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GLOBAL CLIMATE CHANGE: IMPACTS OF GREENHOUSE GAS CONTROL STRATEGIES

WP 12.1

Executive Summary

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EMF 12
Global Climate Change: Impacts of Greenhouse Gas Control Strategies
EXECUTIVE SUMMARY
(Draft #5)

Concern about the extent of global climate change and its potential consequences has increased dramatically in recent years. Many believe that unprecedented climate changes are - or soon will be - occurring as the result of man-made emissions of greenhouse gases. There remain large uncertainties, however, about the relationship between emissions of greenhouse gases and their atmospheric concentrations, about the link between atmospheric concentrations and global climate change, about whether extraordinary changes in climate are actually occurring, and about the impacts of climate changes on people and ecosystems.

The largest man-made source of greenhouse gases is carbon dioxide produced by the combustion of fossil fuels in utility and industrial boilers, and in internal combustion engines. Thus, any effort to reduce greenhouse gas emissions will start with efforts to restrict these activities. Therefore, it seems essential to develop a range of projections of the likely costs of alternative levels of control of carbon emissions from the energy sector.

A fundamental challenge facing policy makers is the need for all or most of the world's large countries to co-operate in restricting greenhouse gas emissions; greenhouse gas emissions anywhere affect atmospheric concentrations (and climate) everywhere. The 24 developed countries that are members of the Organization for Economic Cooperation and Development (OECD) currently produce slightly less than half of the world's carbon dioxide emissions, and that percentage, even in the absence of emissions controls, is projected to decrease dramatically by the middle of the next century (to one third or so of the world total). Thus, if only the OECD countries control emissions, that may have only a very minor impact on world emissions and world climate. If only part of the OECD participates the impact would be even less.

The twelfth Energy Modeling Forum (EMF) working group met five times from September 1990 to May 1992 to compare alternative projections of the impacts of a number of greenhouse gas emission control scenarios. The working group specified thirteen standardized scenarios reflecting a range of carbon emission control levels, as well as sensitivities on key standardized inputs. These scenarios were ultimately implemented by fourteen modeling teams employing a wide variety of techno-economic models, although not every model could implement every scenario. In addition to these model comparisons, ten study groups were formed to analyze issues not being addressed by the fourteen models and thirteen scenarios. These groups used additional models and methods to analyze issues not addressed in the thirteen original scenarios.

BASIC CONTROL SCENARIOS

Six of the thirteen EMF 12 scenarios employed the same GDP, population, resource availability, and technology assumptions, but consider different levels and rates of CO_2 emissions control. 1) Reference - no control; (2) 20% Reduction - a 20% reduction in CO_2 emissions in the developed countries and no more than a 50% increase in the developing countries relative to 1990 levels by 2010; (3) 50% Reduction - the same as (2), but with an additional reduction in CO_2 emissions in the developed countries to 50% below their 1990 levels by 2050, (4) Stabilization - hold CO_2 emissions in the developed countries to their 1990 levels by the year 2000, with the developing countries again constrained to no more than 50% above their 1990 levels, (5) a Phased-In Carbon Tax that escalates from $15 per ton in 1990 at 5% real per year, and (6) a 2% Points Per Year Reduction in emissions relative to the Reference case.

In implementing these scenarios the modeling teams generally used taxes based on the carbon content of fossil fuels to achieve the emissions reductions (except for the government revenues a carbon tax would produce, this formulation is equivalent to a system of carbon emissions permit trading). These carbon tax projections provide us with a rough estimate of the degree of market intervention that will be required to achieve the carbon emission reductions. Most of the models included anticipated results from new technology development and conservation programs in the Reference case. However, in these models there is no explicit consideration of market imperfections that may be causing current energy consumption patterns to differ from what perfectly functioning competitive markets would produce. More efficient, but more expensive, technologies are generally selected in the control scenarios, but no additional technology development is generally assumed to occur. Only one model adds additional conservation programs explicitly in those scenarios, and only one other model includes endogenously determined rates of technological change. Finally, in their initial implementation of these scenarios the modeling teams assumed no international emissions trading, lump sum rebate of any tax revenues collected, and no carbon offsets, such as those that might result from tree planting. A number of general points can be made from examining cost of control projections for these scenarios:

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

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

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

(4). The impact of a carbon tax on Gross Domestic Product (GDP) measures its costs to the economy in terms of lost output resulting from the increase in the price of goods requiring carbon emissions; those goods must either be produced with less carbon or by more expensive processes. The GDP loss also includes the impact of the carbon tax on capital stock accumulation and technological progress although not all models capture these phenomena. The models initially assumed lump-sum redistribution of tax revenues; That is, tax revenues are used to reduce total tax payments by individuals and corporations without affecting marginal tax rates (for example, by reducing the standard deduction). The GDP losses calculated in this manner measure the cost of the distortions to the economy caused by the imposition of the carbon tax without either adding a credit or subtracting a penalty for the way the revenues are used. Under this assumption, and assuming no adverse trade effects, the model projections of the cost of stabilizing CO_2 emissions at today's levels range from .1% to .5% of GDP in 2000 for the U.S. and the cost of achieving a 20% reduction in CO_2 emissions relative to today's level range from .9% to 1.7% of U.S. GDP in 2010. Although 1.7% of U.S. GDP in 2010 amounts to about $130 Billion 1990 dollars, the implied reduction in the GDP growth rate between 1990 and 2010 would only be from about 2.3% per year to 2.25% per year. Thus, it is possible to reduce emissions significantly from their non-controlled level without significantly reducing the growth of the economy.

(5). The way in which carbon tax revenues are used has an important impact on the projected GDP loss. The projected GDP losses could be reduced substantially (relative to those calculated for the lump-sum recycling case) by using the carbon tax revenues to reduce existing taxes that discourage economic activity, particularly capital formation. Simulations with 4 models of the U.S. economy indicate that from 35% to more than 100% of the GDP losses could ultimately be offset by recycling revenues through cuts in existing taxes. On the other hand, if the revenues are used to fund low return government projects, the cost of achieving the carbon emission reductions could be substantially greater than when they are recycled in lump sum fashion.

(6). Regardless of where a model ranks in terms of the cost of controlling emissions, there is a great deal of similarity in how the models project costs will vary over time for a particular level of control, and with respect to the level of control in any particular year. First, the cost of a particular level of control generally increases over time as the reference level of emissions grows and more adjustments must be made to reach a fixed level of emissions. For example, assuming lump-sum recycling of carbon tax revenues, projections of the cost of stabilizing emissions in the U.S. range from .1% to .5% of GDP in 2000 and from .2% to .75% of GDP in 2010. In the longer term, say by 2050 or 2060, low-cost oil and gas reserves are near depletion and the incremental cost of reducing emissions tends to stabilize at the difference between the cost of carbon-free sources of energy, like solar cells and advanced technology nuclear reactors, and carbon-based sources of energy, like synthetic oil and gas made from coal or advanced coal-fired power plants.

(7). Second, the cost of control appears to be non-linear with respect to the level of control in any given year, especially up to about 2040 before old fossil-fuel based energy producing and consuming equipment can be fully retired and new carbon-free technologies can be fully introduced. That is, incremental reductions in allowable emissions cost more as the absolute level of allowed emissions in any particular year is reduced. For example, the cost of stabilizing emissions in the U.S. range from .2% to .75% of GDP in 2010, while the cost of reducing emissions by 20% in that year range from .9% to 1.7% of GDP as shown in Figure 2.

(8). If the OECD, or any other group of countries unilaterally implements a carbon reduction program, resulting changes in international energy prices will cause carbon emissions in other countries to increase relative to reference case levels. Increased carbon emissions by non-participating regions occurs both as a result of increased energy intensity of economic activity and through the migration of energy-intensive production into unconstrained regions. Carbon restrictions place countries who control at a competitive disadvantage in energy-intensive industries. Thus, the cost to countries who control increases with the level of cutback, but the impact on global emissions may drop off sharply if large groups of countries fail to co-operate.

