USING ENERGY-ECONOMIC-ENVIRONMENTAL MODELS IN THE CLIMATE CHANGE POLICY PROCESS

by

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Abstract

In recent years, the political debate over climate change has centered primarily on the credibility of computer models which are designed to represent the planet's ecosystem. In contrast, models which attempt to account for long-term interactions between the energy sector, the economy, and the environment on a global scale have received considerably less attention. However, these energy-economic-environmental models are used to generate emissions scenarios which drive the scientific models.

This thesis takes a close look at how energy-economic-environmental models and their results have been used in the climate change policy process. It asks two key questions: What is the proper role of these models and their results in the policy process? And how can uncertainty be factored into both their analysis and the presentation of their results in a meaningful manner? In answering these questions the thesis critiques 12 studies which used energy-economic-environmental models, and draws on the results of 14 interviews with participants in Intergovernmental Panel on Climate Change.

Finally, the thesis uses the Edmonds-Reilly model to demonstrate an alternative approach for using energy-economic-environmental models called probabilistic scenario analysis. This approach can be used to explore the effectiveness of various policy options in the context of uncertainty.

Thesis Supervisor: Professor Henry Jacoby
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1. Introduction

Problem Statement

In recent years, the political debate over climate change has centered primarily on the credibility of computer models which are designed to represent the planet's ecosystem. Typically, these models are used to predict changes in global climate and sea level based on emission scenarios of future greenhouse gases (GHGs). Both scientists and policymakers have intensely scrutinized these models.

In contrast, models which attempt to account for long-term interactions between the energy sector, the economy, and the environment on a global scale have received considerably less attention. This is unfortunate because these models are used to generate results (i.e., emissions scenarios) which drive the scientific models. However, in comparison to scientific models which are used to predict climate change, socioeconomic models which are used to produce long-term projections of future GHG emissions are in their infancy.

This thesis takes a close look at how energy-economic-environmental models and their results have been used in the climate change policy process. It asks two key questions: What is the proper role of these models and their results in the policy process? And how can uncertainty be factored into both their analysis and the presentation of their results in a meaningful manner?

In answering these questions the thesis critiques 12 studies which used energy-economic-environmental models, and draws on the results of 14 interviews with participants in the United Nations Intergovernmental Panel on Climate Change. It finds that analysts have developed two main approaches for using energy-economic-environmental models.

The first approach focuses on the effects of potential policy intervention on a "best guess", "base case" or "business as usual" scenario. Such scenarios are usually designed as internally consistent plausible future paths; they are not forecasts. However, in the policy process these scenarios have often been interpreted as forecasts of the future under various levels of policy responses to climate change.

The second approach focuses on the inherent uncertainty in forecasting future energy use and GHG emissions. This approach acknowledges that uncertainty in long-term energy-economic-environmental modeling is more fundamental than simply lacking detailed knowledge about future values of various model parameters. In essence, it tries to be honest about the limited predictive capabilities of models of socioeconomic systems.

In terms of being able to provide useful information to the climate change policy process, both of these approaches to scenario analysis are inadequate. The first approach neglects the inherent uncertainty in a model's structure and parameters which drive a model, while the second approach does not explore how policies might effect the future. The real question that energy-economic-environmental models should be used to answer, is not how a particular set of policies will effect a specific future, but how they will effect a range of possible futures.

This thesis demonstrates how an approach for using energy-economic-environmental models, called probabilistic scenario analysis, can be used to investigate the effectiveness of various policy options in the context of uncertainty. It offers both analysts and policymakers an opportunity to move away from arguing about which scenario is the "right" best guess scenario, and towards a discussion of which strategies are effective across an wide range of possible futures.

A Look Ahead

The body of this thesis begins in Chapter 2 with a discussion of eight features of climate change which define it as a policy issue: (1) it epitomizes the idea that we live in an interdependent world, (2) involves interactions between two very complex systems, (3) includes a great deal of uncertainty, (4) is global in nature, (5) is very long-term, (6) is highly dependent on science, (7) involves issues of equity, and (8) has potentially catastrophic effects. Each of these features significantly influences different stages of the climate change policy process.

Then, Chapter 3 explores how energy models have been used in general for planning and policy purposes in the past. In particular it examines the use of energy models for learning and forecasting, and provides a historical background for understanding how energy models have been used in the climate change policy process.

Next, Chapter 4 focuses on how a particular global energy-economic model, the Edmonds-Reilly model, has been used in the climate change policy process for both learning and forecasting. It reviews the results of seven studies which used the model to study global CO_2 emissions and/or climate change. It also looks at how the Edmonds-Reilly model has been integrated into a larger modeling framework called the Atmospheric Stabilization Framework (ASF), and reviews two recent studies which used the ASF.

Chapter 5 looks at how emissions scenarios, generated using the ASF, were used by the United Nations Intergovernmental Panel on Climate Change (IPCC). In particular it discusses how the scenarios were specified, what roles models played in developing the scenarios, and how the scenarios were interpreted by participants in the IPCC process. It draws on the results of interviews conducted with 14 participants in the IPCC process.

Chapter 6 uses the Edmonds-Reilly model to demonstrate an alternative approach for using energy-economic-environmental models in the climate change policy process. This approach—probabilistic scenario analysis—can be used to explore the effects of policies in the context of uncertainty. The chapter both describes the methodology used and discusses the results of six probabilistic policy experiments.

Finally, Chapter 7 draws some conclusions about the efficacy of using a probabilistic approach for energy-economic-environmental modeling in the climate change policy process. The chapter also includes recommendations for future research.

2. Climate Change: Understanding the Policy Process

This chapter is intended to provide background information on the climate change policy process. In the chapter I discuss eight features of climate change which define it as a policy issue. The eight features are:

- it epitomizes the idea that we live in an interdependent world,
- involves interactions between two very complex systems,
- includes a great deal of uncertainty,
- is global in nature,
- is very long-term,
- is highly dependent on science,
- involves issues of equity, and
- has potentially catastrophic effects.

Each of these features significantly influences the policy process and will be discussed individually.

Interdependence

Climate change epitomizes the idea that we live in a highly interdependent world both because it is intimately linked to interactions between very diverse human activities and the natural environment, and because it illustrates that a number of global environmental problems are closely contingent upon each other. For example, climate change, stratospheric ozone depletion and acid deposition are tied together by many of the same chemical species, by common human activities that generate them, and by the ability of each of these phenomena to influence the timing and severity of the others (Mathews 1987, 61). Furthermore, the radiatively important or so called greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_x), and chlorofluorocarbons (CFCs) are generated by numerous human activities. These include burning fossil fuels, agricultural activities, industrial processes, and changes in land use patterns.

As Skolnikoff puts it, "the buildup of greenhouse gases is. . . a product of innumerable independent decisions by individuals, industries, and governments in daily life all over the globe" (Skolnikoff 1990, 81).

The fact that a wide range of human activities produce GHGs has motivated a number of countries, led by the U.S., to advocate using a "comprehensive strategy" for reducing GHG emissions. For example, at the Intergovernmental Negotiating Committee's (INC's) second meeting in June 1991, the U.S. State Department delegation asserted that a framework convention on climate change should be "comprehensive." That is, in order to be most effective environmentally and economically, strategies to understand and address climate change should encompass all the GHGs, their sources and sinks (Reinstein 1991). Advocates of a comprehensive approach want to avoid a situation where actions taken to reduce emissions of a controlled GHG might actually increase emissions of an uncontrolled gas. This concern is also linked to other issues such as controlling substances that deplete stratospheric ozone. For example, under the Montreal Protocol, CFCs and halons are regulated as if they are independent from other environmental issues; however, it has been argued that using certain CFC substitutes requires more energy, thus producing more carbon dioxide and other pollutants (Zimmerman 1991, 5-6).

The interdependent nature of climate change can be viewed as being both a positive and negative feature from the standpoint of the policy process. Interdependence can be a positive characteristic because it provides governments with a great deal of flexibility in choosing policy responses to meet stated goals; however, it can be a negative characteristic because actions proposed to limit climate change will affect and thus mobilize a very diverse set of political interests—this will complicate the policy process both within governments and international organizations.

Two Complex Systems

There are two complex systems interacting in climate change: the planet's ecosystem and the human socioeconomic system. As Skolnikoff points out the most obvious consequence of the interaction of these two systems is that policy responses will need to be sustained over a very long time horizon (Skolnikoff 1990, 82). In addition, even with a concerted global effort to prevent climate change it will still be difficult to overcome the momentum in the system. This means that, due to past emissions of GHGs, we may have already committed ourselves to experiencing some climatic change. Policy responses may reduce the magnitude or delay the timing of climate change. Yet, because of the momentum in the system, if we postpone taking action today we will increase the magnitude of change and extend the effects of change further into the future (Mintzer 1987).

The fact that these two complex systems are interacting is central to understanding the climate change policy process. In the past it has traditionally been the role of physical scientists to study the planet's ecosystem, and the role of social scientists to study the human socioeconomic system. It is now becoming clear that in order to understand how these two systems influence each other a dialogue needs to be opened up between the two groups. This will be a difficult task. For example, Brown summarizes the differences in intellectual frameworks between ecologists and economists as follows:

> Economists interpret and analyze trends in terms of savings, investment, and growth. They are guided largely by economic theory and indicators, seeing the future more or less as an

> extrapolation of the recent past. From their vantage point, there is little reason to worry about natural constraints on human economic activity . . . [On the other hand,] Ecologists think in terms of closed cycles—the hydrological cycle, the carbon cycle, and the nitrogen cycle, to name a few. For them, all growth processes are limited, confined within the natural parameters of the earth's ecosystem. They see more clearly than others the damage to natural systems and resources from expanding economic activity (Brown, et al. 1991, 5).

It is not surprising that economists and ecologists often have difficulty talking with each other. Yet both perspectives are playing important roles in the climate change policy process. Economists have argued that policy intervention will result in a significant loss of much needed economic growth, while ecologists have argued that the single-minded pursuit of economic growth will eventually lead to both environmental and economic collapse. What is crucial to the policy process is not which side is right, but that we need to understand how the planet's ecosystem and the human socioeconomic system are interacting.

This issue is brought to center stage when trying to use models to inform the climate change policy process. Typically, emissions scenarios are generated using models of the socioeconomic system and then these emissions scenarios are fed into models of the climate system. The potential influences of climatic changes on the socioeconomic system are often ignored in the modeling process. The need to link models in a more meaningful manner will be discussed further in chapter 4.

Uncertainty

A key characteristic of climate change is the importance of uncertainty. This is true for both our understanding of the planet's ecosystem and the human socioeconomic system. As Lave describes, in order to form climate change policy we need to ask a number of fundamental questions about uncertainty: What is the uncertainty concerning emissions, atmospheric accumulation, resulting climate change, and effects of climate change on managed and unmanaged systems (Lave 1988, 461)? The IPCC's Science Report presents a frank and honest discussion of where the uncertainties on the science side arise from (IPCC 1990b). The report is careful to point out that much of the scientific uncertainty, in climate projections, is related to feedbacks in the climate system: there are more than 20 known feedbacks in the system. Because of limited understanding of many of these feedbacks only a minority of them are included in the models which the scientific community uses to predict the magnitude and speed of climate change; however, it is important to note that in the context of uncertainty the IPCC scientists concluded that:

> It appears that, as climate warms, these feedbacks will lead to an overall increase, rather that decrease, in natural greenhouse gas abundances. For this reason, climate change is likely to be greater than the estimates we have given (IPCC 1990b, xxvii).

Thus while acknowledging that there is a great deal of scientific uncertainty about the details of potential climate change, the IPCC Science Report makes a number of strong, while somewhat qualified, assertions about the likelihood of climate change.

