The Cost of Mitigating United States Carbon Emissions in the Post-2000 Period

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Abstract

The Second Generation Model (SGM) is employed to examine four hypothetical agreements to reduce emissions in Annex I nations (OECD nations plus most of the nations of Eastern Europe and the former Soviet Union) to levels in the neighborhood of those which existed in 1990, with obligations taking effect in the year 2010. We estimate the cost to the United States of complying with such agreements under three distinct conditions: no trading of emissions rights, trading of emissions rights only among Annex I nations, and a fully global trading regime.

We find that the marginal cost of returning to 1990 emissions levels in the United States in the absence of trading opportunities is approximately $108 per metric ton carbon in 2010. The total cost in that year is approximately 0.2 percent of GDP. Emissions reductions are accomplished via energy conservation across a broad range of residential, commercial, industrial and transportation activities and by replacing coal fired power stations with natural gas facilities.

International trade in emissions permits lowers the cost of achieving any mitigation objective by equalizing the marginal cost of carbon mitigation among countries. This is sometimes referred to as “where” flexibility. “Where” flexibility allows least expensive emissions reductions to be undertaken first, regardless of where they occur among trade participants.

For the four mitigation scenarios in this study, economic costs to the United States remain below 1% of GDP through at least the year 2020. This was the case even in the scenarios where the United States met its mitigation targets without international trading of carbon permits.

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INTRODUCTION

More than 160 nations have signed the Framework Convention on Climate Change (FCCC). That agreement required Annex I nations,[2] the developed nations of the world plus economies of the Former Soviet Union and Eastern Europe, to undertake measures to return emissions to 1990 levels or below in the year 2000. The parties to the FCCC met in Berlin in the Spring of 1995 and determined that additional measures were required to implement the ultimate objective of the FCCC, "*to stabilize the concentration of greenhouse gases in the atmosphere at a level which would prevent dangerous anthropogenic interference with the climate system.*"

Subsequent to the Berlin discussions, nations of the world have begun to consider measures that would set quantifiable emissions limitation requirements in the post-2000 period for Annex I nations. Various measures have been considered. The purpose of this paper is to explore the economic consequences of efficient policy instruments—carbon taxes or tradable emissions permits—which might be employed to achieve a variety of targets in the post-2000 time frame.[3]

Using the Second Generation Model (SGM), we estimate the costs to the United States of complying with four Annex I mitigation scenarios under three permit trading regimes. Specifically, we examine the carbon taxes required for emissions mitigation and provide measures of the costs of mitigation.

We begin by describing the variety of policy options to be considered and our general approach to modeling those policies. We then review some of the necessary assumptions for this exercise, as well as the structure and calibration of the SGM. Finally, we discuss the results of our analysis, including time paths of emissions and measures of cost.

APPROACH

The SGM was used to simulate the impact of mitigation policies on the United States economy. The SGM is a computable general equilibrium economic model that projects economic activity, energy consumption, and carbon emissions for the United States and 11 other world regions. A more complete description of the SGM follows in the next section.

Scenarios

Four scenarios were constructed that reduce carbon dioxide emissions in Annex I countries by 2010. Figure 1 shows United States emissions paths for the four scenarios and the reference case in million metric tons of carbon (MMTC). The reference case, or baseline scenario, is what we project will happen in the absence of a mitigation policy. In each mitigation scenario, allowable emissions are reduced linearly from the reference level in 2000 to the emissions target in 2010. The four policies, designated 'M_', are listed below.

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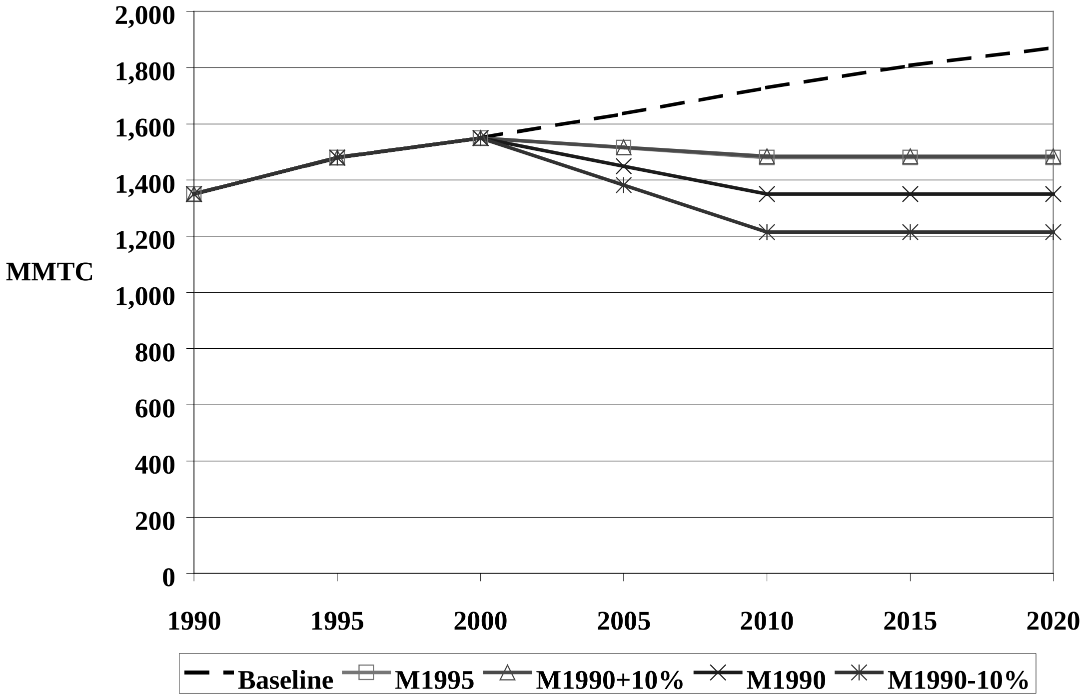
[2] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and the United States.

[3] In the United States, efforts were undertaken by the Interagency Analytical Team (IAT), and results were summarized in United States Government (1997). The Second Generation Modeling team was one of three modeling teams that participated in the evaluation of potential emission mitigation measures under discussion. Note that the results presented in this paper differ from SGM results presented under the auspices of the IAT. The IAT effort assumed higher rates of technical change induced by a response to policy implementation. This study does not make the same assumptions.

M1990	Emissions from Annex I regions must be no greater than 1990 emissions levels beginning in the year 2010.
M1990+10%	Emissions from Annex I regions must be no greater than 10% above 1990 emissions levels, beginning in the year 2010.
M1990-10%	Emissions from Annex I regions must be no greater than 10% below 1990 emissions levels, beginning in the year 2010.
M1995	Emissions from Annex I regions must be no greater than 1995 emissions levels beginning in the year 2010.