(9). The non-linearity of year by year costs of control, the tendency of this non-linearity to decrease over time as new technologies can be more fully phased in, as well as potential problems with recycling large amounts of tax revenues and dealing with large international trade shifts suggest that there is a tradeoff between the cost of meeting an annual emissions target and the emissions generated before the target is reached. Moreover, the cumulative cost of meeting any cumulative emissions reduction target can be reduced if it is phased in over a longer period of time. If a fixed annual emissions rate target is specified, cumulative costs can be reduced with some increase in short-term emissions if: (a) more time is allowed for reaching the target, and

(b) the instrument(s) used to achieve it - say a carbon tax - is phased in gradually rather than abruptly. The cost reduction can be particularly significant if the target date and rate of implementation are set to allow new carbon-free technologies to be phased in smoothly. If discounting of future costs is included in the calculation (as some would argue is required to insure an optimal allocation of society's resources over time), the reduction in costs resulting from a slower phase-in of controls is even greater.

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

The models display a wide range of cost projections for the scenarios considered depending on both the features the modelers have incorporated in their models and the way they have implemented the scenarios. The cost of control projections are also sensitive to variations in standardized input assumptions. We begin by discussing the results for alternative policy scenarios.

ADDITIONAL POLICY OPTIONS

(1). A combination of policies imposed on each of the major greenhouse gases and implemented in a way that allows new technologies to be developed and implemented in a smooth manner, will be much less costly than aggressive pursuit of a single policy option.

(2). In the EMF 12 Emissions Trading scenario, a common carbon tax is imposed in all regions until the same amount of global emissions allowed in the 20% Reduction scenario is achieved. In the near term there is a moderate amount of emissions trading from the developing countries to the developed countries, resulting in a 30-60% reduction in the GDP loss that results from the 20% Reduction scenario. By 2040 or so the developing countries are assumed to have deployed the same large-scale technologies as the developed countries, however, so there are no additional gains to emissions trading beyond that point.

(3). Both carbon and Btu taxes have a bigger impact on CO_2 emissions when imposed at the primary energy production level, e.g. at the point of extraction, rather than at the wholesale or retail level, whereas an ad valorem tax has the largest impact when imposed at the end-use level. In addition, stabilization of CO_2 emissions can be achieved at lower costs when imposed at the primary energy level than at the wholesale or retail level. Also, it is difficult to insure that any emissions target will actually be met if a permit trading system is implemented at the wholesale or retail level, because unintended shifts in upstream fuel choices may result.

(4). The Energy Security study group examined the energy security implications of the alternative emissions control scenarios and concluded that they would have only a minor impact on energy security. The main short-run impact of the control scenarios is to substitute gas, conservation and alternative sources for coal, leaving oil use relatively unaffected.

(5). A gradually phased in carbon tax with the tax revenues recycled proportionally does not appear to result in major impacts on the distribution of income by income level. With the exception of the coal industry, which would experience a significant contraction over the next twenty years, the impact on individual industries is also likely to be small.

SENSITIVITY ANALYSES

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

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

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

DIFFERENCES IN MODEL PROJECTIONS

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

(1). Even when GDP growth rates are standardized, a very wide range of reference case emissions projections are produced by the models included in the study. By the year 2100, projections of CO_2 emissions range all the way from a 20% to a 200% increase over 1990 levels. Relatively small differences in model parameters led to large differences when their effects are compounded over the study's 110 year time horizon. For example, much of the difference in projections from the models for 2100 can be explained by differences in the assumed rate of decrease in energy use per unit of economic output independent of energy price changes. The Global 2100 model uses a value of .5% per year for this parameter, while the Edmonds-Reilly model employs 1.0% per year assumption. The more disaggregate assumptions made in the Global Macro model implies about a 1.25% rate. When compounded over 110 years these differences can explain aggregate energy use and emissions projections that differ by a factor of two or more. Estimates of this aggregate parameter based on historical data range from a rate of decrease of about .5% per year to an increase at about that rate. Researchers who have attempted to extrapolate the types and efficiencies of energy using equipment into the future have argued that the potential exists for a rate of decrease in energy use per unit of economic output from 1% per year to over 2% per year.

(2). In the Reference scenario all models project steady improvements (about one percent per year in the U.S.) in energy intensity over the study's time horizon, but no strong movement towards or away from non-carbon fuels. Increases in energy intensity and switching to less carbon intensive fuels are the major means of satisfying the requirements of the 20% Reduction scenario, with the fuel switching response being greater in the models with more end-use technology detail.

DIRECTIONS FOR FUTURE RESEARCH

Additional research in several areas could significantly improve the estimation of the costs of greenhouse gas emission control strategies and the evaluation of alternative policy options:

(1). This study has identified the amount of energy intensity changes that will take place independent of changes in energy prices over the coming decades as a major determinant of reference case emissions, a major source of differences between the models, and a major determinant of the cost of achieving any emissions target. Yet information about the potential for improved efficiency energy technologies is incomplete and often inconsistent and there is little conclusive analysis regarding their likely rate of adoption. Particularly important here are assessments of market imperfections or distortions that impede the introduction of more efficient technologies. For example, energy pricing in the developing countries and the former Soviet Union has been far below world market levels.

(2). The projections of baseline emissions also depend significantly on long-run GDP and population projections for the main regions of the world. Although some excellent analyses of the outlook for economic growth in the United States are available, more work would help resolve the remaining differences, which are considerable. In addition, very little is known about likely economic and population growth in the future in such important and diverse countries as China, India, Brazil and the independent states of the former Soviet Union.

(3). The adjustment costs that result from any control strategy depend on the availability and cost of non-carbon emitting renewable energy sources, especially before they emerge as mature technologies. The models included in this study all represent these adjustment costs in one way or another, but the different approaches can lead to markedly different results. This suggests the value of additional work on data and models of new technology availability dates and introduction rates, as well as of technology transfer to the developing countries.

(4). It is important to assess the potential of offsets to carbon emissions, like tree planting or slowing de-forestation, and of reducing other greenhouse gas emissions like methane from natural gas system leaks, coal bed seams, or ruminants, as these can be as effective as carbon emissions reductions in slowing climate change. In addition, carbon sequestration and removal technologies while not now economic could easily become competitive in the future especially if carbon taxes reach $100 per metric ton or more.

(5). This study suggests the value of additional work on the linkages between energy and the environment, between environmental policies and world energy markets, and between environmental policies and trade in non-energy goods.

(6). The design of an appropriate control strategy depends on the benefits as well as the costs of control. Although a great deal of work has been completed on the translation of CO_2 emissions into concentrations, on the dependence of climate on atmospheric CO_2 concentrations, and on the impacts of climate change on people, plants, and ecosystems, great uncertainties remain. Research on evaluating the impacts in economic terms has just begun.

Figure 1. Carbon Taxes Required to Achieve Carbon Emission Reductions in the United States in 2020.