In addition to uncertainty on the scientific side, there is a great deal of uncertainty about how socioeconomic systems will evolve over time and how effective various policies will be at reducing GHG emissions. For example, future emissions of GHGs will be determined by complex interactions between economic development, population growth, land use patterns, technology development and many other factors. Compared to the scientific models which are used to predict climate change from a given GHG

Figure 2-1: Stone's Framework for Describing Causal Stories

	Consequences	
Actions	Intended	Unintended
Unguided	Mechanical Cause	Accidental Cause
Guided	Intentional Cause	Inadvertent Cause

Source: Stone 1989, 285

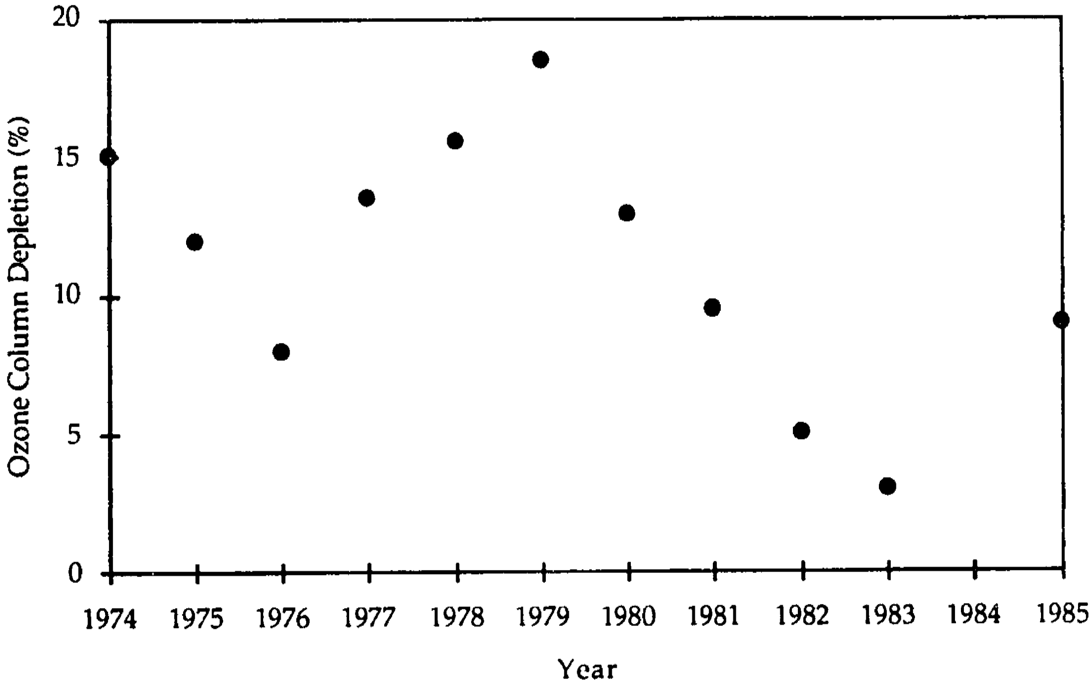
emission scenario, the socioeconomic models which are used to project future GHG emissions are in their infancy. How to incorporate uncertainty in analyses using models of the socioeconomic system will be discussed in greater detail in chapter 6.

The level of uncertainty in our understanding of climate change makes the policy process much more difficult. This is largely due to uncertainty in the consequences of and actions leading to climate change. As Stone describes, in order to move an issue onto the policy agenda, it is very useful to be able to construct a convincing "causal story." Yet, it is difficult to form causal stories when it is unclear whether actions are purposeful or unguided, and whether consequences are intended or unintended (Stone 1989). As shown in Figure 2-1, Stone developed a framework for describing causal stories commonly used in policy arguments.

Traditionally climate has been interpreted as being both unintended and unguided and thus outside of the normal bounds of policy intervention. However, if political actors can build a convincing causal story showing that climate change is both caused by purposeful human actions and results in foreseeable consequences, then climate change will no longer be seen as being accidental. Instead it will be viewed as being controllable and thus within the normal bounds of policy intervention. As Stone puts it, "A bad condition does not become a problem until people see it as amenable to human control" (Stone 1989, 299). Since there is still a great deal of uncertainty about both the causes and effects of climate change it is not surprising that there are currently individuals who are both trying to build and deny causal stories. Thus, as a result of the differences in understanding about uncertainty, we see that on one side there are those who want to delay action until we have a better understanding of the science, impacts, and effectiveness of policy options, while on the other side there are those who want to take action now as a sort of insurance policy against potentially catastrophic consequences.

In terms of the climate change policy process we need to realize that policy is often made within the context of a great deal of uncertainty. The most recent and relevant example is the Montreal Protocol on substances that deplete stratospheric ozone. The Montreal Protocol was negotiated in the context of uncertain and changing predictions of ozone depletion due to CFCs. As shown in figure 2-2, model projections of ozone depletion without policy intervention, 50 to 100 years in the future, went from about 15 percent in 1974, to around 8 percent in 1976, up to almost 19 percent in 1979, then dropped steadily to slightly above 3 percent by 1983, and rose to around 10 percent by 1985 (Benedick 1991, 13). What we learn from the process leading up to and following the signing of the Montreal Protocol is that the policy process, in a global environmental context, can move forward while acknowledging that there is a great deal uncertainty remaining. But in order

Figure 2-2: Various Predictions of Ozone Layer Depletion, 1974-1985



Source: Benedick 1991, 13

to do this, the process must be flexible: It should lead to agreements which can be modified in response to changes in scientific understanding.

Global Nature

The global nature of climate change extends from its causes and effects to the actions and policies which may be required to prevent it. It is truly a global issue. Currently the industrialized countries produce approximately 60% of global GHG emissions; however, according to EPA estimates it is likely that the less developed countries (LDCs) will be producing between 50-60% of global GHG emissions by the middle of the 21st century (EPA 1989, 40).

Clearly, no country can prevent climate change on its own, and the actions of one country or region can be negated if others fail to act.

Essentially climate change is equivalent to a global version of the process described in Hardin's essay, "The Tragedy of the Commons:"

> The rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them. Since this is true for everyone, we are locked into a system of 'fouling our own nest,' so long as we behave only as independent, rational, free-enterprisers (Hardin 1968, 1245).

In terms of climate change we can think of the atmosphere as being a global commons. Historically the atmosphere has been treated as a free and infinite resource. Thus it has been exploited by all without recognition of the possibility of ultimate degradation, or of the access rights of different parties. Now humanity is faced with the realization that the atmosphere is both a valuable and limited resource, and that a portion of the reservoir has already been used up (Grubb 1989, 22).

The global nature of climate change presents significant obstacles to the policy process. For example, in trying to implement policies on a global scale to respond to climate change, there are a range of issues related to national sovereignty that will arise. As Mathews describes, in order to be effective international agreements will require provisions for monitoring, enforcement and compensation, even when damages cannot be assigned a precise monetary value. These are all areas where international law has been weak in the past (Mathews 1989, 176). Thus, in order for climate change policies to be effective the international legal system will need to be strengthened. In essence, if nations want to control emissions of GHGs on a global scale, individual countries will have to be willing to give up some of their national sovereignty.

Long-term

In addition to being global in nature the effects of climate change will take place over a very long time scale. Its near-term effects are undetectable and its potentially significant effects on humans and natural systems, and their well being, may not be felt until the middle of the next century. As the Brundtland Commission pointed out, "Most of today's decision makers will be dead before the planet feels the heavier effects of acid precipitation, global warming, ozone depletion, or widespread desertification and species loss" (World Commission on Environment and Development 1987, 8). The long-term nature of climate change strongly influences the ways in which policymakers think about the issue.

In terms of the policy process, the long-term nature of climate change means that dealing with it will take an unusual degree of political will. One area that will be especially challenging is policy evaluation. As Salamon points out, a convention has evolved in policy evaluation which implicitly assumes that the passage of time affects all types of policy responses in roughly the same way (Salamon 1979, 134). After examining the effects of policy evaluation on the New Deal land-reform experiments, Salamon concluded that we need to acknowledge the importance of the time dimension in policy evaluation. This lesson is important for the climate change policy process: The programs which are least likely to show results in the period normally allotted for policy evaluations are those aimed at bringing about structural changes in social conditions or relationships.

Policy evaluations related to climate change need to explicitly address the long-term nature of the problem. If policy evaluations fail to look at the long-term effects of policy responses then they:

> . . . can unwittingly become a handmaiden of the status quo, systematically discrediting precisely those initiatives which hold the greatest promise of long-term impacts on basic societal processes, and distorting priorities toward those with immediate—though ephemeral—pay-offs (Salamon 1979, 180).

Thus, appreciating the long-term nature of climate change is important for both conducting and interpreting policy evaluations related to climate change policy initiatives.

The long-term nature of the issue also makes transforming the problem into policy concerns more difficult. This is especially true on the socioeconomic side. For example, in order to be able to determine the effectiveness of various policies it would be useful to agree on a base case projection of GHG emissions. Since, energy use is the single largest anthropogenic source of GHGs (IPCC 1991, xxix), producing a base case projection of GHG emissions inevitably involves using long-term energy-economic-environmental models. This was the path used by the IPCC to produce its "business as usual" emissions scenario (IPCC 1991). How emissions scenarios were generated and used in the IPCC process will be discussed in greater detail in chapter 5.

What is often overlooked in the modeling process, are the limitations of long-term energy models. For example, technological change is very difficult to model since future technological changes are inherently unknown (Zimmerman 1990, 10). Landsberg, commenting on long-term energy modeling, states it bluntly:

> All of us who have engaged in projecting into the more distant future take ourselves too seriously. . . What is least considered is how many profound turns in the road one would have missed making 1980 projections in 1930? I am not contending that the emperor is naked, but we surely overdress him (Landsberg 1982, 366).

Because of the long-term nature of the issue and complexity of the systems involved, climate change models inevitably include many simplifying assumptions. Models do provide a way of interpreting the world, yet it is important to use them and their results with caution. This issue will be discussed further in chapter 3, when exploring the use of models for learning vs. forecasting.

Another issue that arises from the long-term nature of climate change has to do with what Downs has called the "issue-attention cycle." Downs observes that public attention focuses on particular topics with a cyclical nature. He describes five stages of the issue-attention cycle: the pre-problem stage, alarmed discovery and euphoric enthusiasm, realizing the cost of significant progress, gradual decline of intense public interest, and the post problem stage (Downs 1972). In order for an issue to avoid going through the cycle, media needs to keep public attention focused on it. It is difficult enough to do this on a national level for a couple of years. The long-term nature of climate change means that, in order to avoid going through the issue-attention cycle, global media attention will need to be focused for tens, perhaps hundreds, of years. Unless there is a very dramatic and swift change in climate it will be very difficult to keep global media attention focused on the issue.

Finally, the long-term nature of climate change may lead to "solving" the problem through re-definition. Wildavsky points out that, "It could be asserted that most problems are solved by redefinition—substituting a puzzle that can be solved for a problem that cannot" (Wildavsky 1979, 57). In terms of climate change there are currently three dominant views on how the policy problem should be defined: more study, adaptation, and prevention. Over time as the debate continues it may become clear that prevention is not a realistic objective—it may have political, social or economic costs which are prohibitive, or policy responses might be delayed until the system is already committed to significant climate change. If this is true then those who currently believe that climate change policy responses should be defined in terms of prevention, may eventually redefine their positions in terms of adaptation.

Dependent on Science

Without modern science and technology, the world would have remained unaware of the potential threat of climate change. This is also true for stratospheric ozone depletion. In fact, scientific understanding was the driving force behind ozone policy: the formation of a commonly accepted body of data and analysis, and the narrowing of ranges of uncertainty were prerequisites to a political solution among the negotiating parties of the Montreal Protocol (Benedick 1991). The policy process with respect to climate change is likewise highly dependent on science.

Yet scientific facts do not exist independent of interpretive lenses: It is the scientist who chooses which questions to ask, what data to collect, how to analyze and interpret the data, and finally how to present the results. Each of these steps involves making value judgments. For example even naming a phenomenon—i.e. climate change vs. global warming—places it in a class and suggests that it is similar to some and different from other phenomenon. While the term global warming conveys images that the world will be a warmer place, climate change is usually intended to imply that in addition to being warmer there will also be greater variability in climate.

Another significant point is that a scientist trained within a given paradigm will tend to frame a research question in a manner that reflects her or his school of thought (Ozawa 1985, 29). Skolnikoff describes this for the climate science community:

> Many scientists would also admit to a considerable degree of incestuousness within the community: Common paradigms are reinforced though intensive interactions among a small group of researchers (Skolnikoff 1990, 86).

In this context, scientists must work closely with policymakers and have to assume responsibility for relating the implications of their findings to alternative response strategies.

In addition, science will play an important role in the evaluation of policies implemented to prevent climate change. Scientists will be responsible for monitoring greenhouse gas emissions and their effects on the environment. Put simply, the climate change policy process is and will continue to be heavily dependent on the scientific community for basic information. This is true for each stage in the policy process: social construction, transformation into policy concerns, establishment of conflicting interests, implementation, and evaluation.

