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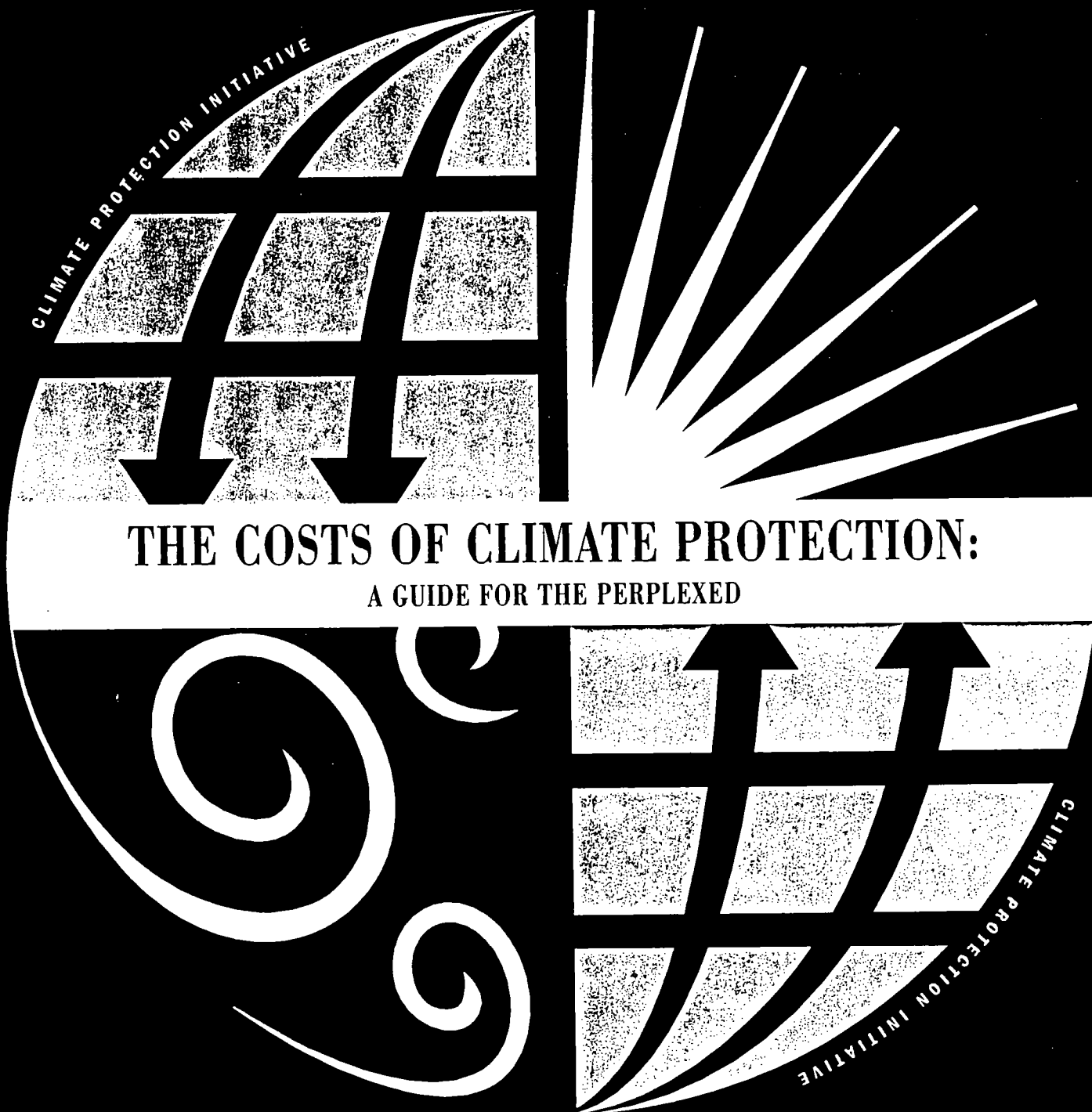
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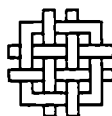
THE COSTS OF CLIMATE PROTECTION:

A GUIDE FOR THE PERPLEXED



ROBERT REPETTO AND DUNCAN AUSTIN

WORLD RESOURCES INSTITUTE



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A GUIDE FOR THE PERPLEXED

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FOREWORD

Nations that have signed the Global Climate Convention are negotiating commitments to stabilize and then reduce emissions of greenhouse gases, which will otherwise continue to build up in the atmosphere and alter global climate. An agreement with binding limitations is essential, since experience in the United States and many other countries over the past five years shows that the purely voluntary efforts pledged in Rio de Janeiro at the Earth Summit are insufficient.

Since the Framework Convention on Climate Change was concluded in 1992, global emissions have continued to rise despite increasing evidence that human activity is having a discernible effect on world climate. The most recent scientific assessment by the Intergovernmental Panel on Climate Change emphasized that the continued buildup of greenhouse gases could have long-lasting climatic effects, some of which would impose significant economic burdens on nations and vulnerable populations.

Before the United States commits itself to specific restrictions on carbon dioxide emissions and timetables for implementation, it is essential that the economic consequences be thoroughly understood. Limiting carbon dioxide emissions will mean significant changes in energy use and energy sources, probably changing energy costs substantially. Household budgets and business profits will be affected. These impacts may affect inflation, international trade, patterns of investment, and thus the macro-economy.

Whether the United States makes these changes unilaterally or in concert with other nations, whether it makes them in a cost-effective way using market-friendly policy instruments, and whether it implements them with adequate time and flexibility for economic adjustments to occur will all affect the macroeconomic impacts.

As the discussion of mandatory policies to reduce greenhouse gas emissions has accelerated, efforts to understand the economic implications of those policies have become intense. More than a dozen economic models have been used to generate simulations of different abatement targets and implementation policies. Not surprisingly, all this activity has produced little apparent consensus: economists derive markedly different predictions from their models about the likely impacts of achieving any specific abatement goal. Various interest groups have seized on particular predictions to support their own policy conclusions.

To sort out the resulting confusion, World Resources Institute vice president and senior economist Robert Repetto and his colleague Duncan Austin explain why different economic models reach different conclusions—because they start from different assumptions. This report, *The Costs of Climate Protection: A Guide for the Perplexed*, provides an overview of 16 leading economic simulation models. According to the report, under a reasonable set of common assumptions, models indicate that the macroeconomic impacts of stabilizing green-

house gas emissions are likely to be modest and, if the environmental benefits are factored in, are likely to be beneficial. Repetto and Austin identify which assumptions are crucial. Their report will help readers form their own judgment about the likely impact of climate protection on the economy.

Building on the findings of earlier reports, including *The Right Climate for Carbon Taxes: Creating Economic Incentives to Protect the Atmosphere*; *Green Fees: How a Tax Shift Can Work for the Economy and the Environment*; and *Breathing Easier: Taking Action on Climate Change, Air Pollution and Energy Insecurity*, WRI continues to explore constructive ways

to resolve the climate problem without undermining economic prosperity. We are committed to working with the private and public sectors in the United States and abroad to achieve this goal.

We would like to thank the MacArthur Foundation, the W. Alton Jones Foundation, the Nathan Cummings Foundation, and the U.S. Environmental Protection Agency for providing generous financial support for the work underlying this report.

Jonathan Lash
President
World Resources Institute

INTRODUCTION

The latest international scientific assessment concludes that human activity is affecting the global climate (IPCC, 1996a). Population growth, rapid industrialization, increasing fossil fuel use, and continuing deforestation imply that without drastic action carbon dioxide concentrations in the atmosphere will double their pre-industrial levels by about the year 2060 and eventually cause average global temperature to rise by 1C-3.5C (IPCC, 1996a). The consequences of warming on this scale are hard to predict. Although some effects, such as rising sea levels and changing agricultural patterns, can be clearly foreseen, other effects, some potentially catastrophic, can only be guessed at. Nations have committed themselves to a precautionary approach designed to limit the accumulation of greenhouse gases.

Policies to prevent climate change focus mainly on carbon dioxide (CO₂) emissions, the most important greenhouse gas. As a first step toward the ultimate goal of stabilizing concentrations, the industrialized nations that signed the Framework Convention on Climate Change voluntarily undertook to return their emissions of carbon dioxide and other greenhouse gases to 1990 levels by the year 2000. However, many countries, including the United States, will fail to meet this target.

In 1995, at the first Conference of Parties to the Convention (COP-1) in Berlin, signatories acknowledged that even if emissions were stabilized at 1990 levels, concentrations would continue to rise rapidly because CO₂, once released, remains in the atmosphere for decades. The Berlin Mandate calls for strengthened commitments from developed countries to reduce their emissions after 2000. Negotiations since COP-1 have led to various proposals, the most stringent calling for industrialized countries to reduce emissions to 20 percent below 1990 levels by 2005 (AOSIS, 1995). The United States Government has stated that it is prepared to accept legally binding commitments in future protocols in the hope that this will prompt other countries to adopt a similar stance. Agreement on future commitments will be embodied in a formal protocol to be signed at the third Conference of the Parties in Kyoto in December 1997.

If the United States and other nations do agree on binding limits on greenhouse gas emissions, they will need to adopt measures to reduce carbon emissions with the least adverse economic impacts. One of the most effective and efficient mechanisms is a carbon tax—a tax levied on all fossil fuels in proportion to their carbon



One of the most effective and efficient mechanisms to reduce carbon emissions is a carbon tax—a tax levied on all fossil fuels in proportion to their carbon contents.

contents. Raising the prices of fuels and energy-intensive products would discourage all fossil fuel uses in proportion to their carbon contents and encourage development of less carbon-intensive alternatives. A recent statement by leading economists points out that a tax mechanism would be much more efficient than a regulatory approach (Economists' Statement on Climate Change, 1997).

An alternative proposal under serious consideration in the United States is a tradable permits program, in which permits would be required in order to sell or use fossil fuels. By limiting the total number of permits, the regulatory authority could control carbon emissions. If the government allowed permits to be bought and sold, the program would create efficient incentives like those of a carbon tax, because the permit price in the marketplace would signal how much firms should reasonably spend on abatement measures. If the government initially distributed the permits through an auction, it could mitigate adverse economic impacts by using the revenues to reduce other taxes without increasing fiscal deficits. In this sense, auctioned-off tradable permits to sell or use fossil fuels have economic implications similar to those of a carbon tax. (In this report, statements about the effects of a carbon tax apply equally to the impacts of tradable carbon permits that are auctioned-off.)

Though one argument for tradable permits is the perceived political

difficulty of proposing a change in the tax structure, the tradable permits approach also faces potential difficulties. It would be less efficient than a revenue-neutral tax and would encounter political opposition if valuable permits were given away to energy companies and utilities. Moreover, it would be difficult to include small fuel users in a tradable permits program, though their aggregate energy use is important, without creating administrative burdens much greater than those implied by raising energy taxes. Furthermore, if new scientific information necessitated further emissions reduction, canceling carbon permits that had been purchased in an auction or market transaction would be more difficult than raising a carbon tax.

Many interest groups claim that a carbon tax or any other efficient policy to reduce carbon emissions, such as a tradable permits policy, would impose high economic costs and reduce economic growth. For support, they point to simulations with economic models, some of which have suggested that stabilizing CO₂ emissions at 1990 levels could require a tax of up to \$430 per ton of carbon by 2030 and could impose total costs of up to 2.5 percent of annual gross domestic product (GDP) (Charles River Associates, 1997). Of course, other economic models predict that similar emissions reductions could be achieved with far smaller energy taxes and negligible, or even favorable, overall impacts on the economy (Gaskins and Weyant, 1993).



Despite the complexity of the models, only a handful of easily understandable assumptions are important in determining the simulation results.

Which predictions should we believe—if any? Interested groups on different sides of the issues have their own preferred models (and modelers), and these tend to produce simulations supporting the policy positions of their respective sponsors. The underlying economic models may contain dozens of complicated equations that are nearly impenetrable to all but trained econometricians. How and why such models reach the predictions that they do is hard to comprehend. Yet, it matters greatly what the economic impacts of policies to reduce the long-term risks of global warming will be.

This report provides a guide for the perplexed—an explanation in simple terms of the key assumptions in the models being used to simulate the

economic effects of carbon taxes or similar policies to control carbon dioxide emissions. The report also provides a quantitative analysis of 16 widely used models, demonstrating how key assumptions affect the predicted economic impacts of reaching CO₂ abatement targets. It turns out that despite the complexity of the models, only a handful of easily understandable assumptions are important in determining the simulation results. By showing the effect of these assumptions on the predicted economic costs, not just in one particular model but in all of them, this report can help readers to apply their own judgments about which models are more realistic and to reach their own conclusions about which economic predictions are more credible.

MODELS, ASSUMPTIONS, AND CONCLUSIONS

1

An economic model is no more than a coherent set of assumptions about the structure and functioning of the economy. A model is used to predict the consequences of some change, often a policy change like the imposition of a carbon tax. Naturally, the prediction depends entirely on the assumptions imbedded in the model—how could it be otherwise? Many of the assumptions of an economic model are simplifications, adopted to make the model easier to analyze or to compute.

Modelers hope that in making these simplifying assumptions the baby is not disappearing along with the bathwater, but, alas, that is not always so. Many are based on empirical studies, often quite sophisticated, of particular relationships in the economy, and the modeler hopes not only that the relationship has been described accurately but also that it will continue in the future as it was in the past.

Many people are critical of the assumptions economists make but none more so than economists themselves. Typically, economic modeling of important issues is subjected to widespread and intense scrutiny within the economics profession, and unrealistic assumptions tend to be identified,

improved, or discarded. Just as climate scientists and modelers over the past decade have criticized and improved the atmospheric models linking greenhouse gas emissions to changes in climate, so have economists improved the modeling of the economic impacts of a carbon tax. There has been prolonged economic debate and significant intellectual progress in making the models used for economic simulation more realistic. This report reflects some of that intellectual history.

Two kinds of assumptions in the models are critical: those that largely determine the predicted economic costs of abating carbon emissions and those relating to the economic benefits from forestalling environmental impacts from fossil fuel emissions. With respect to the costs of limiting carbon emissions, the key assumptions are

1. the extent to which substitution among energy sources, energy technologies, products, and production methods is possible;
2. the extent to which market and policy distortions create opportunities for low-cost (or no-cost) improvements in energy efficiency;



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Predictions of the economic impacts of climate protection policies have been made on the basis of two main kinds of economic analyses, commonly referred to as 'top-down' and 'bottom-up' models. **Top-down** models are aggregate models of the whole economy that represent the sale of goods and services by producers to households and the reciprocal flow of labor and investment funds from households to industries. Models used for policy simulations also describe the role of government in imposing taxes, transferring income, and purchasing goods and services. *Computable general equilibrium* (CGE) models depict the formation of market-clearing prices in the process of matching the demand for goods and services from users to their supply by producers. Demand and supply conditions in such models are based on assumptions that consumers and producers allocate their resources to maximize their welfare or profits, respectively. However, demand and supply conditions are typically based on statistically estimated relationships observed in the past. *Optimizing* models derive their predictions by explicitly maximizing some assumed mathematical formula representing household welfare as a function of present and future consumption. Such general equilibrium models assume that households and industries will eventually respond efficiently to any policy change, though some models describe irreversible investment decisions and imperfect foresight regarding future prices that serve to delay the adjustment process.

In contrast, *macroeconomic* models predict economic behavior from statistically estimated relationships among economic variables in the past. Although such relationships are developed from accepted economic theory, macro models do not derive the predicted response to a policy shift from an explicit assumption that firms and households respond efficiently or with accurate foresight. Because they are estimated from actual macroeconomic behavior, they can reflect the short-term adjustment costs in response to an unexpected economic policy change, including business cycles, inflation, and unemployment. Macro and CGE models can be complementary in predicting short-run and long-run responses to a policy change. Moreover, modelers have learned to combine features of both (Hourcade and Robinson, 1996; Shackleton et al., 1992).

Top-down models used to analyze climate policies emphasize interactions between the energy sector and the rest of the economy. A tax-induced change in the price of carbon fuels directly affects demand and supply for energy, and indirectly affects other markets for commodities, labor, and capital. Therefore, consumer prices, incomes, savings, and labor supply are also affected, resulting in new levels of GDP, investment, and future growth. These can all be compared to baseline projections. More detailed analyses offer insights into distributional incidence on particular industries and income groups. When key assumptions are standardized among models, the range of their predictions narrows (Gaskins and Weyant, 1993).

Bottom-up analyses examine the technological options for energy savings and fuel-switching that are available in individual sectors of the economy, such as housing, transportation, and industry. Information on the costs of these options in individual sectors is then aggregated to calculate the overall cost of achieving a reduction in CO₂ emissions. In contrast to top-down models, in which the scope for technological substitution is extrapolated from past experience, bottom-up analyses estimate possibilities by considering explicitly the actual technologies that firms could profitably adopt at various energy price levels. Bottom-up analyses tend to be more optimistic about the scope for cost-effective energy savings.

To some extent, this optimism comes from overlooking important barriers to implementation, such as management and retraining time, risk-aversion toward unproven technologies, capital constraints, household preferences, or lack of information (Boero et al., 1991). Top-down models based on past rates of substitution and technological change implicitly incorporate such effects. Moreover, bottom-up analyses do not deal as adequately with overall macroeconomic constraints on capital availability or market demand as top-down models do. Despite these limitations, bottom-up analyses have highlighted energy inefficiencies and technological opportunities. Some top-down climate models have adopted features of bottom-up analyses by incorporating detailed descriptions of technological options for energy supply, conversion, and use.



Assumptions about the use of revenues generated from carbon taxes or from auctioning off carbon permits are crucial.

3. the likely rate of technological innovation and the responsiveness of such change to price signals;
4. the availability and likely future cost of non-fossil, backstop energy sources;
5. the potential for international 'joint implementation' of emissions reductions; and
6. the possibility that carbon tax revenues would be recycled through the reduction of economically burdensome tax rates.

Top-down models that assume limited substitution, slow technological change that does not respond to price signals, limited, expensive, or no availability of non-fossil energy sources, and the absence of international cooperation in achieving emissions reductions at least cost unfailingly predict that the economic costs of achieving any given carbon abatement target will be high. At the other extreme, bottom-up analyses that embody optimistic assumptions about the potential availability and rapidity of cost-effective, energy-saving technological improvements, and that neglect capital and other resource constraints can be counted on to predict low abatement costs.

In addition, assumptions about the use of revenues generated from carbon taxes or from auctioning off carbon permits are crucial. These revenues can be used to offset reductions in revenues if rates are cut on other taxes that are economically burdensome,

without raising fiscal deficits. Many existing taxes on incomes, profits, and payrolls discourage savings, work, or investment by lowering after-tax returns to those activities. Economic studies suggest that lowering marginal tax rates for such existing forms of taxation and making up the revenue through a carbon tax would lessen the economic impacts of achieving a carbon abatement target. However, many early economic modeling simulations assumed that revenues from a carbon tax would not be used in this way but somehow returned in arbitrary "lump-sum" distributions to households, with no effect on incentives to work, save, or invest.

The final set of key assumptions concerns the environmental damages a carbon tax would avoid. Though averting these potential damages is the rationale for a carbon tax, most economic models are not constructed in ways that can take these damages into account. However, some models have factored in two types of savings:

1. avoiding the economic damages from climate change (the 'climate benefits'); and
2. reducing other air pollution damages associated with the burning of coal and other fossil fuels (the 'non-climate benefits').

The impact of climate change on the U.S. economy is a matter of great uncertainty, with predictions ranging from potential disasters—floods, hurricanes, droughts, and pestilence—to



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potentially mild or even benign effects. Attempts at comprehensive assessment have projected that, on balance, climate change will impose net economic costs over the next century, rising with the extent and rapidity of the change in climate (IPCC, 1996b; Nordhaus, 1993; Cline, 1992). Some assessments have assumed a degree of risk-aversion that gives more emphasis to low-probability but severely damaging outcomes.

Few models have dealt with the potential environmental side-benefits of a carbon tax that would make coal and petroleum fuels more expensive and discourage their consumption. Since baseline projections predict that without a carbon tax coal burning in power plants and gasoline consumption in motor vehicles will increase in coming decades, air quality might deteriorate, harming human health and necessitating higher medical expenditures. A carbon tax would reduce these risks. Whether or not models take such environmental side-benefits into account substantially affects the economic impacts they predict.

As the next section will demonstrate, the divergent assumptions built into

economic models in these key areas largely explain why their predictions regarding the economic costs of reducing emissions differ so widely. Under a reasonable standardized set of assumptions, most economic models would predict that the macroeconomic impacts of a carbon tax designed to stabilize carbon emissions would be small and potentially favorable.

Aside from the macroeconomic impacts, other considerations enter the debate over climate protection policies: notably, their distributional impacts and their effects on our international competitive position. As discussed in the final section of this report, the disproportionate impact of a carbon tax on low-income households now appears to be less than first thought and could be easily offset by other tax reductions or cost-of-living adjustments in social security and other transfer programs. By contrast, the disproportionate impacts on certain industries, particularly the coal mining industry and coal-carrying railway lines, would undoubtedly be substantial. To put this in context, the baseline projections against which these effects are evaluated predict sub-



Under a reasonable standardized set of assumptions, most economic models would predict that the macroeconomic impacts of a carbon tax designed to stabilize carbon emissions would be small and potentially favorable.

stantial expansion in coal mining in the western United States. The effects of a carbon tax designed to stabilize emissions at something like current levels would be largely to reduce the industry's rate of growth.

Concerns regarding the effects of carbon abatement policies on the international position of the U.S. economy have also weakened in force because of recent developments. The key issues, closely interrelated, are

1. whether reduced energy demand in the United States would help hold down world oil prices, improving our terms of trade;
2. whether higher domestic energy prices would stimulate energy-intensive industries in other countries to expand more rapidly; and
3. whether other countries would also adopt similar policies to restrict greenhouse gases, following the U.S. lead.

The United States is a sufficiently large importer of petroleum products that its demand affects world prices. Baseline projections imply that in the absence of a carbon tax petroleum consumption would continue to outgrow production capacity in non-OPEC regions, so that OPEC would supply an increasing share of the world

oil market. By 2015, OPEC's share would exceed its peak two-thirds share in 1974, when it was able to raise energy prices sharply (U.S. EIA, 1996). A U.S. carbon tax that reduced U.S. energy demand could forestall increases in these prices and shift some of the economic impact on to foreign oil producers.