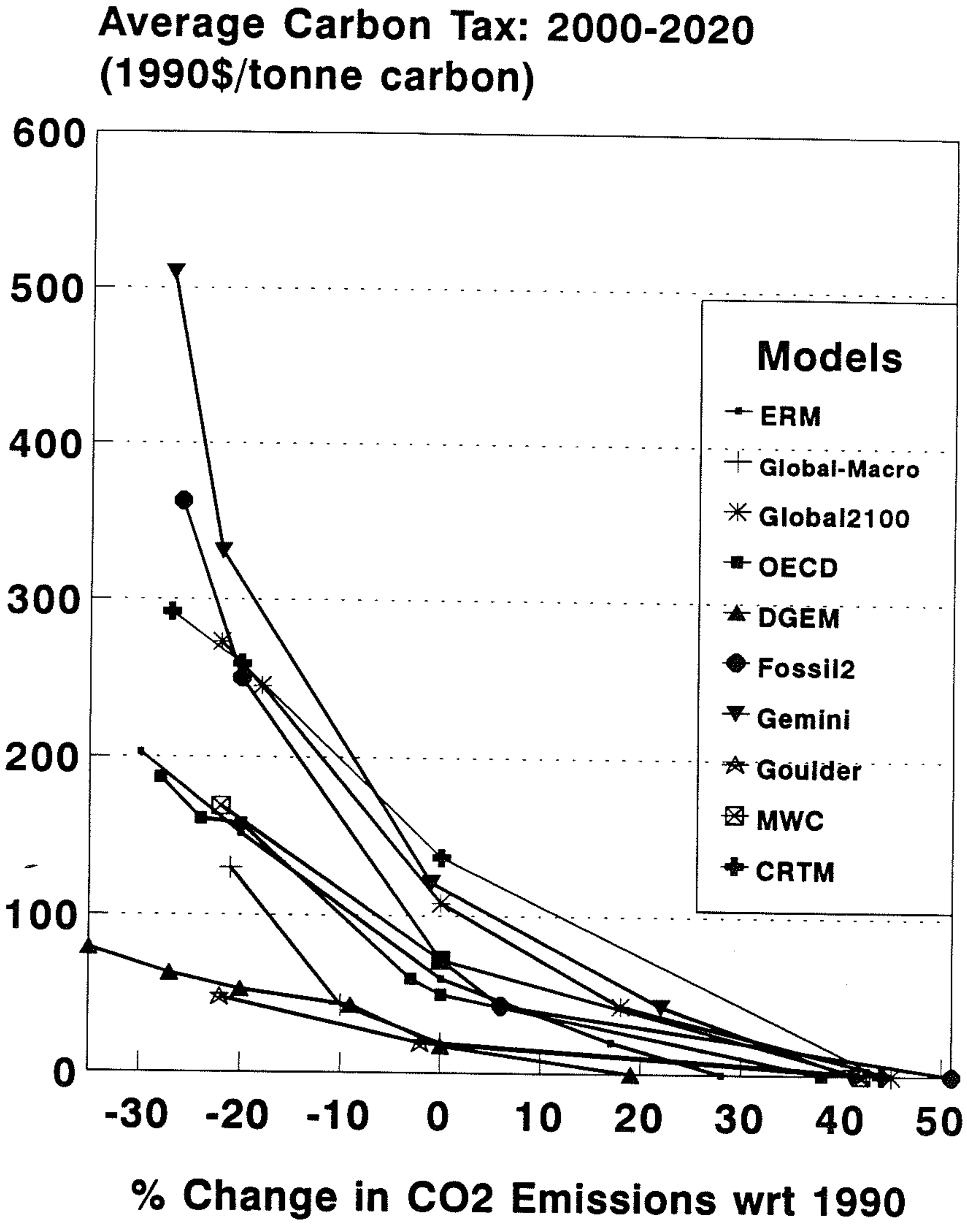
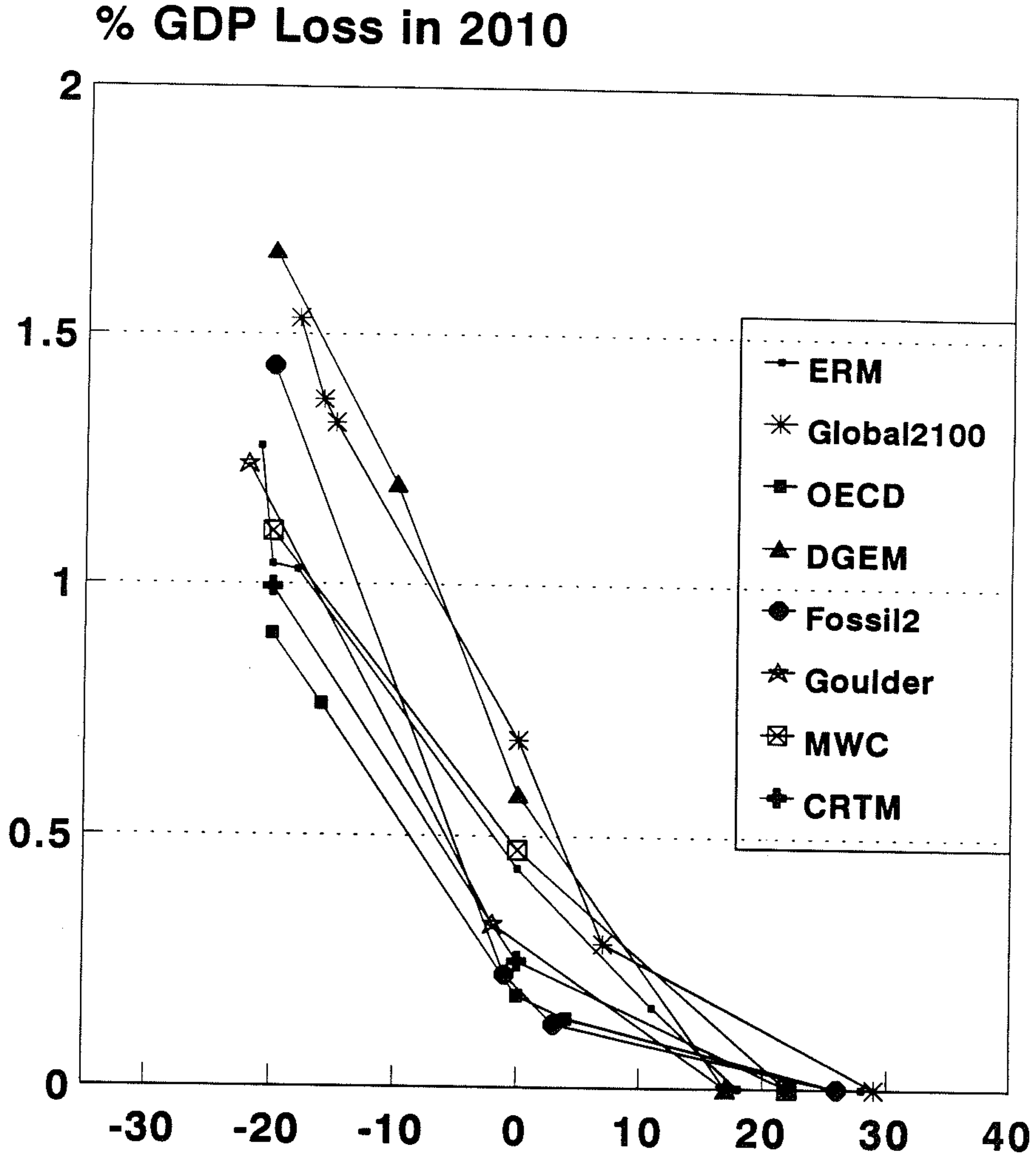


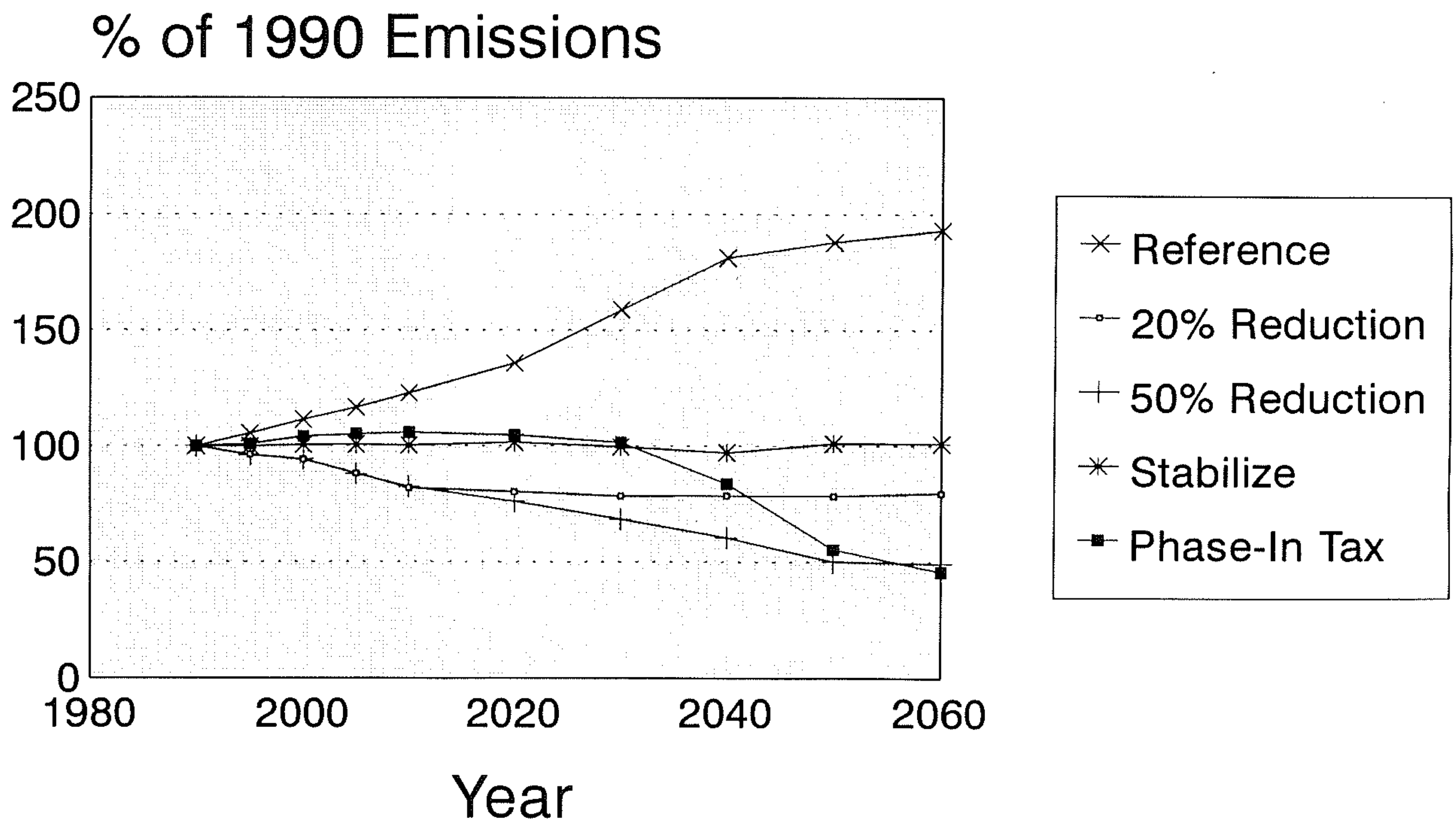
Figure 2. GDP Losses Associated With Carbon Emission Reductions in the United States in 2010.