Equity

The issue of equity between developed countries and less developed countries[1] is very significant to the climate change policy process. This was also an important issue in negotiations related to ozone depletion (Benedick 1991). Basically, less developed countries (LDCs) point out that the developed countries have benefited from using the atmosphere as a sink for their GHG emissions for over a century. Now when the LDCs want to improve their economic standing, the developed countries propose to put limits on the use of that shared resource, the atmosphere. In some ways this leads the LDCs to

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[1] This is also often referred to as the distinction between: north/south, rich/poor.

be wary of, if not outright resistant to, efforts by the developed countries to limit GHG emissions.

On the other hand, if no action is taken to limit GHG emissions, it is likely that a significant amount of climate change will occur. Since, as Mathews point out, adapting to climate change requires strong research capabilities, heavy capital investment, and a government that can mobilize and direct its resources, it will be very difficult for LDCs to adapt to climatic changes. Thus an "adaptionist" approach is likely to leave the LDCs worse off relative to the developed countries than they are now (Mathews 1987, 65).

Part of what makes the equity issue so important to the climate change policy process has to do with the distribution of perceived costs and benefits. Wilson devised a scheme that relates the effects of "costs" and "benefits" to political mobilization (Wilson 1974). In this scheme he uses the terms "concentrated" and "diffused" to describe the intensity of the effects of a policy. In Wilson's scheme diffusion of effects, whether cost or benefits, inhibits organization, while concentration encourages it.

In terms of climate change, various countries have different perceptions about what the cost and benefits of climate change policy responses would be. For example, during INC negotiations on a framework convention on climate change many countries have emphasized the special vulnerability of low-lying areas and small island countries to the effects of climate change. Essentially, small island countries perceive that their physical and cultural survival is threatened by climate change, from both sea level rise and coral bleaching (Intergovernmental Negotiating Committee 1991). Using Wilson's scheme, small island countries would view climate change policy responses as having very concentrated benefits and diffused costs, thus it would make sense that they have organized. Contrastingly, many developed countries perceive that they will be required to bear the majority of the cost of preventing climate change and thus have organized to ensure that all countries will have responsibilities and obligations under a framework convention on climate change (Reinstein 1991). What will have a large impact on the policy process is how the perception of costs and benefits changes over time. Quoting Wilson:

> Not everyone will agree on the distribution of costs and benefits, opinions about any particular distribution will change over time, and occasionally beliefs can be made to change by skillful political advocacy (Wilson 1974, 139).

Thus we can expect countries to continue to modify their positions based on changing perceptions of the costs and benefits of climate change policy intervention.

One way of dealing with the issue of equity is to include mechanisms for technology cooperation between developed and less developed countries in agreements related to climate change.[2] Discussing mechanisms to encourage technology cooperation has been an important part of the INC negotiations. For example during its first session:

> Many countries emphasized the importance of technical co-operation in the fields of training, public awareness and information exchange relevant to the preparation and implementation of a framework convention and to the development of national policies in the field of climate change (Intergovernmental Negotiating Committee 1991, 15).

Technology cooperation will be an important tool for reducing tension between developed and less developed countries. Before signing an agreement, less developed countries need to believe that they will receive

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[2] "Technology cooperation" is intended to imply a cooperative or reciprocal relationship between developed and less developed countries. Thus it is similar to but significantly different from "technology transfer" which implies a relationship between developed and less developed countries where information and technology flow in only one direction (from developed to less developed countries).

sufficient financial and technical help to be able to meet their obligations. On the other hand, developed countries believe that commitments to action and financial resources must be linked, and that the costs associated with action must be quantified before expenditure of resources can be justified (Reinstein 1991).

Potentially Catastrophic

Since the climate system is a very large system, with many feedbacks and non-linear relationships, there is a real possibility that the system could be forced into an unstable domain. If this were to happen, the speed and magnitude of the resulting climatic change could pose profound threats to ecosystems and a real threat to the very future of human civilization. Leggett outlines how this could happen by developing a worst-case scenario involving the 'likely' dominance of amplifying feedbacks in a warming world (Leggett 1991, 171). Such a scenario could lead to serious consequences, including: widespread coastal flooding as a result of rising sea levels, significant declines in agricultural productivity linked to changing rainfall patterns and increased soil erosion, more frequent and severe hurricanes and other storms, increased extinction of many plant and animal species, and the creation of millions of environmental refugees (Benedick 1991, 200). The potentially catastrophic effects of this sort of scenario are difficult, but not impossible, to factor into the policy process.

Lave draws an analogy between policy responses to prevent climate change and building containment vessels around a nuclear reactor. He points out that in the United States strong containment vessels were built around civilian nuclear reactors at the insistence of regulators, even though they regarded the chance of a disaster occurring which would require the containment vessel as being very remote. Contrastingly, in the USSR such safeguards were not required. As a result of these different policies there was a dramatic difference between the problem at Three Mile Island and the tragedy at Chernobyl (Lave 1988, 464). In a sense one could think of policies aimed at preventing potentially catastrophic effects of climate change as a form of insurance similar to the insurance provided by containment vessels built around nuclear reactors. This issue will be discussed in greater detail in chapter 6.

In Summary

Each of the eight features of climate change described above significantly influences different stages of the policy process. Understanding how they influence the different stages of the process—social construction, transformation into policy concerns, establishment of conflicting interest, implementation, and evaluation—provides a great deal of insight into the climate change policy process itself.

In the following chapters the focus of discussion will be on using energy, economic, environmental models in the climate change policy process. During this discussion it will be useful to keep in mind the eight features of climate change discussed above.

3. Using Energy Models: Forecasting vs. Learning

There are a number of sources of greenhouse gas (GHG) emissions including the burning of fossil fuels, agricultural activities, industrial processes, and changes in land use patterns. However, of all the sources of GHG's, the production and use of energy is currently the largest anthropogenic source of GHG emissions. Subsequently energy production and use is the most prominent contributer to increased radiative forcing. In fact, the Intergovernmental Panel on Climate Change (IPCC) estimated that energy production and use was responsible for between 38 and 54 percent of the total change in radiative forcing due to human activities during the 1980's (IPCC 1991, xxx).

Without the implementation of policies aimed at reducing GHG emissions from the energy sector it is likely that energy will remain the major source of human induced radiative forcing throughout the 21st century. Thus it is not surprising that energy models have played an important role in the climate change policy process. However, before discussing the use of energy models specifically in the climate change policy process, it would be useful to talk about how energy models have been used in general for planning and policy purposes in the past. This chapter provides that historical background on energy models. In particular it explores the use of energy models for forecasting and learning.

Historically, energy models have been used primarily to generate forecasts. However, since the 1973 oil crisis there has been a growing realization that energy forecasts (especially long-term energy forecasts) are unreliable. This is largely due to the occurrence of major surprises such as: the 1973-4 oil crisis, the 1979 oil price shocks, changing environmental regulations, changing public attitudes toward nuclear power (caused by the Three-Mile incident in 1979 and Chernobyl in 1986), Washington Public Power Supply System's bond default in 1983, very volatile fuel prices and interest rates, growth in small power producers, etc. Because all of these "surprises" occurred after the 1973 oil crisis, 1973 marks a critical year in the history of energy forecasting.

Before 1973, analysts based their forecasts on the expectation that the future would continue to be stable like the past. At the time this seemed like a reasonable assumption given past experience. However, it led to gross overestimations of future energy demand during the 70's and 80's. Given the experience of the past two decades we need to acknowledge that models can not be used to forecast future energy demand accurately. This stems from the fact that energy systems are very complex and interdependent; further, there is a great deal of uncertainty about how future economic, demographic, technological, and institutional factors will evolve over time. A continued heavy reliance on energy forecasts for planning purposes could lead to unwise policy/planning decisions leading to unnecessary environmental degradation and/or cost to society.

An alternative to using models for forecasting is to use models for learning. As Hanson points out learning conveys a notion of gaining insight into the behavior of the systems being observed (Hanson 1986, 51). Instead of trying to predict the future (by generating a single line forecast), modeling for understanding is aimed at helping participants in the policy process learn about how different components of the overall system interact with each other, gain insight into the limitations of the model itself, identify important uncertainties, and evaluate possible options.

Developing a range of scenarios which incorporate uncertainty is one possible path to using models for learning. However, when using a set of scenarios in the policy process it is important to resist the temptation to focus on a best guess, base case, or median scenario. The energy modeling process itself can help analysts gain a great deal of insight. Yet, using energy models for learning involves transmitting the insights gained during the modeling process into the policy process. This is a difficult task.

The body of this chapter is divided into three main sections. I begin with a general discussion of models and forecasting. This background information is intended to provide the reader with a basic understanding of how models of complex socioeconomic systems (for example energy systems) have limited forecasting capabilities. Second, I discuss both pre- and post-1973 energy forecasting. This section explores how the turbulence of the past two decades led to three innovative approaches to energy modeling/forecasting. These include the development of mega-model's, scenario analysis, and backcasting techniques. Finally, I discuss what we can learn from past energy modeling/forecasting experiences, and how we can begin to move towards using models for learning instead of forecasting.

Models In General

Interest in models stems primarily from our desire to be able to (1) anticipate and prepare for future situations, and (2) to make the world seem simpler and more understandable (Denning 1990, 496). Thus in order to meet various planning/policy needs many different types of models have been developed varying in complexity from simple accounting schemes to sophisticated programs aimed at representing behavioral functions involving intricate feedback mechanisms (Keepin et al. 1986, 57). It is not surprising that a range of perspectives on models have arisen.

For example, one perspective views models as simply being one approach of representing a set of objects, their relationships and their allowable motions. Advocates of this view would argue that models can be used in three principle ways: (1) to describe how a system works, (2) to compute measurements in a given domain, and (3) to predict the future state of a system with a tolerable level of certainty (Denning 1990, 496). This perspective stems from a Newtonian mechanics view of the world. Denning describes it succinctly:

> We have all been brought up in a scientific world view, conditioned by 300 years of successful physics modeling, dating from the time of Newton, which inclines us to believe that all the world's a mechanism, a clock that God created and left ticking. We tend to believe that everything, including the human brain, the human personality, and human social systems, can in principle be modeled by a set of equations (1990, 498).

A contrasting perspective views models as being a systematic codification of cognitive and social structures, developed by actors to promote their interests and/or world views (Baumgartner and Midttun 1987, 11). Advocates of this view would argue that models can be used to (1) aid rational decision making, (2) define reality and shape political debates, and (3) legitimize political decisions (Baumgartner and Midttun 1987, 21). From this perspective modelers may help to shape the future depending on how they present future possibilities and constraints.

The differences between these two perspectives stems primarily from very different conceptions about the relationship between modelers and the systems they model. The first perspective views modelers as neutral observers who do not influence the objects they are observing, while the second perspective views modelers as political actors who both observe and help to shape the systems they are observing. When dealing with energy models which are designed to provide information for policy debates and/or planning purposes it is useful to keep both perspectives in mind.

Models vs. Reality

It is important to distinguish between models and reality. In terms of energy systems this is significant because energy models at the regional, national and global scale inevitably contain many simplifying assumptions. Typically these include: omission of important factors in the real system, approximations of relationships which are not well understood, extending past relationships into the future, and others. Model builders and/or users need to be careful not to persuade themselves that a model's simplifying assumptions are of no consequence or that a specific model contains a complete representation of the real world. Also, when using energy models we need to keep in mind that the intended use of a model, the type of system being modeled, and the model builder's perspective, all have a large influence on a model's structure. For example, as Keepin et al. point out:

> In global energy forecasting, one researcher may be interested in the future role of nuclear power while another may focus on the interactions between the industrialized countries and the Third World. Both researchers will produce global energy models, but the resulting models will be different (1986, 58).

The models will be different both qualitatively and quantitatively. While both models may be valid interpretations of reality, model builders and users should not confuse them with reality. As Denning points out we need to try to refrain from presenting model outputs as "facts" or accurate descriptions of the world, and to resist the temptation to substitute a model for reality and thus confuse our opinions, supported by a model, with "scientific facts" about the world (1990, 498).

Models and Forecasting

Models are often developed as part of an effort to gain insight into the complex and interdependent world in which we live. The process of model building can be a valuable learning experience for its participants; however, we should use complex models and model forecasts (especially over long time periods) with caution.