If, however, the United States alone imposed a significant carbon tax, international trade and investment in some energy-intensive industries might shift sufficiently to expand carbon emissions elsewhere and reduce U.S. production of those products. This now seems unlikely. Differential environmental policies appear to have a weak impact on trade and investment flows, if any (Repetto, 1995). Moreover, many non-OECD countries, including India, China, Mexico, and the republics of the former Soviet Union, have already raised energy prices unilaterally for purely economic reasons. Major OECD countries are likely to follow suit in instituting climate protection policies if the United States takes the lead. A few European countries have already enacted modest carbon taxes; others are seriously considering replacing some labor taxes with environmental taxes (OECD, 1997; Carraro and Siniscalco, 1996). The greater likelihood of coordinated international action means that adverse trade effects can be avoided.

HOW THE MODELS' ASSUMPTIONS DETERMINE WHAT ECONOMIC IMPACTS THEY PREDICT

2

To clarify how key modeling assumptions affect the predicted economic impacts of a carbon tax, we have assembled 162 different predictions from 16 of the most reputable and widely used economic models. Each of the models differs in its basic features and for each model, different simulation “runs” reflect either different policy assumptions (e.g., about the disposition of tax revenues) or different abatement targets and carbon tax rates. Each simulation “run” generates a predicted economic impact—measured here as the percentage change in GDP in some future year—and a corresponding percentage change in carbon dioxide emissions in the same year. Both variables are measured with reference to a baseline scenario, particular to each model, predicting what would happen in that year if no carbon tax or equivalent policy were adopted.

This measure of economic impact—future year GDP—is not ideal but was adopted because it is predicted in all models. If the predicted economic adjustment involves an initial slump from which the economy then recovers, a better measure would be the (discounted) loss of income and consumption over the entire period, but such a measure is not available in all models. More fundamentally, GDP is a measure of economic activity, not economic wellbeing: for one thing, it does not measure the nonmarket value of environmental quality.

The collection of model “runs”—plotted in Figure 1—shows how variable the predicted economic impacts are.

For example, a carbon tax that induces a 35 percent reduction in CO₂ emissions could be expected to *raise* GDP over its projected baseline level by more than 1.5 percent or to *reduce* GDP by about 3 percent, depending on the economic models and modeling assumptions used. The majority of predictions suggest that abating CO₂ emissions will reduce economic activity and that eliminating a greater percentage of emissions will lower GDP more than proportionately. However, this apparent consensus does *not* imply that this prediction is likely to be accurate, but only that most modeling exercises have employed similar assumptions.

For each of these 162 modeling predictions, we have listed the main assumptions underlying the predictions. Some of these revolve around the basic features of the model; others refer to the policy options assumed for the specific simulation. Our list includes most of the key assumptions discussed in the previous section. Of the structural features of the models, the salient distinctions are:

1. Is the model of the CGE type, which assumes that the economy adjusts efficiently in the long-run, or is it a macro-model that assumes the economy suffers persistent transitional inefficiencies?
2. How much scope for inter-fuel and product substitution does the model assume, as indicated by the number of different energy sources and industrial sectors in the model?¹

¹ This is just one indicator of potential substitution; the other, not so easily measured, is the ease with which one product can be replaced by another in response to changes in relative costs.

3. Does the model assume that one or more backstop non-fossil energy sources are available at some constant cost?
4. How many years does the model assume to be available to achieve the specified CO₂ reduction target, expressed as a percentage reduction from projected baseline emissions in the final year?
5. Does the model assume that reducing CO₂ emissions would avoid some economic costs from climate change, or that no such costs exist?
6. Does the model assume that reducing fossil fuel combustion would avoid some damages from air pollution, or not?

FIG. 1

THE PREDICTED IMPACTS OF CARBON ABATEMENT ON THE U.S. ECONOMY
(162 ESTIMATES FROM 16 MODELS)

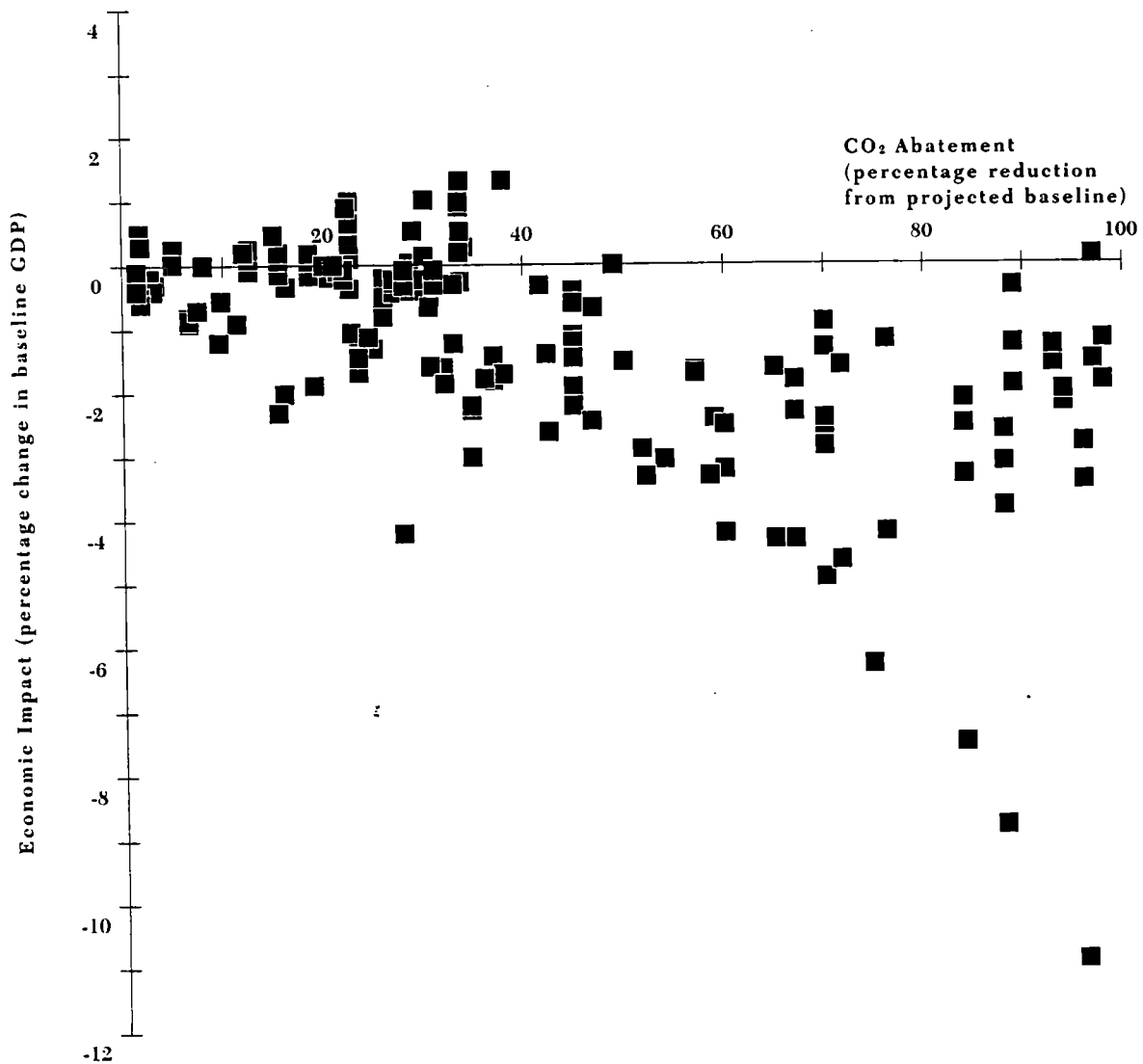
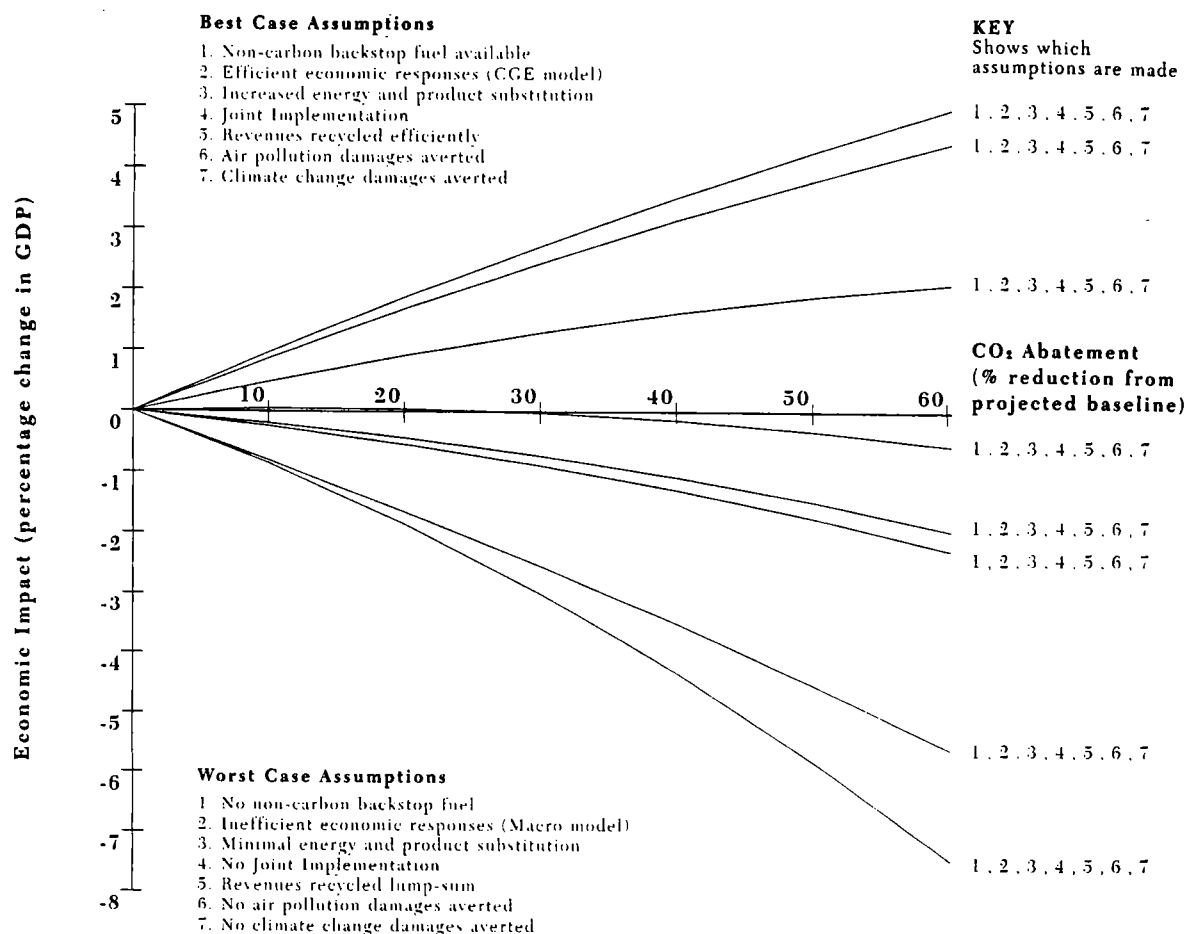


FIG. 2

PREDICTED IMPACTS ON GDP FOR VARIOUS CO₂ ABATEMENT TARGETS IN 2020: THE EFFECTS OF CHANGING UNDERLYING ASSUMPTIONS ONE-BY-ONE



The salient policy assumptions that differentiate the model predictions are:

7. Does the model assume that carbon tax revenues are returned to the economy through the reduction of a distorting tax rate, or through lump-sum rebates?
8. Does the model assume that joint implementation options are available, or not?

To show how these assumptions affect the predicted economic impacts, we expressed these assumptions either as binary variables (yes = 1; no = 0) or numerical variables and used statistical techniques to relate the assumptions to

the data points portrayed in Figure 1. Doing this shows how the assumptions affect the predicted impacts, not in any one model but across all 16 models in 162 different simulations. As suggested by these data points, we assumed that the economic impact of each additional one percent reduction in carbon emissions would be greater, the greater the percentage reduction.² We also assumed (consistent with the definition of the baseline projection) that imposing no carbon tax would not affect the economy's baseline trajectory, so that any statistical function would include the zero point in Figure 1.

Surprisingly, these eight assumptions (along with the size of the CO₂

² Specifically, we assumed that the percentage change in GDP was quadratically related to the percentage change in carbon emissions, both measured relative to the baseline projection.

emissions reduction) account for fully 80 percent of the variation in predicted economic impacts.³ This is remarkable because it implies that all the other modeling assumptions—hundreds of assumed parameter values and relationships—are comparatively unimportant. Together, they account for only 20 percent of the differences among predicted impacts. Only a handful of basic assumptions really matters.

This is good news. People don't have to be Ph.D economists to understand the debate over the economic impacts of climate policy. Rather, people can use their own judgment and common sense to decide which of these basic assumptions are more realistic. Having decided that, they can then determine for themselves which predictions are more credible and what the economic impacts of a carbon tax or a climate stabilization policy are likely to be.

To illustrate, we have used the statistical relationship between predictions and assumptions to plot several cost curves in Figure 2. Each cost curve represents a different set of modeling assumptions selected from those listed above, starting from a set of "worst case" assumptions and then successively replacing them, one-by-one, with more favorable assumptions until a set of "best-case" assumptions is arrived at. In the statistical analysis underlying these curves, the slope of the curve connecting GDP change to emissions reduction was allowed to shift with

each of the eight assumptions, but the year for achieving the abatement target was held constant.⁴

The worst case assumptions are that:

1. there is no non-carbon backstop energy source;
2. the economy does not respond efficiently to policy changes, even in the long-run;
3. the scope for inter-fuel and product substitution is minimal;
4. there is no possibility of joint implementation;
5. revenues are returned through lump-sum rebates;
6. there are no averted damages from air pollution; and
7. there are no averted damages from climate change.

Under these assumptions, many of which are obviously unrealistic, the adverse economic impacts of a carbon tax or equivalent policy would be severe, reaching 6 percent of end-year GDP for a 50 percent reduction in projected baseline emissions by 2020. (*See the bottom-most curve in Figure 2.*)

Scanning Figure 2 from the bottom up reveals the effects on predicted economic impact of changing these worst-case assumptions one-by-one. For

³ This was established by estimating a linear multiple regression model that incorporates variables representing the eight assumptions, taking the percentage change in GDP as the variable to be "explained". (The estimated regression equation can be found in the Annex.) An alternative regression analysis that included only the reduction in carbon emissions as an explanatory variable and excluded all the variables representing model assumptions explained only about half as much of the variation in predictions.

⁴ The variable representing the presence or absence of a backstop energy source was specified to affect the curvature of the cost curve, since backstop sources become relevant only at higher energy prices and then limit the rate of cost increase.



Surprisingly, these eight assumptions (along with the size of the CO₂ emissions reduction) account for fully 80 percent of the variation in predicted economic impacts.



Under all the best-case assumptions, a reduction in CO₂ emissions by 2020 would result in a substantial improvement in GDP relative to its business-as-usual path.

example, assuming that backstop energy sources exist improves the predicted economic impact substantially—by about one percent of GDP for a 50 percent emissions reduction. In Figure 2, what is notable about the predicted impacts on the U.S. economy is that changing only five worst-case assumptions—by assuming backstop energy sources, efficient long-run adjustment in the economy, greater substitution possibilities, joint implementation, and recycling of carbon tax revenues by reducing other burdensome tax rates—dramatically alters the predicted economic impacts. Instead of a six percent loss of GDP by 2020, there would be modest positive impact on GDP relative to the business-as-usual scenario.

Judging from all these simulations using a wide variety of economic models, the doomsday prediction of heavy economic losses if carbon emissions are reduced is implausible. It is more reasonable to predict that with sensible economic policies and international cooperation, carbon dioxide emissions can be reduced with minimal impacts on the economy.

Going further, Figure 2 indicates that if reducing fossil fuel combustion avoids economic damages from climate change or air pollution, then the overall economic impacts could be favorable.⁵ The top-most curve in Figure 2 indicates that under all the best-case assumptions, a reduction in CO₂ emissions by 2020 would result in a substantial improvement in GDP relative to its business-as-usual path.⁶ Of course, there is some

degree of emissions reduction beyond which the incremental abatement costs exceed the value of the environmental damages that more pollution would create. This turning point is not adequately reflected in Figure 2, which should not be interpreted to suggest that if some carbon abatement is good, more is necessarily better. Figure 2 does imply, however, that models that take the environmental benefits of carbon taxes into account predict substantially more favorable economic impacts than models that ignore such benefits.

One target that has been analyzed extensively by the Interagency Analytical Team in preparation for the COP-3 meeting in Kyoto in December 1997 is a freeze on carbon emissions at 1990 levels by 2010 and stabilization of emissions thereafter. For the United States, it has been estimated that this target implies about a 26 percent reduction below projected baseline emissions in 2020, if the baseline is calculated on the basis of policies now in place (U.S. EIA, 1996). Figure 3 uses the same statistical analysis to show in detail the range of predicted long-run economic impacts if this target is attained.⁷ Under unfavorable assumptions, GDP would be 2.4 percent lower in 2020 than under baseline conditions; under favorable assumptions, GDP would be 2.4 percent higher. Figure 3 also quantifies the relative importance of several modeling assumptions in creating this range of predictions.

Four assumptions stand out in terms of magnitude:

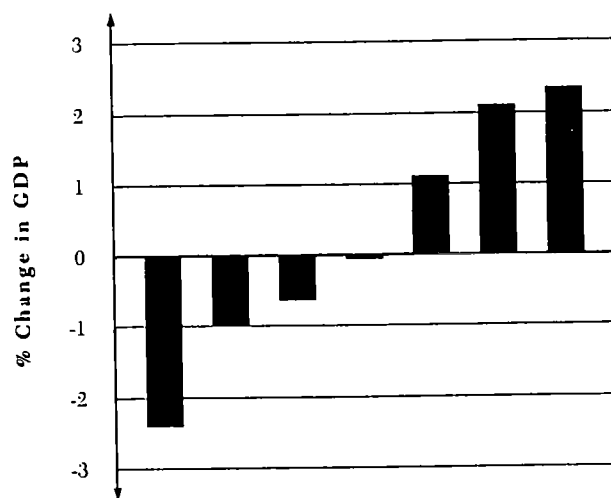
⁵ This prediction is consistent with the interpretation of a carbon tax as a corrective tax that reduces a market failure—namely, the unintended effect of carbon emissions on the global climate. Economists agree that, if set at the proper rate, a tax to correct a market failure should improve an economy's productivity.

⁶ When air pollution damages are assumed, an expanded measure of GDP in which environmental damages are recorded is the relevant indicator of economic impact.

⁷ This analysis cannot encompass short-run transitional impacts predicted by some macroeconomic forecasting models.

FIG. 3

THE PREDICTED IMPACTS ON GDP IN 2020 OF STABILIZING CO₂ EMISSIONS AT 1990 LEVELS: THE EFFECT OF CHANGING UNDERLYING ASSUMPTIONS



Worst Case Assumptions

1. Inefficient economic responses*
2. No non-carbon backstop fuel
3. No Joint Implementation
4. Revenues recycled lump-sum
5. No air pollution damages averted
6. No climate change damages averted

↑

↑

↑

↑

↑

↑

↑

Best Case Assumptions

1. Efficient economic responses*
2. Non-carbon backstop fuel available
3. Joint Implementation
4. Revenues recycled effectively
5. Air pollution damages averted
6. Climate change damages averted

* Macro Model

* CGE Model

- whether the economy will adapt efficiently;
- whether international joint implementation will be achieved;
- whether carbon tax or permit auction revenues will be recycled by reducing other taxes; and
- whether there will be economic benefits from abating pollution.

Most economists believe that the U.S. market economy, with high mobility of capital and labor, can adapt efficiently to moderate the impacts of policy

changes. There is general agreement that a carbon tax that discouraged coal use in electricity generation would have the effect of reducing air pollution, even with current air pollution regulations in place. Whether to use revenue-raising policy instruments to limit emissions and how to dispose of resulting revenues are decisions that the U.S. government must make. Finally, international cooperation in joint implementation of carbon reduction targets is a possibility subject to negotiation. Under reasonable assumptions, the predicted economic impact of stabilizing emissions at 1990 levels would be neutral or even favorable.

The preceding analysis looked broadly at the key assumptions that turn out to determine very largely the predicted economic impacts of climate protection policies. These broad distinctions among the modeling assumptions explain most of the differences among predictions. Nonetheless, other aspects of the key assumptions, which could not be adequately built into the preceding analysis need to be recognized and understood. This section addresses such issues.

A. THE SCOPE FOR REDUCING ENERGY INEFFICIENCIES

Top-down models typically assume that all cost-effective improvements in energy efficiency have already been realized, an assumption contradicted by actual experience (DeCanio, 1993). For example, large companies that joined the Environmental Protection Agency's voluntary Green Lights Program to reduce their energy use found numerous opportunities to save both energy and money in their ongoing operations.

Bottom-up studies have found inefficiencies in energy use that could be remedied through building improvement measures, such as better insulation and low-energy lighting; through

technological advances in transport efficiency; or through conversion of industrial processes. Assessments based on engineering studies suggest that from 20 to 25 percent of existing carbon emissions could be eliminated at an overall cost savings and that substantial further cutbacks could be made at relatively low cost (IPCC, 1996b; National Academy of Sciences, 1991; Office of Technology Assessment, 1991).

Some of these inefficiencies undoubtedly persist because of energy market imperfections, such as the divergence in incentives between tenants and landlords, builders and home purchasers; because of energy subsidies; or because of suboptimal decision-making within organizations. However, some reported savings opportunities might be illusory if the management costs of locating and implementing energy investments were overlooked or the differences in product and service characteristics of various energy-conversion technologies were ignored. Energy service companies, which seek to find and implement energy-saving opportunities on a contractual basis, have not found unlimited business opportunities at current low energy prices.



Top-down models typically assume that all cost-effective improvements in energy efficiency have already been realized, an assumption contradicted by actual experience.

