Model Comparisons of the Costs of Reducing CO_2 Emissions

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Concern about the extent of global climate change and its potential consequences has increased dramatically in recent years. Many believe that unprecedented climate changes are—or soon will be—occurring as the result of man-made emissions of greenhouse gases. The largest man-made source of greenhouse gases is carbon dioxide produced by the combustion of fossil fuels in utility and industrial boilers and in internal combustion engines. Thus, any effort to reduce greenhouse-gas emissions will start with efforts to restrict these activities. Therefore, it seems essential to develop a range of projections of the likely costs of alternative levels of control of carbon emissions from the energy sector.

The EMF 12 working group of the Energy Modeling Forum specified 13 standardized scenarios reflecting a range of carbon emission-control levels, as well as sensitivities on key standardized inputs. These scenarios were ultimately implemented by 14 modeling teams employing a wide variety of technoeconomic models, although not every model could implement every scenario. In addition to these model comparisons, ten study groups were formed to analyze issues not being addressed by the 14 models and 13 scenarios. These groups used additional models and methods to analyze issues not addressed in the 13 original scenarios.

I. Basic Control Scenarios

Six of the 13 EMF 12 scenarios employed the same GDP, population, resource availability, and technology assumptions, but considered different levels and rates of CO_2 emissions control:

(i) *Reference.*—No control;
(ii) *20-percent Reduction.*—A 20-percent reduction in CO_2 emissions in the developed countries and no more than a 50-percent increase in the developing countries relative to 1990 levels by 2010;
(iii) *50-percent Reduction.*—The same as (ii), but with an additional reduction in CO_2 emissions in the developed countries to 50-percent below their 1990 levels by 2050;
(iv) *Stabilization.*—Hold CO_2 emissions in the developed countries to their 1990 levels by the year 2000, with the developing countries again constrained to no more than 50-percent above their 1990 levels;
(v) *Phased-In Carbon Tax.*—A tax that escalates from $15 per ton in 1990 at 5 percent real per year;
(vi) *2 Percentage Points Per Year Reduction.*—Annual reduction in emissions relative to the reference case.

In implementing these scenarios the modeling teams generally used taxes based on the carbon content of fossil fuels to achieve the emissions reductions (except for the government revenues a carbon tax would produce, this formulation is equivalent to a system of carbon-emission permit trading). These carbon-tax projections provide us with a rough estimate of the degree of market

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intervention that will be required to achieve the carbon-emission reductions. Most of the models included anticipated results from new technology development and conservation programs in the reference case. However, in these models there is no explicit consideration of market imperfections that may be causing current energy consumption patterns to differ from what perfectly functioning competitive markets would produce. More efficient, but more expensive, technologies are generally selected in the control scenarios, but no additional technology development is generally assumed to occur. Only one model adds additional conservation programs explicitly in those scenarios, and only one model includes endogenously determined rates of technological change. Finally, in their initial implementation of these scenarios the modeling teams assumed no international emissions trading, lump-sum rebate of any tax revenues collected, and no carbon offsets, such as those that might result from tree planting. A number of general points can be made from examining cost-of-control projections for these scenarios:

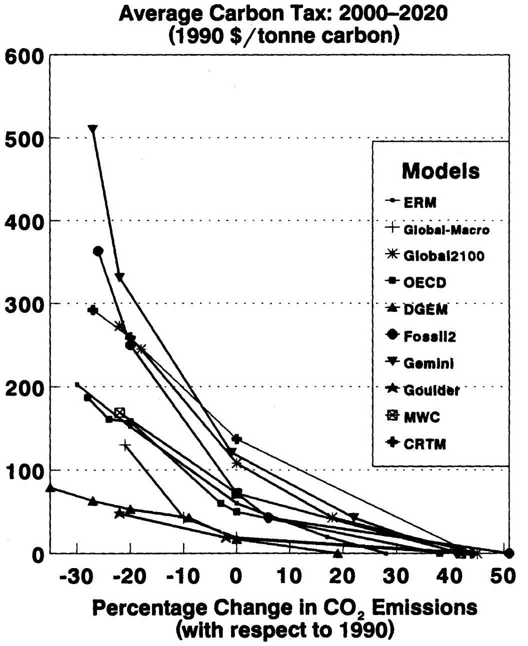

FIGURE 1. CARBON TAXES REQUIRED TO ACHIEVE CARBON-EMISSION REDUCTIONS IN THE UNITED STATES IN 2020

1.—The impact of these control options on global climate change over the next 20 years may be quite limited. Even in the most tightly controlled scenarios, the reduction in cumulative CO_2 emissions over this period are projected to be no more than 25 percent relative to the reference case. The impact of the control programs on atmospheric concentrations of CO_2 and climate change over that time period would be even less. By 2050, however, the 50-percent reduction scenario results in cumulative emissions that are as much as 55-percent below those projected in the reference case.

2.—Despite the inclusion of improved technologies and improved energy efficiencies in the reference case, all models project that market intervention will be required to achieve each of the emissions targets in all regions. When the more stringent carbon limits are considered, many models project the intervention required to be equivalent to carbon taxes of hundreds of dollars per metric ton. For example, the projections of the average carbon tax required during 2000–2020 to reduce U.S. carbon emissions by 20 percent by the year 2010 with respect to their 1990 level range from $50 to $330 dollars per metric ton as shown in Figure 1.

3.—These carbon taxes would generate substantial tax revenues that could be used for a number of purposes including reducing other taxes, deficit reduction, and additional government spending. For example, the projections of the average annual tax revenues raised in the United States from 2000 to 2020 to achieve the 20-percent reduction in CO_2 emissions range from $65 billion to $300 billion.

4.—The impact of a carbon tax on gross domestic product (GDP) measures its costs to the economy in terms of lost output resulting from the increase in the price of goods requiring carbon emissions; those goods must either be produced with less carbon or by more expensive processes. The GDP loss also includes the impact of the carbon tax on capital stock accumulation and technological progress, although not all models capture these phenomena. The models initially assumed lump-sum redistribution of tax revenues; That is, tax revenues are used to reduce total tax payments by individuals and corporations without affecting marginal tax rates (e.g., by increasing the standard deduction). The GDP losses calculated in this manner measure the cost of the distortions to the economy caused by the imposition of the carbon tax without either adding a credit or subtracting a penalty for the way the revenues are used. Under this assumption, and assuming no adverse trade effects, the model projections of the cost of stabilizing CO_2 emissions at today's levels range from 0.1 percent to 0.5 percent of GDP in 2000 for the United States, and the cost of achieving a 20-percent reduction in CO_2 emissions relative to today's level range from 0.9 percent to 1.7 percent of U.S. GDP in 2010. Although 1.7 percent of U.S. GDP in 2010 amounts to about $130 billion 1990 dollars, the implied reduction in the GDP growth rate between 1990 and 2010 would only be from about 2.3 percent per year to 2.25 percent per year. Thus, it is possible to reduce emissions significantly from their noncontrolled level without significantly reducing the growth of the economy.

5.—The way in which carbon-tax revenues are used has an important impact on the projected GDP loss. The projected GDP losses could be reduced substantially (relative to those calculated for the lump-sum recycling case) by using the carbon-tax revenues to reduce existing taxes that discourage economic activity, particularly capital formation. Simulations with four models of the U.S. economy indicate that from 35 percent to more than 100 percent of the GDP losses could ultimately be offset by recycling revenues through cuts in existing taxes. On the other hand, if the revenues are used to fund low-return government projects, the cost of achieving the carbon-emission reductions could be substantially greater than when they are recycled in lump-sum fashion.

6.—Regardless of where a model ranks in terms of the cost of controlling emissions, there is a great deal of similarity in how the models project that costs will vary over time for a particular level of control, and with respect to the level of control in any particular year. First, the cost of a particular level of control generally increases over time as the reference level of emissions grows and more adjustments must be made to reach a fixed level of emissions. For example, assuming lump-sum recycling of carbon-tax revenues, projections of the cost of stabilizing emissions in the United States range from 0.1 percent to 0.5 percent of GDP in 2000 and from 0.2 percent to 0.75 percent of GDP in 2010. In the longer term, say by 2050 or 2060, low-cost oil and gas reserves are near depletion, and the incremental cost of reducing emissions tends to stabilize at the difference between the cost of carbon-free sources of energy, like solar cells and advanced-technology nuclear reactors, and carbon-based sources of energy, like synthetic oil and gas made from coal or advanced coal-fired power plants.