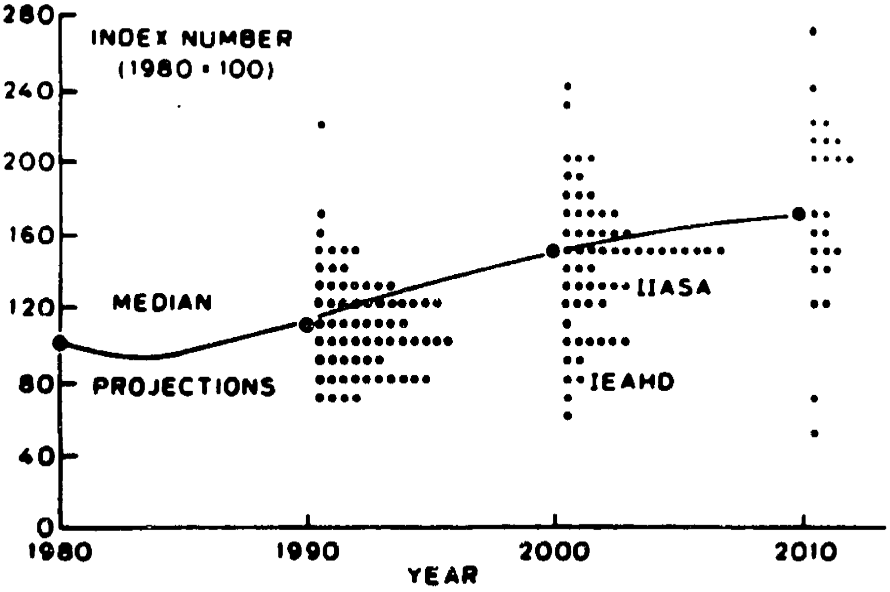
When using a model we need to determine the domains over which it is reliable. We also need to acknowledge that there are some phenomena which are too complex to model well enough for predictive purposes (Denning 1990, 498). In fact Denning, who is the director of the Research Institute for Advanced Computer Science at the NASA Ames Research Center, is very wary about using models of complex systems for predictive purposes:

> We need to ask ourselves whether our drive to model human complexities might not be an over extension of science, and whether our drive to use scientific models to solve world problems might not reflect the hubris of science (1990, 498).

Thus as the level of complexity of a system increases we should become more and more wary of model generated forecast.

In addition, we should be concerned about how far into the future a model is used to forecast. For example, models which are used to generate forecasts of future energy demand are typically very sensitive to assumptions about future demographic, economic, technological, and institutional factors. The values chosen for these types of factors are often based on projections of recent trends or on an analyst's judgment. As time scales increase, the

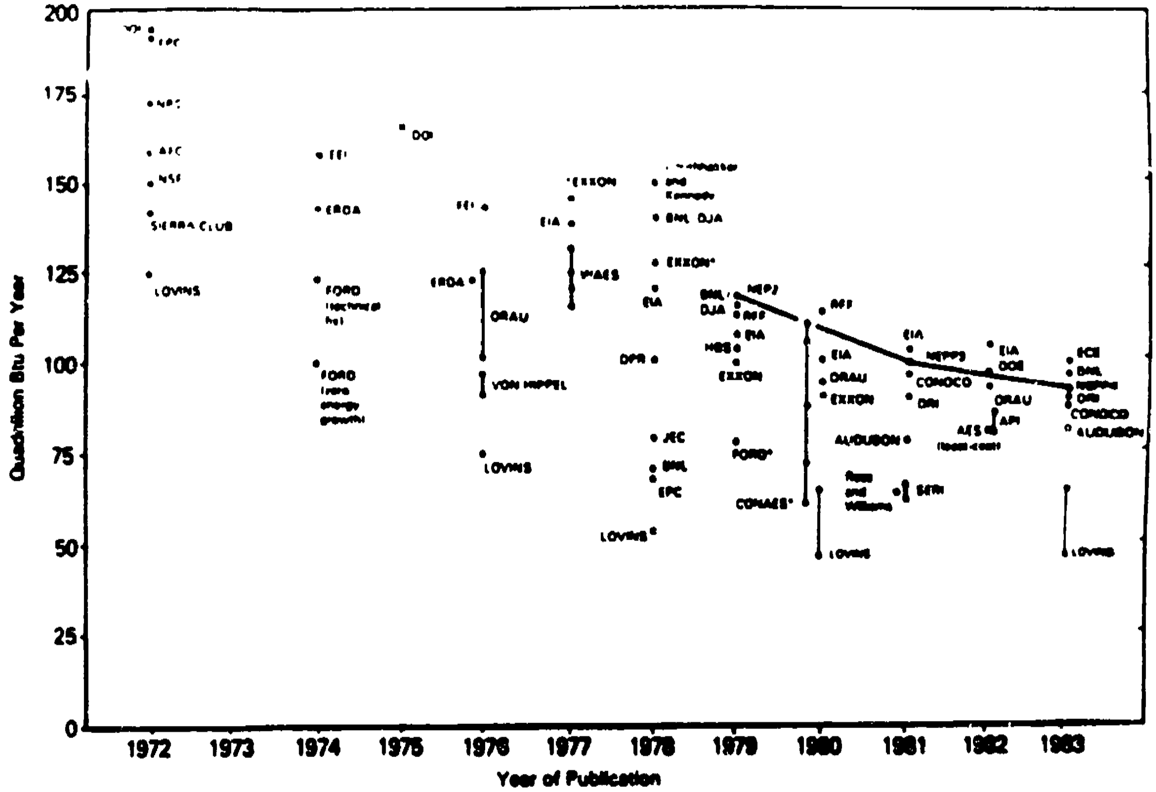
Figure 3-1: Projections of the International Price of Crude Oil (1980=1)



Source: Manne and Schrattenholzer 1984, 48.

importance of uncertainty in these factors increases, and thus the often unstated uncertainty in a model's results increases. For example, in 1983 Manne and Schrattenholzer conducted a survey of future international oil prices. They requested estimates of international oil prices from over 300 governmental and international agencies, corporations, individuals, research institutes, and universities. As shown in figure 3-1, they found that estimates of the international price of crude oil varied by a factor of three for the year 1990, by a factor of four for 2000, and by a factor of five for 2010 (Manne and Schrattenholzer 1984, 48). It is interesting that in constant dollars the international price of crude oil in 1990 was about half the 1980 price (British Petroleum 1991, 12). This is well below all of the estimates included in Manne and Schrattenholzer's study.

Figure 3-2: Projections of US Primary Energy Consumption for the Year 2000



Source: DOE 1983, 7-10.

At this point it should be clear that models of very complex socioeconomic systems have limited forecasting abilities. However, over the past 20 years, there has been a focus on developing more complex energy models which generate forecasts over longer periods of time. It is striking that during the 1970's and 1980's the trend in long-term energy forecasts has been monotonically down. For example, figure 3-2, shows forecasts made between 1972 and 1983 of U.S. primary energy for the year 2000 as a function of the year of publication of the forecasts. All of the projections made in 1983 are lower than the lowest projection made in 1972. In addition, Baumgartner and Midttun's book on the politics of energy forecasting (1987), shows that this downward trend in long-term energy forecasts has also occurred in West Germany, The Netherlands, Great Britain, Denmark, France, Norway, and Canada. What figure 3-2 and Baumgartner and Midttun's book show is that organizations with a vested interests in higher levels of energy use tend to generate higher forecasts, while those with an interests in lower levels of energy use tend to generate lower forecasts. Next I will discuss both pre- and post-1973 energy forecasting.

Energy Forecasting Pre-1973

Energy forecasting in the pre-1973 era basically consisted of using a simple "rule of thumb" to project past trends into the future. Weinberg describes this approach nicely:

> In those days [pre-1973], several energy analysts used as a rule of thumb that the number of quads [in the U.S.] equaled the last two digits of the calendar year—78 quads in 1978, 79 in 1979, and so on. However the reality turned out very differently. Who, in 1973, would have predicted that the total amount of energy used in 1986 would be only 74 quads, the same as in 1973? (1990, 212-3)

In retrospect, it is clear that this approach did not work well after entering a period of unpredictable energy markets. However, it was a reasonable approach to use given the previous experience of energy forecasters.

The pre-1973 experience is described in a thorough review of energy forecasts, in the United States, conducted by Ascher (1978). Ascher looked at the accuracy of forecasts going back from those made in the early 1970's to forecasts made in the 1950's for total energy consumption, the 1940's for electricity consumption and the 1930's for petroleum consumption. From his review of energy forecasts Ascher found that by the 1960's forecasters had learned to expect rapid growth in the future from the fact that rapid growth was occurring at that time. Thus they were steadily adjusting their projections upwards based on their expectations that energy use would continue to increase. They continued to extend these existing trends into the late 1960's and thus generated energy forecasts for 1975, the last year Ascher looked at, higher than the level reached in 1975 (Ascher 1978, 107). In other words, pre-1973 forecasters were basing their forecasts on the expectation that the future would continue to be stable like the past! But what does this tell us about energy forecasting? As Ascher put it:

> There is no question that forecasting energy demands in the face of volatile economic and energy supply conditions is a much more difficult task than forecasting for stable periods. . . circumstances involving a high degree of uncertainty, pose an important dilemma: the more uncertain the future, the more imperative the need to anticipate it. The need for accurate forecasts is greatest when forecasting is likely to be at its worst (1978, 94).

In retrospect this seems obvious. However, it has been a very difficult lesson for the energy forecasting community to learn. This is largely because it is rare for forecasters themselves or decision makers who use forecasts to take time, as Ascher has done, to review the accuracy of past forecasts. Instead, as Mulvey describes it, forecasts are often used in the policy process as "policy instruments." That is, a model's results are used "to justify government action, to show that a proposed project is cost-effective, to convince a skeptical congressional committee that a particular constituency will be put at risk, and so on" (Mulvey 1987, 39). Nevertheless, after being used in a policy debate the forecasts are often forgotten. What is important to understand is that model predictions used in this manner can lead to unwise policy/planning decisions.

Energy Forecasting Post-1973

Since the 1970's there has been a substantial increase in the lead time required for electric utilities to bring new generating capacity on line. This increase in lead time was caused by a number of interacting factors including: new environmental concerns, the introduction of more complex and larger scale generation technologies, longer regulatory proceedings, etc. The result has been an increased reliance on the use of peak load (kW) and electricity consumption (kWh) forecasts for electric utility planning purposes (Huntington et. al 1982, 455).

Huntington et al. describe what is at stake when utilities depend on forecasts for planning purposes:

> If the forecasts overstate actual future electricity demands, excess generation capacity will be built, causing significant rate increases for electricity customers. On the other hand, forecasts that understate these load requirements may cause the possibility of brownout or emergency purchases of extremely expensive oil generation capacity (1982, 455).

In addition, inadequate generation capacity can result in costly imports from other service areas and/or growth restrictions (Hanson 1986, 53). Thus, utilities have come to rely on forecast in order to insure that they will be able to meet future demand, or more likely to avoid having to use makeshift, i.e. low efficiency and high cost, measures to provide an adequate supply of energy.

During the same period that utility and government planners were relying more heavily on forecasts, the forecasts themselves were becoming less reliable. This was largely caused by the occurrence of major surprises in energy markets after 1973. In response to the post-1973 turbulence in energy markets there were at least three innovations in the approaches used for energy modeling/forecasting. These include the development of mega-model's, scenario analysis, and backcasting techniques. I will discuss each of these approaches individually.

Mega-Modeling

Mega-Modeling was basically an attempt to gain greater predictive capacity by building more complex models which incorporate new attributes of the social system. Essentially the builders of mega-models tried to learn from the unanticipated social, economic, and structural developments which had taken place during the 1970's. However, as Baumgartner and Midttun point out (1987, 302) there are at least two weaknesses to this approach:

- Making a model more inclusive often involves the introduction of behavioral variables that are hard to measure and difficult to forecast, and
- The increase in complexity, and technical skills required to understand a model's operation and to replicate its conclusions, creates a situation in which it is difficult for the scientific community to check a model's results.