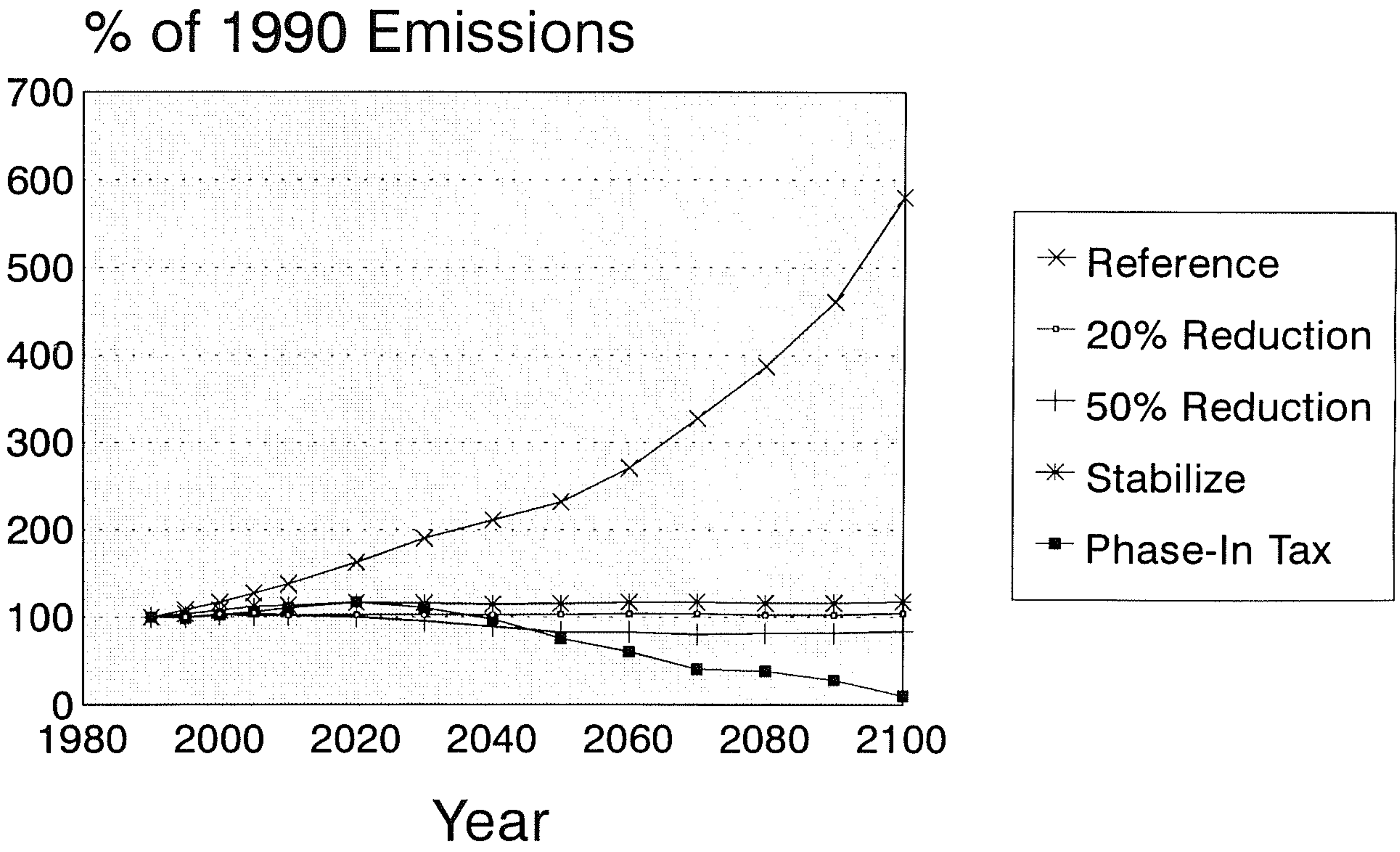
DRAFT GRAPHICS FOR EMF 12

SUMMARY REPORT

Average U.S. Carbon Emissions
as a Percentage of 1990 Emissions

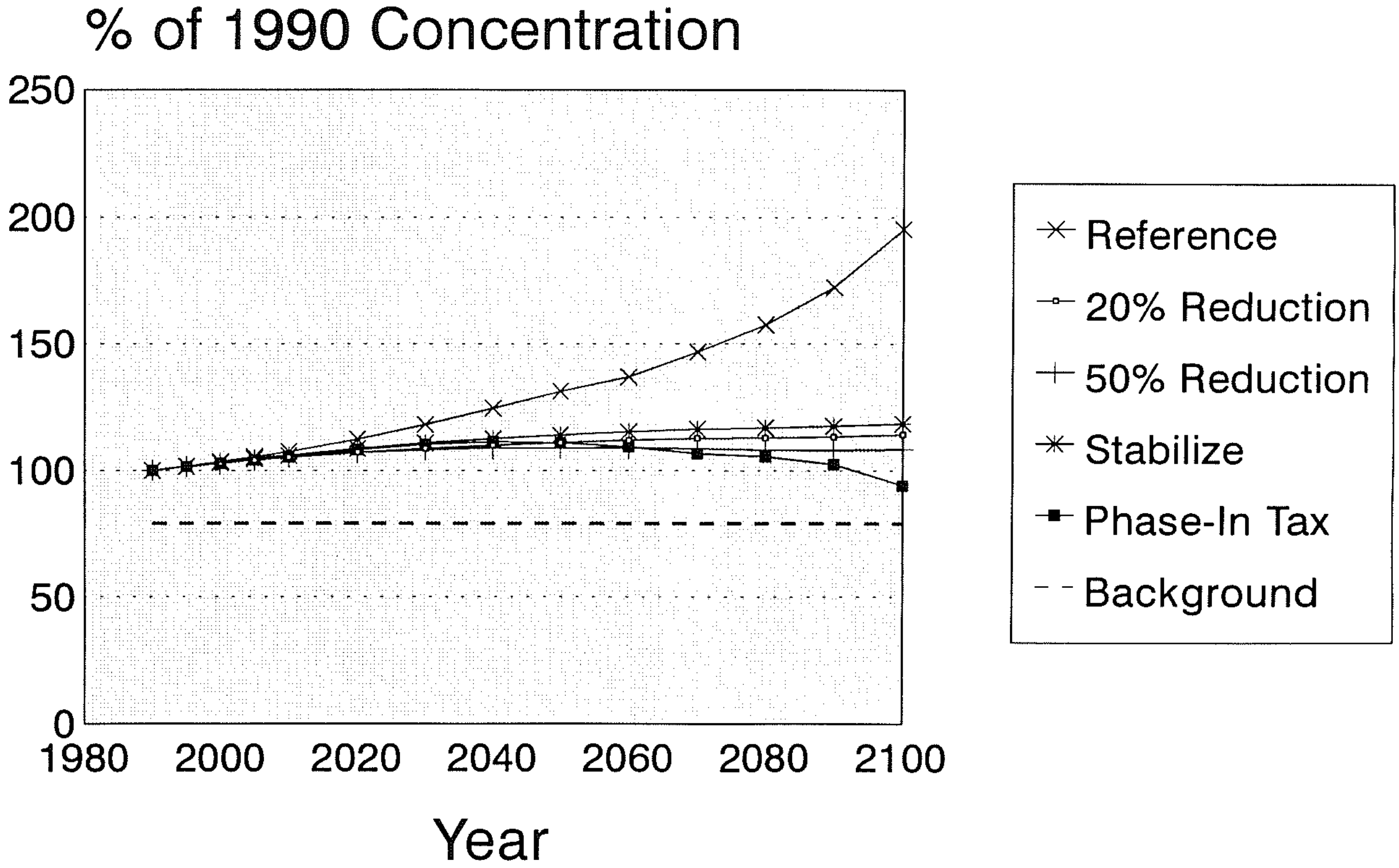


World CO2 Emissions as Percent of 1990 Level
Average of Results From Global Models