7.—Second, the cost of control appears to be nonlinear with respect to the level of control in any given year, especially up to about 2040 before old fossil-fuel-based energy-producing and energy-consuming equipment can be fully retired and new carbon-free technologies can be fully introduced. That is, incremental reductions in allowable emissions cost more as the absolute level of allowed emissions in any particular year is reduced. For example, the cost of stabilizing emissions in the United States range from 0.2 percent to 0.75 percent of GDP in 2010, while the cost of reducing emissions by 20 percent in that year ranges from 0.9 percent to 1.7 percent of GDP, as shown in Figure 2.

8.—If the OECD, or any other group of countries unilaterally implements a carbon-reduction program, resulting changes in international energy prices will cause carbon emissions in other countries to increase relative to reference-case levels. Increased carbon emissions by nonparticipating regions occurs both as a result of increased energy

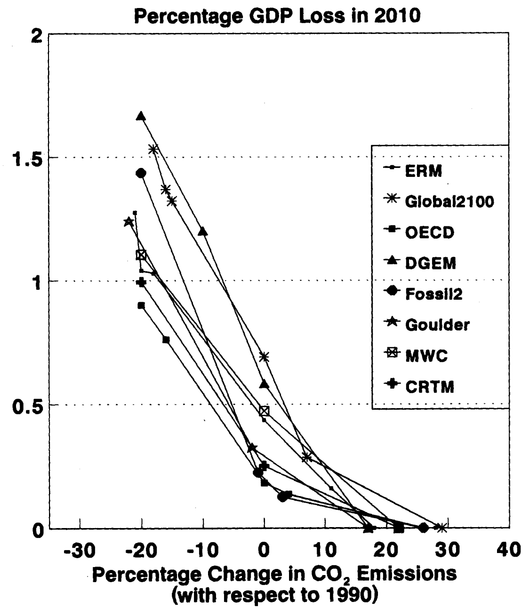

FIGURE 2. GDP LOSSES ASSOCIATED WITH CARBON-EMISSION REDUCTIONS IN THE UNITED STATES IN 2010

intensity of economic activity and through the migration of energy-intensive production into unconstrained regions. Carbon restrictions place countries that control emissions at a competitive disadvantage in energy-intensive industries. Thus, the cost to countries that control increases with the level of cutback, but the impact on global emissions may drop off sharply if large groups of countries fail to cooperate.

9.—The nonlinearity of year-by-year costs of control, the tendency of this nonlinearity to decrease over time as new technologies can be more fully phased in, and potential problems with recycling large amounts of tax revenues and dealing with large international trade shifts suggest that there is a trade-off between the cost of meeting an annual emissions target and the emissions generated before the target is reached. Moreover, the cost of meeting any cumulative emissions-reduction target can be reduced if it is phased in over a longer period of time. If a fixed annual emissions-rate target is specified, cumulative costs can be reduced with some increase in short-term emissions if (a) more time is allowed for reaching the target and (b) the instrument used to achieve it—say, a carbon tax—is phased in gradually rather than abruptly. The cost reduction can be particularly significant if the target date and rate of implementation are set to allow new carbon-free technologies to be phased in smoothly. If discounting of future costs is included in the calculation (as some would argue is required to insure an optimal allocation of society's resources over time), the reduction in costs resulting from a slower phase-in of controls is even greater.

10.—More greenhouse gases in the atmosphere may impose additional costs on society, though, so it may not be optimal to delay the imposition of constraints indefinitely. These costs depend on atmospheric concentrations of greenhouse gases, which depend on cumulative emissions over time rather than a single year's emissions rate. The 20-percent reduction scenario leads to high short-run adjustment costs according to the models included in this study. They project that almost the same reduction in cumulative CO_2 emissions reductions (and no more than a 20-percent increase in cumulative carbon emissions) can be achieved with the phased-in tax by the middle of the next century with a reduction of 30–40 percent in cumulative costs (even without discounting of future costs).