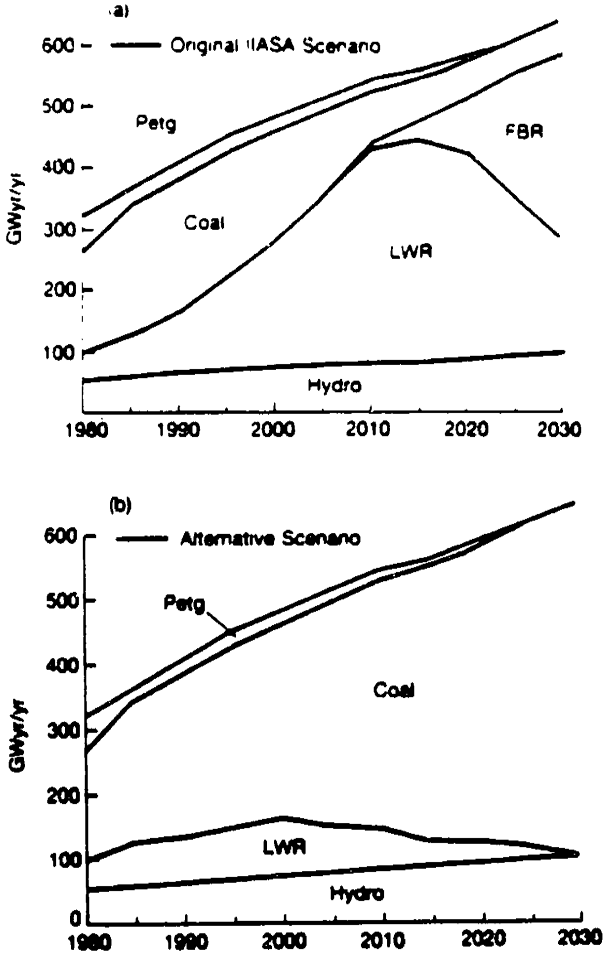
Since it is difficult to check the results of a mega-model and because of its complexity, it is possible for modelers to include (consciously or unconsciously) personal biases into a mega-model's results. For example, estimating growth rates, energy elasticities and technology innovation rates can be a highly subjective process. It is crucial to note that while the actual values chosen for these sorts of factors can have a significant impact on a model's results, often the values chosen are not explicitly spelled out. Instead they are buried within a mega-model's complexity.

Example of Mega-Modeling: IIASA's World Energy Model

Probably the best example of a mega-model built during the 1970's is IIASA's World Energy Model. The scope and scale of this modeling project was unprecedented. For instance, the IIASA model took over 7 years, approximately $10 million, and 225 person-years of effort to complete (Keepin and Wynne 1987, 34). IIASA's stated goal in developing its model was to "understand and to conceptualize by qualitative and quantitative means the global long-range aspects of the energy problem" (Hafele 1981, xiii). During the project IIASA stressed internal consistency and global comprehensiveness (Hafele 1980, 175). The mega-model which came out of this process divided the world into seven regions and contained three sub-models with in it (IMPACT, MESSAGE, and MEDEE-2). Through an iterative procedure using all three sub-models, the model was used to generate two internally consistent scenarios. These scenarios were intended to span the plausible evolution's of the energy system over a fifty year period (1980-2030) and were used as the basis for IIASA's policy recommendations on how to deal with the "energy problem."

Keepin and Wynne provide an insightful critique of the IIASA model (see: Keepin and Wynne 1987; Keepin 1984; and Wynne 1984). Essentially, they show that the iterative process used to arrive at internally consistent scenarios involved a great deal of craftsmanship and judgment on the part of IIASA's modelers. Further, they show that the supply model (MESSAGE) was very sensitive to minor changes in input cost assumptions. As shown in figure 3-3, by using a different set of input cost assumptions, which were credible for the mid to late 1980's, they showed that the model results changed dramatically: the nuclear futures were replaced by coal.

Figure 3-3: Sensitivity of IIASA Model to Cost Assumptions



Sensitivity to cost assumptions in IIASA scenario of energy demand for USA and Canada

Region I, low.
(a) Original scenario results for electricity generation; (b) new scenario results, assuming that nuclear costs are increased 16% and that the coal extraction limit is raised 7%.

Source: Keepin and Wynne 1987, 50.

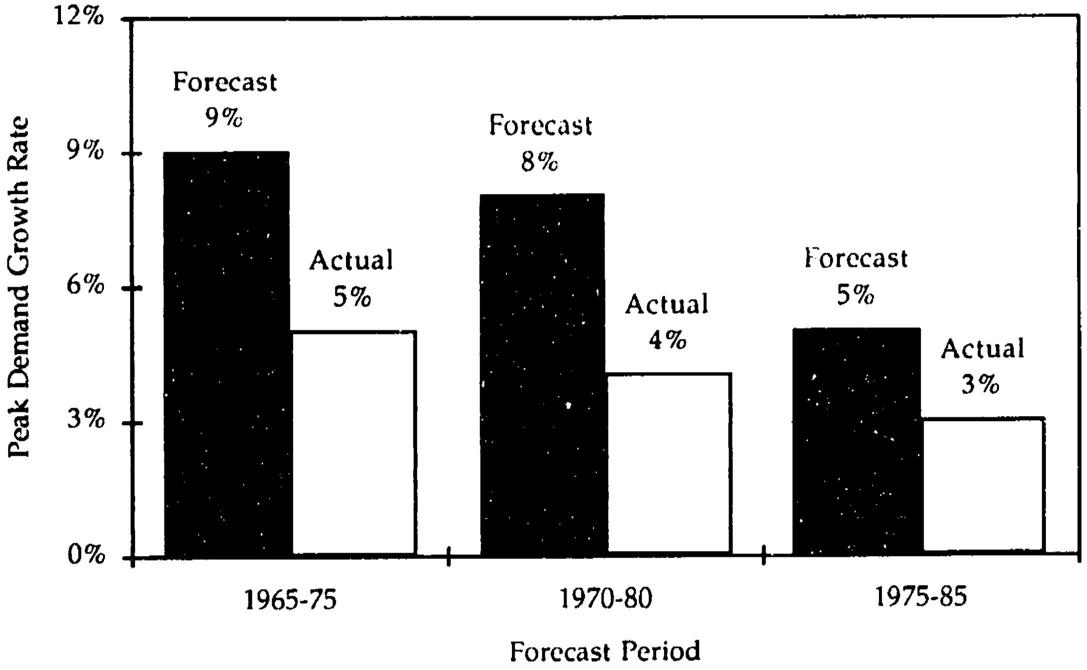
What we learn from Keepin and Wynne's critique of the IIASA world energy model is not whether the IIASA results are right or wrong, but that the process of running the IIASA model incorporates a great deal of judgment. For example, in the MESSAGE sub-model there are approximately 1,600 constraint variables and 2,600 activity variables. Clearly, with this level of complexity a mega-model becomes so overwhelming and impenetrable that it can easily divert attention from highly questionable and politically loaded input variables (Baumgartner and Midttun 1987, 269). In essence, instead of being a process which leads to a more objective representation of reality, building a mega-model is usually an exercise aimed at producing a desired set of results in a consistent manner.

Scenario Analysis

Scenario analysis was developed in order to try to capture uncertainty in future developments and to incorporate the possibility for political choices to effect the future. A scenario approach acknowledges that some model variables may be outside the control of political decision makers, such as international oil prices, while others may be represented as alternative policy choices such as energy conservation, heavy investment in energy technology research and development, energy taxes/tax credits, etc.

One approach to scenario analysis involves developing a range of scenarios which incorporate uncertainty about important exogenous model variables in the absence of policy intervention. Many forecasters took this approach in the early 1970's in conjunction with the development of mega-models (Baumgartner and Midttun 1997, 304). An other approach to scenario analysis involves developing a range of scenarios to represent various levels of and/or types of policy intervention. This approach is often aimed at creating a political debate in which various scenarios will be compared and then one scenario, or a set of scenarios, will be chosen based on social acceptability (Baumgartner and Midttun 1987, 304). A third approach to scenario analysis, which includes both the effects of uncertainty and policy intervention, will be discussed in Chapter 6.

Figure 3-4: SCE's Forecasting Record (1965-85)



Source: SCE 1988, 131

Example of Scenario Analysis: Southern California Edison

A good example of a regional utility's use of scenario analysis in its long-term (ten year) planning is the approach currently used by the Southern California Edison Company (SCE). Until 1985 SCE based its long-term planning on the most likely forecast, the best estimate forecast, or medium forecast of a high-medium-low forecast. However, during 1985 they reviewed their past plans and found that, over the previous 20 years, only 9,000 megawatts out of 34,000 megawatts of planned projects were actually built (SCE 1988, 119). As shown in figure 3-4, SCE consistently forecasted higher growth than they realized. This analysis lead SCE to switch from a focus on using forecasts for planning to a scenario planning approach.

Instead of tying their planning process to a single forecast, SCE's 1986 plan involved developing a set of 12 scenarios in order to plan for the future in the context of uncertainty. The 12 scenarios were based on a wide range of assumptions about variables related to "alternative economic conditions, growth rates, regulatory, environmental, technological, social, political, and business environments" (SCE 1988, 134). Essentially they changed their planning focus from trying to forecast capacity expansion requirements to being responsive to change. The main consequence of this shift in planning is that SCE's current resource plan depends on a number of relatively small, modular, short lead-time supply options in conjunctions with a number of demand-side options (SCE 1988, 148). While this approach may have potential costs associated with it, such as increased rates to consumers if demand increases rapidly, it provides SCE with a great deal of flexibility.

Backcasting—The Amory Lovins Approach

Lovins had a very different view about forecasting. In his book, *Soft Energy Paths,* he began his discussion of energy forecasting with a quote by Niels Bohr, "It is very difficult to make predictions, especially about the future" (1977, 63). In fact, Lovins thought energy forecasting models produced little more than "elaborate extrapolations." He expressed his attitude toward using energy models for forecasting as follows:

> Such models have trouble adapting to a world in which, for example, real electricity prices are rapidly rising rather than falling as they used to do. More generally, such models have a certain inflexibility that tends to lock us into a single narrow vision of lifestyles and development patterns. . . Extrapolations assume essentially a surprise-free future even when written by and for people who spend their working lives coping with surprises such as those of late 1973. Formal energy models can function only if stripped of surprises, but then they can say

> nothing useful about a world in which discontinuities and singularities matter more than the fragments of secular trend in between (Lovins 1977, 64).

In the place of using models for forecasting Lovins advocated a more normative scenario approach he called "working backwards" or backcasting.

The backcasting approach begins by describing what one considers to be a desirable and feasible future "scenario" and then works back to the present in order to design an internally consistent development path for society to follow between the two points. Thus one comes up with a "scenario" which describes how future events could unfold. This scenario includes a set of "transitional tactics" described in chronological order and at least qualitatively in sufficiently vivid detail for readers to readily imagine themselves participating in the events described (Lovins 1977, 65-6).

What Have We Learned?

The most important lesson from the energy modeling experience of the past 20 years is that uncertainty in long-term forecasting is more fundamental than simply lacking detailed knowledge about future values of various model parameters. While models may be able to tell us were we are headed if the future is simply an extension of the past, they can not tell us how likely it is that the future will be like the past. Thus, it is not sufficient to simply project past trends into the long-term future. This means that we need to move beyond using models to generate forecasts; instead, we need to use models for learning.

Using models for learning involves helping participants in the policy/planning process learn about how different components of the overall system interact with each other, gain insight into the limitations of the model itself, identify important uncertainties, and evaluate possible options.

Developing a range of scenarios instead of a single line forecast is central to the learning process. In addition, using models for learning involves being sensitive to how a model's results are going to be used. For example, we need to ask if a model's results are going to be used for short to medium term planning (less than 20 years) for a regional or local utility, or for long-term planning on a national or international scale.

If a model's results are intended to be use for the internal planning of an electric utility, then developing a set of scenarios (like SCE's scenarios) for planning over a 5 to 20 year period would make sense. This is because of three interacting factors: (1) over the course of 20 years, or less, it is likely that a pretty accurate prediction of available technologies for the electric power sector can be made, (2) developing, testing and building new electric generation capacity requires long lead times, and (3) it takes time for the current capital stock to turn over. Clearly when developing scenarios of this sort one needs to be sensitive to the structural constraints on a utility.

On the other hand, over longer time periods the nature of forecasting itself changes. As Thompson describes it, "instead of the problem containing some uncertainty, it is the other way around, it is the uncertainty that contains the problems" (1984, 335). In the long-term since there is a great deal of uncertainty about future economic, demographic, and technological conditions, it is unclear how energy systems will evolve. Thus when planning over longer periods of time the process of generating scenarios becomes much more speculative. Both analysts and decision makers need to acknowledge this.

