both the base year and the budget year. If a country has a net accumulation, however, it counts as negative emissions only those accumulations of carbon that are the result of actions taken since 1990 in the areas of afforestation and reforestation. This method has come to be known as the "gross-net" approach in that net emissions are ignored in the base year but counted in the budget period.

Many issues remain to be worked out. The protocol stipulates that

> *The net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period shall be used to meet the commitments in this Article of each Party included in Annex I.*

This presents an interesting problem in what to count. Do soils beneath the forests count? Can normal anthropogenic forest management be counted? Given the nature of forest growth, the rate of carbon uptake in 2008 would be small for a program that began in 1998 due to the carbon absorption cycle by forests. Therefore, to the extent that net carbon uptake by sinks, or stores of carbon, is credited in the first budget period, it will largely be determined by an interaction between the rules and actions that were taken earlier. Unless interpreted very broadly, the language of the Protocol limits the potential impact of new initiatives.

For this analysis, we assume that the "gross-net" approach applies for all Annex I regions except Australia, for which we used the "net-net" approach. Because of the uncertainty surrounding the actual quantity of credits to be given for net land-use change emissions in the first budget period, we defined three levels of credits for each Annex I region, as shown in Table 11: no sinks credits, "half" sinks credits, and "full" sinks credits.[8] This quantity is specified exogenously in the budget period and is not priced in our analysis. For the analysis presented thus far, we have used the "no sinks" assumptions.

Table 11. Land-Use Change Emissions Assumptions for the First Budget Period (Million Tonnes of Carbon Equivalent)

	Land-Use Change Emissions Credits (MMTCe)		
	No Sinks	**Half Sinks**	**Full Sinks**
Canada	0	40	80
former Soviet Union	0	103	205
Japan	0	13	25
United States	0	52	104
Western Europe	0	30	60
Australia	-36	-36	-36
Eastern Europe	0	4	8

Varying the land-use change credit assumptions has significant impacts on the permit prices required for independent compliance for some regions and on the price under Annex I joint compliance. Figure 15 shows the permit prices for the Annex I regions for the three sinks options under independent compliance. The application of "full sinks" credits in the Canadian case more than covers Canadian mitigation requirements in 2010 thereby bringing its permit price in the independent compliance case to zero. The "half" and "full sinks" cases offer the former Soviet Union and Eastern Europe even more "base mitigation credits" than in previous cases, increasing their potential benefit from permit trading. The increased "base mitigation credits" also reduces the 2010 permit price of competitive Annex I joint compliance from $73 per tonne in the "no sinks" case to $46 and $23 per tonne in the half and full sinks cases, respectively.

[8] Australia values from Working Group on Public Health and Fossil Fuel Combustion, 1997. Other values from personal communication with Joe Aldy, Council of Economic Advisers.

The economic implications of alternative treatments of land-use change emissions are large and their treatment was one of the most hotly debated issues in the Kyoto negotiations. As discussed above, the size of regional carbon stores has a substantial impact on regional costs in the budget period. However, this is a short-term consideration. In the long term, land-use emissions mitigation potential is limited. Eventually all forestry programs approach steady-state carbon-to-land ratios. If a given plot of land is to continue to provide carbon uptake services, the existing biomass must be removed. Since the biomass resources can be used as a zero-cost energy form to replace fossil fuels, forestry programs ultimately mature into biomass energy programs.