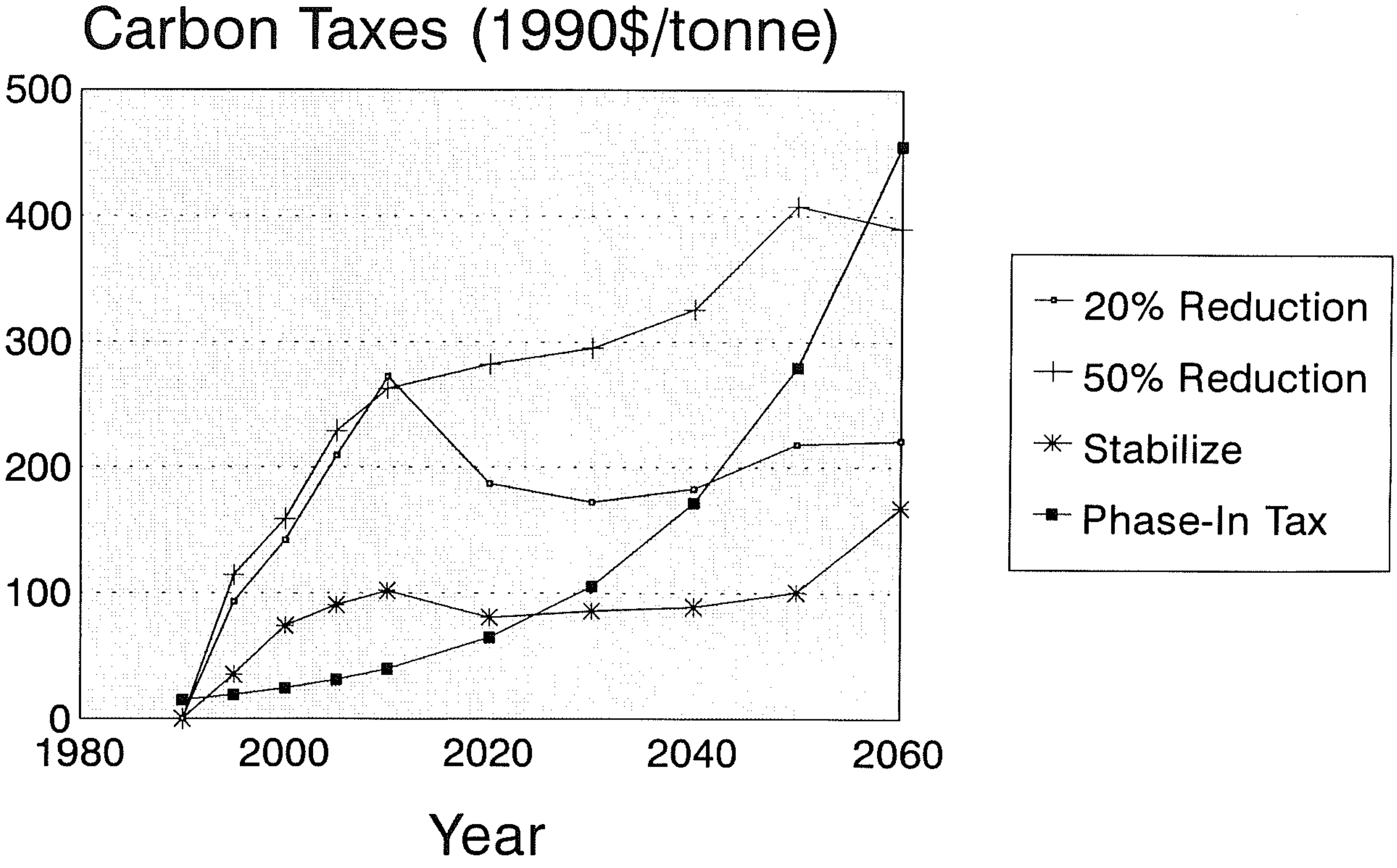


Atmospheric CO2 Concentrations as Percent of 1990 Level

Average of Results From Global Models

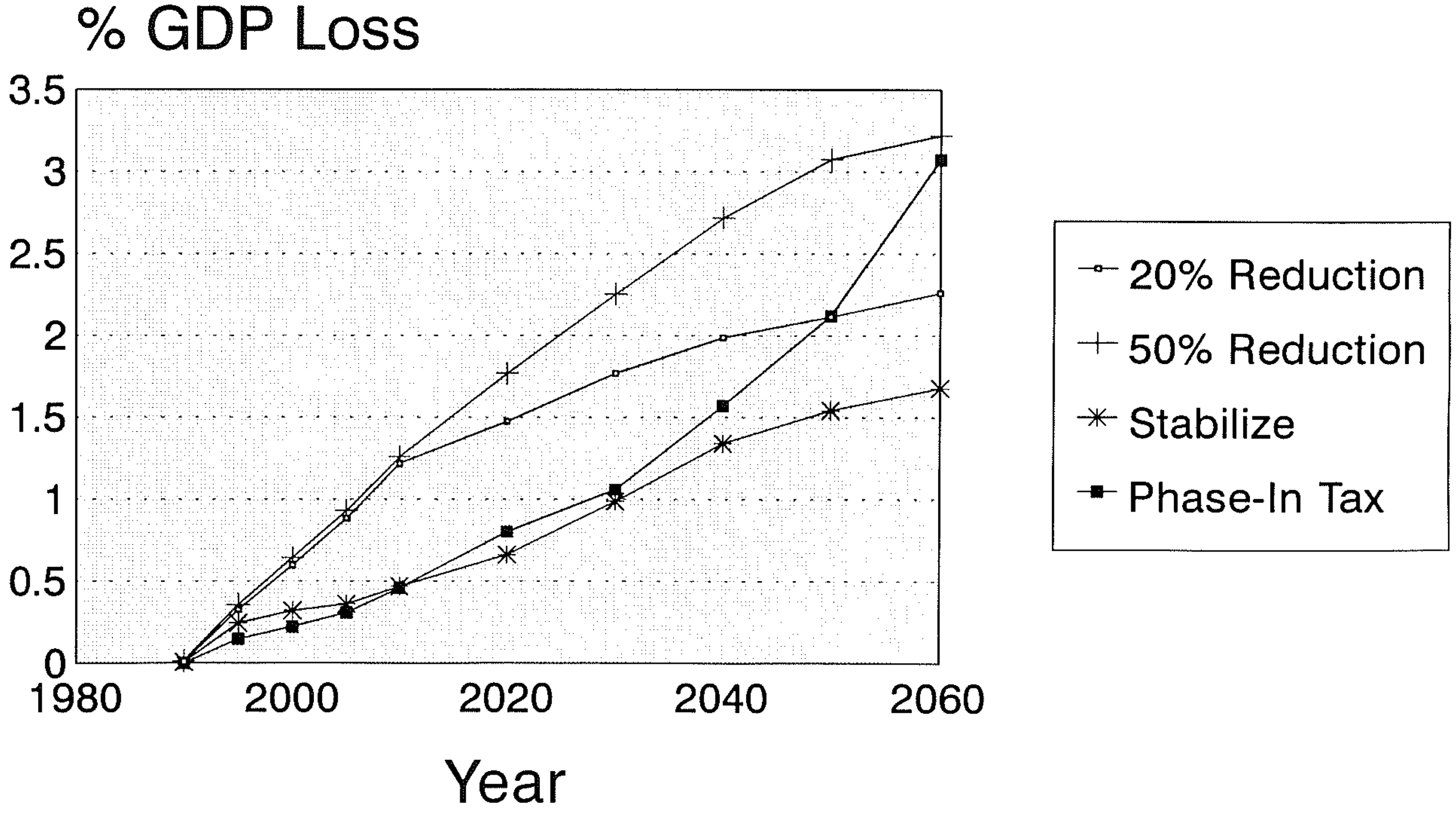


Average U.S. Carbon Taxes

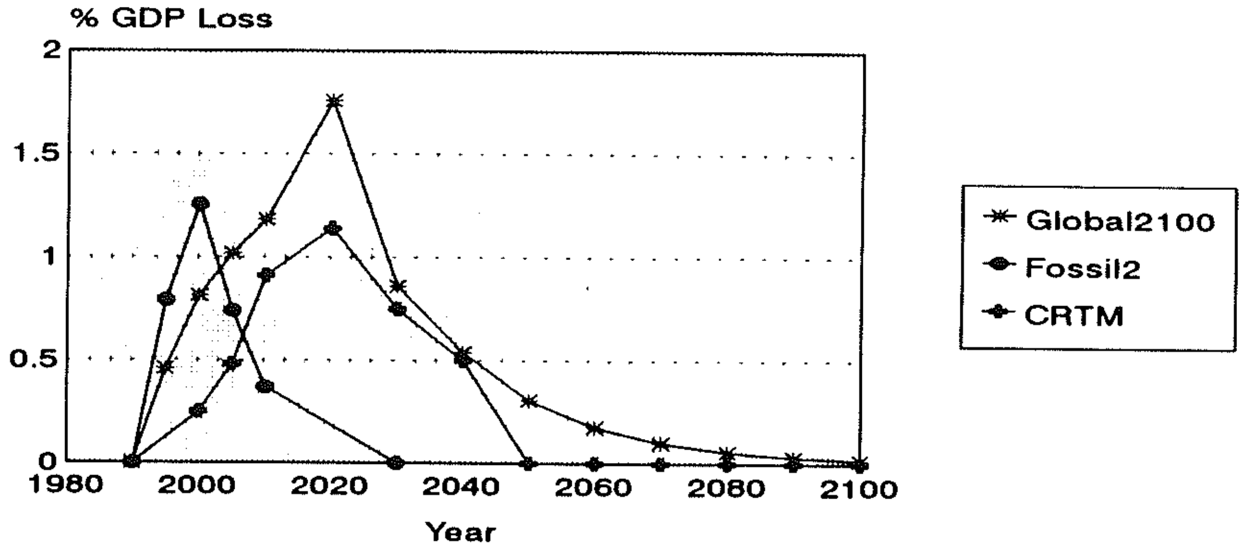


U.S. GDP Loss Projections

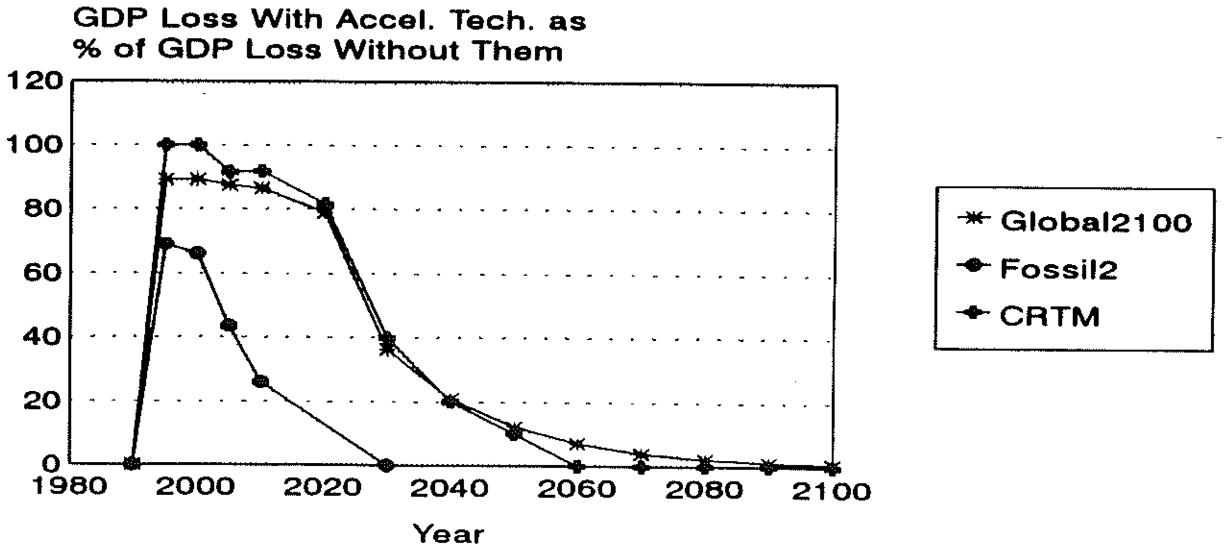