Instead of providing decision makers with a particular forecast, analysts should use models to help decision makers explore the consequences of various policy choices over a range of alternative futures. Analysts can try to do this by presenting a set of results, or scenarios, generated by changing key model parameters over reasonable ranges. Thus participants in the policy process can move away from arguing about which forecast is the "right" forecast, and toward a discussion of which strategies are robust over a range of possible futures.

Another important lesson from the post-1973 energy modeling experience is that while energy modeling itself can be a process in which its participants gain a great deal of insight, it is very difficult to transmit this insight into the policy/planning process. This problem is caused by both the policy process itself, how it uses the results of models, and the way modelers present their results. On one hand, policymakers and/or the funders of modeling exercises are often willing to accept a forecast if it supports a decision they want to make anyway. On the other hand, modelers often provide decision makers with a single line projection of the future. Analysts need to be sensitive to the way the process will use their model generated results. This issue will be discussed further in Chapter 5.

Beyond Forecasting

In light of the post-1973 energy modeling experience it is clear that models can not forecast future energy demand accurately. Even the best energy models available today would have been unable to predict the major surprises, in energy markets, which occurred during the past two decades. Further, and more importantly they would not have been able to predict how these surprises influenced energy markets. To help illustrate how difficult long-term forecasting is one should think about how little current models would have helped us to predict all of the dramatic changes that have taken place during the past century including: two world wars, the great depression, the discovery and commercialization of nuclear fission, the disintegration of the Soviet Union, etc. Clearly, instead of using energy models to produce single line forecasts, they should be used for learning. One way of using energy models for learning is to generate a range of scenarios designed to help policymakers make their own judgments about the relative merits of various policy options over a range of uncertain futures.

4. Energy Modeling in the Context of Climate Change

Early studies of the "CO_2 question" simply modified existing energy models so that in addition to producing forecasts of future energy use, they would also generate forecasts of future CO_2 emissions. Adapting energy models to study carbon emissions was relatively straight forward: After calculating the total energy production and consumption in a given year, one would apply appropriate emission coefficients at each point in the production and consumption process. Using this approach the total carbon emissions from a given level of energy use can be calculated fairly accurately.

Then during the 1980's analysts began to link energy models with other model's in order to gain a more comprehensive understanding of the relationship between multiple sectors of the economy and the planet's ecosystem. Thus instead of focusing only on future CO_2 emissions, analysts began to discuss a range of greenhouse gas (GHG) emissions, the resulting atmospheric concentrations of GHGs and the effects on climate.

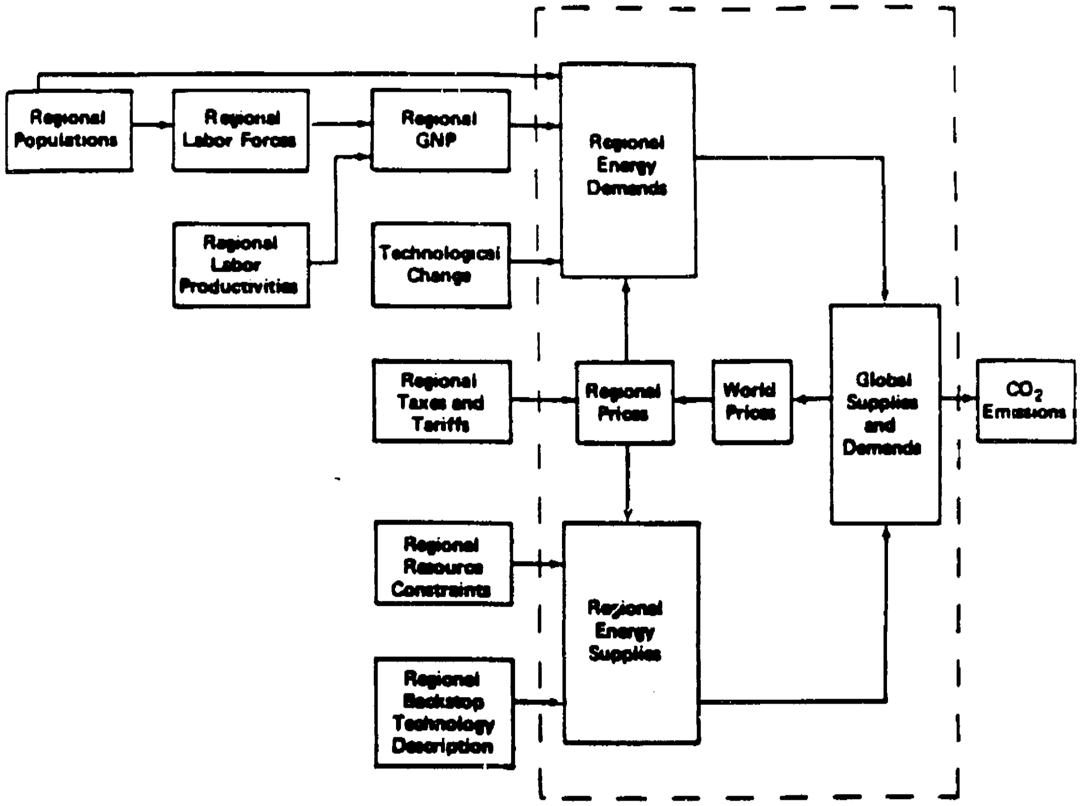
This chapter focuses on how a global energy-economic model, developed by Jae Edmonds and John Reilly, has been used in the climate change policy process. The body of the chapter is divided into four sections. First, I provide a basic overview of the Edmonds-Reilly model. Second, I review the results of six studies which used the model to study global CO_2 emissions. Third, I look at how the Edmonds-Reilly model has been incorporated into a larger modeling framework called the Atmospheric Stabilization Framework (ASF). And fourth, I discuss how the ASF was used in two recent studies of global climate change.

The Edmonds-Reilly Model

The Edmonds-Reilly Model is a recursive (i.e. partial equilibrium) energy-economic model which balances energy demand and supply during each forecast period at market clearing prices. The model is primarily based on classical economics and was developed in the early 1980's by Jae Edmonds and John Reilly at the Institute for Energy Analysis, Oak Ridge Associated Universities. Originally the model was designed to forecast CO_2 emissions from fossil fuels 75-125 years into the future, to estimate the range of uncertainty surrounding forecasts of future CO_2 emissions, and to identify the principal contributors to variances in the forecast (Edmonds and Reilly 1985). In order to make long-term projections about global energy use and CO_2 emissions, Edmonds and Reilly tried to integrate economic, demographic, technological, and policy interactions in the model. At every stage in developing the model Edmonds and Reilly tried to use the simplest possible representation of policy interactions in order to create an "open" rather that a "closed" box model. They developed a set of "minimum" modeling requirements which included: (1) disaggregation by fuel type, (2) very long-term applicability, (3) global scale, (4) regional detail, (5) energy balance, and (6) CO_2-energy flow accounting (Edmonds and Reilly 1985, 242). Despite the desire for a simple model they had to incorporate several levels of detail to reasonably capture interactions in the energy-economic-CO_2 system.

As shown in figure 4-1, the Edmonds-Reilly model consists of four primary parts: (1) energy supply, (2) energy demand, (3) energy balance, and (4) CO_2 emissions. The model divides the world into nine regions: (1) United States, (2) Western Europe and Canada, (3) Japan, Australia and New Zealand, (4) Centrally Planned Europe, (5) Centrally Planned Asia, (6) Middle East, (7) Africa, (8) Latin America, and (9) South East Asia (Edmonds and Reilly 1985,

Figure 4-1: Structure of the Edmonds-Reilly Model

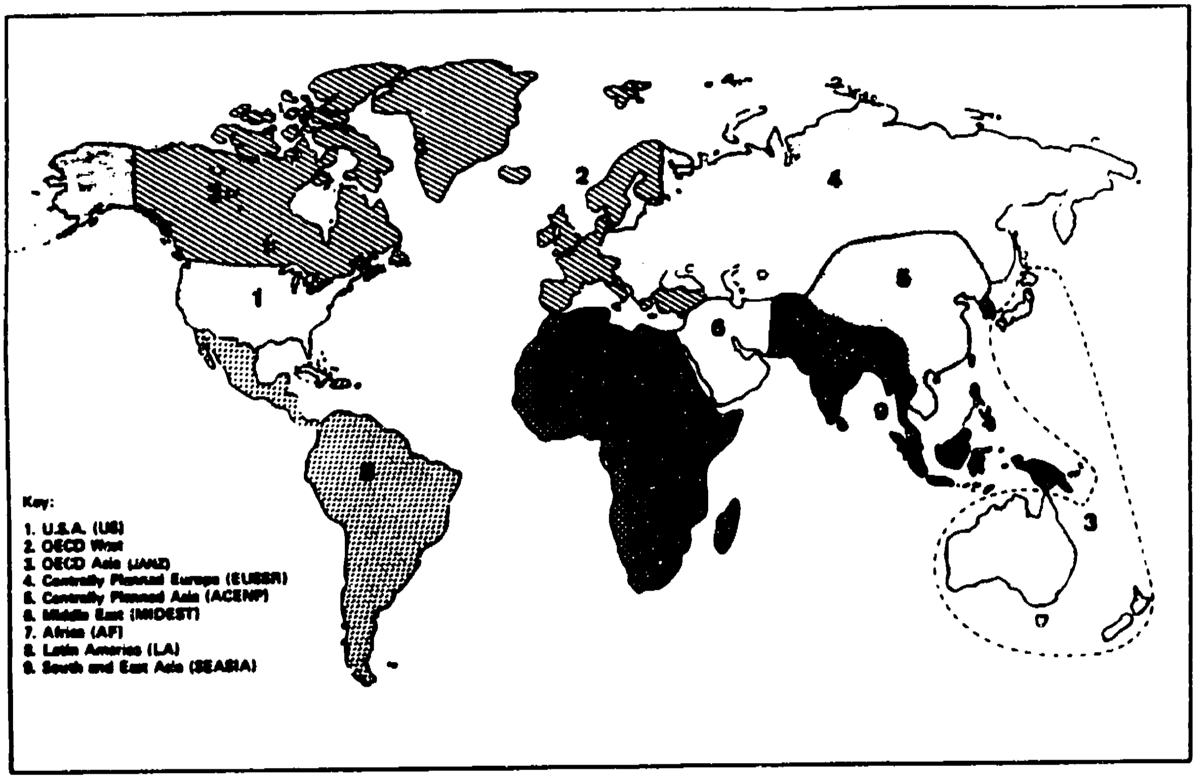


Source: Edmonds and Reilly 1985, 17.

5). The nine regions are shown in figure 4-2. The model contains nine primary fuels: two resource-constrained nonrenewable fuels (conventional oil and gas), two resource-constrained renewable fuels (hydroelectricity and biomass), and five unconstrained fuels (coal, nuclear, unconventional oil and gas from coal and shale oil, and solar energy). And the model contains four secondary fuels: liquids, solids, gases, and electricity (Edmonds and Reilly 1983a).

During each forecast period the available supply for each of the nine primary fuels is calculated. The supply of resource constrained nonrenewable

Figure 4-2: Nine Regions of the Edmonds-Reilly Model



Source: Edmonds and Reilly 1985, 4.

fuels is determined by a logistics curve which reflects historic supply levels and estimates remaining deposits. Thus fuel production rates are relatively insensitive to price changes. The supply of resource-constrained renewable fuels is limited by the availability of the resource. The unconstrained fuels are treated as backstop technologies. Thus a base level of production is assumed if real prices remain constant over time; however, short term supplies reflect both this base level and increases or decreases in production due to changes in fuel prices.

The model calculates the demand for energy services in each region during each forecast period based on five major exogenous inputs: (1) population, (2) economic activity, (3) technological change, (4) energy prices and (5) energy taxes and tariffs. The technological change inputs allow non-price induced increases in energy efficiency to be incorporated into a scenario. Energy prices in each region are determined from world prices and region-specific taxes and tariffs. First, the model determines the need for energy services based on population and economic activity. Then, the model determines the demand for secondary energy based on the demand for energy services, technological change, and prices. And finally, the model determines the demand for primary fuels based on the demand for secondary fuels.