Figure 1. Carbon Dioxide Emissions Scenarios for the United States



The four emissions mitigation scenarios each define a set of emissions rights for the Annex I countries. In a mitigation scenario, countries must possess permits, or rights to emit, for every million metric ton of domestic carbon dioxide emissions. Three emissions permit trading regimes were modeled under each mitigation policy: independent emissions mitigation, Annex I joint mitigation, and Annex I mitigation with global permit trading. The 12 SGM regions listed in Table 1 provide the necessary global coverage to simulate these trading systems. Carbon taxes were used to constrain emissions for each of the policy-trade combinations.

Table 1. Regions in the SGM

Annex I	Non-Annex I
United States	China
Canada	India
Western Europe	Mexico
Japan	South Korea
Australia	Rest of World[4]
Former Soviet Union	
Eastern Europe	

In the independent mitigation case, each Annex I region must individually meet its required emissions targets without trading permits across regions. The SGM computes a time series of carbon taxes for each country that are just large enough to reduce emissions to the target level.

With Annex I joint mitigation, a common carbon tax is applied to all Annex I regions to meet the overall Annex I emissions target. However, regions are allowed to trade permits amongst themselves so long as the total constraint is met in each time period. 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.

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 and 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 carbon tax just large enough to meet the global emissions target.

In none of the above scenarios and trading combinations are non-Annex I regions forced to constrain their emissions below reference levels. No mitigation targets or emissions trajectories are imposed on those regions. Under the global permit trading regime, non-Annex I regions participate in the market for carbon 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 are only required to reduce their emissions by an amount equal to the number of permits they wish to sell.

Eastern Europe and Former Soviet Union Permit Allocations

While carbon dioxide emissions in most regions are anticipated to continually increase over time beyond 1990 levels, this is not true 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. The downturn in emissions poses a special problem when allocating emissions rights. Two approaches to permit allocations for the regions have been discussed in recent months. The first allocates permits based on the stated policy scenario (e.g., M1990 allocates permits based on 1990 emissions level) so that permits are allocated to them in the same way as they are to other Annex I regions. Because of the decline in emissions in those regions from 1990 to 1995, however, this approach results in emissions permits being granted to Eastern Europe and the Former Soviet Union in the policy years that are greater than their reference level emissions. These 'paper credits' are equal to the difference between

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[4] The Rest of World includes Latin America, Africa, and other Asian countries.

the lower post-1990 emissions and the policy-level (i.e., 1990) emissions. For example, the Former Soviet Union’s reference emissions level in 2010 is 836 MMTC, significantly lower than its 1990 emissions of 1050 MMTC. If granted permits equal to its 1990 emissions, it would receive 214 MMTC worth of permits more in 2010 than its projected emissions, giving it 214 MMTC worth of permits to sell without incurring any emissions reductions of its own.

The second approach to allocating permits to Eastern Europe and the Former Soviet Union is to grant permits equal to reference level emissions in each period until the projected path is constrained by the policy. For example, in the M1990 case, the Former Soviet Union would be granted permits equal to its projected reference emissions through 2020 because emissions in the policy years never recover to 1990 levels.

For the purpose of this exercise, we chose to emphasize the latter approach in allocating emissions to Eastern Europe and the Former Soviet Union. This reference allocation scheme ensures that the stated Annex I emissions targets are achieved in both the independent mitigation and permit trading scenarios. For the purpose of comparison, we also include a short discussion of the impacts of the mitigation policies utilizing the first approach.

MODEL OVERVIEW

The SGM is designed specifically to address issues associated with global change. The model is designed to perform 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 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 is shown in Table 2.

Table 2. 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*. In other words, the SGM 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 on not just 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 and taxes are also solved for by the SGM as part of the market equilibrium. Emitters of carbon pay a tax based on the carbon content of the fuels they combust. 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.

Carbon Taxes and Revenue Recycling

The SGM uses a carbon tax within each region to provide an economic incentive for the economy to substitute away from carbon. Revenues obtained from the carbon tax 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 tax revenues are recycled back to consumers through a lump-sum government 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 the stated mitigation policy (e.g., 1990 emissions levels for the M1990 scenario). Carbon permits can then be traded between countries at a price that clears the global 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 to the year 2050, with results reported here to 2020. 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, nontradable, 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 nontradable goods, the quantity of trade is fixed in advance. The following assignments are used when the United States model is operated independently:

Numeraire Sector: everything else (price always equals 1)

Fixed World Price: crude oil

Fixed Trade Quantities: agriculture, coal, nuclear fuel, refined petroleum, electricity

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 nontradables 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% 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, that market is tradable carbon emission permits. The model searches for a global carbon tax, which can be interpreted as a world carbon 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. 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.

REFERENCE CASE AND CALIBRATION

The cost of reducing greenhouse gas emissions is dependent on the reference case. The higher the growth rate of emissions in the reference case, the greater the cost of returning to 1990 emissions. 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 1997 (AEO97). Since AEO97 projects only up to the year 2015, projections beyond 2015 are SGM model results and are not calibrated to any other established projections. Projections of carbon emissions, population, gross domestic product (GDP), energy consumption, and electricity generation for the United States are described below.

For the other global regions, economic and energy consumption growth rates were roughly calibrated to regional projections from the World Energy Outlook 1996 (WEO96). For the Eastern Europe and Former Soviet Union regions, projected energy consumption levels were adjusted downward from the WEO96 projection to reflect recent events. 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 AEO97 projections. As mentioned earlier, the international crude oil price trajectory was also taken from the AEO97. Prices for all other fuels and goods in the model were determined endogenously.

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.

Carbon Emissions

In 1990, total carbon dioxide emissions from the combustion of fossil fuels in the United States were 1,350 million metric tons of carbon. Model results show that total carbon dioxide emissions continue to rise as fossil fuel consumption increases and emissions reach 1,871 million metric tons by 2020. This amounts to a 39 percent increase in total emissions and an emissions growth rate of 1.1 percent per year. Reference case carbon emissions were shown earlier in Figure 1.

Gross Domestic Product

The two most important determinants of GDP are population growth and rates of change in productivity. Total population levels for the United States were taken directly from AEO97. United States population grows from 250 million in 1990 to 323 million in 2020. This represents an annual population growth rate of 0.85 percent per year.