II. Sensitivity Analyses

The cost-of-control projections are sensitive to variations in standardized input assumptions:

1.—The cost of carbon constraints also depends significantly on the assumptions made about the cost of carbon-free technologies relative to the cost of carbon-emitting ones. To explore this sensitivity, the group examined an *accelerated technology* scenario in which the cost of noncarbon energy supply technologies (e.g., solar or advanced nuclear) in the 20-percent reduction scenario are assumed to be reduced to the cost of carbon-based ones (synfuels and coal-fired electric generation) by 2010. According to all the models, this scenario reduces the annual cost of achieving the carbon constraint to zero by the latter part of the 21st century. The costs of the constraint during the early part of the next century are not nearly as significantly reduced (only 10–30 percent), however, because conventional fossil-fuel technologies are still being used and because of constraints on the introduction of the new carbon-free technologies that cause additional costs to be incurred until large-scale introduction of the new technologies can be completed. This latter effect reinforces the large cost-of-adjustment effect observed above. Up until about 2040, the required carbon tax exceeds the zero difference in the costs of carbon-based and carbon-free backstop technologies by a substantial margin.

2.—The study design includes a 2.2-percent growth rate in GDP for the United States over the next 30 years. Two of the models included in the study produced independent GDP projections of 2.0 percent and 1.4 percent per year over that time frame. This results in lower carbon taxes being required to meet any particular emissions target. Interestingly, though, the computed GDP losses are not significantly less than in the other models, because higher energy prices are projected to diminish productivity growth. The lower GDP growth rate was adopted for a *low GDP growth* sensitivity scenario. This scenario does lead to a significant reduction in the cost of control because it directly reduces the reference level of emissions projected by each model. In addition, when all the models are run with the assumption of a low GDP growth rate, they produce carbon taxes that are more closely consistent with those projected by the lower-growth models.

3.—The cost of the transition to the non-carbon-based energy technologies can be significantly affected by the availability of natural-gas resources. Since gas has a lower carbon emissions rate than oil or gas, more fossil energy can be consumed within any emissions constraint if the use of natural gas can be increased. The *high natural-gas resources* scenario postulates a quadrupling of natural-gas resources in each region in the 20-percent emissions-reduction case. Although a number of analysts would now argue for more gas reserves than assumed in the EMF 12 study design, the quadrupling assumption is probably quite a bit more optimistic than anyone currently projects. This assumption does lead to a 30–40-percent reduction in the discounted cost of satisfying the emissions constraint over the next 20 years.

III. Differences in Model Projections

Estimates of the cost of achieving an emissions target relative to the 1990 level of CO_2 emissions by some future date are sensitive to the reference-case emissions trajectory projected by the model. A model with a higher reference-case projection of total emissions will require more adjustments to reach the fixed target than one with a lower reference-case emissions projection.

1.—Even when GDP growth rates are standardized, a wide range of reference-case emission projections are produced by the models included in the study. By the year 2100, projections of CO_2 emissions range from a 20-percent to a 200-percent increase over 1990 levels. Much of the differences in model projections from the models for 2100 can be explained by differences in the assumed rate of decrease in energy use per unit of economic output independent of energy price changes. For example, the "Global 2100" model uses a value of 0.5 percent per year for this parameter, while the Edmonds-Reilly model employs a 1.0 percent per year assumption, which over 110 years leads to aggregate energy use and emissions projections that differ by almost a factor of two. Estimates of this aggregate parameter based on historical data range from a rate of decrease of about 0.5 percent per year to an increase at about that rate. Researchers who have attempted to extrapolate the types and efficiencies of energy-using equipment into the future have argued that the potential exists for a rate of decrease in energy use per unit of economic output from 1 percent per year to more than 2 percent per year.

2.—In the reference scenario, all models project steady improvements (about 1 percent per year in the United States) in energy intensity over the study's time horizon, but no strong movement toward or away from carbon-based fuels. Decreases in energy intensity and switching to less carbon-intensive fuels are the major means of satisfying the requirements of the 20-percent reduction scenario, with the fuel-switching response being greater in the models with more end-use technology detail.