After calculating the supply and demand during a given forecast period the model checks to see if supply and demand match. If supply and demand do not match (with in a given tolerance level) across all regions and fuels then a new estimate of world energy prices is made and supply and demand are recalculated. This process continues until a global energy balance is achieved.

Once an equilibrium between energy supply and demand is achieved the calculation of CO_2 emissions is straightforward: Appropriate carbon emission coefficients are applied at the points in the energy flow where CO_2 is released (production and consumption). Biomass, nuclear, hydro and solar energy are assumed to produce no net CO_2 emissions. Thus in the model CO_2 emissions are due solely to consumption of oil, gas, and coal. Under this scheme the production of shale oil from carbonate rock, as well as the production of synthetic fuels from coal, release large amounts of CO_2.

The minimum modeling approach used by Edmonds and Reilly led to a model which is transparent in the sense that its key assumptions and the principles upon which it is based have been clearly articulated (see Edmonds and Reilly 1985) and can be easily modified. In fact, a personal computer version of the model and Fortran source code are readily available from the

Carbon Dioxide Information Center at Oak Ridge National Laboratory (IBM formatted diskettes are included with Edmonds and Reilly 1986).

The model was intended to be used to help policymakers screen for the most useful solutions to the "CO_2 problem." In addition the model can be used to test if a set of policy objectives can be met by a particular long-term strategy. From the beginning Edmonds and Reilly described the purpose of the model clearly:

> The future, and particularly the distant future is impossible to predict. What is hoped for is that conditional scenarios can be constructed to explore alternatives in a logical, orderly, consistent, and reproducible manner. The model is not a crystal ball in which future events are unfolded with certainty, but rather an energy-CO_2 assessment tool, of specific applicability, which can shed insight into the long-term interactions of the economy, energy use, energy policy and CO_2 emissions (Edmonds and Reilly 1983a, 75).

Clearly, Edmonds and Reilly intended their model to be used as a learning tool.

Studies Using the Edmonds-Reilly Model

There have been a number of studies of global CO_2 emissions and/or climate change which have incorporated results obtained using the Edmonds-Reilly model. Some studies have used the model primarily as a learning tool while some have used the model principally for forecasting. Table 4-1 provides a summary of the projected CO_2 emissions in 2050 from eleven studies which used the Edmonds-Reilly model. The year 2050 was chosen because it is the latest year that all of the studies included. As shown in table 4-1 the results of various studies differ significantly. This is true for both "base case" emission scenarios and the range of emissions due to uncertainty

Table 4-1: Projected CO_2 Emissions in 2050 by Studies Using the Edmonds-Reilly Model

Author (date of publication)	Base Case Emissions (GtC/yr)	Range (GtC/yr)
Edmonds and Reilly (1983)	26.3	15.7-26.3 [a]
Rose et al. (1983)	15	2.7-15 [a]
Seidel and Keyes (1983)	15	10-18 [b]
Edmonds et al. (1984)	14.5	6.8-47.4 [b]
Edmonds et al. (1986)	----	2.3-58.1 [b]
Mintzer (1987)	13	3.5-24.5 [c]
Chandler (1988)	15	6-15 [a]
EPA (1989)	7.8-15.3	4.4-15.3 [c]
CBO (1991)	19	11-19 [a]
IPCC (1990)	13.5	3.0-13.5 [a]
IPCC (1992)	13	7-20 [b]

[a] range due to potential policy intervention
[b] range due to uncertainty
[c] range due to both potential policy intervention and uncertainty

and/or policy intervention. Next, each of the studies listed in table 4-1 will be discussed individually.

Edmonds and Reilly (1983, 1984)

In 1983 Edmonds and Reilly described the structure of their "Global Energy-Economic Model" and documented their "base case" scenario. The model is briefly described above. The base case has a number of important qualities including: large quantities of inexpensive fossil fuels (particularly coal) are available, energy end-use efficiency increases 1%/year in the industrial sector of the OECD countries, energy end-use efficiency stays constant in the transportation and residential/commercial sectors of the OECD countries, and energy end-use efficiency stays constant in all sectors of non-OECD countries. The base case scenario led to very high emissions in 2050 (26.5 GtC/yr).

In addition to developing their base case scenario they began to investigate how policy responses could effect CO_2 emissions (Edmonds and Reilly 1983b). They developed three "CO_2 policy cases" to investigate the effects of carbon taxes on the "critical dimension" of the CO_2 problem. In this study they defined the "critical dimension" as a doubling date of the level of atmospheric carbon from pre-industrial concentrations (Edmonds and Reilly 1983b, 40). The three CO_2 policy cases were: (1) low end-use U.S. CO_2 tax, (2) high U.S. CO_2 tax with coal export curtailment, and (3) high global CO_2 tax with U.S. coal export curtailment. Implementing the policies resulted in a range of emissions between 15.7 to 26.3 GtC/yr in 2050; however, atmospheric concentrations of carbon were effected only marginally. From this analysis Edmonds and Reilly concluded that it is unlikely that policies of this sort will shift the doubling date back by more than a decade (Edmonds and Reilly 1983b).

In 1984 Edmonds et al. published a new set of scenarios: a base case, a high case and a low case. The high and low cases were developed by "varying key parameters within the bounds of currently expected future values" (Edmonds et al. 1984, iii). The parameters varied included: population growth rate, solar power generation costs, nuclear power generation costs, energy efficiency improvement rates, gross national product growth rates, and estimated coal and shale oil supplies. The new base case used median estimates of these model parameters (Edmonds et al. 1984, 4). What is surprising is that in the new base case CO_2 emissions in 2050 are only 14.5 GtC/yr, or 45 percent lower than in the 1983 base case.

Two other independent studies using the Edmonds-Reilly model were published during 1983. These studies were conducted by Rose et al. at MIT and by Seidel and Keyes at the Environmental Protection Agency.

Rose et al. (1983)

The 1983 Rose et al. study explored the technical possibilities of reducing CO_2 emissions from the energy sector. They used the base case developed by Edmonds et al. (1984) and then created eleven new scenarios using the Edmonds-Reilly model. All eleven scenarios assume higher end-use efficiencies and ten out of the eleven scenarios have higher synfuel costs than the Edmonds-Reilly Base case. They explored evolutionary changes in energy supply such as higher costs for fossil fuels and lower cost for solar energy. They also explored abrupt changes in the energy supply such as cutting off the supply of oil from the Middle East and a moratorium on nuclear-generated energy.

From their analysis Rose et al. concluded that, "the rate of increase of atmosphere CO_2 due to fossil fuel consumption can be significantly reduced via the adoption of realistic energy strategies that are relatively 'CO_2-benign'" (Rose et al. 1983, 11). They labeled three of their scenarios CO_2-benign and argued that these are at the lower limit of possible realities, yet do not appear to be impossible. The lowest emission scenario they generated resulted in 2.7 GtC/yr in 2050. This is well below projections in most other studies.

However, Rose et al. acknowledged that obtaining a CO_2-benign future would "require a global awareness and collaboration starting very soon" (Rose et al. 1983, 45).

The report includes a chapter dedicated to "mini-assessments" of selected energy supply and demand technologies. This is useful in the sense that it provides insight into the opportunities for and constraints on introducing new technologies into the electric power system. Further, it helps the reader understand how they arrived at the assumptions used in their scenarios. Thus Rose et al. went beyond the Edmonds and Reilly studies by including the effects of technological change in their analysis. Implicit in their analysis is a belief that in order to achieve a CO_2-benign future, policies would need to be developed to bring about the appropriate technological changes. However, they do not recommend adopting a particular set of policies.

Seidel and Keyes (1983)

The 1983 Environmental Protection Agency (EPA) study conducted by Seidel and Keyes took a very different approach from that used by Rose et al., and resulted in very different conclusions. Seidel and Keyes used the Edmonds-Reilly model with a global carbon cycle model developed at Oak Ridge National Labs and a one-dimensional radiative/convective atmospheric temperature model developed at the Goddard Institute for Space Studies. The three models were coupled together in order to be able to see the effects of policies on temperature change. In their study Seidel and Keyes developed two sets of scenarios: baseline projections and policy assessments.

The baseline projections depict alternative future patterns of energy use in the absence of any "overt" public effort to lower CO_2 emissions. The baseline projections included a reference baseline (15 GtC/yr in 2050), four low CO_2 baselines (high renewable, high nuclear, high electric, and low demand), and one high CO_2 baseline (high fossil). These "baseline" projections were intended to give insight into the overall <u>uncertainty</u> in estimating future CO_2 emissions and the relative importance of specific assumptions concerning energy behavior. Taken together the baseline projections go from 10 to 18 GtC/yr in 2050.

The policy assessments were designed to evaluate the effectiveness of specific policies intended to reduce CO_2 emissions and thus delay atmospheric warming. Seidel and Keyes examined two policy options (applied to their reference baseline) to reduce CO_2 emissions from the energy sector: (1) fossil fuel taxes based on the relative quantity of carbon emissions from each energy source (both unilaterally by the U.S. and globally), and (2) bans on future worldwide consumption of coal, synfuels, and shale oil in various combinations. The rational behind this approach was to institute policies which would reduce CO_2 emissions indirectly by decreasing aggregate energy demand and/or directly by shifting fuel-use patterns away from fuels with high net CO_2 emissions. In addition, Seidel and Keyes discussed three non-energy policy options: CO_2 emissions controls, forestation programs, and injection of SO_2 into the stratosphere to increase atmospheric reflectivity.

To measure the effectiveness of their policies Seidel and Keyes defined as their "critical dimension" a 2 degree C warming. They argued that a 2 degree C temperature rise represents a warming significantly beyond the historical change over any 120 year period, and one which is "guaranteed to produce substantial climatic consequences" (Seidel and Keyes 1983, 1-17).

From their policy assessments Seidel and Keyes concluded that the only way to significantly delay a 2 degree C warming would be to institute a ban on coal, or a ban on shale and coal, by the year 2000. However, they concluded that this would be both economically and politically infeasible. In addition they concluded that energy taxes (up to 300%) would have little effect on when a 2 degree C warming would occur and that non-energy options to limit global warming were very speculative at best. In sum they concluded that while there is a great deal of uncertainty about CO_2 and temperature projections, the onset of global warming can not be significantly delayed by policies implemented in the near future (Seidel and Keyes 1983, 7-5).

The Seidel and Keyes study was innovative in that it distinguished between options and uncertainty, yet it only considered a very narrow range of options and uncertainty. In addition, they ignored the ability of policies to influence technology development. This helps explain why their results are very different from the results of Rose et al.

Edmonds et al. (1986)

Edmonds et al. looked at the effects of uncertainty on their base case CO_2 emissions forecast in a report published in 1986. The report presented the results of an uncertainty analysis using the Edmonds-Reilly model. First they defined uncertainty ranges for 79 input variables. Then they used Monte-Carlo sampling to generate 400 scenarios. For each scenario they tracked 95 output variables. Finally, they determined the relative contributions of each of the input variables to the overall uncertainty of the output variables. A very large range of CO_2 emissions (2.3 to 58.1 GtC/yr in 2050) is required to include 90 percent the scenarios from their analysis.

The results of this study will be discussed in detail in Chapter 6. Here it is sufficient to note that while Edmonds et al. attempted to quantify uncertainty about future CO_2 emissions, they did not explore how policies aimed at reducing CO_2 emissions might influence the range of possible futures.

Mintzer (1987)

Learning from the earlier studies by Seidel and Keyes (1983) and Edmonds et al. (1986), Mintzer published a report in 1987 which developed and used "The Model of Warming Commitment." Mintzer's Model linked the Edmonds-Reilly model and several other smaller specialized models together to "generate and analyze internally consistent scenarios" (Mintzer 1987, 7). This was the first model to take a number of radiatively important gases into account including: CO_2, N_2O, and CFC's.

Mintzer developed four scenarios of future emissions and warming by changing key assumptions in the model. The key assumptions that were varied include: (1) end-use energy efficiency improvements, (2) the price and availability of synfuels and solar energy, (3) the rate of tropical deforestation and land-use conversion, and (4) the impact of changes in income levels and energy prices on future energy demand. Mintzer translated changes in these assumptions into "policy measures" such as: (1) consumption taxes on commercial energy use proportional to carbon content, (2) environmental taxes on production of fuels, and (3) limits on production, use and release of CFCs. Then he applied these policy measures to his base case scenario and looked at their effect on warming.