Energy
Subsidies

Top-down models typically assume away energy subsidies that may encourage excessive fuel use and must be financed through higher levels of economically burdensome taxes. Energy subsidies, though not as prevalent in the United States as in some other countries, still include favorable tax and credit treatment for energy producers, below-market provision of power from public sector installations, and federally sponsored research and development. Two recent studies quantify annual federal energy subsidies at between \$4.9-\$14.1bn and \$21-\$36bn respectively (Alliance to Save Energy, 1993; U.S. EIA, 1992). Some of these subsidies, such as federally subsidized hydropower, actually reduce carbon emissions by replacing fossil fuels with hydroelectricity. Others, such as tax breaks for independent oil drillers, have no effect on U.S. oil consumption or carbon emissions, but merely replace foreign produced oil with domestically produced oil. Nonetheless, a study on the effects of removing U.S. energy subsidies concluded that significant reductions in CO₂ emissions could be achieved at no cost to the economy (Shelby et al., 1995).

B. SUBSTITUTION EFFECTS

A carbon tax will raise the price of fuels in proportion to their carbon content, increasing coal prices more than oil or gas prices and having little direct effect on hydro or nuclear power costs. Higher fuel prices will induce firms and households to seek ways to mitigate the cost increases. In particular, they will tend to

- substitute less carbon-intensive fossil fuels, such as gas, for carbon-intensive fossil fuels, such as coal (intra-fossil fuel substitution);
- substitute non-fossil energy sources for fossil fuels (non-fossil fuel substitution);

- substitute other factors of production (materials, labor and capital) for energy; and
- substitute less energy-intensive goods for energy-intensive goods (Cline, 1992).

The easier these substitutions are, the lower the overall burden of reducing CO₂ emissions. In addition, all such substitutions become easier as the time for adjustment increases. For example, in the short-term, a firm's production technique will be constrained by its existing equipment, but as new equipment and processes are brought on line, energy use can be reduced more readily. Similarly, consumers need time to replace durable goods and fully adapt purchasing habits to altered prices.

Economic models differ in the degree to which they represent these substitution possibilities. Highly aggregated models, which might have only a single producing sector (i.e., a sector producing a composite commodity called GDP), cannot incorporate the possibility of substituting one product for another. Similarly, models that recognize only two primary fuel sources cannot adequately represent inter-fuel substitution possibilities. More disaggregated models, such as the Markal-Macro model, which recognizes 11 primary fuel sources and dozens of fuel conversion technologies, are potentially better able to deal with such substitution possibilities (U.S. DOE, 1996).

However, this potential may or may not be realized. Despite being more or less disaggregated, models differ in the assumed ease of substitution among products and technologies in response to cost changes. Some models assume only one technology available to produce a given output, with no scope for substituting other inputs for energy. Others assume technologies will switch

in response to small changes in relative input price. Some models assume that once an investment is made, it cannot be altered until its useful lifetime is finished. Still other models assume that capital and labor can be shifted costlessly and instantaneously from one use to another. Clearly, models can either overstate or understate the range and ease of possible substitutions. It is difficult for modelers to get it right.

C. TECHNOLOGICAL CHANGE AND ENERGY EFFICIENCY IMPROVEMENT

Redesigning existing products and processes and introducing new ones can also save energy, but the oversimplified assumptions about technological change in most aggregated models are unrealistic. Most models assume a steady annual percentage improvement in energy efficiency, constant across all industries and over time. This percentage rate of improvement, captured by a variable entitled 'autonomous energy efficiency improvement' (AEEI), strongly influences projected energy consumption and emissions, with or without a carbon tax. Though it has been difficult to reach consensus on a proper value for this parameter,⁸ its effect is critical: assuming an annual rate of improvement in energy efficiency of 1 percent rather than 0.5 percent can cut projected 2100 emissions levels by half, markedly affecting the projected costs of meeting a CO₂ emissions target (Gaskins and Weyant, 1993). The higher the AEEI, the lower the projected baseline emissions will be without any carbon tax and the lower the additional emissions reduction that will be required to meet any target.

For example, one model predicts that the present value of the cost of reducing emissions to 20 percent below 1990 levels drops from \$1 trillion to a negligible level as AEEI rises from 0.5 percent to 1.5 percent (Manne and Richels, 1990a). With these assumptions, most of the fall in emissions comes from energy efficiency improvements that occur with or without a carbon tax.

More critical than the assumed value for AEEI, though, is the assumption that the pace of energy efficiency improvements is independent of energy price changes and policies. Technological changes do react to market incentives provided either by regulation or by energy prices. Deregulation of electricity markets in the United States has already accelerated market penetration by high-efficiency, low-cost generating technologies. In general, the phenomenon of "induced technological change" is well-recognized (Binswanger and Ruttan, 1978). Economists have shown that rising energy prices induce more rapid rates of energy-saving innovation (Newell et al., 1996; Grubb et al., 1995). Recent modeling analysis in which higher energy prices are assumed to stimulate energy-saving technological change predict lower economic costs of meeting given carbon abatement targets (Goulder and Schneider, 1996).⁹

D. BACKSTOP ENERGY SOURCES

Non-fossil energy sources do exist: hydroelectricity, nuclear power, wind and solar energy, and biomass, to name the most significant. As the prices of fossil fuels rise, these and other alter-

Induced
+ AEEI

⁸ The Clinton administration's Interagency Analytical Team, convened in early 1997 to examine the economic impacts of carbon abatement policies through modeling exercises, settled on a value of 1 percent per year.

⁹ If induced technological change is assumed and abatement costs fall in response to a carbon tax, more abatement will occur and *total* (as opposed to per unit) abatement costs will be higher than if technological change is not induced. Then, since total emissions will be lower, the predicted economic impact will depend on whether the economic damages from climate change are taken into account.



Economists have shown that rising energy prices induce more rapid rates of energy-saving innovation.

TABLE 1 COST OF ELECTRIC POWER GENERATION IN THE UNITED STATES, 1985, 1994, 2000			
Technology	1985	1994	2000
	(in 1993 cents per kilowatt-hour)		
Natural Gas	10-13	4-5	3-4
Coal	8-10	5-6	4-5
Wind	10-13	5-7	4-5
Solar Thermal ¹	13-26	8-10	5-6
Nuclear	10-21	10-21	- ²
¹ With natural gas as a backup fuel ² No plant ordered since 1978 Source: Worldwatch Institute, 1994			

native energy sources become more attractive. Though too expensive to be widely used today, technological improvements may eventually bring the costs of alternative energy sources down below the costs of fossil fuels in many applications if carbon taxes or comparable policies raise fossil fuel prices. As Table 1 shows, wind and direct solar energy have become more nearly competitive with coal and natural gas sources over the past two decades. Hence, at some point, if carbon emissions are restricted, non-carbon 'backstop' technologies may begin to replace conventional fuels as major energy sources. The concept of a backstop technology was popularized during the oil crises of the 1970s. It refers to an alternative energy source available in virtually unlimited quantities at some price. One example is solar energy.

Modelers have treated non-fossil energy sources in various ways, making different assumptions about their availability, initial cost, and subsequent cost changes. Some models, which have excluded backstop technologies, overstate the economic impacts of a carbon tax because the economy was assumed to rely indefinitely on conventional fuels even after their costs were higher than the costs at which alternative

energy sources would be profitable. Accordingly, the carbon tax would have to continue to rise indefinitely to hold carbon emissions constant despite economic growth (Dean and Hoeller, 1992).

Other models have recognized non-fossil energy sources, but assume that their availability is limited so that their prices will rise when used in greater volumes. This assumption is reasonable for sources such as hydroelectricity from dams, since the number of suitable dam sites is limited, but it may not be appropriate for solar energy. Hence, although the early Edmonds-Reilly model predicted an unexceptional tax of \$351 per ton of carbon to reduce emissions by 45 percent in 2020, by 2095 the predicted tax for an 88 percent cut below the baseline projection was \$2,754 per ton, reducing annual GDP by an estimated 8.8 percent (Barns et al., 1992; Dean and Hoeller, 1992).

Other models assume that backstop energy sources will be available at non-increasing prices, making the key issue how high that price is assumed to be. Models that assume a very high price (e.g., one equivalent to six times today's average fossil fuel prices) make the



Merely stabilizing the emissions rate would allow concentrations to continue rising for centuries.

availability of non-fossil energy sources virtually irrelevant because it would be uneconomic to use them until the distant future, if at all (Charles River Associates, 1997). Models that assume a more reasonable price predict that stabilizing CO₂ concentrations will cost much less. For example, the GLOBAL 2100 model assumes that non-fossil backstop energy sources will become available at future prices as low as twice current electricity prices. In this model, the estimated carbon tax falls from \$354 per ton in 2020 to \$208 by 2050 and remains at that level (Manne, 1992). As a result, the model predicts gross costs of only 3.1 percent of GDP, instead of 8.8 percent, for the same 88 percent reduction in projected baseline emissions (Dean and Hoeller, 1992).

Furthermore, were it assumed that the costs of alternative energy sources would decline over time with technological improvements and economies from large-scale production—just as fossil energy costs have done—then the predicted costs of stabilizing CO₂ concentrations would also decline over time. Most models, however, fail to make this plausible assumption about the future costs of non-fossil energy sources, even though their costs have fallen substantially in past decades.⁴

E. THE TIME PATH FOR STABILIZING CO₂ CONCENTRATIONS

Ultimately, the goal of climate policy must be to stabilize the atmospheric concentration of carbon dioxide and other greenhouse gases rather than

the rate of CO₂ emissions. These two objectives differ substantially because emissions remain aloft in the atmosphere for substantial periods of time. Merely stabilizing the emissions rate would allow concentrations to continue rising for centuries. However, since national and international policy commitments have been framed in terms of emissions, modelers have adopted the same perspective. Recent analysis shows that adopting an explicit long-term target for atmospheric concentrations and then choosing policies to achieve the most efficient time path for emissions reductions to meet the target could significantly lower the economic impact (Wigley et al., 1996).

of 1,000
p. 1/2

A target for atmospheric concentrations of CO₂ is like a 'carbon budget' that limits total CO₂ emissions within a specified period of years. Under some circumstances, it might be cheaper to use up more of the budget early on, postponing cutbacks until later (Richels and Sturm, 1996). Because the capital stock is durable and because so much equipment and building will ultimately have to be changed, adjustment is a costly process. If the time allowed for transition to a lower emissions path is increased to allow capital stock to be replaced as it wears out, overall abatement costs could be reduced. Also, as research and development yields new superior energy-savings technologies, more low-cost substitutes should be available in later years. Finally, postponing costs reduces them because, with a positive return on investment, fewer resources need to be set aside today to meet future costs.

With these assumptions, some models have suggested that it may be more cost-effective to allow emissions to rise for some decades before restricting them significantly below 1990 levels. According to one analysis of the cost-effective pattern of emissions reductions for the period 2000 to 2050, flexibility in the timing of global reductions could lower overall costs by more than 35 percent, compared to a less flexible program that achieved the same atmospheric concentration (Richels et al., 1996). Annual GDP losses would be higher towards the end of the period but would be more than offset by considerably smaller losses in earlier years.

Under other assumptions, however, the least-cost approach would be to avoid the buildup of emissions and consequent steep decline later in the period by instituting carbon taxes earlier on. The key is adopting policies to encourage early development of energy-efficient and low-carbon technologies and to discourage long-lived investments in carbon-intensive energy facilities. According to one recent assessment,

The window of opportunity for reducing cost implies a need for immediate and continuing action to develop new low-carbon technologies and to begin shifting long-lived investment decisions toward alternatives that lower carbon emissions. Absent these actions, the rapid future emissions reductions included in the delayed emissions scenario may be more costly than more evenly paced, and earlier,

reductions (Jaccard and Montgomery, 1996).

Some models assume that policy-makers can take advantage of their constituents' foresightedness by simply announcing their intention to limit emissions later in the period without taking any such measures immediately. These models assume that businesses and households will immediately revise their research and investment strategies in response to such an announcement to minimize their exposure to expected future energy price increases. Under these assumptions, the economy can start enjoying the benefits of redirected R&D expenditures and investments without incurring the costs of higher energy carbon taxes.

More realistically, investors may doubt whether a government that declines to institute carbon taxes or equivalent policies to meet its international commitments today will be certain to do so ten or more years into the future. Skeptical investors may adopt a wait-and-see attitude. Should that be the case, equipment and buildings embodying high-carbon technologies will continue to accumulate, making the sharp future reductions needed to stay within a carbon budget all the more expensive. To quell such doubts, sending a credible policy signal by instituting a small but unmistakable policy measure right at the start would be less costly in the long run. A carbon tax that is introduced at a low level and rises—perhaps significantly—in future years would make sense.



Sending a credible policy signal by instituting a small but unmistakable policy measure right at the start would be less costly in the long run.



International joint implementation of CO₂ emissions reductions would allow a utility in Norway to achieve an emissions reduction by contracting to pay a factory in Poland to install more fuel-efficient furnaces.

F. THE POSSIBILITY OF INTERNATIONAL JOINT IMPLEMENTATION

The U.S. Environmental Protection Agency has long recognized that allowing emissions sources to contract with each other to implement required emissions reductions can substantially reduce the costs of achieving any overall abatement target. When able to enter into such transactions, a facility that could reduce emissions only at great cost can compensate another facility with less expensive abatement possibilities to make the cuts for it. This is called "joint implementation." If the emissions from both facilities contribute equally to the ambient pollution problem, joint implementation of an abatement target—or voluntary emissions trading, as it's also called—can be advantageous to both parties and save money. Emissions trading has been used in the United States to reduce the costs of cutting lead, hydrocarbon, and sulfur oxide emissions. The United States has been a leader in developing this policy approach.

International joint implementation of CO₂ emissions reductions would allow a utility in Norway to achieve an emissions reduction by contracting to pay a factory in Poland to install more fuel-efficient furnaces. It would allow a major multinational company to achieve a targeted emissions reduction by energy-saving measures at any of its facilities around the world. Since CO₂ has the same effect on climate wherever it is released, finding the lowest-cost

abatement possibilities is cost-effective. Making such trades voluntary would ensure that both parties to the transaction gain from it.

So far, joint implementation of CO₂ abatement has been tried only in experimental pilot programs: U.S. utilities have financed reforestation programs in Central America to capture CO₂ from the atmosphere, for example. Joint implementation cannot be used more widely until countries have set binding emissions reduction targets (Zollinger and Dower, 1996). But, getting countries to agree on the baselines that should apply to each, from which emissions reductions will be measured, is a formidable task. Moreover, monitoring and verification of emissions reductions, along with some mechanism to enforce contractual obligations, will be essential if joint implementation is to work. Nonetheless, such implementation offers a promising opportunity to lower CO₂ abatement costs and the economic impacts of protecting the climate. Models focussed only on the U.S. economy generally assume this possibility away. Efforts to model other parts of the world along with the United States have explored the potential savings from joint implementation and have found them to be substantial.¹⁰

G. HOW REVENUES ARE RECYCLED INTO THE ECONOMY

A carbon tax would generate significant tax revenues—up to \$300bn per year by 2020 for a policy that holds

here

JZ =
int. trading

¹⁰ International emissions trading can be modeled as if all countries set the same carbon tax rate, so that cost-effective emissions reductions are advantageous to undertake in whatever country they arise.

carbon emissions to 80 percent of their 1990 levels (Gaskins and Weyant, 1993). Starting from a position of fiscal balance, some mechanism for recycling these revenues into the economy is needed to prevent a general deflationary impact. Assuming that revenues would not be fully recycled was one of the reasons for an early pessimistic conclusion that a carbon tax of \$100 per ton phased in over 10 years would reduce GDP by 2 percent annually and cut projected baseline emissions by only a small amount (CBO, 1990).

Economic modelers then began assuming that revenues would be returned in the form of lump-sum rebates. (A lump-sum tax or rebate is one in which the amount transferred is completely independent of all taxpayer behavior. Increasing the personal exemption in the income tax would be an example of a lump-sum rebate.) By assuming neutral lump-sum recycling, modelers tried to separate the economic impacts arising from climate abatement policy from those arising from other tax cuts (Gaskins and Weyant, 1993).

However, the baseline projections from which economic impacts are estimated implicitly or explicitly recognize that the U.S. economy's tax structure reduces private incomes by far more than a dollar for every dollar of tax revenue collected. The disincentive effects of taxes on payrolls, incomes, and profits either reduces work, investment, and savings or diverts them into less productive forms to reduce tax liabilities. Economists pointed out long ago that using carbon tax revenues to

reduce existing taxes that penalize work, savings, and investment would lower the net cost of reducing emissions (Terkla, 1984). Indeed, this tax-shifting opportunity is one of the principal reasons for favoring a carbon tax (or carbon permits that are auctioned off) over alternative climate policy instruments.

Taxes on labor earnings drive a 'wedge' between the price paid by firms for labor and the wage received by the employee. As a consequence, fewer workers are employed at a lower real wage rate, and the economy suffers accordingly (MaCurdy et al., 1990; Triest, 1990; Browning, 1976). Similarly, taxes on investment earnings reduce the amounts saved, resulting in lower rates of capital investment and economic growth. Empirical work suggests that these efficiency losses may be large: for every dollar of revenue raised from taxes on labor earnings, private income might ultimately fall by \$1.10 to \$1.25; and, per dollar of revenue from taxes on investment earnings, income might fall by \$1.50 to \$1.95 (Nordhaus, 1993; Fullerton, 1991; Jorgenson and Yun, 1990; Ballard, Shoven and Whalley, 1985).

The use of carbon tax revenues to reduce existing tax rates benefits society not only by correcting a market failure in energy use but also by reducing the costs of other distorting taxes, a so-called "double dividend" (Repetto et al., 1992). If the efficiency benefit from reducing existing taxes on labor and capital is incorporated into the analysis, the projected net economic



Using carbon tax revenues to reduce existing taxes that penalize work, savings, and investment would lower the net cost of reducing emissions.

TABLE 2

GDP LOSS (1990-2010) UNDER ALTERNATIVE RECYCLING OPTIONS

Recycling Option	Model			
	DRI	LINK	DGEM	Goulder
	(Percentage change in discounted constant price GDP)			
Lump Sum Tax Cuts	-0.58	-0.46	-0.62	-0.24
Personal Income Tax Cuts	-0.56	-0.53	-0.16	-0.16
Corporate Income Tax Cuts	0.40	-0.11	0.60	-0.17
Payroll Tax Cuts				-0.18
Employee Only	-0.58	-0.53		
Employer Only	0.19	-0.25		
Investment Tax Credit	1.55	1.67		0.00

Source: Shackleton et al. (1992).

impacts of a carbon tax are substantially more favorable than they appear to be when lump-sum revenue recycling is assumed (Goulder, 1995).

Pro-
1
Tax
re-
cycling.

One analysis of this issue compared six revenue-recycling options, using four different models (Shackleton et al., 1992). Despite modeling differences a clear hierarchy of recycling options emerges, with lump-sum rebates among the least attractive. As Table 2 shows, using revenues to lower corporate income tax and payroll taxes instead of giving lump-sum rebates significantly reduces the adverse economic impacts of a carbon tax. Not surprisingly, the analysis reveals that recycling revenues by reducing taxes on capital investment earnings and thereby encouraging capital formation reduces the economic impacts more than lowering taxes on consumption. In two models, recycling revenues by introducing an investment tax credit leads to net gains in GDP and consumption. (In a third model, the same recycling mechanism exactly offsets the costs of mitigation.) More recent studies support these findings (McKibbin and Wilcoxon, 1996; Goulder, 1995; Jorgenson et al., 1995).

Models suggesting that the substitution of a carbon tax for other taxes could provide net economic benefits, *irrespective of the environmental gains*, prompted some economists to propose a stronger form of the double dividend hypothesis, claiming that a carbon tax could be justified even apart from environmental benefits. This has led to a debate about whether the revenue recycling effect alone is sufficient to justify the levying of a carbon tax (Goulder, 1995; Parry, 1995; Bovenberg and de Mooij, 1994). This is obviously not always true. If the environmental benefits and the welfare gain from correcting a market failure are ignored, a tax on fuels distorts energy markets just like any excise tax does. It may be more or less distortionary than another tax already being levied, depending on the size of energy markets, the price sensitivity of energy demands, the structure of pre-existing energy taxes, and other conditions. Though Table 2 shows particular tax substitutions that suggest a strong double dividend, economists doubt whether a strong double dividend would generally be available. The key issue is how an energy tax would interact with existing taxes on capital

Several economists have pointed out that when distorting taxes on labor and capital income already exist in an economy, the effects of replacing some of these taxes with a carbon tax are complicated. A carbon tax, which raises the prices of energy and energy-intensive goods, would raise consumers' cost of living and, with wage and salary levels unchanged, would lower real wages. In this respect, a carbon tax would have much the same effect as a direct tax on labor incomes. By lowering the real rewards from working, both kinds of tax would distort labor markets and reduce labor supply. Substituting one for another might not reduce the labor market distortion. Indeed, because a carbon tax—with a narrower tax base—would require a higher tax rate than a direct payroll tax to raise the same revenue, a revenue-neutral tax shift might even reduce labor supply further. Using this reasoning, these economists have questioned the likelihood of a strong double dividend and the extent of a weak double dividend.

However, this argument rests on special assumptions. It assumes unrealistically that a carbon tax would be borne entirely by working consumers, not at all by owners of coal mines, stockholders in energy companies, or foreign oil sheikhs. Clearly, this assumption is not shared by these parties themselves, as they vigorously oppose the imposition of a carbon tax or any equivalent policy. To the extent that a carbon tax would not reduce the real value of labor incomes but would fall instead on earnings from capital and property or on foreign suppliers, it would not have the effect of reducing labor supply.

More importantly, this line of reasoning ignores the effects of environmental damages on the cost of living. A carbon tax would raise energy prices but reduce CO₂ emissions and other pollutants stemming from fossil fuel combustion: sulfur and nitrogen oxides, hydrocarbons and other smog precursors, particulates, and carbon monoxide. Cutting back

emissions of these pollutants would decrease medical expenses and the number of work days lost to sickness. For example, a recent comprehensive study estimated that improved air quality under the Clean Air Act has resulted in striking health benefits to the American population, including 80,000 fewer heart attacks in 1990, 10,000 fewer strokes, 15,000 fewer cases of respiratory illness, 13,000 fewer cases of hypertension, and a long list of other health benefits (U.S. EPA, 1996). These improvements are much more than an additional fuel tax would generate, but make the point that health benefits from reducing air pollution are substantial. Improved health and reduced health expenditures stemming from a carbon tax would offset the tax's modest negative impact on incentives to work.