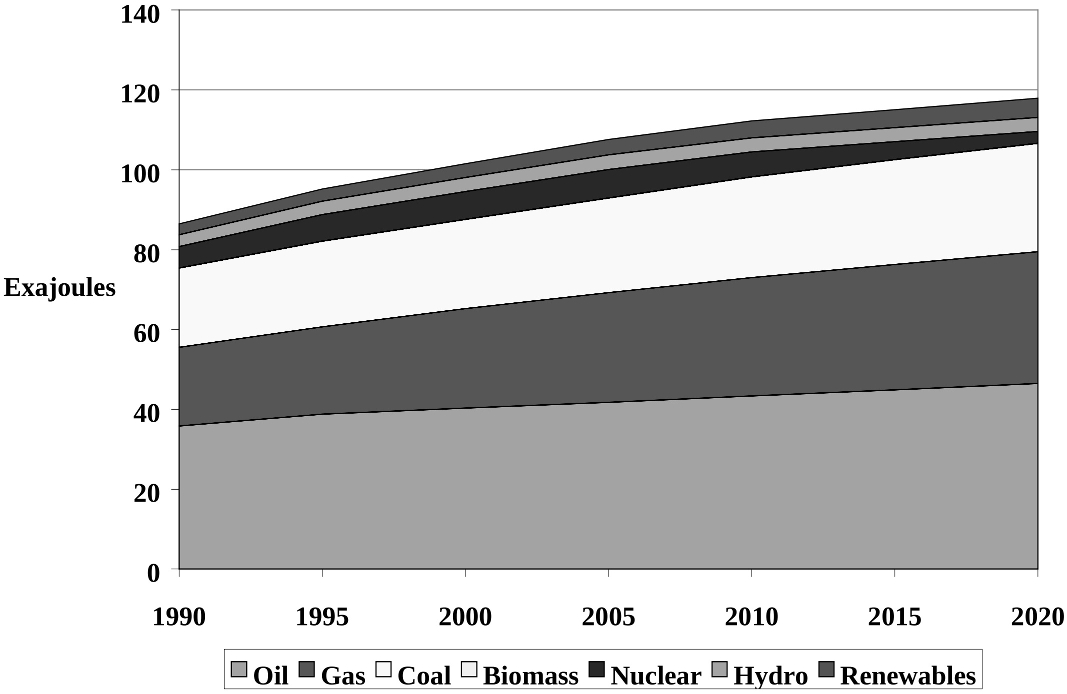
GDP for the United States was matched to AEO97 projections by changing the total factor productivity parameter for the ‘everything else’ sector. Beginning with the 1990 GDP of 6.1 trillion dollars, the economy grows at nearly 2 percent annually to reach 10.6 trillion dollars by 2020.

Energy Consumption

Total energy consumption from 1990 to 2015 was calibrated to within 2 percent of projections from AEO97. Energy consumption by fuel is shown for the United States in Figure 2. Total consumption increases from 86 EJ in 1990 to 118 EJ in 2020. This increase represents an average annual growth rate of 1.1 percent over that period. The annual growth rate in energy consumption declines over time and by 2020 decreases to 0.5 percent per year.

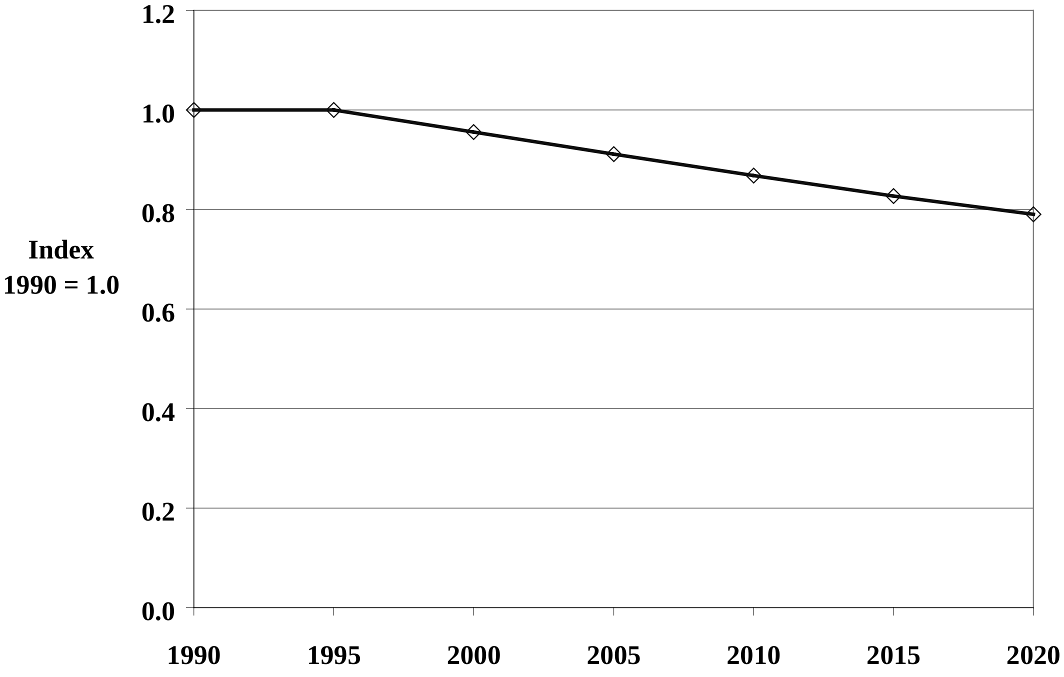
Petroleum remains the major source of energy through 2020, but its share of total consumption declines over time, giving way to natural gas and, to a lesser extent, renewable energy sources. Coal is the third largest source of energy and its consumption grows steadily at slightly less than 1 percent per year. Nuclear energy’s contribution to energy consumption declines over time.

Figure 2. Energy Consumption – United States Reference Case



Energy consumption does not grow as fast as GDP, which results in the energy-GDP ratio falling over time at an average annual rate of 1.0 percent per year. Figure 3 shows the energy-GDP ratio generated by the SGM for the United States reference case.

Figure 3. Energy-GDP Ratio – United States Reference Case



Electricity Generation

Projections of electricity generation are similar to those of the AEO97. Total electricity generated in 1990 is nearly 11 EJ, which grows at 1.5 percent per year to reach 17 EJ by 2020. The major source of electricity is the combustion of coal; however, electricity generation from natural gas plays a significantly larger role with time. In 1990, electricity generation from coal contributed 53 percent of the total generation, while that from natural gas combustion contributed 17 percent of the total. By 2020, the shares of electricity generation from coal and natural gas are closer. Electricity generation from coal and natural gas comprise 44 and 34 percent shares of the total, respectively. Highly efficient and low-cost natural gas combined cycle power plants incorporated into the SGM contribute to the growth of natural gas as the choice fuel for electricity generation. Nuclear power's contribution to the overall demand for electricity declines with time as existing power plants are retired and no new additional plants are constructed.[5] Renewable energy sources for electricity generation include hydroelectricity, solar photovoltaics and others. Generation of electricity from renewable sources increases slightly from 1990 to 2020; however, renewable energy's share of total electricity remains below 10 percent of the total.