Average of all Models



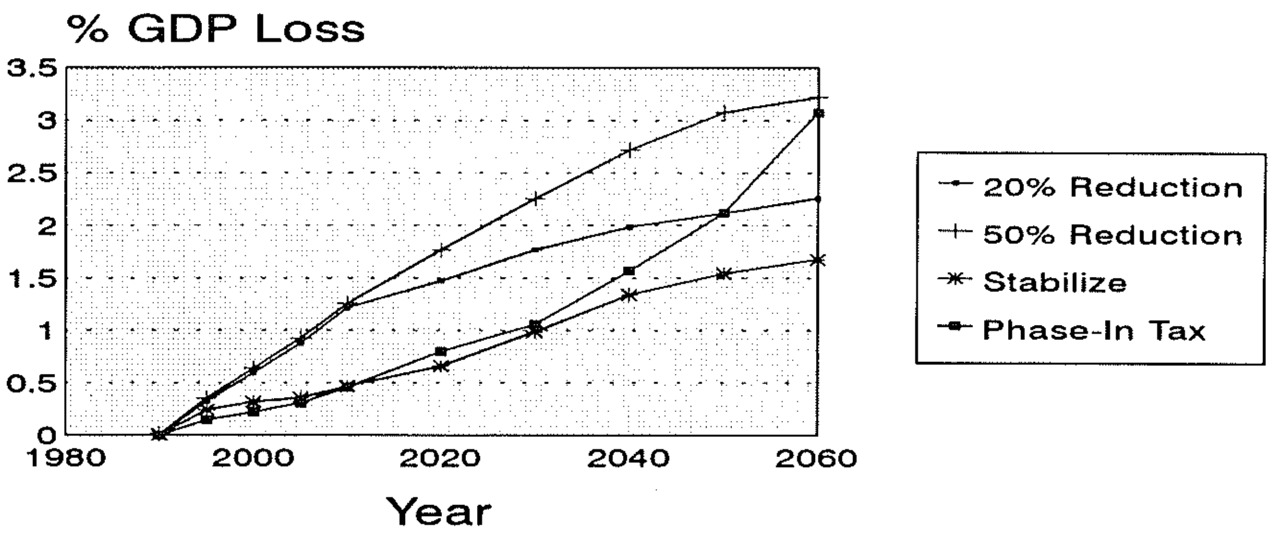
Cost of 20% Target to United States
With Accelerated Technologies



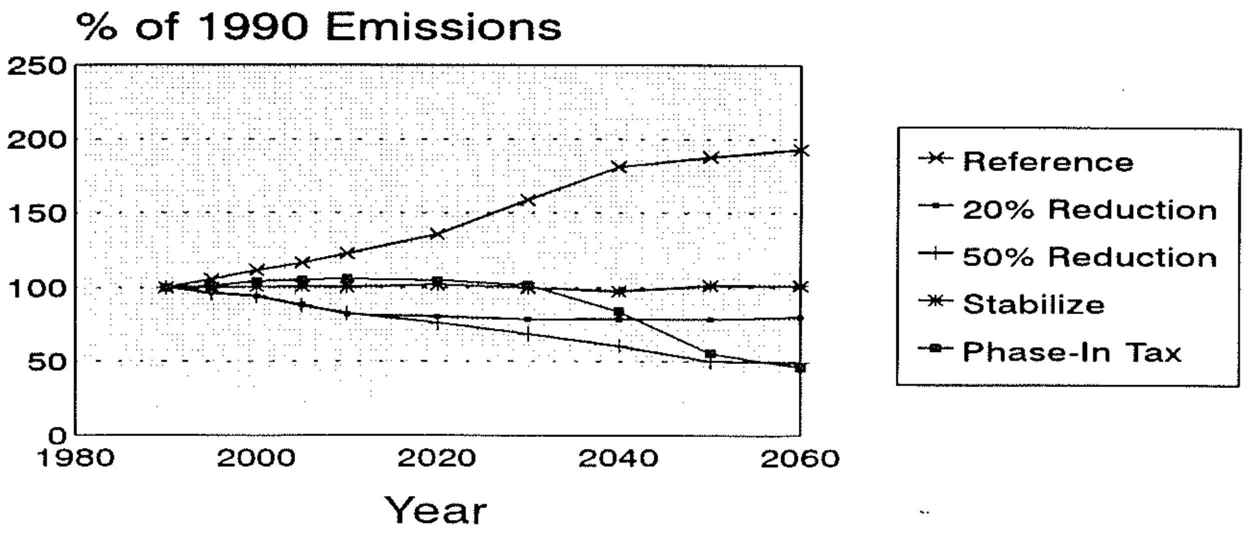
Value of Accelerated Technologies to the United States
Cost of 20% Reduction with Accelerated Technologies as % of Cost Without Them