Similarly, all assessments of the risks from climate change emphasize that global warming may raise production costs in affected industries. Increased evapotranspiration may reduce crop yields and water availability, raising agricultural production costs. Higher temperatures may raise air conditioning and cooling costs (though lowering heating bills). Rising sea levels may increase coastal flooding and storm damages. Warmer climates may increase the range of agricultural pests and disease vectors. Production losses from a doubling of CO₂ concentrations are estimated at 1 or 2 percent of GDP (Fankhauser, 1995; Tol, 1995; Cline, 1992). Again, these estimated damages are larger than those that a modest carbon tax would eliminate, but make the point that forestalling climate change would reduce many production costs. Therefore, though a carbon tax would raise energy costs it would *lower* costs in a range of other industries, with uncertain effects on the overall cost of living. On balance, taking both costs and benefits into account, the interaction of a carbon tax or equivalent policy with pre-existing taxes is as likely to magnify the double dividend as to shrink it.

and labor. (See Box 2.) Nonetheless, models that ignore the potential gains from substituting a market-correcting tax for a market-distorting tax are excessively pessimistic about the economic impacts of a carbon tax.

H. AVOIDING THE COSTS OF CLIMATE CHANGE

Most models used to simulate the economic impacts of carbon taxes have been adaptations of existing models designed for energy planning or for



Heat waves, severe storms, and other extreme weather episodes may become more frequent as average temperature and precipitation increase.

general macroeconomic forecasting, and were not able to incorporate the benefits of preventing climate change, or equivalently, the costs of doing nothing. Instead, they have simply measured the economic impacts of meeting emissions abatement targets, implicitly assuming in the baseline projections that climate change would have no effect on the economy.

Granted, predicting the physical effects of global warming is difficult enough, let alone estimating the effect on human welfare. Climate change is likely to have many economic effects, some favorable and others not, especially on agriculture, fishing, forestry, recreation, flood control, water supply, and other industries dependent on natural resources. Other impacts will occur not through market mechanisms but through ecological changes, altered rates of human morbidity and mortality, heat-related distress and discomfort, and migration (IPCC, 1996b).

Several studies have estimated damages from a doubling of CO₂ concentrations midway through the next century.¹¹ Available estimates rely on questionable simplifying assumptions and are little more than best guesses, expressed as wide ranges. Estimates for the U.S. economy range from 1.0 to 1.5 percent of GDP annually (Fankhauser, 1995; Tol, 1995; Cline, 1992; Nordhaus, 1991). Titus (1992) predicts annual damages of 2.5 percent of GDP, largely because he assumes that CO₂ doubling will lead to higher temperatures than other researchers do. Damages for the global economy

as a whole are closer to 2 percent of world GDP annually and up to 9 percent of national GDP for some developing countries (Fankhauser, 1995; Tol, 1995; Fankhauser and Pearce, 1994).

These estimates might be too pessimistic (Fankhauser and Tol, Energy Policy, 1996). They do not adequately reflect the possibility that adaptations to gradual climate change, such as changed agricultural practices, may be available to forestall damages at relatively low cost (Mendelsohn, 1996; Adams et al., 1994; Nordhaus, 1994). They may give too little weight to potential cost savings from climate change, such as reduced heating costs (Rosenthal et al., 1995). And they may not adequately reflect changing scientific perceptions of likely ecological changes, such as lowered predictions of sea level rise (Yohe et al., 1996).

On the other hand, these estimates refer only to CO₂ doubling, when much higher concentration levels are likely in the more distant future. Even if emissions are successfully stabilized and held at 1990 levels, concentrations will double by 2100 and increase subsequently thereafter (IPCC, 1996a). Moreover, if emissions continue rising, concentrations could exceed 700 ppmv by the end of the next century, and damages may increase more than proportionately (IPCC 1996a; Cline, 1992).

In addition, estimates typically are based on increases in average temperature and precipitation, but heat waves, severe storms, and other

¹¹ 'Doubling' refers to CO₂ concentrations of 560 ppmv (parts per million by volume), twice the pre-industrial level of 280 ppmv that forms the standard benchmark. IPCC (1996a) estimates the temperature rise from doubling at 1-3.5C with a 'best guess' of 2.5C—the figure adopted by most researchers.

extreme weather episodes may become more frequent as average temperature and precipitation increase. Omitting these extremes probably understates the impacts of climate change, since gradual changes in average temperature and rainfall have much less effect than the occasional extreme event does. The ultimate manifestation of this is the unlikely possibility of catastrophic events such as the disintegration of the West Antarctic ice sheet, the redirection of the Gulf Stream, the spread of disease vectors into unresistant populations, or the possibility of a 'runaway' greenhouse effect, where positive feedbacks overwhelm negative ones (IPCC, 1996b). Potential catastrophes seem more likely the longer the time frame under consideration and cannot be assigned a zero probability.

Uncertain though they are, there are costs associated with doing nothing in the face of rising greenhouse gas concentrations. These are typically not reflected in the baseline projections of most models. Therefore, the net economic impacts of carbon taxes tend to be overstated. The few models that do take expected damages from climate change into account predict that a carbon tax set at an appropriate rate, with revenues recycled efficiently back into the economy, actually improves economic welfare (Nordhaus and Young, 1996; Jorgenson et al., 1995; Nordhaus, 1994, 1993).

I. AVOIDING OTHER ENVIRONMENTAL DAMAGES

By discouraging coal and other fossil fuel consumption, a carbon tax would reduce emissions of such air pollutants as carbon monoxide, sulfur and nitrogen oxides, and toxic trace pollutants in exhaust gases. Though most of these pollutants are already regulated, this usually takes the form of a maximum rate of emissions per million BTUs. Thus, despite regulations, reducing the number of BTUs generated by fossil fuel combustion would lower emissions. This would almost immediately reduce damages to health, visibility, materials, and crops.

A simple approach to assessing non-climate benefits is to calculate the tax-induced reduction in fossil fuel consumption and use emissions profiles for individual fuels to estimate overall emissions reductions (Scheraga and Leary, 1993). This approach suggests that a carbon tax set to keep CO₂ emissions at their 1990 levels by the year 2000 would reduce various atmospheric emissions below projected baselines by 1 to 7 percent. EPA estimates that the economic savings in the year 2000 from the resulting pollution abatement would be between \$300 million and \$3 billion.

Other studies in Europe and the United States estimate that the non-climate benefits of a carbon tax would probably be as large or larger than the benefits of avoiding climate change (Ekins, 1995; Jorgenson et al., 1995).



Studies in Europe and the United States estimate that the non-climate benefits of a carbon tax would probably be as large or larger than the benefits of avoiding climate change.

These estimated economic savings from reduced air pollution damages may be sufficiently large to offset from 30 to 100 percent of carbon abatement costs (IPCC, 1996b).

Large as these sums are, this approach underestimates damages over time because it ignores the fact that in baseline projections, in the absence of carbon taxes, rising population and economic growth would increase exposure to air pollution while increased fuel consumption would reduce air quality. Current environmental standards typically limit emissions on a per-BTU basis for stationary sources and on a per-mile basis for vehicles. As the economy grows, trying to maintain environmental quality by making each mile traveled or BTU generated less polluting can become increasingly costly. At some point, fuel taxes that provide incentives to conserve energy and limit the amount of driving become cost-effective adjuncts to such regulations (Eskeland and Devarajan, 1996).

One of the few models to incorporate the savings from reducing pollution damages estimates how much reduction in CO₂ emissions could be had for "free" under a "no regrets" policy—a policy under which net abatement costs are exactly offset by non-climate benefits. When firms are assumed to be able to substitute labor and capital for energy, a reduction of nearly 50 percent of baseline emissions can be attained with no loss in economic welfare (Boyd, Krutilla and Viscusi, 1995).

Despite these impressive magnitudes, most models of carbon abatement policies have ignored the potential savings in pollution damages, and the remaining few have incorporated them rather crudely. More recent and comprehensive research on the benefits of air pollution control is now available to be incorporated into climate models (U.S. EPA, 1996). Other benefits from lower energy consumption, such as reduced road congestion and fewer environmental impacts from fuel mining, refining, and transport, could also be taken into account.

TRADE AND EQUITY ISSUES

A. TRADE ISSUES

Concerns about adverse international trade consequences are strong among businessmen who fear that if the United States unilaterally adopted a carbon tax its energy-intensive industries almost certainly would become less competitive in international trade. International shifts in the location of production, so-called 'leakage' effects, would mean that cuts in domestic emissions would be partially offset by increases in emissions abroad as energy-intensive industries expanded overseas (Barrett, 1994; Gaskins and Weyant, 1993). For these reasons, a carbon tax adopted unilaterally would be more costly to the U.S. economy and less effective in reducing global emissions than one adopted by many countries acting together.

Empirical research into the magnitude of leakage effects is somewhat inconclusive. The penalty for acting unilaterally would be greater for small economies than for large economies like that of the United States. Studies of unilateral emissions reduction policies in OECD countries predict leakage rates of between 3.5 and 70 percent¹² (Manne, 1993; Oliveira-Martins et al., 1992; Pezzey, 1992; Rutherford, 1992). Studies in the United States suggest that cost differences created by international differences in environmental policies have minor impacts on trade and investment flows (Repetto, 1995).

There would also be international trade gains, however. Given the size of the U.S. market, a tax-induced fall in U.S.

energy consumption would help restrain world fuel prices, improving our terms of trade as a net oil-importing economy. Baseline projections suggest that in the absence of higher energy taxes, fossil fuel consumption in the United States and the rest of the world will continue to grow substantially in coming decades. One implication, given the already declining oil production in this country, is that OPEC will supply an increasing share of world petroleum markets, and the United States will become increasingly dependent on imports from OPEC producers. OPEC's world market share might reach 72 percent by 2015, more than in 1974 when its supply restrictions precipitated the first "oil shock" (U.S. EIA, 1996). A carbon tax would mitigate these energy security and trade risks.

If the United States adopted a carbon tax unilaterally, the risks of climate change faced by other countries would fall, reducing their incentive to act (Barrett, 1994). However, increasing international coordination within the Framework Convention on Climate Change means that unilateral action is unlikely. European countries have stated their willingness to adopt a carbon tax if major trading partners—the United States in particular—do the same (Commission of the European Communities, 1992). Sweden and Norway already have signaled willingness by adopting small taxes. Developing countries are clearly unwilling to commit themselves to action unless industrial countries that have emitted most of the carbon dioxide to date take the lead. Nonetheless, substantial economic

¹² The leakage rate is measured as the increase in emissions outside the tax region over the emissions reduction within the region.

reforms and restructuring of energy markets have taken place in developing and transitional economies, for purely economic reasons. Energy subsidies have been reduced, subsidies to energy-intensive industries have fallen, and institutional changes have opened the energy sector to improved technology and greater efficiency. These significant changes have already reduced CO₂ emissions in these countries well below their projected levels (Reid and Goldemberg, 1997). Though undertaken for strictly economic reasons, these policy changes in other countries have greatly reduced the risks of unilateral U.S. action.

B. DISTRIBUTIONAL EFFECTS

Even if the macroeconomic economic impacts of a carbon tax were small or positive, some household, regional and sectoral groups might be adversely affected, if they are highly dependent on fossil fuels and have limited ability to adjust to price changes. These distributional considerations are important policy issues: a carbon tax program may be considered undesirable if costs are felt disproportionately by low-income groups or specific industry sectors, even if predicted overall economic burdens are small.

1. DISTRIBUTIONAL EFFECTS ON HOUSEHOLDS

It is commonly reckoned that a carbon tax would be regressive, hitting lower-income households proportionately harder than those better off. To illustrate, a \$100 per ton carbon tax instituted in 1990 would have created a

burden amounting to 10.1 percent of income for the lowest decile of households arrayed by household income but only 1.5 percent for the top decile (Poterba, 1991). However, when households are arrayed by expenditure instead of income the carbon tax is much less regressive, accounting for 3.7 percent to 2.3 percent of total expenditures for the bottom and top deciles respectively. Household expenditure is a better indicator of long-term ability to pay—and hence a better base against which to judge distributional effects—because it is more stable over time than household income. Short-term fluctuations in income are typically cushioned by borrowing or adding to savings. At any time, there will be many households whose incomes are temporarily and abnormally inflated or depressed.

At best, such calculations provide imperfect guides: they reflect only the direct effect of higher energy prices on expenditures, omitting the fact that goods whose production relies on fuel—everything from cars to food-stuffs—will exhibit price rises too. A Canadian study that accounted for direct and indirect effects by assessing the carbon-intensity of the complete set of purchases made by different income or expenditure groups found that a \$100 carbon tax would only be mildly regressive even for households grouped by income. The burden was 2.9 percent for the bottom income quintile and 1.8 percent for the top quintile (Hamilton and Cameron, 1994).

However, since the long-run distributional impact will also depend on



European countries have stated their willingness to adopt a carbon tax if major trading partners—the United States in particular—do the same.



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changes in employment, wages, and asset prices, only overall economic models can make comprehensive estimates. An analysis using a general equilibrium model traced the welfare impacts of a carbon tax on 16,128 separate household groups categorized by family size, age and sex of household head, race, region, type of residence, and wealth. The model predicted that, on the whole, the distributional effects of a carbon tax would be modest, ranging from mildly progressive to mildly regressive, depending on underlying assumptions (Jorgenson et al., 1992).

Of course, the overall distributional effect of a carbon tax would depend on the use of the revenues. Expanding the earned-income tax credit would benefit low-income households; reducing capital gains taxes would benefit the rich. There are trade-offs between equity and efficiency concerns. Efficiency gains seem greatest if taxes on investment income are reduced; equity objectives are better served if taxes on labor earnings are reduced. A combination of the two—using the revenues to cut both capital and labor taxes—would balance these objectives.

Moreover, the distributional impacts of a carbon tax should be judged against the impacts of a business-as-usual policy. A number of studies predict that global warming would lead to higher food prices. Since food is as much a necessity as energy is, a business-as-usual policy might also be regressive (Scheraga et al., 1993). Similarly, since poorer households typically inhabit areas of lower environmental quality

and are generally in poorer health, they benefit disproportionately from an improvement in air quality (Yin, 1993). However, they may value these relatively large benefits absolutely less than the smaller benefits felt by better off households (Harrison and Rubinfeld, 1978). All in all, the effects of a carbon tax on the distribution of income and expenditures among households would probably be small; and effects on vulnerable groups could rather readily be offset by cost-of-living adjustments in government transfer programs and by other policy instruments.

2. DISTRIBUTIONAL EFFECTS BY SECTOR AND REGION

The energy industry generally, and the coal mining industry particularly, will experience the greatest impacts from a carbon tax, under which the tax rate on coal, a carbon-intensive fuel, will be relatively high. Compared to the business-as-usual scenario, coal output may decrease by 25 percent and prices may rise by 35 percent by 2020 under a tax that stabilizes emissions at 1990 levels (Jorgenson et al., 1992). Electric utilities, the next most affected sector, face output losses and price increases of just over 5 percent compared with the projected baseline, mainly because they use coal. But these reductions do not imply absolute declines because substantial growth in output is projected for both sectors in the baseline. Some railroads would suffer adverse impacts since coal makes up a substantial fraction of their freight traffic. Of course, other industries, such as the

natural gas and renewable energy industries, would probably do better if a carbon tax were enacted.

Regional impacts of a carbon tax inevitably correspond to sectoral impacts. Coal mining states, such as West Virginia and Wyoming, would be disproportionately affected. But, according to one study, the Pacific Northwest would fare relatively well because of the availability of cheap hydropower—assuming such power continues to be heavily subsidized (DeWitt, Dowlatabadi, and Kopp, 1991). Global warming, like a carbon tax, would also affect some regions and industries disproportionately. Along with coastal areas, regions dependent on agriculture, water sup-

ply, and forestry would suffer most (OECD, 1996).

To summarize, studies predict that a carbon tax will be only mildly regressive for households, and those effects could be offset by revenue recycling and cost-of-living adjustments in government transfer programs. The distribution impacts of a carbon tax might well be no worse than those of global warming itself. However, coal mining and coal mining regions would be significantly affected, since coal output would fall relative to a business-as-usual scenario and, assuming a sufficiently high tax, would fall absolutely as well.

CONCLUSIONS AND RECOMMENDATIONS

5

Despite the wide range of predicted economic impacts of CO₂ abatement, two areas of policy agreement among the underlying economic models stand out. First, the economic impacts will be much more favorable if revenue-raising policy instruments are used to control CO₂ emissions and the revenues are used to reduce other burdensome tax rates. As explained above, the two principal revenue-raising policy instruments are carbon taxes and tradable permits that are auctioned off by the government rather than given away. Both instruments imply that carbon-based fuels will become more expensive to the users, raising costs throughout the economy. However, using the revenues to lower taxes on labor and capital would offset some of these higher costs and improve the economic impacts.

Giving permits away to energy users and sellers or using regulations to force industries to reduce their CO₂ emissions are alternative policy approaches that forgo potential revenues. These approaches would also make fossil fuels more expensive to the users, raising costs throughout the economy. But, they would have quite different economic implications because they create no opportunities to

generate offsetting efficiency gains by reducing the marginal rates of distorting taxes.

Instead, the potential revenues from auctioning off permits to burn fossil fuels remain with the firms that received free permits or regulatory permission. Conceding these permits to firms may be politically advantageous because it awards a valuable right to certain firms and industries that might otherwise oppose any climate protection policy. However, economic models agree that this political advantage would be bought at a high economic price. Income and economic growth would be lower if this approach were adopted, just as they would be if revenues from a carbon tax were recycled through lump-sum rebates.

Similarly, forgoing carbon tax revenues would limit the government's opportunities to finance offsetting tax cuts and other programs to cushion the distributive burden of higher energy prices on lower-income households and other vulnerable groups. Instead, those companies permitted to sell or use the limited quantities of carbon fuels available would obtain windfall profits. For both equity and efficiency reasons, the U.S. Government should base its climate

No benefits
from
grandfathering



Climate protection plans should be revenue-neutral. They should include explicit proposals for offsetting cuts in distorting taxes on labor and investment incomes.

protection plans on policy instruments such as a carbon tax or auctioned-off carbon permits that yield revenues to finance tax reductions. Moreover, climate protection plans should be revenue-neutral. They should include explicit proposals for offsetting cuts in distorting taxes on labor and investment incomes. Identifying these tax cuts in advance and ensuring that the government's spending and deficit are unchanged should help allay economic concerns about climate protection.

The second area of agreement among economic models that have examined the issue is that joint implementation will reduce the overall costs of achieving carbon abatement targets. Emissions trading among domestic U.S. firms and facilities has already proven to be cost-effective in reducing conventional air pollutants. The gains from international joint implementation of CO₂ abatement programs should be even larger because the costs of reducing fossil fuel use vary so widely among nations. International joint implementation is compatible both with a U.S. carbon tax and with a carbon permit trading system. The United States has consistently favored joint implementation in principle as a cost-effective market-based policy approach. Ironically, many countries with emerging market economies have not approved the principle of such implementation even though they would benefit significantly from the infusion of technology and investment that it would bring. The U.S. Government should continue to consult and negotiate with other

nations to gain international acceptance for joint implementation among nations adopting CO₂ reduction commitments, and to promote joint implementation through pilot projects and institutional development.

Aside from the effects of these two policy choices, the remaining variation in the predicted economic impacts of climate protection stems from differences in underlying assumptions built into economic simulation models. Predictions that a carbon tax or a cap-and-trade policy to reduce CO₂ emissions would seriously harm the economy are unrealistic. They stem from worst-case modeling assumptions. Under more reasonable assumptions and preferable policy approaches, a carbon tax is a cost-effective way of reducing the risks of climate change and would do no damage to the economy. More likely, taking the environmental effects into account, it would bring long-term benefits.

This point is likely to be obscured as the debate over U.S. climate policy becomes increasingly intense and politicized as international negotiations proceed. Various interests will tout their preferred predictions and experts. The media, on the principle that controversy generates interest, will highlight the divergent predictions rather than informing the public about the underlying sources of disagreement. The public may become confused, disillusioned, or indifferent.

To counter this, it is important that when the administration finalizes its



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proposed climate policy it issues a public statement incorporating its best predictions of the impacts these proposed measures would have on the economy, making clear the assumptions and models on which these estimates are based. When Congress holds televised hearings on this issue, expert witnesses and administration officials should be questioned closely on the assumptions underlying their predictions regarding the effects of climate protection on the economy. The press and other media can contribute significantly to public understanding and debate of this important policy issue by in-depth reporting and analysis that

goes beyond the formulaic juxtaposition of opposing viewpoints.

The real issues that need resolution are how to cushion the impacts on those few industries, regions, and communities that would be adversely affected and how to negotiate international agreements that will bring about coordinated actions by all major economic powers. In addition, an overall tax restructuring agenda is needed that would incorporate a phased-in carbon tax or auctioned-off tradable carbon permits and equivalent reductions in other taxes to achieve equity and economic objectives.

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ANNEX

DETAILS OF THE STATISTICAL ANALYSIS

The data set is made up of 162 simulations derived from 16 models. From each simulation, the percentage change in CO₂ emissions and the percentage change in GDP, both relative to the baseline projections for the terminal year of the simulation, were recorded. In addition, a set of descriptive variables was recorded for each model simulation, representing basic structural assumptions and policy assumptions embedded in the model. These were represented either as binary dummy variables or as discrete numerical variables. All the variables considered in the analysis are presented in Table A.1 and include the following:

GDP	percentage change in real GDP relative to projected baseline, in terminal year
CO₂	percentage reduction in CO ₂ emissions relative to projected baseline, in terminal year
MACRO	1 if a macro model, 0 if a CGE model
NCBACK	1 if there is a constant cost, non-carbon backstop
RECYCLING	1 if revenues from policy instrument are used to reduce existing distorting taxes
CLIMATE	1 if averted climate change damages are modeled
NON-CLIMATE	1 if averted air pollution damages are modeled
JI	1 if joint implementation or global emissions trading is modeled
PRODUCTION	1 if the model allows for product substitution
FUELS	the number of primary fuel types recognized for possible inter-fuel substitution
YEARS	the number of years available to meet the abatement target

Using the data, multiple regression analysis was performed to show how these modeling assumptions affected the predicted relationship between the change in GDP and the change in CO₂ emissions. The regression equation, with GDP as the dependent variable, was specified as a quadratic (through the origin) in the extent

of CO₂ abatement from the projected baseline. The variables listed above were assumed to shift the coefficient of the linear term in CO₂, except that the variable for the non-carbon backstop was specified to affect the coefficient of the quadratic term in CO₂ because the presence of a backstop fuel source mainly affects the curvature of the abatement cost curve at high levels of abatement.