COST OF EMISSIONS MITIGATION

Although this exercise employed the 12-region version of the SGM, discussion of results in this paper will focus on the United States. The SGM provides output on regional GDP and its components and a detailed description of the composition of energy supply. In this analysis, we focus on the broad economic impacts to the economy. Specifically, we discuss the permit prices required to meet the various mitigation requirements and the costs to the United States economy of undertaking such policies. We also discuss the impacts of the domestic carbon taxes on energy consumption.

Permit Prices

Table 3 shows the permit prices by trading regime required for the United States to meet its emissions targets under the four mitigation scenarios. Permit prices in the United States must reach $108 per metric ton of carbon to reduce United States emissions to 1990 levels in 2010 in the independent mitigation case. This price increases significantly with the tighter constraint imposed under the M1990-10% case. Permit prices in the M1995 and M1990+10% scenarios are very similar as only 5 MMTC separate the constraints in the two cases in 2010.

Table 3. United States Carbon Taxes Required to Meet Policy Goal
Eastern Europe & FSU Allocated Reference Case Permits
(1992 US$ per Metric Ton of Carbon)

	Independent Mitigation		**Annex I Joint Mitigation**		**Annex I Mitigation with Global Trade**	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
M1990	108	170	72	87	26	27
M1990+10%	60	110	42	58	16	18
M1990–10%	173	260	109	122	38	36
M1995	61	112	70	106	26	32

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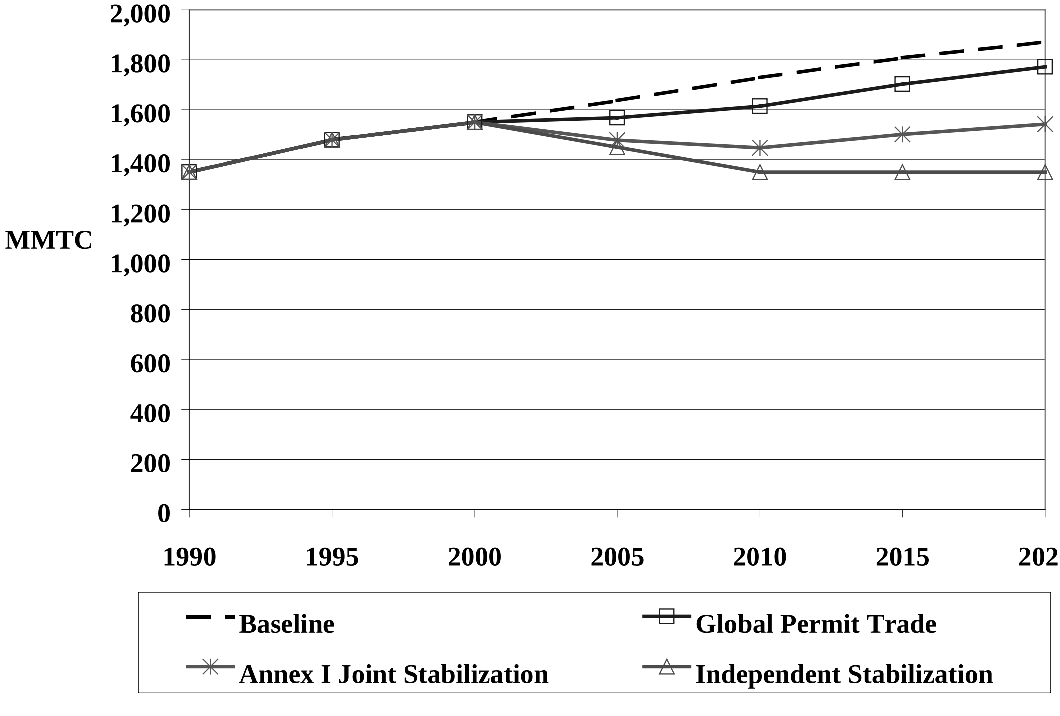
[5] The assumption of no new starts reflects a de facto nuclear moratorium. Were nuclear power to be allowed to compete against other energy forms on the basis of price alone, the model would continue to build new facilities.

Permit prices fall as more regions are included in the market for carbon permits. In the independent emissions mitigation case, carbon emitters in the United States may undertake emissions mitigation options available only within the United States. In the Annex I joint and global permit cases, however, regions are included that have mitigation options with significantly lower costs, thereby lowering the marginal cost to the carbon permit market of meeting the desired emissions targets. As we will discuss, this ‘where’ flexibility in meeting emissions targets has a significant impact on costs as well as permit prices.

A fixed emissions target and an increasing reference case emissions level imply both a rising percentage emissions reduction and a rising price of meeting the fixed emissions target. 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. The availability of relatively inexpensive abatement options in the developing world allows the permit price to remain relatively constant over time in those cases.

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 4 shows United States emissions for the M1990 case across the three trading regimes. Under the independent emissions mitigation regime, the United States is limited to emitting only what it is allocated under the scenario, its 1990 emissions level. With Annex I trading, however, the United States purchases 209 MMTC worth of permits in 2010 and 244 MMTC in 2020 from the Former Soviet Union and Eastern Europe. The purchases increase to 316 MMTC and 436 MMTC in 2010 and 2020, respectively, under the global trading regime. Again, ‘where’ flexibility reduces the amount by which a permit-buying region must reduce its emissions and, therefore, reduces the cost to the region.