U.S. GDP Loss Projections
Average of all Models

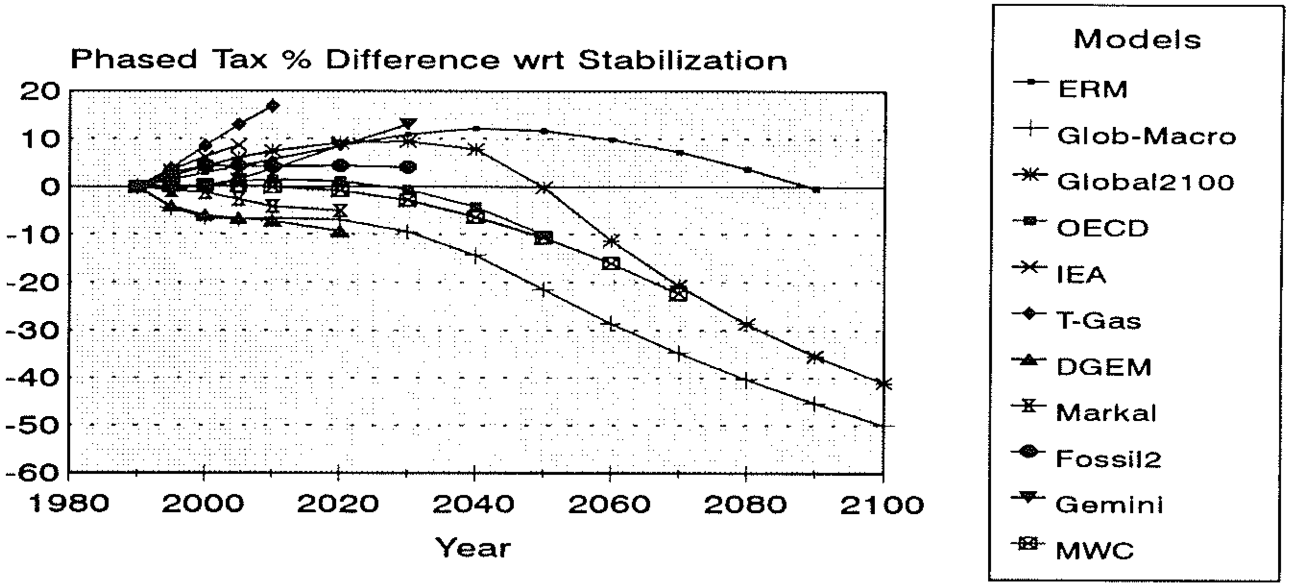


Average U.S. Carbon Emissions
as a Percentage of 1990 Emissions



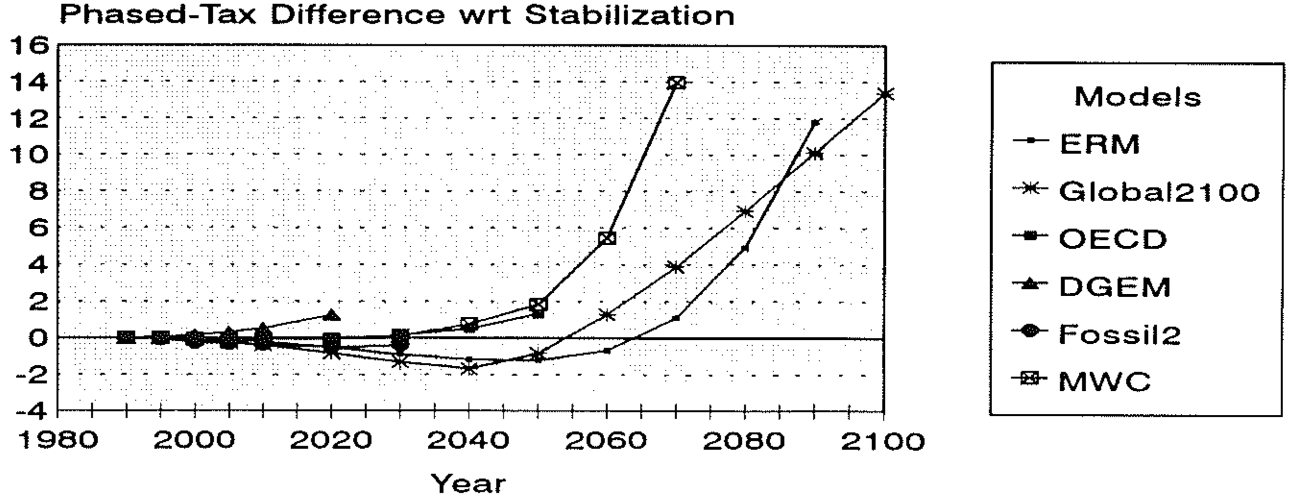
Cumulative CO2 Emissions - U.S.

Percentage Difference
Phased-In Tax wrt Stabilization



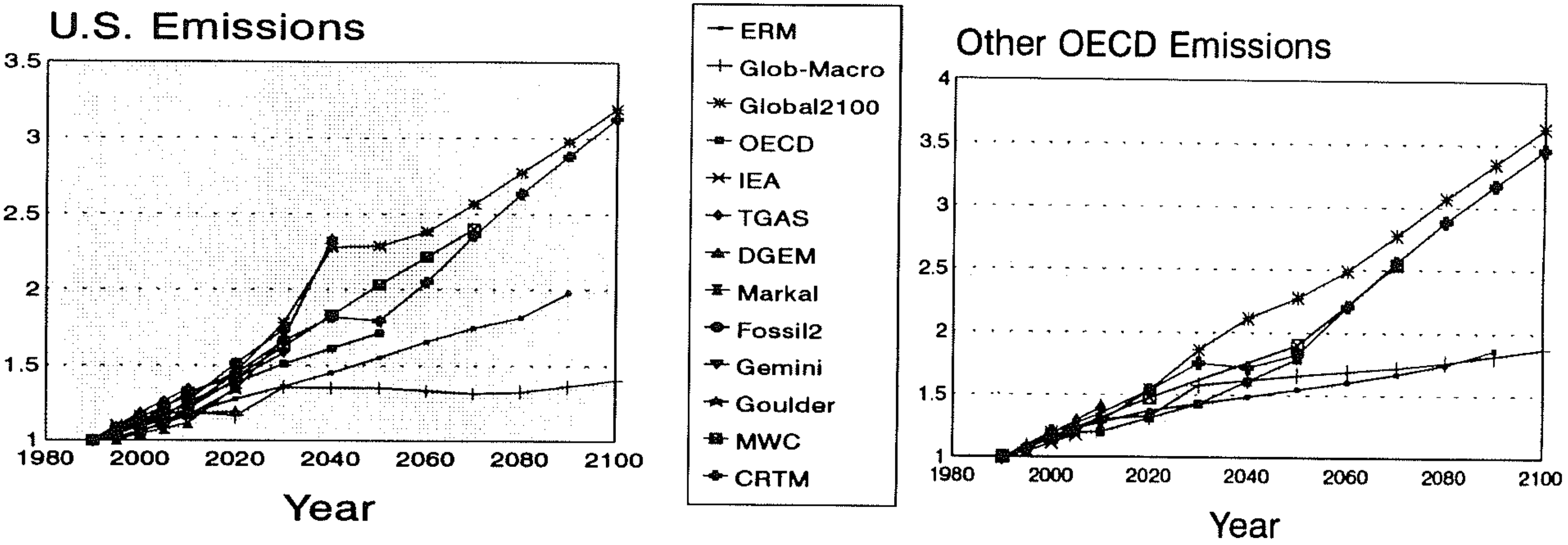
Cumulative GDP Loss - U.S.