FORM OF REGRESSION:

$$GDP = \alpha_1 \cdot CO_2 + \alpha_2 \cdot (CO_2)^2 + \sum_{i=1}^8 \beta_i \cdot X_i \cdot (CO_2) + \beta_9 \cdot X_9 \cdot (CO_2)^2$$

REGRESSION RESULTS

No. of observations: 162

R² : 0.83

	Coefficient	Standard Error
CO ₂	-0.02319	0.00907
(CO ₂) ²	-0.00079	0.00011
MACRO	-0.05548	0.01395
NCBACK	0.00051	0.00005
RECYCLING	0.04427	0.00652
CLIMATE	0.00943	0.00399
NON-CLIMATE	0.03823	0.00778
JI	0.02337	0.00327
PRODUCTION	0.00378	0.00365
FUELS	0.00018	0.00116
YEARS	0.00005	0.00006

} insignificant

Notes

1. Including an intercept term in the regression adds little to the regression's overall explanatory power. Moreover, the assumption that the regression passes through the origin is consistent with the models' definition of a baseline projection.
2. The inclusion of dummy variables to represent the individual models adds little to the explanatory power of the regression beyond that provided by variables representing underlying modeling assumptions.
3. The R² for a regression of GDP against CO₂ and (CO₂)² terms alone was 0.35.
4. Typically, the number of primary fuel types differs substantially from the number of energy sectors and energy technologies included in the models.

TABLE A.1

SUMMARY OF DATA

Model	Primary reference	Number of model runs	Years (range of end years)	Number of primary fuel types
BKV	Boyd, Krutilla and Viscusi (1995)	9	2000-2040	3
CRTM	Rutherford (1992)	9	2010-2100	7
DGEM	Jorgensen and Wilcoxon (1992)	24	2010-2050	3
DRI	DRI (1994)	12	2000-2020	7
Edmonds-Reilly-Barns	Edmonds and Reilly (1983, 1985)	14	2020-2095	7
EPPA	Yang et al. (1996)	8	2020-2100	5
Fossil2	AES (1990)	7	2000-2020	9
G-Cubed	McKibbin and Wilcoxon (1992)	9	2000-2020	2
Global 2100	Manne and Richels (1990a)	9	2010-2100	7
Goulder	Goulder (1995)	14	2010-2050	3
GREEN	Burniaux et al. (1990)	12	2010-2050	6
IIAM	Charles River (1997)	6	2010-2030	4
LINK	Kaufman et al. (1992)	8	2000-2010	5
Markal-Macro	Hamilton et al. (1992)	3	2020-2030	11
MERGE2	Manne and Richels (1995)	12	2050-2100	7
SGM	Edmonds et al. (1993)	6	2010-2030	7

Notes

1. '1 or 0' signifies that different runs from the same model incorporate alternative assumptions.
2. The number of observations from each model varies with the number of alternative assumptions and end dates considered by the model.
3. Despite its name, the Markal-Macro model has optimizing characteristics and is not a macro model according to the distinction made in Box 1.
4. Because the Boyd et al. model is a comparative static model, the terminal years have been interpolated.
5. The results from the IIAM model come from the model's Single Open Economy Section of the model which does not include the effects of J1 that appear in the Multi-Regional Trade (MRT) section.
6. The IIAM model is characterized as having $\bar{\pi}$ no backstop because the backstop does not affect the time frame for which results were available.
7. Although the Edmonds-Reilly-Barns model has several non-carbon fuel sources, all are subject to increasing marginal costs, inconsistent with the definition of a backstop energy source adopted here (see Section 3.D for discussion).

SUMMARY OF DATA (CONTINUED)

Production substitution (1) or not (0)	Non-carbon backstop (1) or not (0)	Macro (1) or CGE (0)	Efficient revenue recycling (1) or lump-sum (0)	Joint implementation (1) or not (0)	Averted climate damages (1) or not (0)	Averted pollution damages (1) or not (0)
1	0	0	0	0	0	1
1	1	0	0	0	0	0
1	0	0	1 or 0	0	1 or 0	1 or 0
1	0	1	1 or 0	0	0	0
1	0	0	0	1 or 0	0	0
1	1	0	0	1 or 0	0	0
0	1	0	0	0	0	0
1	0	0	1 or 0	0	0	0
1	1	0	0	0	0	0
1	0	0	1 or 0	0	0	0
1	1	0	0	1 or 0	0	0
0	0	0	0	0	0	0
0	0	1	1 or 0	0	0	0
0	1	0	0	0	0	0
0	1	0	0	1	1 or 0	0
1	0	0	0	1 or 0	0	0

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The Climate Protection Initiative (CPI) is a partnership between WRI and private firms to identify acceptable policies and business strategies for achieving strong climate protection goals. This institute-wide effort is motivated by the belief that there is a positive link between climate protection and a sound economy. Wider recognition of this linkage is essential for the development and implementation of an effective international climate treaty.

WRI's CPI team is working with leading corporations to define Safe Climate, Sound Business Scenarios—policy pathways for stabilizing greenhouse gas concentrations and meeting world energy demand, while maintaining a healthy economic environment. We are contributing to business strategies by developing case studies of how companies have overcome barriers to implementing carbon dioxide reduction initiatives and achieved financial and productivity benefits. And, we are investigating how the development of advanced technologies could position such industries as electronics and communications as leaders in climate protection.

The build-up of greenhouse gases in the atmosphere and human-caused warming of the Earth is the largest global environmental challenge facing society as it approaches the 21st century. According to the Intergovernmental Panel on Climate Change, if action is not taken to slow and reverse the growth of greenhouse gas emissions, there could be ecological impacts on a

scale outside all of human experience. In turn, these impacts would have serious economic and social consequences. Significant technological, economic, and policy changes are needed now and in the coming decades to head off these risks.

The actions needed to address the threat of climate change, however, provide an opportunity to chart a more sustainable course into the future as individual firms and national economies become more efficient, embrace environmentally-sound technologies, and accelerate the transition to a global economy fueled by renewable energy resources.

The CPI team is committed to designing and advancing policy options that are flexible and market-based, allow least-cost mitigation strategies, and are sensitive to competitiveness issues within and among nations. Through this initiative, WRI seeks to reduce the risks of climate change while nurturing sustainable economic development worldwide.

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June 20, 1997

Dr. Janet Yellen
Chair, Council of Economic Advisers

Dear Janet,

This paper asks how we should go about designing a global-warming protocol if we take seriously both the economics and the environment.

It was fun to see at Commencement. George and I had an interesting session in NYC.

Sincerely,

Wm

**CLIMATE ALLOWANCES PROTOCOL (CAP):
COMPARISON OF ALTERNATIVE GLOBAL TRADABLE EMISSIONS REGIMES**

William D. Nordhaus

June 17, 1997

Preliminary

Abstract

Recently, the U.S. government proposed an international emissions-trading protocol to cope with the threat of global warming due to emissions from greenhouse gases (GHGs). While such a proposal is superior to earlier approaches (such as the country-specific emissions targets of the Rio Treaty or the Berlin protocol), it leaves open a number of crucial questions. These include the appropriate objectives, the distribution of emissions budgets among countries, a mechanism to discover countries' perceived benefits from such an arrangement, as well as a set of incentive and enforcement procedures.

This paper develops a Climate Allowances Protocol (CAP) that addresses many of the outstanding issues. It is based on the view that the system should balance costs against benefits, be economically efficient, and respect *the realpolitik* fact that sovereign nations must find it in their self-interest. The CAP plan integrates climate policy with an underlying cost-benefit approach that maximizes global incomes and allows countries to arrive at a level of the public good that reflects an aggregation of individual country preferences.

Simulations of the efficiency and realism of the CAP plan using an updated version of the RICE model indicate that it has major economic advantages, leads to benefits for most participants, and has equivalent environmental benefits as compared to current international proposals.

**CLIMATE ALLOWANCES PROTOCOL (CAP):
COMPARISON OF ALTERNATIVE GLOBAL TRADABLE EMISSIONS REGIMES**

William D. Nordhaus¹

June 17, 1997

Preliminary

1. Background and Motivation

Recently, the U.S. government proposed an international emissions-trading protocol to cope with the threat of global warming due to CO₂ emissions from combustion of fossil fuels and other greenhouse gases (GHGs).² While a market mechanism is superior to earlier approaches (such as country-specific emissions targets), it leaves open a number of crucial questions. These include the appropriate ultimate concentrations and emissions targets, the distribution of allowable emissions among countries, a mechanism to discover countries' perceived benefits from such an arrangement, as well as the issues of incentive and enforcement procedures.

To date, there has been virtually no attention to the economic aspects of the design of such a protocol, and surprisingly little attention to making the design consistent with sound economic and political principles. This paper describes a regime (the "Climate Allowances Protocol" or CAP) that takes into account current economic theory of public goods and compares this approach with current proposals that are being discussed in government circles. The basic philosophy here is that the system should balance costs against benefits, be economically efficient, and respect the fact that the agreement must be among sovereign nations and must be in the self-interest of participating nations.

Global warming poses especially nasty obstacles to reaching efficient and effective policies. It is a public good over space and time in the sense that emissions in any place affect climate everywhere and for centuries in the future. There is no obvious technological fix. The scientific and economic uncertainties are sufficiently large that those who would be harmed by policies can easily generate a smokescreen to confuse people by arguing that the

¹ The author is A. Whitney Griswold Professor of Economics and on the staff of the Cowles Foundation, 28 Hillhouse Avenue, Yale University, New Haven, CT 06520, USA.

² See U. S. Department of State, *U. S. Draft Protocol and Fact Sheet on Climate Change Proposal*, January 17, 1997.

scientific case is weak or trumped up. And the economic stakes are enormous, with the present value of costs and future damages of many proposals likely to run in the hundreds of billions of dollars annually. These features are exacerbated by the fact that there is no obvious anchor or “focal” point for policy. In this respect, global warming differs from other policies that have focal strategies, such as trade regimes (zero tariffs and trade barriers) or nuclear non-proliferation agreements (no weapons or weapons-grade material). Without focal policies, agreement is more difficult because reasoned disagreement is so easily sustained.

While this discussion is aimed at the threat of greenhouse warming, I think of it as a prototype for any important global economic public good. A global economic public good in one for which there are huge numbers of economic agents in a large numbers of countries and where the costs and benefits of action do not indicate any obvious focal policy or technological fix. While global warming might or might not turn out to be a critical issue for humanity or natural ecosystems, it is useful to think through how we might design a global economic regime when and if a crucial global economic public good appears on the radar screen. If you think global warming is a critical issue, this should interest you; if not, then imagine a global economic public good that is critical and apply these principles there.

This sketch will begin with a summary of the mechanisms and then proceed to see how it addresses the major design hurdles. It is meant only to sketch the major issues because a full treatment would be longer than the tolerance of most mortals.³

2. The Thorny Issues of Regime Design

Current international proposals for limiting greenhouse gases (such as those set out in the Rio Treaty or in the current U.S. proposal) are deeply flawed. They are based on arbitrary historical benchmarks for emissions limitations and make no attempt to link the path of emissions to any economic or environmental objective. They provide no incentives for countries to join or to follow the rules once they have joined. It is not surprising that every serious economic analysis of these proposals finds them highly inefficient.

³ This discussion will contain only a few references from the vast literature on the subject. An excellent overview with a bibliography to most of the literature is contained in B.S. Fisher, S. Barrett, P. Bohm, M. Kuroda, J.K.E. Mubazi, A. Shah, and R.N. Stavins, “An Economic Assessment of Policy Instruments for Combatting Climate Change,” Chapter 11 in James P. Bruce, Hoesung Lee, and Erik F. Haites, *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Cambridge University Press, Cambridge, U.K., 1996, pp 397-439. Many of the legal principles are laid out in Stewart???

What first principles would be look to in designing a regime that is economically efficient and politically viable? The most important characteristics are the following:

- The regime should be moderately efficient from an economic and administrative point of view.
- There must be positive incentives for countries to participate in the regime and to fulfill their obligations.
- The regime must contain a decision process which will induce countries to agree to efficient levels of greenhouse gas reduction.

I believe that the proposal discussed below satisfies the first three criteria reasonably well. The next three points are ones that are troubling and have no obvious solutions:

- The regime must recognize that countries with inept or corrupt governments may subvert the process or use it for personal gain.
- The regime must not injure other international agreements, particularly international trade agreements.
- The decision process should be simple and familiar to countries.

3. The Basic Mechanism

The alternative regime considered here — which is called the Climate Allowance Protocol (CAP) — would embed the price and quantity targets within a framework that considers both environmental and economic objectives and sets the policies to maximize net benefits. CAP proceeds by having a set of tradable emissions allowances or permits with carbon price ceilings and floors. The major innovation is that the emissions limits and carbon prices are derived from a dynamic cost-benefit analysis that incorporates all costs and benefits of slowing climate change. The costs are estimated from engineering and economic models, and will be tested in each accounting period. The benefits will be derived from a public goods mechanism of participating countries.

Participant countries will be allocated a number of emissions permits for each budget period. A major and fundamental difference between the CAP and current proposals is that the emission baselines for individual countries are rolling targets rather than ones set on the

basis of an arbitrary historical benchmark. In addition, there are expectations that countries will begin to participate as their economies develop. In CAP, countries will be expected to make small emissions reductions when their per capita incomes reach an “entry-level income” and to participate fully when their incomes reach “full-participation income.”

In each budget period, the number of permits will be allocated according to a formula that reflects each country’s uncontrolled emissions and its ability to pay. Because carbon prices are equalized across participating countries, there will be no need for tariffs or border tax adjustments among participants. The incentive to participate — and sanctions against violations — will come from import duties on the carbon content of imports of non-participants into participating countries. Unlike current proposals, there is no need for financial transfers among countries, which raise severe political complications. The balance of the paper describes these points in detail.

4. The Trading Rules

The basic approach of the Climate Allowance Protocol is to have an agreement among the participating countries to limit the total annual emissions of greenhouse gases. The overall limitation will be allocated to individual countries, who will receive their *basic allowances of greenhouse gases*. Nations will be allowed to buy, sell, barter, and borrow other countries’ allowances as long as all the rules are obeyed. The fundamental rule is that a country’s emissions shall not exceed the sum of its own allowances plus net purchases of allowances from other countries.

CAP would initially include “covered fuels,” which comprise the consumption of fossil fuels. For accounting purposes, consumption will be equal to domestic production of fossil fuels plus net imports. For example, for the U.S., consumption would include production of crude oil, natural gas, coal, as well as net imports of those fuels and net imports of petroleum products such as gasoline. Consumption would exclude derivative products such as petrochemicals, electricity, chemicals, as well as the fuels embodied in manufactured products. In the CAP, because emissions limits are pegged to uncontrolled emissions, there are no significant distributional or efficiency impacts of the exact definition

of covered fuels.⁴ There is a complication for imports from non-participants, which is discussed later in the paper.

Each nation will be allowed to administer its emissions limitations in its own manner. In a market economy, it would be natural to require that each producer or importer of covered fuels purchase the requisite emissions allowances. For reasons discussed below, it is recommended that governments auction or sell their allowances. We estimate that the cost of the allowances would be shifted forward to consumers except for fuels that are highly price-inelastic in supply.

5. Balancing Costs and Benefits in the Emissions Trading Regime

The fundamental philosophy of the CAP is that global emissions targets are chosen to balance costs and benefits of emissions reductions. This approach is radically different from current approaches in international negotiations (such as those under the Rio Treaty), which have targets and timetables for emissions limitations with no rationale for the targets and timetables. The Rio emissions limits are ones that occurred during a particular historical period in a particular country; they are easy to understand and explain. But they make no sense; there is no link between the targets and timetables, on the one hand, and the economic or environmental benefits.

The proposal here is to link the targets explicitly to economic and environmental benefits through the use of dynamic cost-benefit analysis. The state of the art in cost-benefit analysis of climate change are “integrated assessment” (IA) models, of which a wide variety are currently available and in use.⁵ Most of the inputs into these models are of a scientific and technocratic nature. Such inputs include parameters of the carbon cycle, engineering and scientific data on global warming potential and carbon content of different fuels, and

⁴ The general principle is to define covered fuels in a manner that monitoring and enforcement costs are minimized. For that purpose, covered fuels are production of fossil fuels plus net imports of fuels and direct products. The only subtlety here is that consumption includes net imports, which will require some careful thought to ensure consistency and efficiency. Under the principles for allocation of allowances used here, the definition is of no importance for efficiency and is only of second-order importance for distribution. The definition would have great importance under current international proposals that have a fixed as opposed to a rolling base.

⁵ An excellent overview of Integrated Assessment models by lead author John Weyant and collaborators is contained in Chapter 10 of James P. Bruce, Hoesung Less, and Erik F. Haites, eds., *Climate Change 1995 — Economic and Social Dimensions of Climate Change*, Cambridge University Press, 1996.

climate models. Two sets of non-technocratic data are, however, crucial for the results: the costs of emissions reduction and the damages from (or willingness-to-pay to avoid) climate change. Derivation of these will be described below.

The full output of the dynamic cost benefit analysis will be an “indicative plan” for global GHG emissions and carbon taxes. This indicative plan will be the basis of the overall limits on emissions. For each accounting period (say five years), countries will be allocated emissions allowances whose sum equals the optimized emissions from the IA models.

The CAP mechanism relies on allocating emissions rather than carbon taxes because there is no mechanism for allocating carbon taxes. But carbon taxes or prices are a central part of the plan and will be introduced by having price ceilings and floors. Should emissions limits within a budget period be tighter than expected because of model mis-estimates, countries may buy emissions allowances at a ceiling price that is a premium (say, 150 percent) of the optimized carbon tax. Too-low prices will be ignored for the moment.

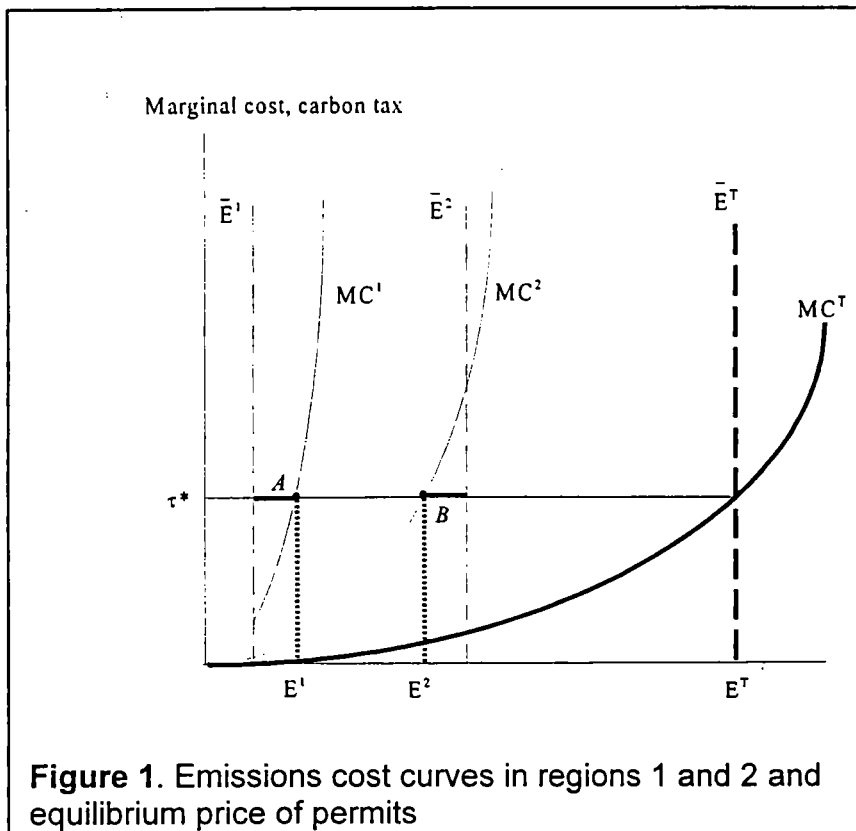
Deviations of prices or quantities from the levels projected in the IA planning models for the budget period will automatically be corrected by model revisions for the next budget period. This automatically incorporates a procedure by which the latest scientific and economic information and revised national priorities will be incorporated into the prices and quantities each period.

6. Costs of Emissions Control

In our summary, we stated that the cost side of the cost-benefit analysis would be automatically revealed in the emissions-trading market. We explain that point in this section.

The revelation is seen most clearly for a private market economy. Suppose that the price of an emissions permit is $\tau = \$10$ per ton of carbon. This means that firms can produce output using covered fuels at a marginal cost of $P + \tau$ or substitute inputs at a cost of R . This implies that the marginal cost of reducing emissions is $MC = R - P = \tau$.

The revelation of marginal cost is illustrated in Figure 1. The curves MC^1 and MC^2 are the marginal cost curves for emissions reductions in regions 1 and 2. The efficient global cost-of-reduction curve is shown as MC^T . The vertical line at $\bar{E}^T$ is the sum of the emissions limitations of the regions, $\bar{E}^T = \bar{E}^1 + \bar{E}^2$.



Firms in each regions will purchase or sell permits to the point where their MC of emissions reduction equals the permit price. The efficient allocation is shown in Figure 1 at a permit price of τ^* . At that price, region 1 buys permits shown by the segment A , while region 2 sells segment B . The balancing condition is $B + A = 0$.

The key point to note is that (for cost minimizing entities), the permit price will be equal to the marginal cost of emissions reductions for each region. We will thus be able to observe the marginal cost curve

for emissions reductions as individual entities make their decisions.