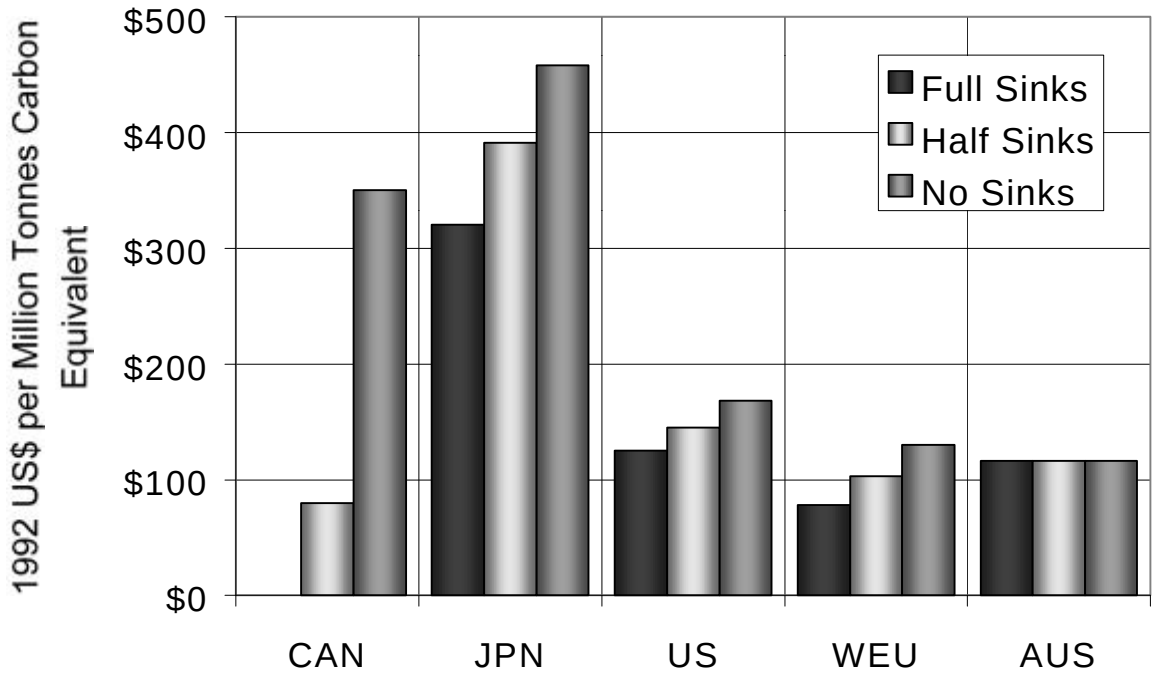

Figure 15. Permit Prices in 2010 Under Three Sink Options – Independent Compliance

DISCUSSION

In this section, we consider some of the lessons learned from this analysis and present further discussion of issues relevant to this type of analysis. First, the method used to measure costs can significantly vary the representation of the potential burden placed on an economy by a particular policy. Second, economic costs depend a great deal on our assumptions about future carbon emissions. Third, the distribution of costs among countries in a system of global permit trading is sensitive to assumptions on exchange rates as well as the initial allocation of permits. Fourth, any system of global trade in carbon permits implies potentially large transfers of wealth from one region to another. Finally, we discuss how some of our assumptions affect the results on costs.

Measurement and Reporting of Costs

As mentioned earlier in the paper, our cost measure is a direct cost net of international transfer payments due to permit sales between countries. Direct cost is defined here to be the area under the marginal abatement curve for carbon, which can be approximated as one-half of the marginal price of carbon multiplied by the amount of carbon abatement. This approximation is the same as that for deadweight loss. To provide a sense of scale to the rest of the economy, we often express cost as a percentage of GDP.

Of ultimate interest, however, is the impact on some broader measure of economic activity such as GDP or real consumption. There are many reasons why a change in GDP may differ from direct cost. In addition to direct cost, other cost components include the effects of pre-existing taxes, changes in terms of trade, and how tax revenues are recycled. Also, measurement of GDP or real consumption depends on the choice of index and base year used to construct that index. This reflects real-world problems in constructing a quantity index when relative prices are changing.

Determining the size of the indirect cost components has proven difficult, and is a topic of study for modeling groups participating in Stanford University's Energy Modeling Forum. Some modeling groups, including the SGM group, have chosen to report only direct costs net of sales of emissions rights. Other groups have reported overall changes in economic welfare, but without an indication of the relative sizes of the other cost components.