Figure 4. United States Carbon Emissions – M1990 Cases

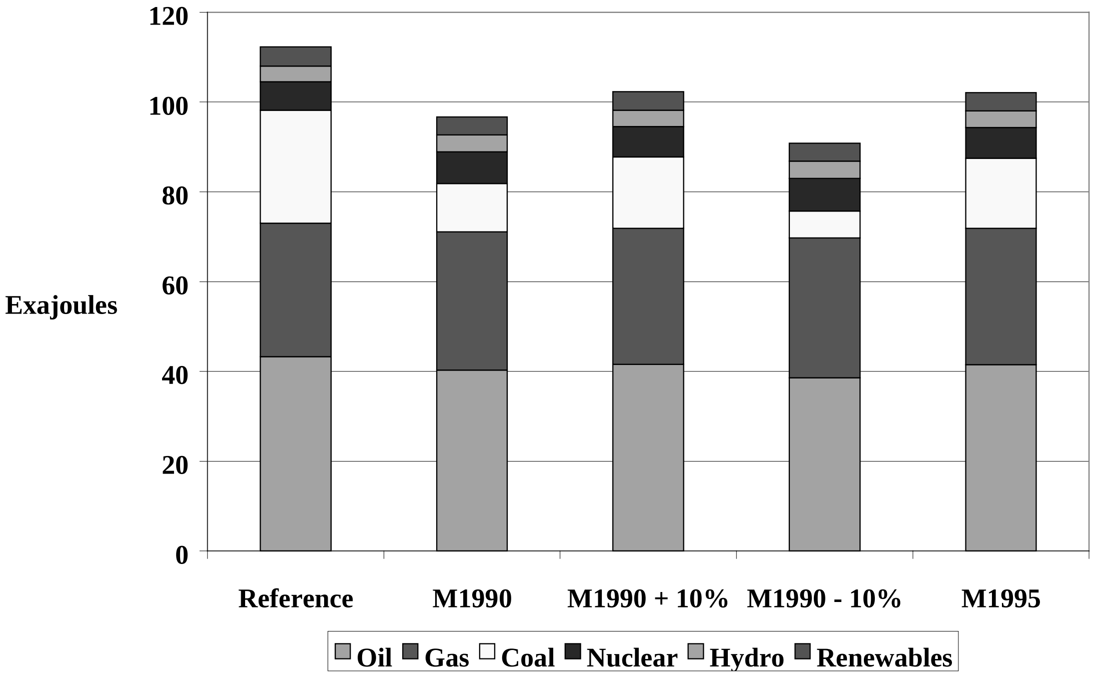


The M1995 Annex I trading case is the only case in which the United States sells permits to other regions. The permit price under independent mitigation in 2010, as shown in Table 3, is less than that shown under Annex I trading. Because the United States can mitigate emissions less expensively in 2010 than other Annex I regions, it reduces its emissions beyond the required 1995 target and sells permits to other Annex I regions. By 2020, however, the United States begins to purchase permits from Eastern Europe and the Former Soviet Union.

Energy Consumption

Emissions mitigation is achieved primarily through two mechanisms: energy conservation - reduction in total energy consumption - and replacement of coal-fired capacity with less carbon-intensive fuels such as natural gas and renewables in the electricity sector. In the no-trading cases, fuel switching from coal to natural gas and renewable fuels in the electricity generation sector accounts for roughly 60 percent of the reduction in total emissions. Energy conservation makes up the remaining 40 percent of the reduction. The domestic carbon tax of $108 in 2010 in the M1990 case results in a reduction of total energy consumption by 14 percent relative to the reference case. Consumption of coal drops by 57 percent while consumption of petroleum drops by 7 percent. Consumption of natural gas, however, increases by 4 percent due to fuel switching. Figure 5 shows energy consumption by fuel in the year 2010 for the four mitigation scenarios. Note that even when emissions are returned to 1990 levels, the scale of the total energy system still exceeds the 1990 energy consumption level of 86 EJ. 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. United States Energy Consumption in 2010



Fuel substitution in the electricity sector results in the share of electricity generated from coal dropping from 45 percent in the reference case to 20 percent in the M1990 case. The reduction in electricity generation from coal is compensated for by increased generation from natural gas. The share of electricity generation from natural gas increases from 29 percent in the reference case to 51 percent M1990 case.

As discussed above, the domestic cost of stabilizing emissions at 1990 levels in 2010 without trade is \$108 per metric ton of carbon. This cost roughly reflects the cost of abandoning existing coal-fired power generation capacity and replacing it with a new combined-cycle natural gas-fired unit. A \$108 per metric ton tax adds approximately \$0.02 per kilowatt-hour to the operations and maintenance (O&M) cost of power generation in a coal-fired plant. This additional cost makes the O&M cost of the coal plant higher than the levelized cost of installing a new gas-fired combined-cycle unit, roughly \$0.05 per kilowatt-hour. The \$108 tax, therefore, provides an emissions mitigation plateau for permit prices that is not exceeded until most of the existing coal capacity is replaced.

Certain caveats apply to the discussion above concerning the marginal cost of substituting natural gas-fired electricity generation capacity for existing coal-fired capacity. The cost analysis requires that the tax be levied indefinitely. If the tax policy is believed to be only temporary, the amount of substitution is likely to be much less substantial and the tax level required for stabilizing emissions could be higher. The tax level required for mitigation also depends on the cost of developing the 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.

Cost Calculations

A very convenient way to characterize the response of any SGM region to a carbon tax is by constructing a marginal cost of carbon curve. Figure 6 is a scatter plot of various carbon taxes applied to the United States economy and the corresponding reduction in carbon emissions. Data points plotted in Figure 6 are from the four independent mitigation scenarios for the United States. Note that a positive tax is required to achieve any reductions in carbon emissions.

The marginal cost curve is used to calculate one measure of cost that we will call the *direct cost*. For any level of carbon emissions mitigation, the direct cost is defined as the area under the marginal cost curve up to that amount of mitigation.[6] While the first units of emissions reductions are very inexpensive, successive units become more and more expensive. So, as the constraints on emissions become tighter across cases and over time, the cost of mitigation increases. Figure 7 shows the direct costs for the United States for the four independent mitigation scenarios. Direct costs are shown at 5-year intervals through 2020 as a percentage of GDP. These costs are plotted as negative numbers.

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[6] Note that these costs do not include the costs of establishing a domestic or international permit trading system nor do they include the transaction costs associated with permit trading among firms and/or regions.