7. Public Goods Mechanism

In contrast to cost of controls, the value of emission reductions (or averted damages of climate change) cannot be determined by a market mechanism. Most of the damages will be felt far in the future, and indeed even the “experts” have only the haziest notions about what those costs may be and who will bear them. It is therefore necessary to design a process whereby reliable estimates of different countries’ willingnesses to pay can be derived.

Slowing harmful climate change is a global public good. Individual people, countries, and generations make but a small contribution to slowing climate change, and this leads to the possibility of free-riding, posturing, temporizing, and insincere statements of position. On top of this intrinsic difficulty is the further complication that environmental policy is largely in the hands of environmentalists and large companies, neither of which adequately represents the interest of consumers. A final difficulty is that global warming involves countries with highly divergent incomes and priorities. The major difficulty in any plan, therefore, is to design a *public goods mechanism* that can find a tolerably good solution to this very nasty public goods problem.

The mechanism proposed here responds to these problems by containing two stages.

- The first stage is the *constitutional stage*. In this part, countries agree on the basic framework of the process. This stage involves the choice of international instrument, the accounting framework, the voting procedure, setting sanctions for non-participation or infractions, and the legal ratification and amendment processes. Given the long time horizon of the global warming problem, this stage effectively operates behind a Rawlsian veil of ignorance because costs and particularly benefits lie far in the future compared to most current investments and elections. Given the nature of the public good, this stage is largely distributional and could easily lead to protracted impasses.
- The second stage contains the *decision-administrative processes*. Given the constitution of the global warming agreement, heterogeneous country preferences will have to be aggregated into a single global level of emissions. Among the alternative processes we suggest that a voting mechanism is likely to be the most fruitful.

Before discussing the constitutional and decision-administrative phases, some background comments are necessary. The mechanism proposed here treats the massive public goods problem by having nations serve as trustees of future generations and by separating the costs today from the benefits in the future. The central idea is that countries will vote a given “value” of reducing climate change (or the willingness to pay [WTP] to reduce slow climate change). When the different values are aggregated, this will imply an efficient level of emissions control and an associated carbon emissions price or carbon tax today. None of these numbers will be a surprise to the countries who are voting on the decision -- rather the final outcome will be the result of negotiations, persuasion, recalibration, models runs, bargaining, and further negotiations until an agreed level of control and carbon price is agreed upon.

It should be emphasized that the design of the public goods mechanism is both the core of the proposal and its most problematic feature. While countries routinely use voting mechanisms to decide upon national public goods, there are a very few supranational examples of functional public goods mechanism. Those used by the European Union may be the closest in nature to the proposal here.

8. The Constitutional Stage

Before voting, countries need to know how they will be “taxed” to pay for the public good of slowing climate change. The mechanism outlined here presumes that nations are

likely to vote resources to emissions reductions primarily out of concern for the future rather than because they believe that they are likely to be differentially affected. Nations which have high willingness to pay and low discount rates will select higher control rates and carbon emission prices than those who are primarily concerned with today's economic and political issues.

The payment mechanism will start with a zero base of uncontrolled emissions. This initial condition reflects the realistic fact of life that the status quo of doing nothing has a privileged position under custom and international law. Starting from the status quo, countries then pay according to both horizontal and vertical equity principles.

- The *horizontal equity* principle is that countries with the same per capita incomes should contribute proportionally to their current emissions. Assuming that price elasticities of supply and demand are equal across countries, this implies that each horizontally equivalent country shall receive permits that are a fixed fraction of baseline or uncontrolled emissions; equivalently, this means that the expected emissions reduction rate is equal for all horizontally equivalent country. If the elasticities are equal, this implies that the cost of participating in and complying with such a mechanism will be an equal fraction of national income for all countries that have the same level of emissions.
- The *vertical equity* principle would be that poor countries should be required to pay less than rich countries. The formula that is explored below proposes a floor of \$5000 per capita (below which a nation would have no expectations of emissions reduction) and a ceiling of \$15,000 per person (above which a nation would be expected to have full participation). The participation rate would then vary linearly over that range. (I consider alternative progressivity schedules below.)

Formally, nation i would in accounted period t receive a number of emissions permits equal to $E_{i,t} = E_{0,i,t} [(1-f(y_i))\mu_t^*]$. Here $E_{0,i,t}$ is the baseline or uncontrolled level of emissions in period t , $f(y_i)$ is a fraction running from 0 to 1 as a function of the country's per capita income (y_i), and μ_t^* is the agreed target level of global emissions reduction for full participants in period t . The actual level of global emissions reduction (μ_t^{act}) will be less than the maximum level (μ_t^*) depending upon the degree of participation, the progressivity of the vertical equity schedule f , and the degree of compliance. The total $\sum E_{0,i,t} f(y_i)$ is the amount of emissions that is subject to control and is called "reducible emissions."

The functioning of the mechanism is sketched in Figure 2. Estimates of the marginal costs of emissions are based on engineering and economic models for the first period. In

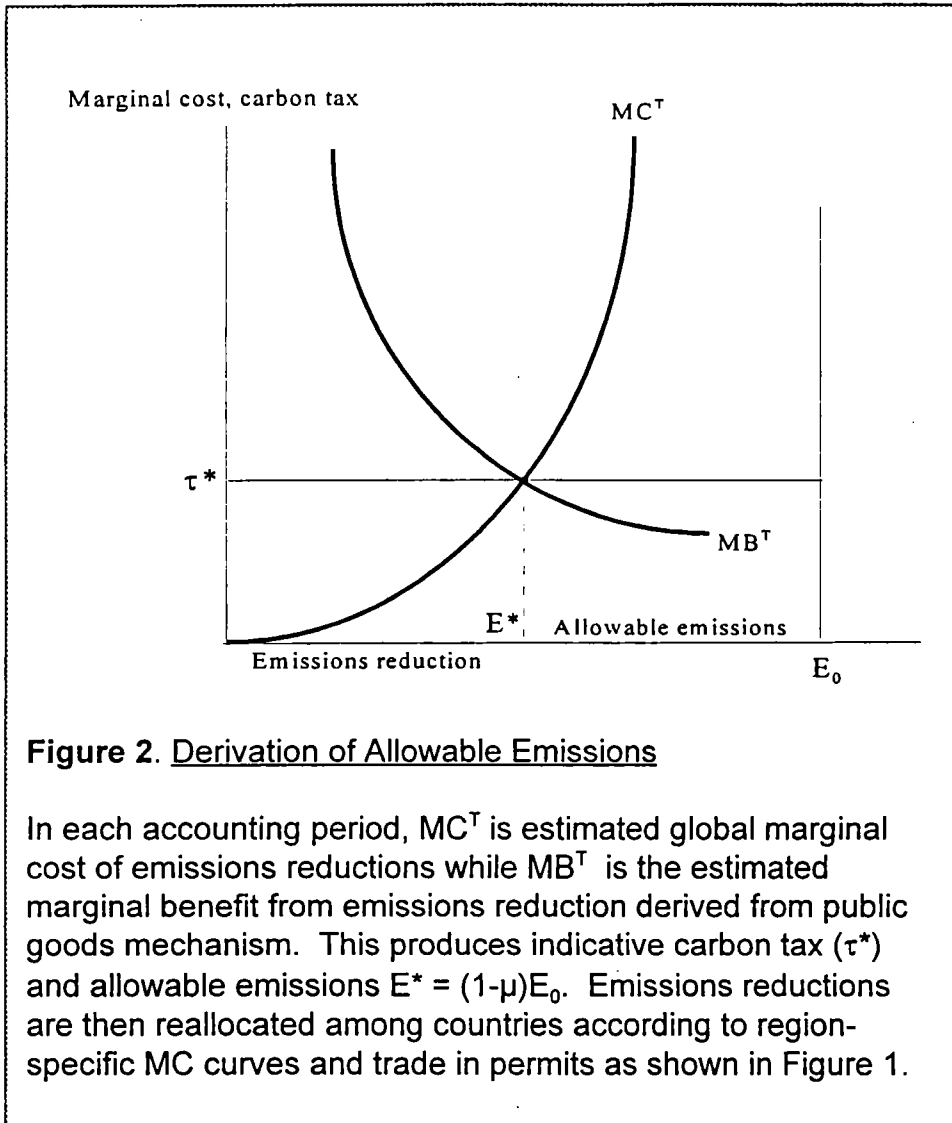


Figure 2. Derivation of Allowable Emissions

In each accounting period, MC^T is estimated global marginal cost of emissions reductions while MB^T is the estimated marginal benefit from emissions reduction derived from public goods mechanism. This produces indicative carbon tax (τ^*) and allowable emissions $E^* = (1-\mu)E_0$. Emissions reductions are then reallocated among countries according to region-specific MC curves and trade in permits as shown in Figure 1.

subsequent periods, more reliable estimates will be obtained as countries begin reducing emissions and the price of permits rises above zero. The marginal benefit function is derived from the voting mechanism described below. These two fundamental building blocks are then used to generate the associated allowable emissions $[(1-\mu^{act})E_0]$ and carbon permit price (τ^*) as shown in Figure 2.

With no uncertainty, we could in principle use either the tax or emissions limitations. In fact, the tax approach is unworkable because it cannot be accurately verified against a background of other

policies (such as fuel taxes and coal subsidies). We therefore use the emissions limitation approach as the most easily administered.

Given the uncertainty about the cost function, it is not sensible to ignore prices, however. To avoid costly mistakes, it is suggested that a cap on carbon prices be set at some premium (say 50 percent) over the estimated efficient price. (It may be possible to determine the optimal premium from IA models.) The revenues from the sale of extra permits at the premium price can be used as determined by the participating countries. For the case of prices that fall below the estimated price, it is suggested that countries be allowed to “bank” the excess permits for future use. We leave open the question of whether it would be useful to have a fund for stabilization purposes.

9. The Voting Mechanism

The second stage of the process is the decision-administrative process in which the revelation of the value of the public good is the essential issue. From an analytical perspective, there are many proposals for mechanisms to facilitate revelation of preferences for public goods. Most share the feature that they are “one-dimensional” in the sense that agents vote for a level of public goods with a payment mechanism in place. The major desideratum of an effective public goods mechanism is that it be *incentive compatible*. An incentive compatible mechanism is one in which agents have an incentive to reveal their true preferences.

There are a large number of potential ways that countries can decide upon a global emissions-reduction target.⁶ (a) One approach is simply to allow countries to decide on their own. In the case of a *Nash equilibrium* where countries pursue only their own self-interest, calculations indicate that the degree of emissions reduction would be minuscule. (b) The *Lindahl equilibrium* asks countries to reveal their own individual prices and then sets the global rate of emissions reduction to maximize global welfare. This is defective because countries have strong incentives to misstate their own preferences. (c) One approach is simply allow countries to *bargain* until they reach agreement. Under the so-called Coase theorem, this process would reach an efficient outcome. (The transactions costs here are trivial relative to the economic costs and benefits.) While bargaining might reach a solution, it seems more likely to get bogged down and to be subject to serious free riding by non-participants. (d) A theoretically attractive approach is to use the *Clarke-Groves mechanism*. In this approach, countries bid the value of different global warming strategies. They are then taxed on the basis of their bids, with individual taxes calculated as the contribution of each country to the net cost imposed on other countries. This mechanism has attractive theoretical properties but is extremely complex, is far too intricate to explain to busy politicians, and has never to my knowledge been implemented.

The approach proposed here is to use a voting mechanism. This has the advantage that it is incentive compatible, is likely to come close to the efficient outcome (as long as tastes are not too skewed), and is familiar to most people. The major disadvantage compared to efficient public-goods mechanisms or bargaining is that it can impose significant costs on those whose preferences deviate significantly from the mainstream. The basic idea is the following:

⁶ I omit what seem fruitless or highly inefficient approaches like moral suasion and mandatory technical standards. While these are highly popular among politicians and can sometimes be useful supplements, they cannot form the core of an efficient and effective global public goods mechanism.

Voting Mechanism. The rate of emissions reduction is determined on the basis of the globally aggregated willingness to pay for reducing climate change. The willingness to pay is aggregated from the individual willingnesses to pay of different countries as expressed by their votes. The individual willingnesses are then averaged across participants on the basis of their reducible emissions.

In other words, the targeted emissions reduction is decided by voting of participants in the plan. Each country expresses its willingness to pay (call it parameter ω_i). The individual countries willingnesses are then aggregated into a global willingness (Ω) by averaging across the participants. Using the globally averaged willingness, then, we can estimate the optimal emissions reduction and carbon tax or permit price.

To make this more concrete, we would define the willingness to pay parameter as the annual willingness to pay to avoid the damages accompanying an equilibrium doubling of CO_2 (or alternatively of a 3 degrees C warming). For example, a country might express a willingness to pay 2 percent of GDP to prevent the equilibrium climate change associated with a doubling of atmospheric CO_2 . To obtain the economically correct emissions reduction, we would use the global average willingness to pay ($\Omega = \sum \omega_i \lambda_i$) which is obtained by averaging the individual country willingness to pay (ω_i) by their shares of a world income (λ_i). Unfortunately, this presents serious incentive problems. Weighting WTP by future incomes or total emissions (which is the appropriate measure of damage) would allow rapidly growing countries or countries with low emission reductions fractions (f) to free ride on current emitters.

To avoid free riding, we need to work with a variant of global WTP that is incentive compatible. To do this, we weight each nation's expressed WTP by its share of reducible emissions. This mechanism will give an unbiased estimate of current WTP if WTP is uncorrelated with $f(y_i)$. Weighted median voting is simple, robust to strategic distortions, and prevents free riding:

Voting Mechanism. The voting mechanism in the plan would be to set the global willingness to pay (Ω) equal to the median WTP. In this calculation, each unit of reducible emissions would have an equal vote.

This mechanism is incentive compatible because there is no advantage for any country with single-peaked preferences⁷ to vote anything other than its most preferred policy. To do

⁷ All studies of the damage from climate change indicate that countries have single-peaked preferences with respect to the willingness-to-pay parameter.

otherwise would either have no effect if it did not change the outcome or would lower its economic welfare if it did change the outcome.

10. Calculation of Baseline Emissions

Baseline emissions play a critical role in the mechanism because determine the economic interests of countries, affect the equity of the system, and have a major impact upon incentive compatibility. One of the major flaws in current proposals (such as the Rio Treaty or the 1996 U.S. emissions-trading protocol) is that they rely on historical emissions to determine future allowances. This leads to growing inequities among countries and provides a major roadblock to reaching an agreement. Under current proposals, countries have emissions limits that are determined by their 1990 emissions levels. This penalizes efficient countries (like Sweden) or rapidly growing countries (like Korea). It also gives a premium to slow-growing countries (like Britain) while historically inefficient countries (like Russia or Germany after unification) are rewarded by having too high a base. This point can be illustrated as follows. We estimate that industrial CO₂ emissions for the U.S. in 2000-2009 will be about 1.64 billion tons of carbon per year. This represents a growth of 18 percent over the prior decade and an increase of about 20 percent over 1990 emissions. Under current proposals, the U.S. would continue to live with its 1990 base in the indefinite future. By contrast, Russia and Germany had emissions in 1994 of about 20 percent less than 1990 levels; they would receive large windfalls if the 1990 base were continued in the future.

One of the major distinguishing features of the CAP is the calculation of each country's base emissions.

Emissions base: Each country's emissions base would be equal to its uncontrolled emissions in each budget period. This base would roll forward with the change in each country's growth in output and population.

Under CAP, a country's base for reductions would be its uncontrolled level of emissions. This base would then roll forward with each budget period. Countries that experience rapid growth in their economies would not thereby be penalized, nor would countries receive windfalls if they were historically inefficient. There definitely would be penalties from higher emissions, but penalty would be proportional to the level of emissions rather than some irrelevant historical experience.

Aside from better equity properties, the CAP approach of a rolling base also improves the possibilities of reaching an agreement. As noted above, the CAP approach has the

feature that it would lead to a unanimous decision if countries have the same demand and supply elasticities and the same damages from climate change (even if their growth rates differ). The historical base has the unfortunate feature that the decision will depend upon the growth rate; indeed, some countries (like Germany or Russia) might vote for very large emissions reductions because they have such large emissions bases relative to their actual emissions that this would drive up the price of their emissions allowances. Other countries like the U.S. or Japan with growing emissions would find themselves with a severe relative disadvantage. Indeed, they might even find that their optimum would be for *negative* emissions reductions given their small base.

One problem with the rolling base is the possibility of countries having an incentive to “ratchet” up their emissions in one period to increase the base in the next period. The “ratchet effect” is a phenomenon observed in planning systems wherein individual agents have incentives to increase spending (or in this case emissions) to increase their base for the next planning period. Two points are important here. First, ratchet effects at the individual or firm level are minuscule because these agents have such a tiny impact upon national emissions levels. Second, while the rolling base definitely attenuates the incentive to reduce emissions at the country level, it does not give the wrong incentives as long as the real price of allowances is not rising too rapidly. For constant emissions reduction rates, the ratchet effect will be neutral when the carbon permit price is rising at the real interest rate. In the more likely case where the carbon permit price is rising more slowly than the real interest rate, the value to a country of an additional unit of emissions is negative. Again, note that the ratchet effect applies only to countries, who receive permits, and not to individuals, who must buy them.⁸

11. Participation and Sanctions

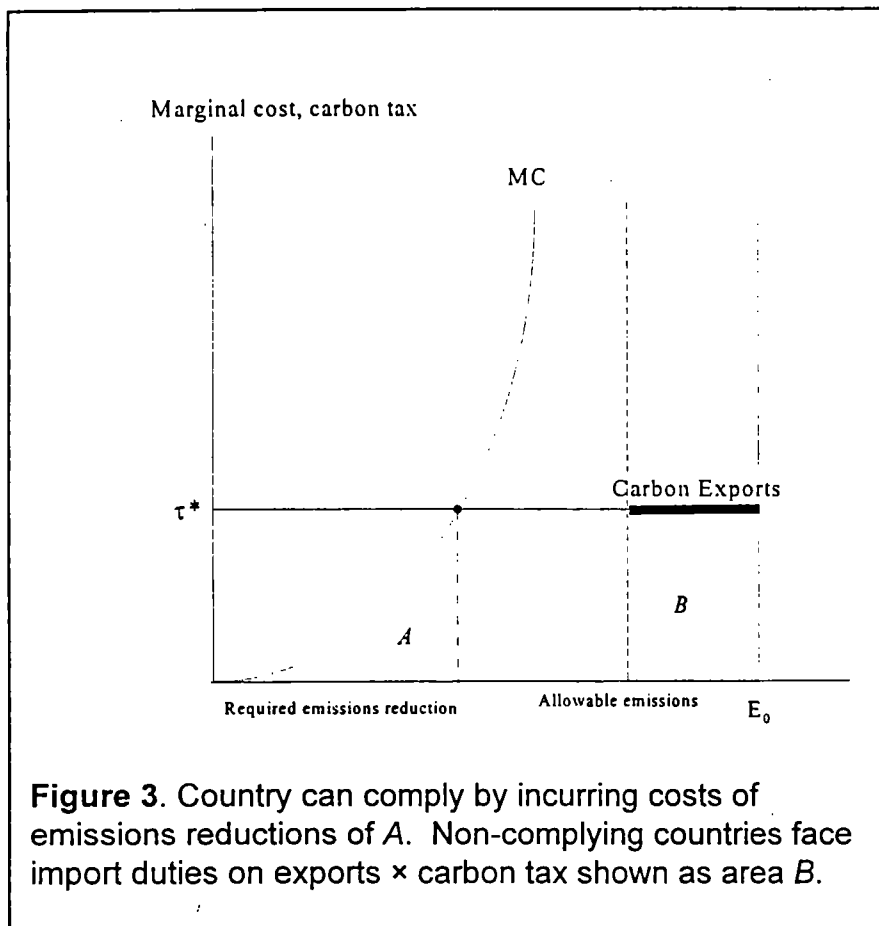
Whatever the moral imperative to protect the planet, it seems likely that the present costs will outweigh future benefits for most countries unless there is a cooperative arrangement with sanctions on disinclined and wayward countries. One indication of the tendency for free-riding is the estimate of the Nash-equilibrium. If countries take into account only their own national interests, the control rates and carbon prices are likely to be only a small fraction of the cooperative prices. Countries are unlikely to benefit from global

⁸ The present value of a unit of emissions in period t is $-\tau_t + [\tau_{t+\theta}(1-\mu_{t+\theta})]/[(1-\mu_t)(1+r)]$. In this expression, τ_t is the price of permits in accounting period t , μ_t is the emissions control rate, r is the real interest rate, and θ is the length of the accounting period. This value is negative as long as the permit price is rising less than the real interest rate and as long as the control rate is not falling. These conditions are met in virtually all simulations.

warming policies for at least half a century.⁹ To make joining such an agreement for individual countries worthwhile, therefore, not only must it impose reasonable, efficient, and equitable burdens, but it must also impose serious and proportional sanctions on the wayward and those who will not participate.

The most workable sanction would be carbon import duties levied on non-participating and non-complying countries. There would be a number of different sanction designs, but the simplest would be to have participating countries impose duties equal to the current price of emissions permits times the carbon content of the imports of non-complying countries into participating countries. For example, suppose that the U.S. were a participant which persistently ignored its targets, which were a 10 percent reduction from a base emissions of 1640 million tons of carbon. If the carbon emissions fee were \$10 per ton, the U.S. would face an import duty of that amount on its exports into participating countries. If the U.S. exported one-fifth of its carbon output, then this would amount to duties of $\$10 \times 0.2 \times 1640 = \$3.28$ billion annually. The estimated annual cost of compliance is, by my estimate, \$0.85 billion, so it would definitely pay for the U.S. to comply rather than face the import duties.

⁹ This point is clearly shown in W. Nordhaus and Z. Yang, "A Regional Dynamic General Equilibrium Model of Optimal Climate-Change Policy," *American Economic Review*, September 1996.



The tradeoff is shown in Figure 3 for a country considering whether or not to join the plan. Compliance costs are area *A* under the marginal cost curve. Noncompliance would cost the country the current carbon price times the carbon content of exports, shown as area *B* in Figure 3. For small open economies, relatively low emissions reductions, and a large group of participating countries, the incentives to participate are likely to be quite strong. Numerical calculations indicate that if the plan gets off the ground by including more than half of countries, and if it is not overly ambitious, the incentive to participate would be

powerful except for very closed economies.