Trillion 1990 Dollars
Phased-In Tax wrt Stabilization



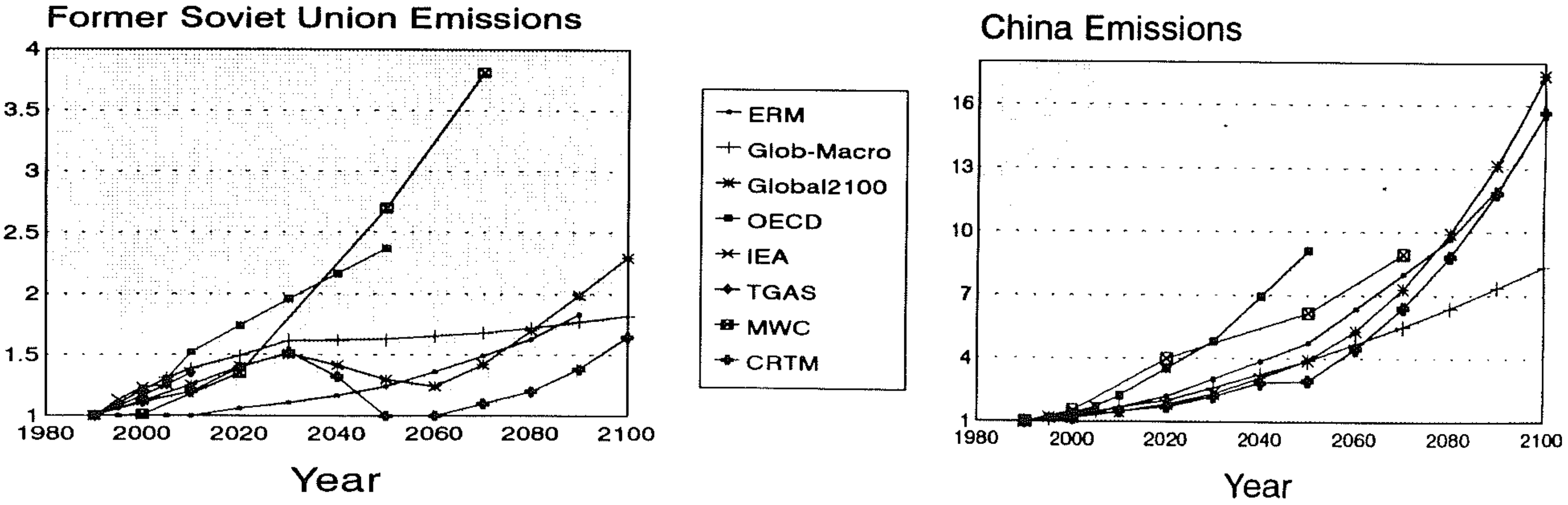
Regional Carbon Emissions

Indexed to 1990 = 1.0



U.S. Emissions

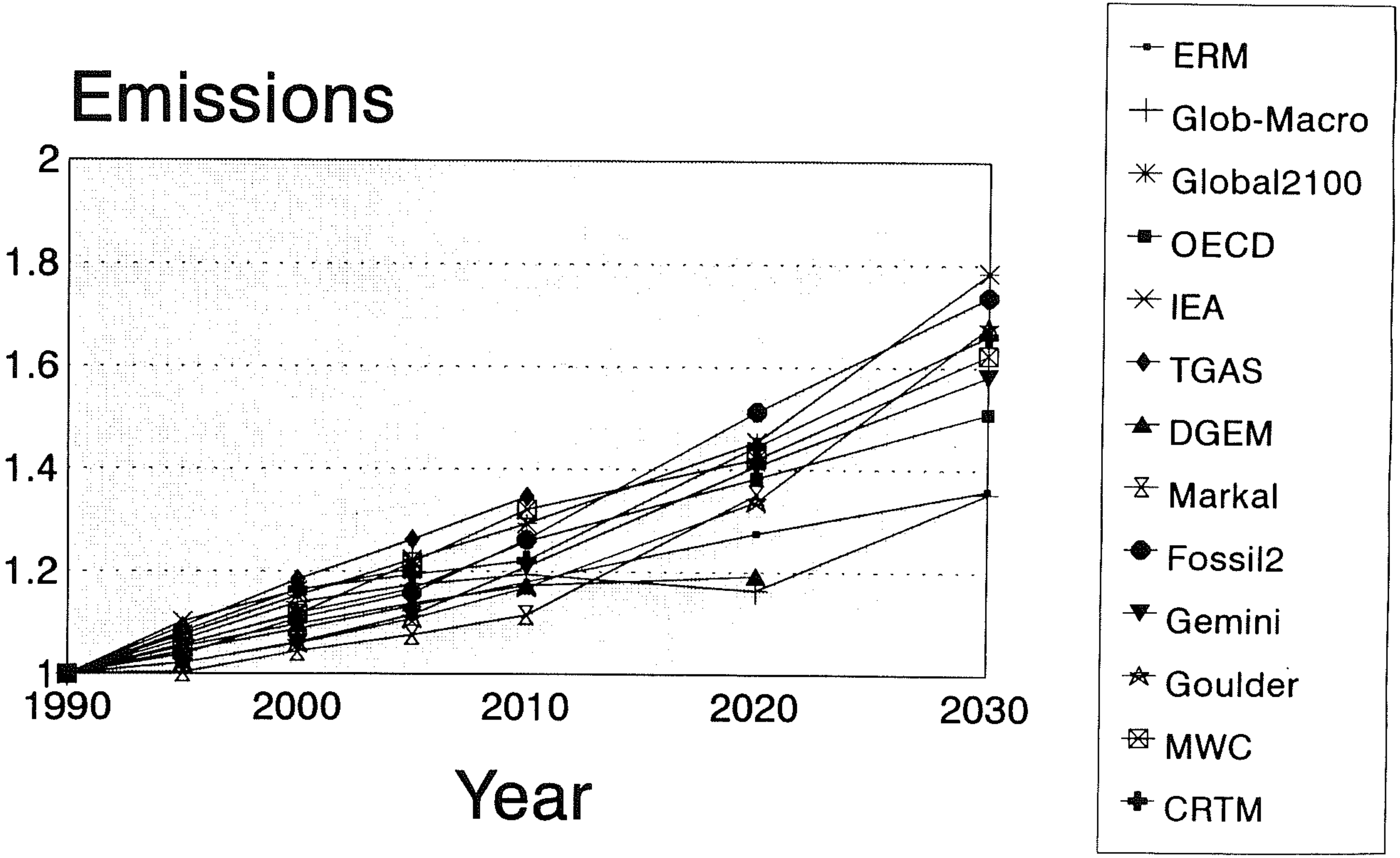
Other OECD Emissions



Former Soviet Union Emissions

China Emissions

U.S. Carbon Emissions
Indexed to 1990 = 1.0



Average annual growth rate between 1990 and 2010

Reference Scenario

	Fuel Switching	Energy Intensity	GDP	Total Effect (Carbon Emission)
Global 2100	0.25	-1.19	2.22	1.28
CRTM-RD	-0.13	-1.10	2.22	1.00
Edmonds/ Reilly	-0.32	-1.08	2.22	0.83
Fossil 2	0.12	-1.18	2.22	1.17
Gemini	-0.03	-1.24	2.22	0.95
TGAS	1.18	-1.92	2.22	1.49
US Markal	-0.20	-1.48	2.22	0.54
Global-Macro	-0.15	-1.19	2.22	0.89
GREEN	-0.17	-0.91	2.22	1.15

Average annual growth rate between 1990 and 2010

Stabilized by 2000 Scenario

	Fuel Switching	Energy Intensity	GDP	Total Effect (Carbon Emission)	Carbon Tax (In 2010)	Average Carbon Tax *
Global 2100	-0.61	-1.84	2.19	-0.26	83	120
CRTM-RD	-0.50	-1.71	2.21	0.00	92	160
Edmonds/ Reilly	-0.79	-1.41	2.20	0.00	61	60
Fossil 2	-0.25	-2.00	2.22	-0.03	61	77
Gemini	-0.75	-1.52	2.22	-0.05	156	104
TGAS	-0.10	-2.15	2.22	-0.02	360	-
US Markal	-0.29	-1.48	2.22	0.45	-	-
Global-Macro	-0.20	-1.97	2.22	0.06	25	16
GREEN	-0.31	-1.91	2.22	0.00	54	48

*Average of 2000 and 2020