Figure 6. Marginal Cost of Carbon

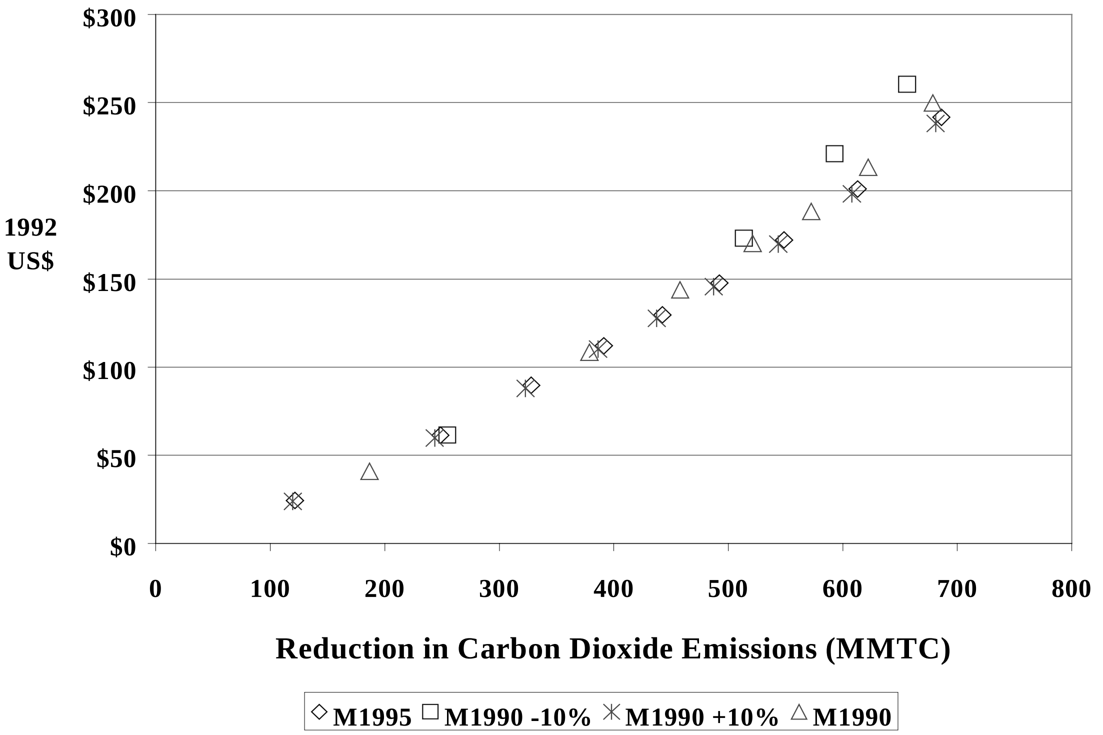


Figure 7. Cost of Emissions Mitigation – No Trading

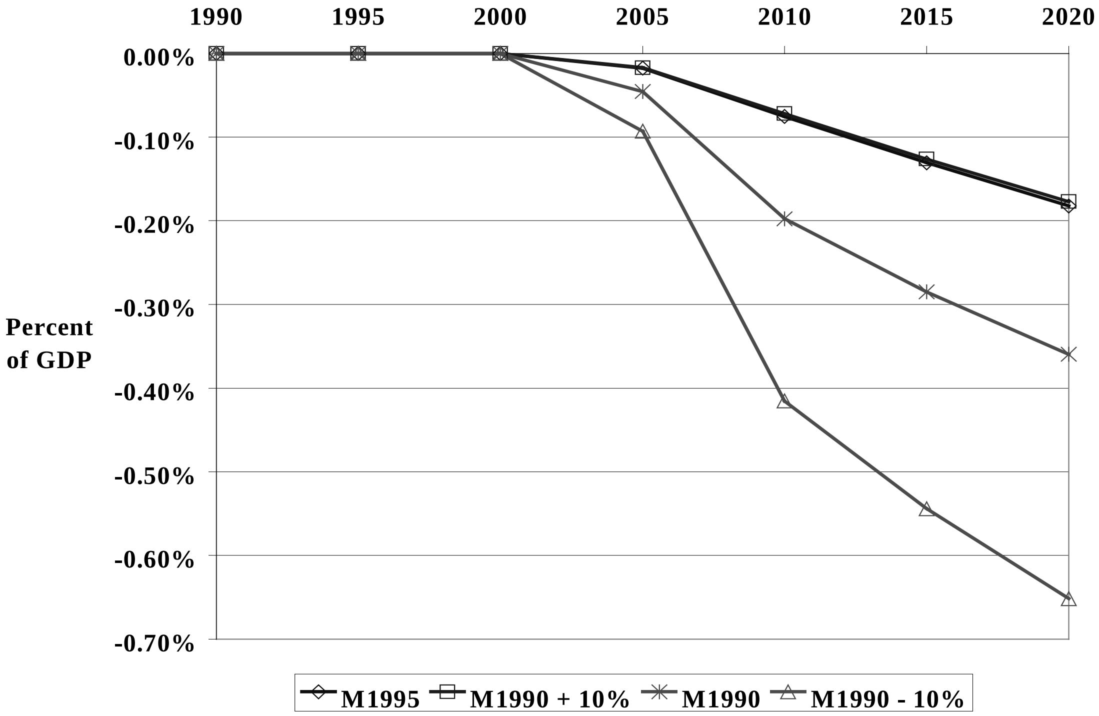
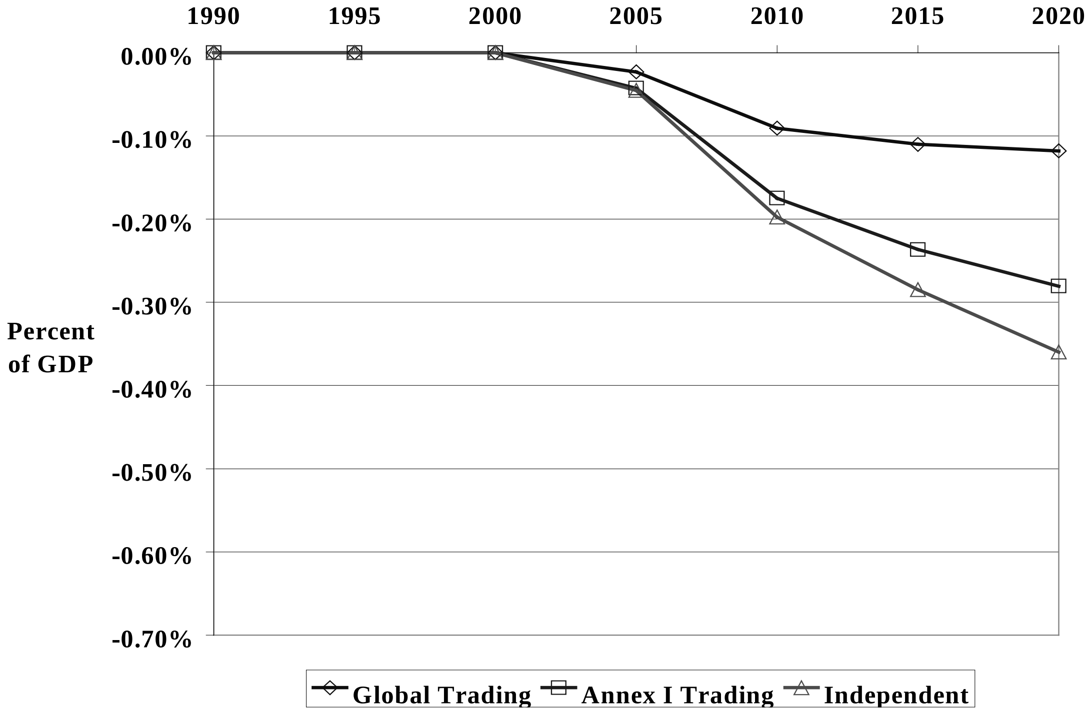