12. Corruption and Standards for Country Behavior

A mechanism for emissions trading contains a troubling paradox. While it imposes present costs on countries by requiring them to reduce emissions, it also creates valuable assets in the form of tradable emissions permits. Because limiting emissions creates a scarcity where none previously existed, such a plan allows “green revenues” to flow to the owners of the permits. The fact of wealth creation is troubling because the value of the permits might be dissipated or used for corrupt purposes.

We can think of three different ways that the valuable permits could be allocated: (a) auction, (b) building political consensus, and (c) corruption.

- The optimal approach would be for governments to auction these permits and use the revenues for worthwhile purposes -- to lower existing taxes, reduce budget

deficits, or expand valuable programs. Such use would be the fairest way to dispose of the revenues and would enhance efficiency if the revenues were used to lower other taxes. If the permits are auctioned and the revenues recycled, the net impact on the country could be quite low.

- Given political imperfections and the need to buy political support, a government might give permits to those politically powerful groups who were adversely affected by the plan. This occurred when the U.S. instituted its sulfur emissions-trading regime, where the permits were allocated to polluters on the basis of historical emissions. This approach is defective for a number of reasons: it overcompensates polluters, it sets up terrible incentives for firms to ratchet up their emissions, and it unnecessarily increases the deadweight loss of taxation. While the plan might strongly recommend against such allocations, they would probably not constitute a violation of the agreement.
- The real difficulty arises with respect to non-democratic and corrupt regimes. In a polar case, we might imagine a venal dictator who sells most of the permits (perhaps to another country), pockets the proceeds, turns the screws tightly on the population by severely limiting fuel imports, and moves the assets abroad to Riviera villas and fine Bordeaux wines. This might even worsen the environmental condition of the country and world by encouraging desperate foraging for firewood and increased deforestation.

As examples, consider the cases of Iraq and Nigeria, each of which had emissions of around 30 million tons of industrial CO₂ emissions in 1994. These could easily sell for \$300 million or more each year of hard currency on the open market (or \$3 billion annually if the environmentalist plans were imposed). We would clearly want such countries to participate, but we could not be confident that the revenues from the permits would not be used for acquiring nuclear materials or bolstering Swiss bank accounts. To avoid antisocial activities, we would probably impose conditionality requirements on the sale and use of emissions permits; for example, renegade countries (however that is defined) might not be permitted to sell permits to other countries. Of course, the more burdensome are the “ethical” restrictions on the disposition of the permits, the less attractive participation becomes for countries, so there is a delicate tradeoff here.

13. Simulations Using the RICE Model: The Setup

An important question is the relative efficiency of different climate-policy regimes. For this analysis, I use an updated version of the “RICE model” of global warming¹⁰ as modified for this analysis. The RICE model is an integrated assessment model that includes output, emissions, concentrations, climate change, and climate-change damages for a number of world regions. The model uses the data for 13 regions of the world for the estimates (U.S., Europe, China, India, Russia, and 8 other groups of countries). Most of the parameters are from the original RICE model, but the data are updated to 1994 levels of output and emissions. Using the model, we can calculate both the costs of compliance and the benefits of slowing climate change in each region for the different policy proposals.

The model is then run for a number of different policy proposals.

- A baseline is the “market” or “no-control” case where no climate policies are in place.
- The “optimal” policy corresponds to complete participation with lump-sum redistribution.
- There are three CAP regimes with three different schedules for participation. The one described above is the “middle progressivity.” There are in addition a regressive and a more progressive plan.¹¹

Finally, we investigate three proposals that correspond to plans that are currently under discussion.

¹⁰ See Nordhaus and Yang, *op. cit.* for a complete discussion.

¹¹The “middle progressive” CAP protocol assumes an entry-level income of \$5000 per capital and full-participation income of \$15,000. More precisely, the percent participation (the f function) goes linearly from 0 at a per capita income of \$5000 to 100 percent at \$15,000. Alternative progressivity schedules have entry levels and full participation of (\$10,000 and \$20,000) for a “progressive” approach and (\$0 and \$5000) for a “regressive” approach. For the simulations, we assume that there is perfect compliance and that countries do not join ahead of schedule. We have simplified the calculations by using the actual damage function rather than the median-allowable-emissions voting function. In addition, we assume that the economic and technological variables are known with certainty.

- The Rio Treaty plan, which has emissions limits at 1990 levels for the OECD region.
- The U.S. proposal, or Rio limits with emissions trading among the OECD countries.
- The “Berlin mandate,” which follows the Rio Treaty but has 20 percent cuts in emissions from 1990 levels starting in 2010 and does not allow trading.

The basic point is to investigate the comparative performance of the different regimes. That is, what fraction of the benefits of the optimal control policy is captured by the emissions regime, and how well do the different regimes attain the ultimate goal of slowing climate change?

14. Empirical Results

The enclosed figures and tables show the major results. Figures 4 and 5 shows the emissions under different plans. Figures 6 and 7 show the levels of concentration and temperature change for the different proposals. There are significant reductions in emissions, concentrations, and global temperature change in all the plans. Current approaches in the Rio and Berlin plans do relatively well for the next century or so in terms of the environmental objectives. In the longer run, they lag behind the CAP plans because they have no mechanism to bring in big developing-country emitters in the future. Under the CAP plans, all important countries (including India and China) incur reduction obligations in the next century, so most emissions are covered relatively quickly.

While the environmental picture does not differ much among the different approaches, there is an enormous difference in the economics. Figure 8 shows the net benefits of the alternative plans. These measure the present value of control costs and climate damages from 1990 on, in 1994 prices, discounted at a goods discount rate of 5 percent annually (the measurement convention is that costs are negative and measured relative to no controls). Table 1 shows the basic data, with 1A showing the absolute levels and 1B showing the impacts as a share of national outputs. The bottom half of the tables show the impact relative to no controls for each region and for the world.

Two fundamental findings emerge from these simulations:

- *Economic turkey.* The three current proposals on the international agenda (Rio, the U.S. modification of Rio, and the Berlin protocol) have negative net benefits, and substantial ones. These plans impose more than \$100 billion of discounted costs for

the Rio approaches and \$1 trillion of discounted costs for the Berlin approach. By contrast, the CAP proposals all have positive global benefits. The Rio-based plans suffer from limiting emissions to a small fraction of emissions, by having rigid targets, and (except for the U.S. plan) by proscribing emissions trading.

- *Political clunker.* The three Rio-style options are politically inept and cannot survive the political market place in most democracies. They impose enormous costs on the major participants — the high-income countries — and confer large benefits on those who do nothing. The U.S. fares extremely poorly under all three of the current proposals, including its own. These plans would be rejected by countries acting in their self-interests. By contrast, the CAP plans have positive or at worst small negative net benefits for all countries.

Figure 9 shows the distribution of gains and losses under two plans -- the middle CAP plan and the U.S. plan of Rio targets with trading. This shows the difference in the distribution of benefits of the different approaches. Figure 10 shows the carbon emissions prices that are estimated for the different plans. The Rio-with-trading and the Berlin mandate have extremely high emissions prices, reaching \$100 quickly and heading north from there very quickly. These carbon taxes are unrealistically high from an administrative and political point of view. For example, the mine-mouth price of U.S. coal would rise by between 60 and 2000 percent over current prices depending on the time period and plan. The carbon tax in the CAP plan, by contrast, starts around \$6 per ton carbon and rises to \$35 per ton by 2100.

Table 2 summarizes the economic impacts and efficiencies of the different approaches relative to the optimal emissions reduction, which has a benchmark of 100 percent economic and environmental efficiency. The first two columns show the overall net economic impacts. The three current proposals have benefit-cost ratios well below 1. Trading improves the benefit-cost ratio of the Rio approach, but does not raise it anywhere near unity. Focusing on the long term concentration and temperature effects in the middle and right-hand columns, we see that — in addition to having much better economic efficiency — the CAP plans also have better long-term environmental benefits than the Rio-style proposals. Finally, Table 3 shows the impact of different plans on the United States. The U.S. has little net gain or loss under the CAP plans but is a major loser under the Rio-style proposals.

The most important conclusions that come from these simulations are (a) that current approaches are no-starters in any negotiations in which countries take actions based on their self-interest and the (b) current approaches are highly inefficient in their design. In short, they are both bad politics and bad economics.

15. Conclusions

The CAP proposal described here is an attempt to flesh out a emissions-trading proposal in the context of the global public good of global warming. In principle, it satisfies most of the design criteria discussed in section 2. An efficient trading regime would have the advantage of integrating policy with an underlying cost-benefit approach that maximizes global incomes. Further, it would allow countries to arrive at a level of the public good that reflects individual country preferences.

Model simulations indicate that the CAP plan would achieve between 40 and 75 percent of the potential economic benefit — and more than 96 percent of the long-term environmental benefit — depending upon the time frame and progressivity schedule. These compare with current proposals — such as the original Rio targets, the Berlin mandate, and the U.S. modification of the Rio targets to allow emissions trading — which have less favorable long-run environmental impacts and have significantly negative economic impacts.

At the same time, we must register some important reservations about the proposal. Many will think that the proposal to have sanctions linked to punitive import duties for non-participants is a dangerous and unwarranted distortion of international trade. Additionally, the mechanism for determining country preferences is complicated and may seem arcane to political decision makers (although it is simple compared to many “familiar” issues such as tax or real-estate law). And the treatment of inept and corrupt countries poses particular problems. Most of these issues will, however, necessarily arise in any effective plan. Notwithstanding these difficulties, the CAP proposal or some relative has the advantage of being both economically advantageous and politically workable whereas all current proposals are politically unrealistic and economically wasteful while conveying no environmental advantage over the CAP plan.