If the overall economic cost differs from direct cost, or if the market price of carbon does not reflect all costs to a nation, there are cases where nations will not gain from participating in a carbon emissions trading program. If social costs are much greater than private costs, sellers of emissions permits may be made worse off by selling permits and would not participate in emissions trading. More specifically, if the average social cost of permits sold exceeds the world permit price (marginal private cost), sellers of permits are worse off than if they had not sold any permits. That is, trade may make some **nations** (in this case nations selling carbon emissions rights) worse off rather than better off, even though the individual trading parties (in this case companies or persons) were all made better off. The implications of a substantial divergence between public and private interests, in the absence of apparent market imperfections, is important and goes to the heart of the motivation for free and open trade.

If we are to create mitigation scenarios where emissions trading is assumed, then we should verify that our cost measure is consistent with gains from emissions trade in all regions. The simple measure of direct cost net of permit sales does indeed report gains from trade in all regions. Beyond this, it would be informative to calculate as many indirect costs components as practical, and then determine whether any of these components could affect a nation's choice to participate in emissions trading.

For example, one of the indirect cost components is the additional deadweight loss due to pre-existing energy taxes. For a seller of permits, the additional loss is approximately equal to the reduction in tax revenue of the pre-existing tax, as a carbon tax is imposed to reduce carbon emissions below that country's emissions allocation. This cost component could be large enough to offset other gains from emissions trade. This suggests a bottom-up approach to measuring costs, beginning with direct cost net of permit sales, and then accounting for indirect cost components one at a time.

Role of Reference Emissions in Shaping Marginal Mitigation Costs

All of the results in this study depend on assumptions used to create a reference emissions scenario from the present to 2020. The amount of regional emissions mitigation required to satisfy the Kyoto emissions limitation depends directly on reference case emissions. In the Annex I trading cases, carbon permit prices are particularly sensitive to reference scenarios for potential sellers of permits, especially Eastern Europe and the former Soviet Union.

Among the Annex I countries, projecting future carbon emissions is especially uncertain for Eastern Europe and the former Soviet Union. Of particular importance is when emissions in these regions will once again reach 1990 levels. If this point is reached before 2010, then we model Eastern Europe and the former Soviet Union just as any other Annex I country. If this point is reached after 2010, then emissions restrictions are not binding in those regions until that point in time.

Foreign Exchange Rates

Permit prices for the global permit trading cases are very sensitive to assumptions about exchange rates. And while the United States follows a largely free market approach to exchange rates, most developing nations do not. Therefore, while it may be perfectly reasonable to assume that over the long-term the United States exchange rate with other free market trading partners would tend toward the purchasing power parity rate, this assumption is questionable with other partners. This is particularly true for developing countries where market exchange rates, in local currency per U.S. dollar, can be three to five times the corresponding exchange rate based on purchasing power parity. A global permit price of $100 per tonne translates, at market exchange rates, into a much higher relative price in the developing countries than in the United States.

Exchange rates based on purchasing power parity are usually used to compare income levels between countries, but market exchange rates must be used for goods actually traded between countries. This creates a potential problem for developing countries considering participation in a global permit trading program; carbon permits would be traded at market exchange rates, while GDP losses are better measured using purchasing power parity. For developing countries, losses in GDP could be greater than the value of carbon permits sold.

International Transfer Payments

We have modeled an international system of carbon permit trading that implies potentially large wealth transfers from buyers to sellers of permits. These transfers also change the pattern of other goods traded internationally. For a buyer of permits, this annual transfer of wealth is equal to the annual quantity of permits purchased times the world market price of the permits. The size of these transfers depends directly on the initial allocation of permits between countries. The initial allocation determines not only the number of permits traded by each country, but also whether a country is a buyer or seller of permits.

Each region in the SGM is assigned a period-by-period balance of payments constraint. Buyers of carbon permits must, therefore, export more of other traded goods than otherwise to pay for the purchased permits. Conversely, sellers of permits use the permit revenues to increase imports of other goods.

Sensitivity of Costs to Model Assumptions

Economic costs reported by the SGM for the Annex I nations are sensitive to model inputs, such as the choice of exchange rate and the modeling of revenue recycling.