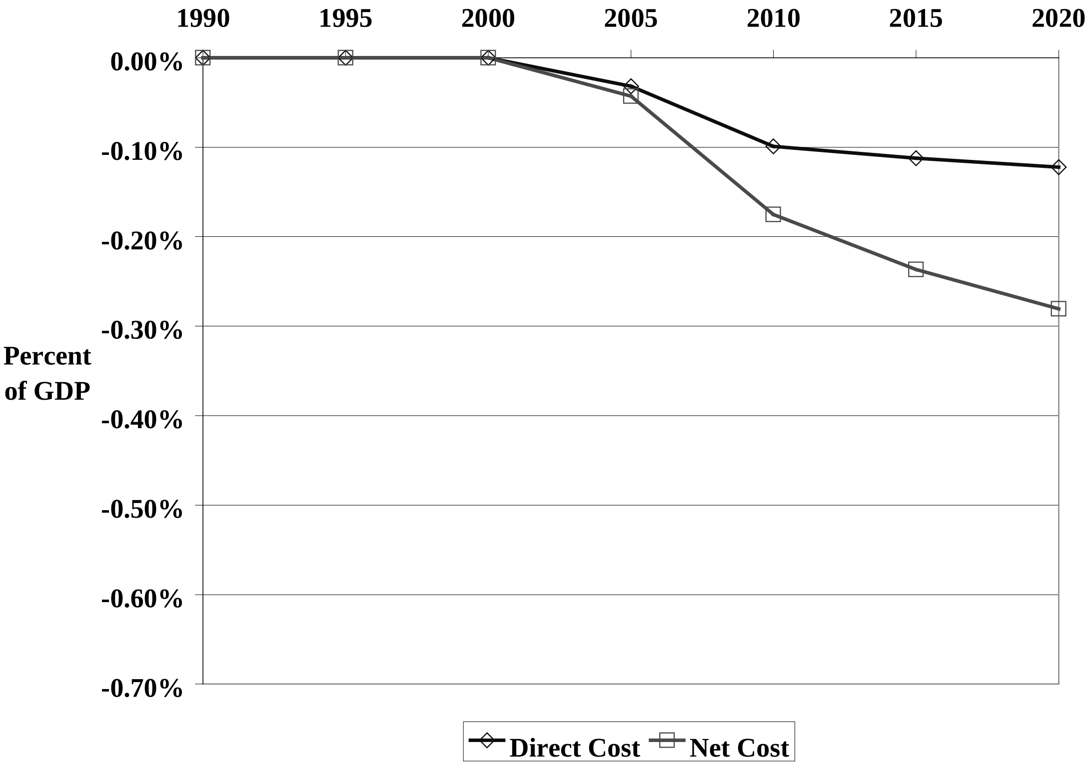
Figure 8 focuses on the M1990 case and shows how costs to the United Sates are reduced with trade in emissions permits between countries. The 'independent' cost line shown in Figure 8 is the same as the M1990 cost line in Figure 7. In 2010, costs are reduced somewhat with Annex I trading and reduced by about one-half with global trading. In later years, the flexibility in where emissions reductions are undertaken impacts mitigation costs even more significantly.

Figure 8. Illustration of 'Where' Flexibility – Costs for M1990 Cases



Cost calculations for the emissions trading cases are different than in the independent case. Costs for the trading case take into account the value of permits traded. For a buyer of permits, such as the United States, net cost includes the direct cost plus expenditures on carbon permits. A breakdown of these two cost components is shown for the M1990 Annex I trading case in Figure 9. Direct cost is roughly half of the net cost. 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.

Figure 9. Cost Breakdown – M1990 Annex I Trading Case



Impact of Alternative Permit Allocation Approach

The results discussed thus far have been based on the assumption that Eastern Europe and the Former Soviet Union are allocated permits equal to the minimum of their reference-level emissions and the policy-level emissions. This section will discuss the impacts of an alternative permit allocation method in which Eastern Europe and the Former Soviet Union are granted permits equal to their policy-level emissions in every period. Recall that ‘policy-level’ refers to the emissions target set by the chosen mitigation policy. For example, the policy-level emissions in the M1990 case would be 1990 level emissions starting in 2010, and for the M1995 case they would be 1995 level emissions beginning in 2010. This assumption results in the ‘paper credits’ discussed earlier that significantly impact the permit prices required to meet Annex I emissions targets in the Annex I and global trading cases.

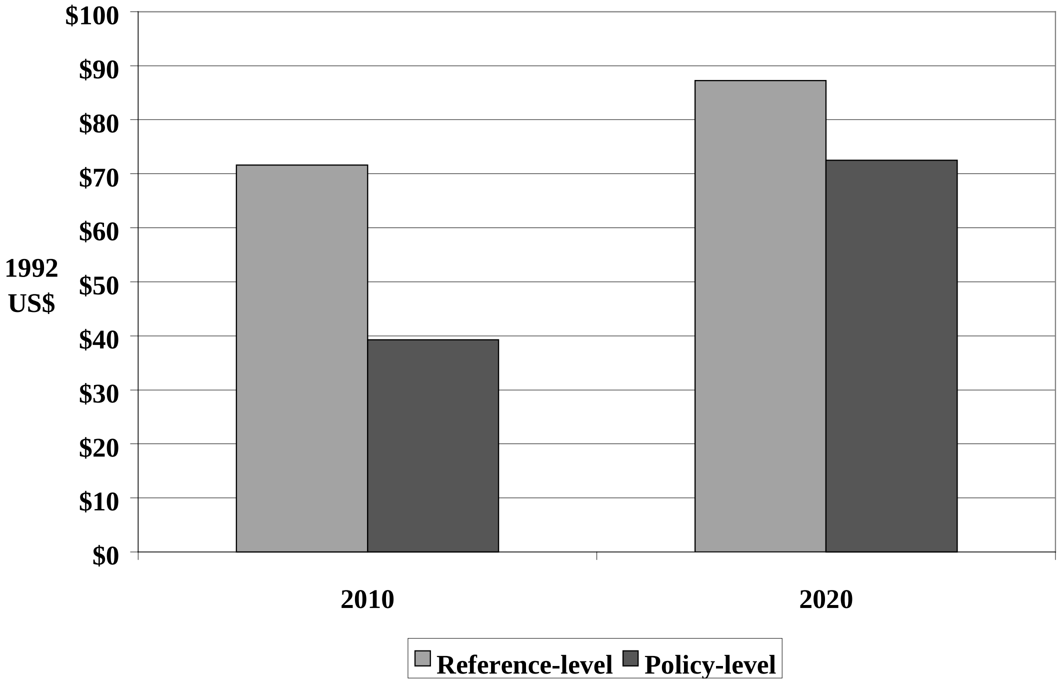
Table 4 shows the permit prices required to meet the policy goal under the policy-level permit allocation approach. The prices required for independent mitigation in the United States do not change from Table 3 above because the paper credits in those cases are not available for purchase outside Eastern Europe and the Former Soviet Union. Permit prices also remain unchanged under the M1995 case because by that time the two regions have already suffered the worst of their economic downturns so that emissions levels are at their lowest point in the 1990 to 2020 time frame. The permit prices under the other trading scenarios are significantly less under this allocation approach, however, because the regions are able to sell the paper credits without incurring any cost domestically. In the M1990 case in 2010, the paper credits allocated to Eastern Europe and the Former Soviet Union account for 37 percent of the emissions reductions necessary for the remaining Annex I regions to meet their target emissions. This addition of permits available for purchase reduces the permit price by $33, or by 46 percent, relative to the permit price under the reference-level allocation approach. Figure 10 shows the difference in permit prices for the M1990 case with

Annex I trading between the two permit allocation approaches in 2010 and 2020. Note that the difference decreases over time as emissions in Eastern Europe and the Former Soviet Union approach the policy goal.