Figure 4

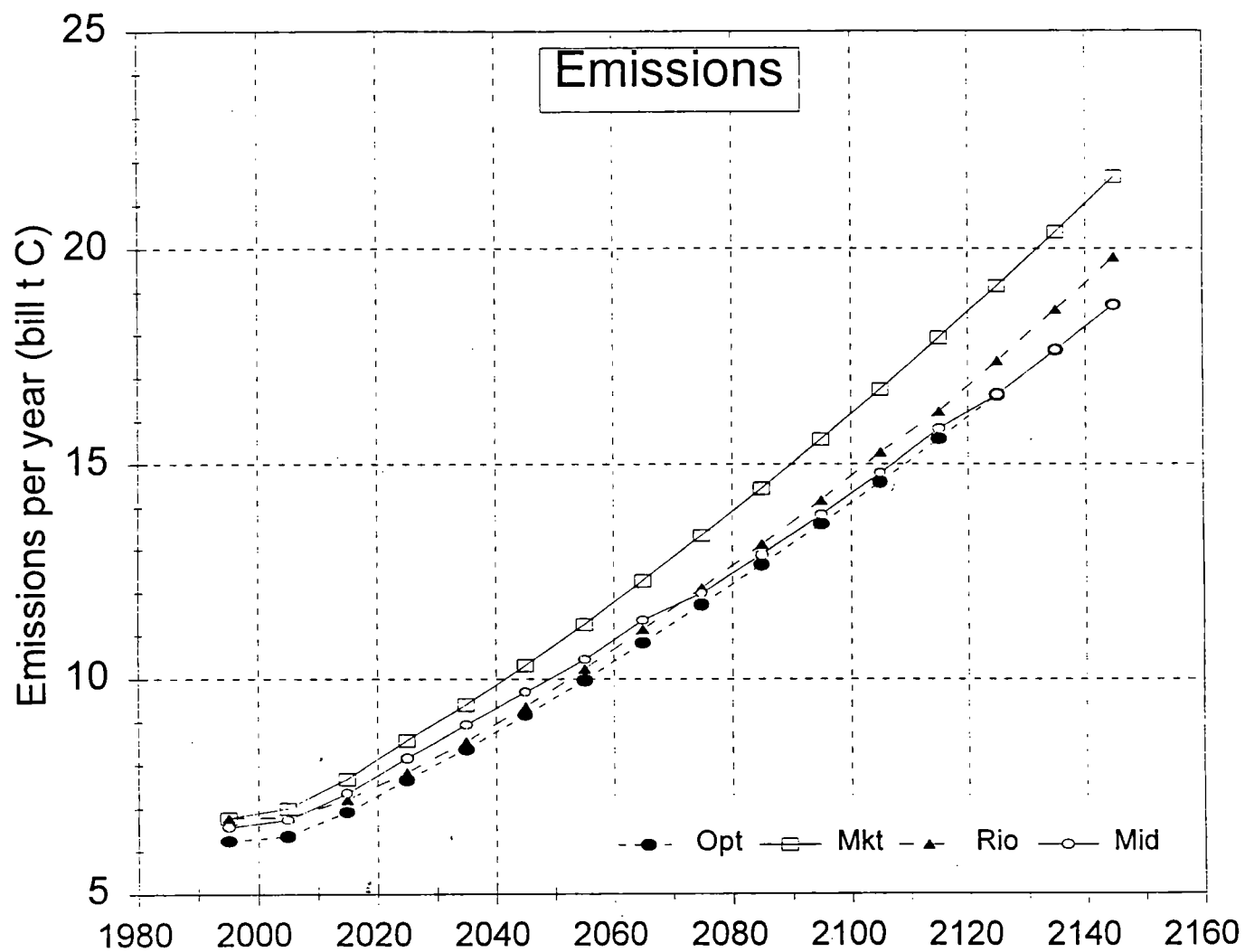


Figure 5

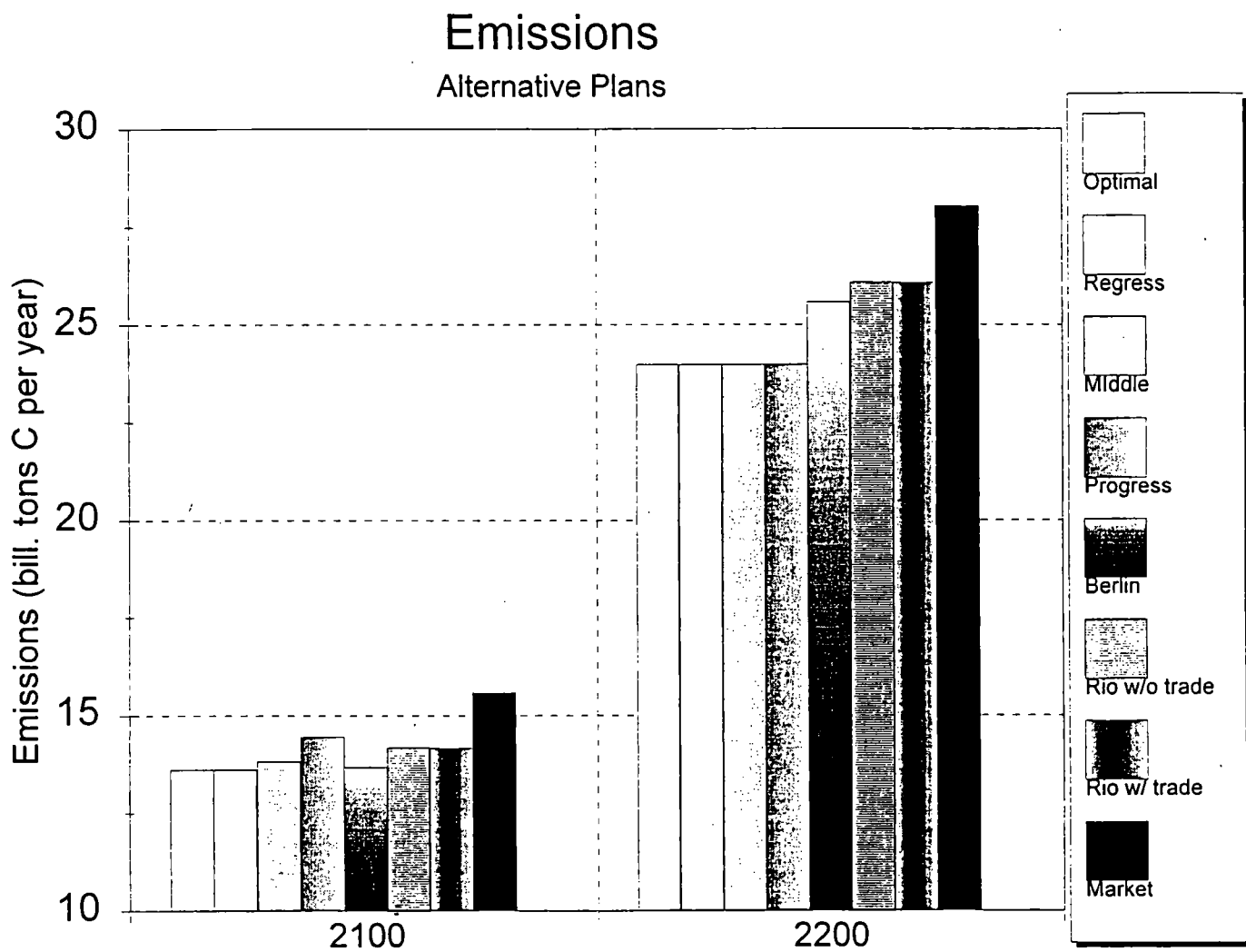


Figure 6

Concentrations Alternative Plans

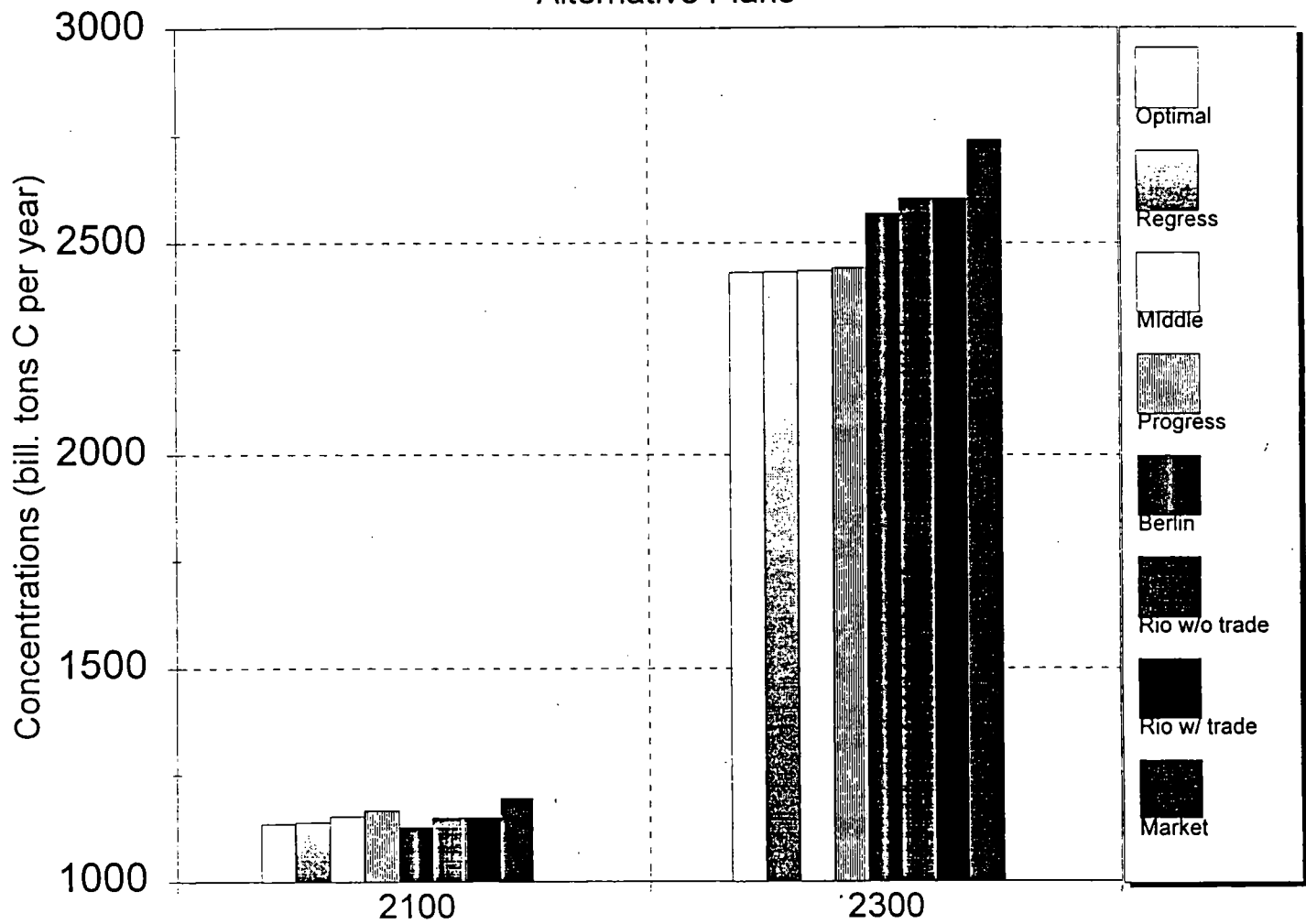


Figure 7

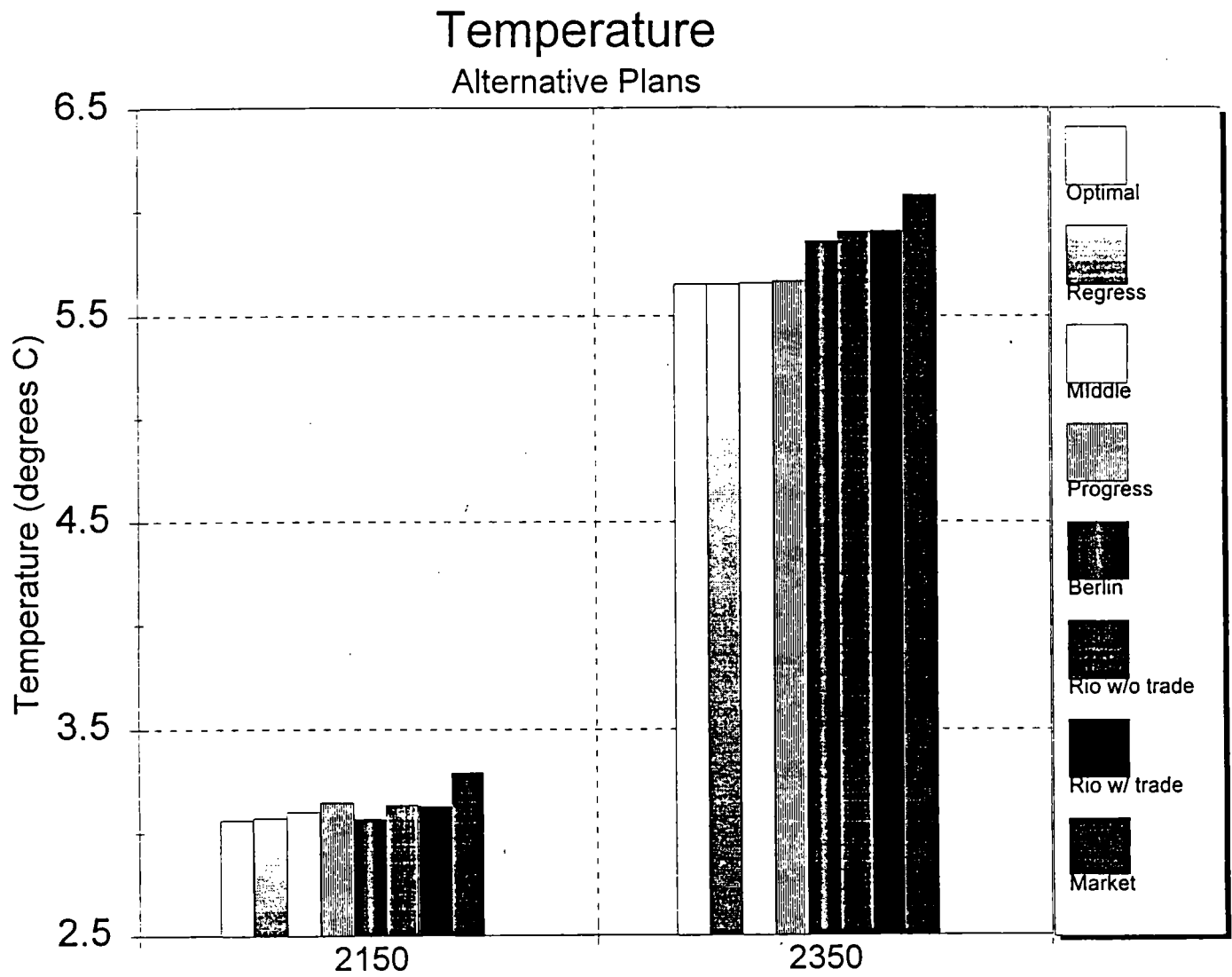


Figure 8

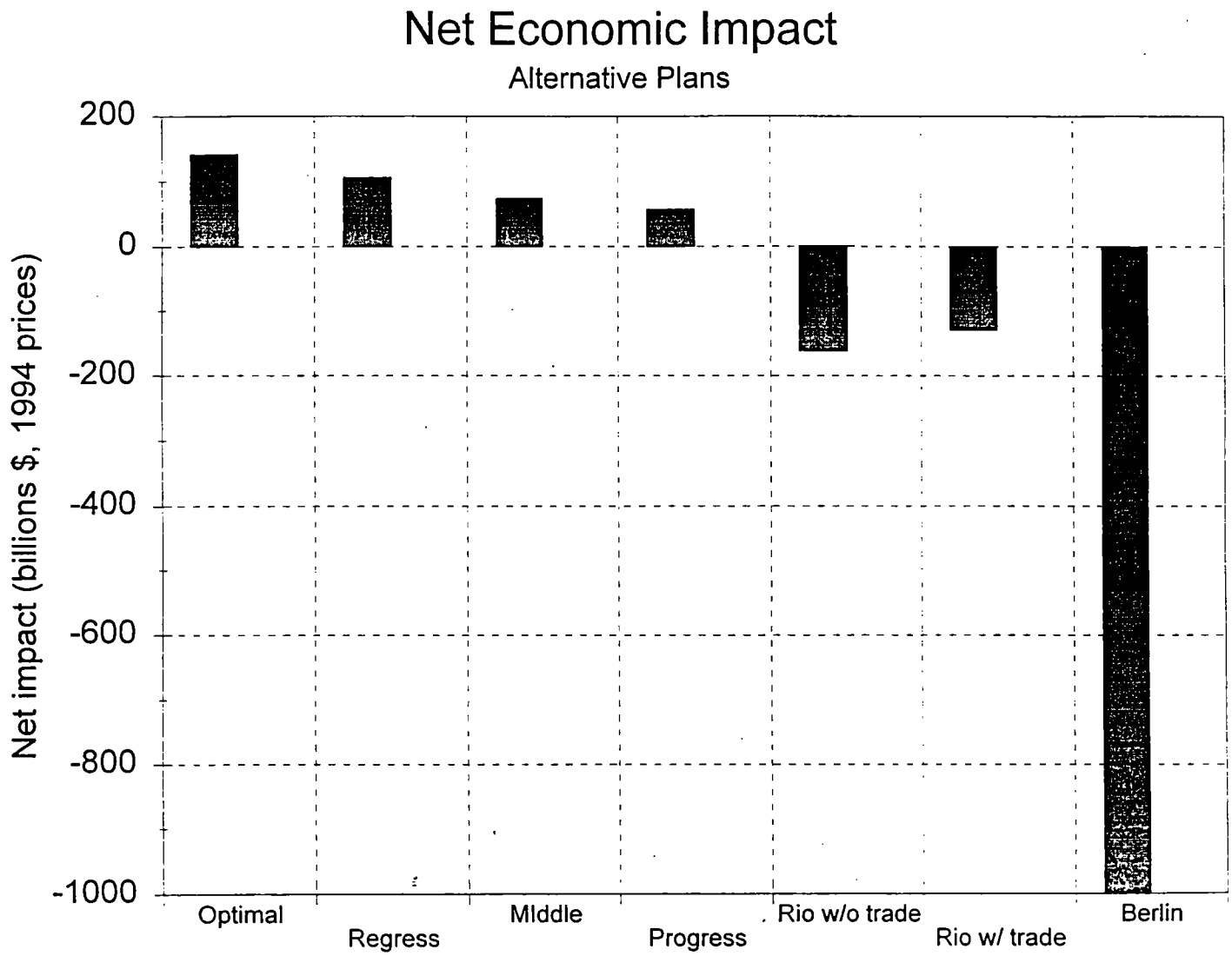


Figure 9

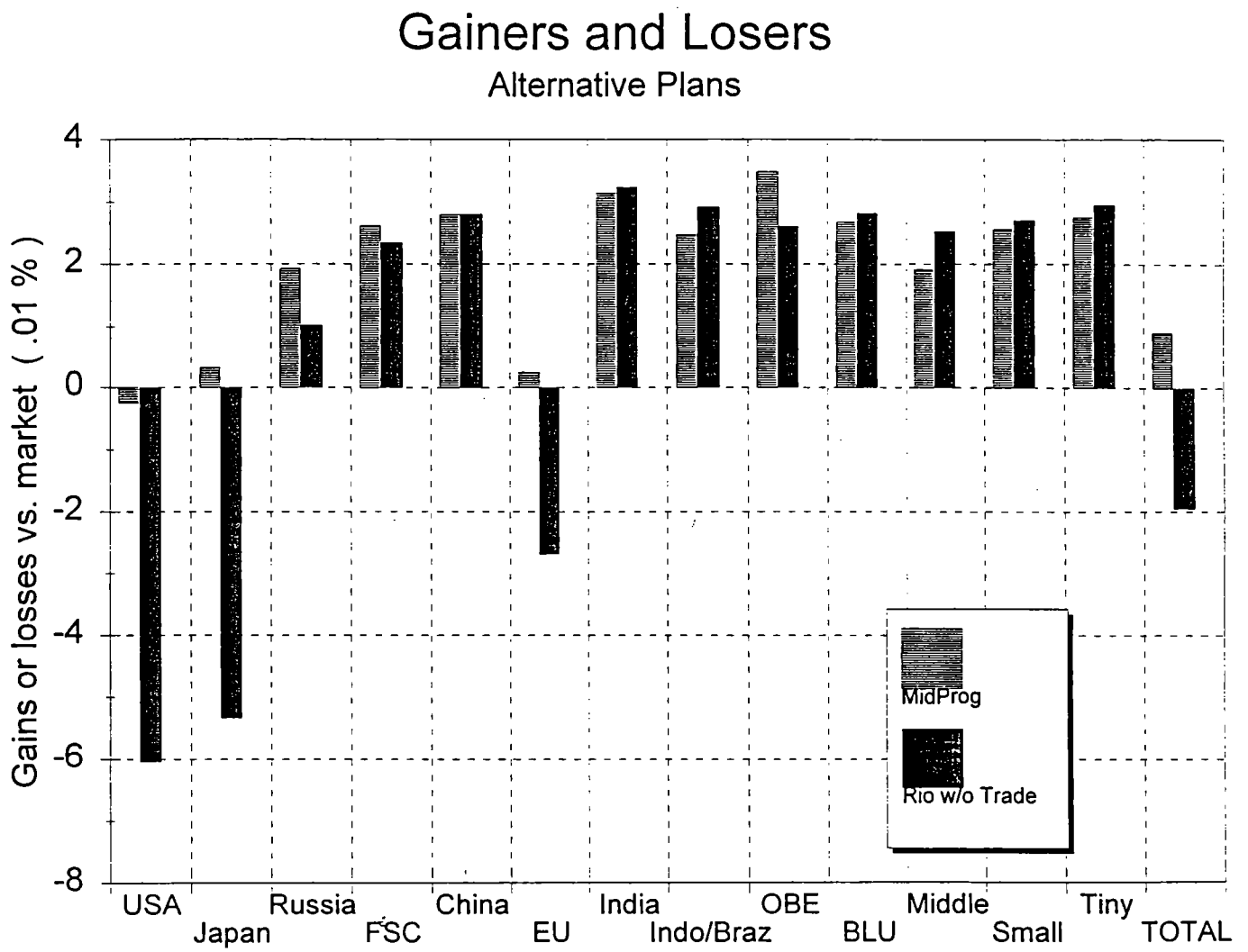


Figure 10

Carbon Tax Rates in Different Plans

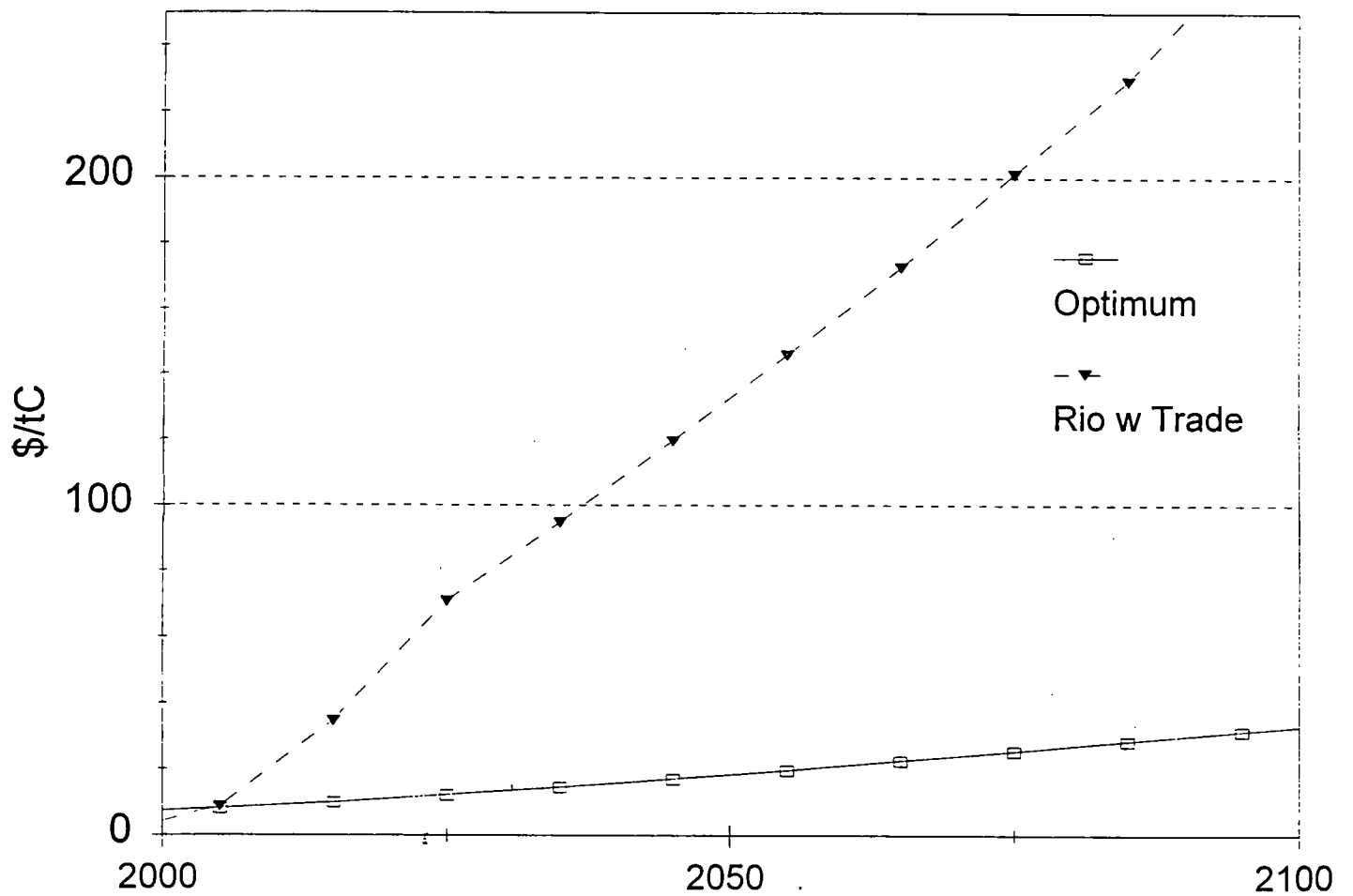


Table 1A

Net Benefits of Alternative Trading Regimes														
	Billions of 1994 US dollars													
<i>Relative to No Global Warming</i>								Indon/						
	USA	Japan	Russia	FSC	China	EU	India	Brazil	OBE	BLU	Middle	Small	Tiny	TOTAL
Market	-520.8	-336.4	-32.2	-39.3	-232.9	-695.4	-123.7	-228.7	-56.8	-104.2	-695.6	-260.0	-116.1	-3442
Optimal	-504.9	-318.9	-36.5	-40.7	-231.2	-661.3	-119.9	-214.7	-57.8	-98.6	-659.7	-246.5	-109.1	-3300
Regress	-520.1	-328.7	-29.3	-35.7	-218.5	-681.3	-115.7	-219.3	-51.2	-98.6	-678.6	-248.1	-110.0	-3335
Middle	-525.2	-332.7	-29.8	-37.6	-222.2	-689.5	-118.5	-220.6	-53.8	-100.2	-675.1	-250.1	-111.6	-3367
Progress	-523.6	-333.8	-31.0	-38.2	-225.4	-690.9	-119.9	-222.4	-55.0	-101.2	-677.8	-252.5	-112.7	-3385
Rio w/o trade	-636.5	-396.1	-30.9	-37.8	-222.1	-759.1	-118.3	-219.2	-54.5	-100.0	-668.5	-249.5	-111.2	-3604
Rio w/ trade	-617.5	-382.1	-31.0	-37.9	-222.4	-757.1	-118.4	-219.4	-54.6	-100.1	-669.3	-249.8	-111.3	-3571
Berlin	-1057.3	-578.7	-29.7	-36.4	-213.3	-1064.5	-113.7	-210.6	-52.4	-96.1	-642.7	-239.9	-106.9	-4442
<i>Relative to No-Control Solution</i>								Indon/						
	USA	Japan	Russia	FSC	China	EU	India	Brazil	OBE	BLU	Middle	Small	Tiny	TOTAL
Market	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Optimal	15.8	17.4	-4.3	-1.4	1.8	34.1	3.8	14.0	-1.1	5.6	35.8	13.4	7.0	142
Regress	0.6	7.7	2.8	3.6	14.5	14.1	8.0	9.3	5.6	5.7	17.0	11.9	6.1	107
Middle	-4.4	3.6	2.4	1.7	10.8	5.8	5.2	8.1	3.0	4.1	20.5	9.9	4.5	75
Progress	-2.8	2.6	1.1	1.1	7.5	4.5	3.8	6.3	1.7	3.0	17.7	7.5	3.4	57
Rio w/o trade	-115.8	-59.8	1.3	1.5	10.8	-63.7	5.4	9.5	2.2	4.3	27.1	10.5	4.9	-162
Rio w/ trade	-96.8	-45.8	1.2	1.4	10.6	-61.7	5.3	9.3	2.2	4.2	26.3	10.2	4.7	-129
Berlin	-536.5	-242.3	2.4	2.9	19.7	-369.1	10.0	18.1	4.3	8.1	52.8	20.1	9.2	-1000
Item: Discounted GDP (trillions)	191.6	111.7	12.2	6.3	38.5	236.0	16.6	32.5	8.6	15.2	107.4	38.7	16.5	831.9

Table 1B

Net Benefits of Alternative Trading Regimes															
	Percent of Discounted GDP (x 100)														
<i>Relative to No Global Warming</i>								Indon/							Stand.
	USA	Japan	Russia	FSC	China	EU	India	Brazil	OBE	BLU	Middle	Small	Tiny	TOTAL	Dev.
Market	-27.2	-30.1	-26.4	-62.1	-60.4	-29.5	-74.5	-70.3	-65.9	-68.7	-64.7	-67.2	-70.5	-41.4	18.3
Optimal	-26.3	-28.6	-29.9	-64.2	-60.0	-28.0	-72.2	-66.0	-67.1	-65.0	-61.4	-63.7	-66.2	-39.7	17.3
Regress	-27.1	-29.4	-24.1	-56.4	-56.7	-28.9	-69.7	-67.5	-59.4	-64.9	-63.2	-64.1	-66.7	-40.1	17.0
Middle	-27.4	-29.8	-24.4	-59.5	-57.6	-29.2	-71.3	-67.9	-62.4	-66.0	-62.8	-64.6	-67.7	-40.5	17.3
Progress	-27.3	-29.9	-25.4	-60.4	-58.5	-29.3	-72.2	-68.4	-63.9	-66.7	-63.1	-65.3	-68.4	-40.7	17.5
Rio w/o trade	-33.2	-35.5	-25.3	-59.7	-57.6	-32.2	-71.2	-67.4	-63.3	-65.9	-62.2	-64.5	-67.5	-43.3	15.6
Rio w/ trade	-32.2	-34.2	-25.4	-59.8	-57.7	-32.1	-71.3	-67.5	-63.3	-65.9	-62.3	-64.6	-67.6	-42.9	15.9
Berlin	-55.2	-51.8	-24.4	-57.5	-55.3	-45.1	-68.5	-64.8	-60.8	-63.3	-59.8	-62.0	-64.9	-53.4	11.0
<i>Relative to No-Control Solution</i>								Indon/							Stand.
	USA	Japan	Russia	FSC	China	EU	India	Brazil	OBE	BLU	Middle	Small	Tiny	TOTAL	Dev.
Market	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Optimal	0.8	1.6	-3.5	-2.1	0.5	1.4	2.3	4.3	-1.3	3.7	3.3	3.5	4.2	1.7	2.4
Regress	0.0	0.7	2.3	5.7	3.8	0.6	4.8	2.9	6.5	3.8	1.6	3.1	3.7	1.3	1.9
Middle	-0.2	0.3	1.9	2.6	2.8	0.2	3.1	2.5	3.5	2.7	1.9	2.6	2.8	0.9	1.1
Progress	-0.1	0.2	0.9	1.7	1.9	0.2	2.3	1.9	2.0	2.0	1.6	1.9	2.1	0.7	0.8
Rio w/o trade	-6.0	-5.4	1.0	2.3	2.8	-2.7	3.2	2.9	2.6	2.8	2.5	2.7	3.0	-1.9	3.2
Rio w/ trade	-5.0	-4.1	1.0	2.3	2.7	-2.6	3.2	2.8	2.5	2.7	2.4	2.6	2.9	-1.5	2.8
Berlin	-28.0	-21.7	2.0	4.6	5.1	-15.6	6.0	5.6	5.0	5.4	4.9	5.2	5.6	-12.0	11.6

Table 2

<i>Regime</i>	<i>Efficiency</i>					
	<i>Economic</i>		<i>Temperature*</i>		<i>Concentrations*</i>	
	Percent of Optimum*	Benefit/Cost Ratio**	2150	2350	2100	2300
Market	0	0.00	0.0	0.0	0.0	0.0
Optimal	100	2.88	100.0	100.0	100.0	100.0
Regress	75	2.87	96.2	99.6	93.0	99.8
Middle	53	2.87	82.7	98.5	70.7	98.8
Progress	40	2.87	61.9	96.3	46.3	96.5
Rio w/o trade	-114	0.44	67.7	41.0	73.8	44.2
Rio w/ trade	-91	0.49	69.4	40.1	72.8	43.6
Berlin	-704	0.20	97.3	51.9	111.5	55.5

* Percentage gain in net benefits, temperature, or concentrations as percent of optimal relative to market.

**Ratio of reduction in climate damages to abatement costs.

Table 3

Costs and Benefits for the United States

[Billions of dollars, 1994 prices; costs and damages measures negatively*]

Relative to no controls	Costs	Benefits	Net Benefits	Benefit-Cost Ratio
Market	0.0	0.0	0.0	na
Optimal	-14.0	29.9	15.8	2.13
Regressive	-20.8	21.4	0.6	1.03
Middle	-19.4	14.9	-4.4	0.77
Progressive	-14.3	11.5	-2.8	0.80
Rio w/o Trading	-131.9	16.2	-115.8	0.12
Rio with Trading	-112.3	15.6	-96.8	0.14
Berlin with 20 percent cuts	-571.1	34.6	-536.5	0.06

* Calculations are from the 1997 version of the RICE model. All numbers cover the period 1990 through 2400 and include the present value of the costs of compliance (including both resource costs and permit purchases) and the climate damages discounted at a 5 percent discount rate back to 1990 in 1994 prices. The "Costs" column measures the compliance costs and the "Benefits" column measures the averted climate damage.