If purchasing power parity exchange rates were used instead of market exchange rates for the developing countries, then any given world permit price would translate into a lower carbon tax in that country's local currency. For global trading cases, this would increase the global permit price needed to meet a global emissions limit, and the SGM would report higher costs for the United States.

In this study, we assume that all revenues from permit fees are recycled as a lump sum to consumers. If the government collects the fees for the emissions permits, another option is to use the revenues to offset other taxes. This has the potential to reduce overall costs, since revenues from permit fees would displace other distortionary taxes.

SOME FINAL OBSERVATIONS

Economic costs are reduced with a permit-trading program that equalizes the marginal cost of carbon between countries. The least expensive emissions reductions are taken first, regardless of where they occur. The permit prices shown in Figure 12 provide a good example of the importance of maximizing the degree of participation in the Protocol. Compliance costs are low only if participation is broad, including both Annex I and non-Annex I, and essentially competitive. Failure of major energy using regions to participate in the Protocol or the failure of markets to effectively access low-cost emissions mitigation potential raises compliance costs.

Limits on permit trading or monopolistic behavior on the part of the permit sellers, Eastern Europe and the former Soviet Union, affect the permit prices and resulting costs to the regions of participating in an international market. The number of participants in the market and the addition of regions with a large number of permits, such as China, will also impact the market price. The ability of these permit selling regions, whomever they may be, to price discriminate across regions will largely determine where in each region's range of permit prices the final price for permits will fall.

The incorporation of the non-CO_2 gases into the Protocol, the cost of mitigating those gases, and the credits granted for land-use change emissions will directly affect the type and amount of mitigation required by each nation.

The compliance costs to the regions will depend heavily on their current energy systems and the degree to which carbon capture and sequestration, energy conservation, and fuel switching are possible within those systems.

The range of possible costs for complying with the terms of the Kyoto Protocol varies by more than an order of magnitude, depending on how the Protocol is interpreted and implemented. Under the most favorable circumstances, costs could be zero for several regions as a direct consequence of the treatment of land-use emissions. The nature and degree of international participation has a similarly large influence on the cost of compliance. For the United States, permit prices could be as low as $26 per tonne of carbon equivalent emissions if all nations were engaged in an effectively competitive carbon market. On the other hand marginal compliance costs could be more than an order of magnitude higher if compliance is limited to domestic measures and mitigation opportunities are limited.

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APPENDIX

ANNEX B TO THE KYOTO PROTOCOL
Listed by SGM Region

1	**Australia**	**108**	**AUS**
2	**New Zealand**	**100**	
3	Bulgaria	92	**EEUR**
4	**Croatia**	**95**	**EEUR**
5	Czech Republic	92	**EEUR**
6	Finland	92	**EEUR**
7	**Hungary**	**94**	**EEUR**
8	**Poland**	**94**	**EEUR**
9	Romania	92	**EEUR**
10	Slovakia	92	**EEUR**
11	Slovenia	92	**EEUR**
12	Estonia	92	**FSU**
13	Latvia	92	**FSU**
14	Lithuania	92	**FSU**
15	**Russian Federation**	**100**	**FSU**
16	**Ukraine**	**100**	**FSU**
17	**Japan**	**94**	**JPN**
18	**Canada**	**94**	**CAN**
19	**The United States of America**	**93**	**US**
20	Austria	92	**WEU**
21	Belgium	92	**WEU**
22	Denmark	92	**WEU**
23	European Community	92	**WEU**
24	France	92	**WEU**
25	Germany	92	**WEU**
26	Greece	92	**WEU**
27	**Iceland**	**110**	**WEU**
28	Ireland	92	**WEU**
29	Italy	92	**WEU**
30	Liechtenstein	92	**WEU**
31	Luxembourg	92	**WEU**
32	Monaco	92	**WEU**
33	Netherlands	92	**WEU**
34	**Norway**	**101**	**WEU**
35	Portugal	92	**WEU**
36	Spain	92	**WEU**
37	Sweden	92	**WEU**
38	Switzerland	92	**WEU**
39	United Kingdom of Great Britain and Northern Ireland	92	**WEU**