Table 4. United States Carbon Taxes Required to Meet Policy Goal - Eastern Europe and the Former Soviet Union Allocated Policy-level Permits (1992 US$ per Metric Ton of Carbon)

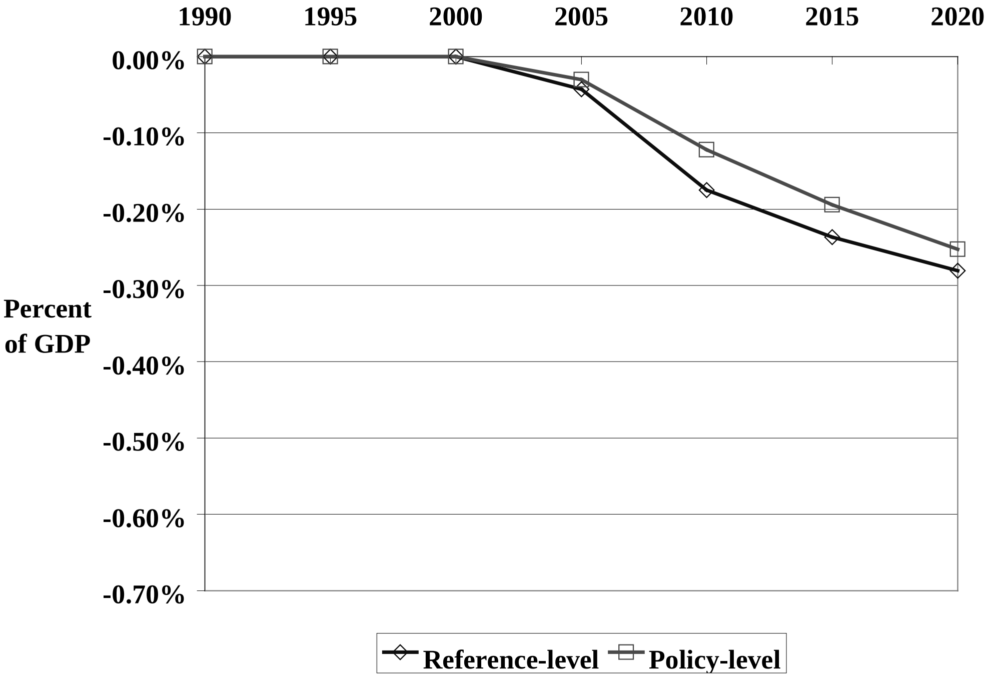
	Independent Mitigation		Annex I Joint Mitigation		Annex I Mitigation with Global Trade	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
M1990	108	170	39	73	15	22
M1990+10%	60	110	6	35	2	11
M1990–10%	173	260	88	124	31	36
M1995	61	112	70	106	26	32

Figure 10. Permit Prices under Alternative Permit Allocation Methods for Eastern Europe and the Former Soviet Union – M1990 Annex I Trading Case



The lower permit prices under the policy-level approach result in lower total costs of emissions mitigation to the United States. In the M1990 Annex I trading case, costs as a percentage of GDP are reduced from 0.18 percent under the reference-level allocation approach to 0.12 percent under the policy-level approach in 2010. Figure 11 shows costs as a percentage of GDP for the M1990 Annex I trading case for both allocation methods.

Figure 11. Cost to the United States of Emissions Mitigation under Alternative Permit Allocation Methods for Eastern Europe and the Former Soviet Union – M1990 Annex I Trading Case



DISCUSSION

In this section, we summarize some of the insights gained from our modeling activities using the SGM. First, economic costs depend a great deal on our assumptions about future carbon emissions. Second, several measures of cost are available from the SGM. 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.

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 mitigation required to return to 1990 levels depends directly on reference case emissions for each region. 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 the two regions until that point in time.

Measuring and Reporting 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.

Of ultimate interest, however, is the net impact on some broader measure of economic activity (such as GDP) or on economic welfare (such as real consumption). There are many reasons why the change in GDP (or real consumption) is different than direct cost net of transfer payments. These other components of cost include the effects of pre-existing distortionary taxes, changes in terms of trade, and how tax revenues are recycled. In addition, 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 for GDP when relative prices are changing.

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 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 metric ton 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 amount of permits traded by each country, but also whether a country is a buyer or seller of permits.

For this study, the initial allocation of permits among Annex I countries is simply the emissions targets defined by the four mitigation scenarios. Non-Annex I regions were allocated permits equal to reference case emissions. These four mitigation scenarios represent only a few of the many possible ways of setting global emissions limits and allocating emissions rights among countries to meet those limits. Each allocation implies a different pattern of wealth transfers among countries.

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 United States are sensitive to many of the model inputs. These include the choice of exchange rate, the inclusion of paper permits, and the method 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.

For Eastern Europe and the Former Soviet Union, carbon permits were allocated based on their reference case, and not on 1990 emissions. If we had allocated permits based on 1990 levels, these extra 'paper credits' would create a less-stringent Annex I target. The model would then report a lower permit price for the trading cases, and a lower cost to the United States.

In this study, we assumed that all revenues from a carbon tax would be recycled as a lump sum to consumers. Another option is to use the carbon tax revenues to offset other taxes. This has the potential to reduce overall costs, since carbon tax revenues would displace other distortionary taxes.

KEY 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. Costs shown in Figure 8 provide a good example of the importance of this 'where' flexibility.

For the four mitigation scenarios in this study, economic costs to the United States remain below 1% of GDP through at least the year 2020. This was the case even in the scenarios where the United States met its mitigation targets without international trading of carbon permits.

Each region in the SGM can be characterized by a marginal cost of carbon curve, as was shown in Figure 6. This shows the approximate carbon tax required for any given level of carbon emissions reduction. For the amount of emissions reductions needed in 2010 to return to 1990 levels, a carbon tax of $108 per metric ton of carbon is required.

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