From his analysis Mintzer concluded that the onset of global warming can be delayed significantly by policies implemented in the near future, and that unless policies are implemented soon intolerable levels of global warming will result. In Mintzer's words, "controlling the emissions of greenhouse gases must begin immediately and the choice of policies implemented in the next few decades could substantially affect the timing and magnitude of future global warming" (Mintzer 1987, 43). In addition, Mintzer went on to say that:

> The challenge now facing policy-makers and analysts interested in global warming is to go beyond the rough investigations reported here to identify country-specific or regional policy options that minimize the rates of future greenhouse gas emissions while sustaining high rates of economic growth" (Mintzer 1987, 44).

It is important to note that the report does not try to assess the cost associated with controlling emissions of greenhouse gases nor does it try to prioritize the policies which should be pursued. Instead, it asserts that it is technically possible to control GHG emissions and that we should try to develop policies to do this.

The report is in some ways a response to the earlier study by Seidel and Keyes (1983). As described above Seidel and Keyes concluded that the onset of global warming could not be significantly delayed by policies implemented in the near future. Contrastingly, while using the same energy model linked to other models in a similar fashion, Mintzer ends up with very different conclusions. This is largely due the use of different input assumptions: Mintzer's analysis incorporates a wider range of assumptions about how policies can effect the rates of improvement in energy efficiency and alternative supply technologies (Mintzer 1987, 43).

Chandler (1988)

In 1988 Chandler published a report in which he used the Edmonds-Reilly model to assess the effects of using carbon emission control strategies both in China and globally. Chandler modified the Edmonds-Reilly model to allow the assessment of China by shifting the relatively small populations of

Kampuchea, North Korea, and Vietnam out of the Centrally Planned Asia region and into the South East Asia region (Chandler 1988, 252).

Chandler set out to assess the relative effectiveness of Chinese and global initiatives to reduce atmospheric concentrations of carbon, and the effects of these initiatives on Chinese income levels. He chose to focus on China because it represents 20% of the human population, uses large quantities of coal, and is likely to be adversely affected if a significant amount of global warming occurs (Chandler 1988, 243). Chandler developed 12 scenarios which incorporated changing assumptions related to: (1) family planning (i.e. population growth rates), (2) carbon taxes, and (3) technical efficiency improvements.

Chandler supplements his traditional "top down" analysis by providing a brief "bottom up" analysis to justify his assertions about the technical plausibility of achieving high levels of "cost effective" energy efficiency improvements in China. He argues convincingly that China could maintain a 2% rate of energy efficiency improvements for almost eight decades without any technological breakthroughs (Chandler 1988, 258). In using this approach Chandler has attempted to overcome one of the largest shortcomings of the Edmonds-Reilly model: lack of energy end-use detail.

The results of Chandler's analysis indicate that acting alone China could make important but not decisive reductions in global CO_2 emissions and atmospheric carbon concentrations. Thus he concludes that, "a truly international effort will be required to keep atmospheric carbon dioxide levels well below a doubling relative to preindustrial levels" (Chandler 1988, 263). Further, he argues that only energy efficiency improvements can both reduce CO_2 emissions significantly and increase Chinese per capita incomes.

By focusing on a single country and using a bottom up analysis to supplement his argument Chandler used the Edmonds-Reilly model in more of a learning mode than a forecasting mode. He attempted to use the model to assess technical and economic measures for their efficacy. On the other hand, since the Edmonds-Reilly model only calculates CO_2 emissions, and CO_2 is only one of many greenhouse gases, the usefulness of Chandler's analysis is limited by the Edmonds-Reilly modeling framework.

By the time Chandler's analysis had been published participants in the climate change policy process were beginning to desire a modeling framework which would integrate multiple sectors of the economy and the environmental system. Such a framework would also need to include multiple greenhouse gases.

A New Modeling Framework: The ASF

In 1986 the Environmental Protection Agency (EPA) received a congressional charge to examine policies that would stabilize atmospheric concentrations of greenhouse gases at current levels (EPA 1989, I-3). The EPA was to conduct a study which would address:

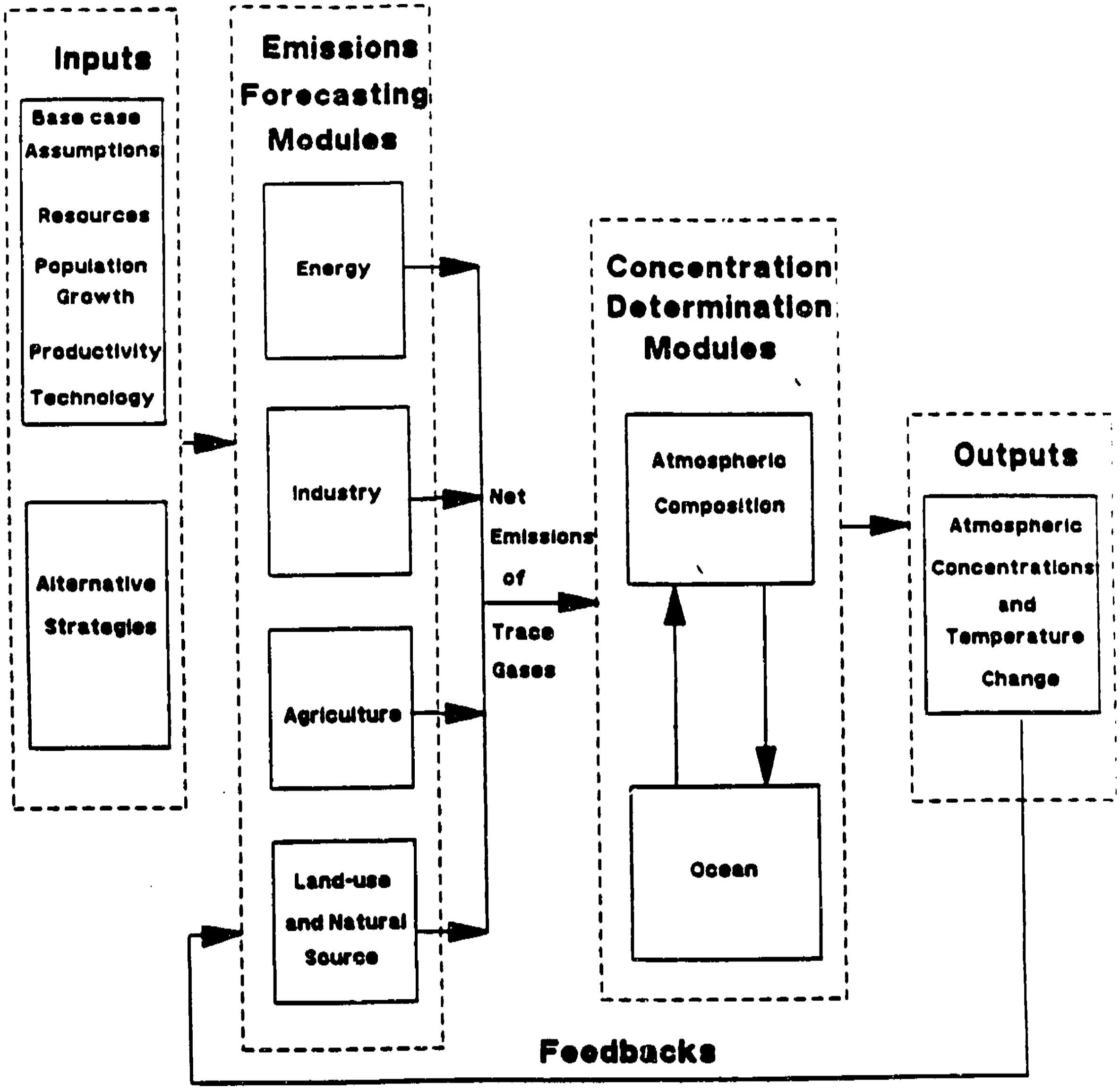
> the need for and implications of significant change in energy policy, including energy efficiency and development of alternatives to fossil fuels; reductions in the use of CFC's; ways to reduce other greenhouse gases such as methane and nitrous oxide; as well as the potential for and effects of reducing deforestation and increasing reforestation efforts (EPA 1989, I-3).

An important part of EPA's response to this request was to develop a new (multi-sector, multi-gas) modeling framework for climate change policy analysis. This modeling framework, the Atmospheric Stabilization Framework (ASF), integrated a number of different models into a consistent framework which could then be used to estimate the magnitude of future greenhouse warming under a wide range of assumptions about economic activities, emissions, atmospheric chemistry and climate sensitivity. The ASF combined input data, user specified scenario specifications, and a number of models to estimate trace gas emissions from a range of human and natural activities, changes in the atmospheric concentrations of trace gases, ocean uptake of heat and CO_2, and temperature rise (EPA 1989, A-5).

The basic structure of the ASF is shown in figure 4-3. As shown in figure 4-3 the ASF consists of four emissions modules: energy, industry, agriculture, and land-use change and natural systems. The energy module incorporates a modified version of the Edmonds-Reilly model and end-use models developed at Lawrence Berkeley Laboratory (see Sathaye et al. 1989) and the World Resources Institute (see Mintzer 1988). The primary component of the industry module is EPA's CFC model which was developed to assess stratospheric ozone depletion. The agriculture module is based on the International Institute of Applied Systems Analysis' Basic Linked Systems model. And the land-use and natural source module uses the Terrestrial Carbon Model developed at Woods Hole Marine Biological Laboratory (EPA 1989, 7).

The emissions modules are linked to a set of concentration modules which translate emissions into atmospheric concentrations and temperature change. The concentration modules consist of an atmospheric composition module and an ocean module. The atmospheric composition module incorporates a modified version of a model developed at NASA (see Prather 1988). The NASA model includes a highly simplified model of global chemistry and a parameterization of the impact of changes in greenhouse gas concentrations on the radiation balance of the earth. The ocean module consists of a modified version of a model developed at the Goddard Institute

Figure 4-3: Structure of the ASF



Source: EPA 1989, 8.

for Space Studies (GISS). The GISS model simultaneously calculates carbon dioxide and heat uptake by the ocean. The ocean module also includes four additional CO_2-ocean uptake models developed at the University of New Hampshire (EPA 1989, 7).

As noted above the energy module of the ASF includes a modified version of the Edmonds-Reilly model. Since energy use is responsible for a large percentage of greenhouse gas emissions, the ASF version of the Edmonds-Reilly Model is central for conducting "policy experiments" with the ASF. In fact in the EPA report eight out of their eleven "policy strategies" were simulated by changing energy related input assumptions: improving transportation efficiency, achieving other efficiency gains, instituting energy emissions fees, promoting natural gas, installing emission controls, developing solar technologies, commercializing biomass, and promoting nuclear power.

Important modifications which were made to the Edmonds-Reilly model for use with the ASF include: (1) defining 3 energy end-use sectors in each region, (2) using a 5 year time step (instead of 25 year time step) between 1985 and 2025, (3) incorporating results from the Lawrence Berkeley Laboratory and World Resources Institute end-use models between 1985 and 2025, (4) calculating emissions from energy of CO_2, CH_4, N_2O, and NO_x, and (5) altering many calculations related to electric power generation, primary energy supply, energy demand and GNP.

These modifications addressed a number of earlier criticisms of the model; however, the model still has many shortcomings. For example the model does not adequately assess the penetration of new technologies, retire and install new capital stocks consistently, include the effects of control strategies on capital investment and economic growth, or include the interactions between activities in different sectors. These shortcomings mean that model users have to check their results carefully for consistency when constructing or modifying a scenario.

Environmental Protection Agency (1989)

The EPA used the ASF to generate four scenarios. Two of the scenarios explored how, "the world may evolve in the future assuming that policy choices allow unimpeded growth in emissions of greenhouse gases" (EPA 1989, 20). These were called the Rapidly Changing World and Slowly Changing World "No Response" strategies. Essentially they were an attempt to understand the impact of alternative economic development strategies on climate change. The other two scenarios, "start with the same economic and demographic assumptions, but assume a world in which policies to limit anthropogenic emissions have been adopted" (EPA 1989, 20). These were called the Rapidly Changing World and Slowly Changing World "Stabilizing Policy" scenarios. These scenarios were developed to explore the relative impact on climate change of various policy choices aimed at reducing greenhouse gas emissions.

Thus EPA generated a "no policy response" range and "policy response" range. What distinguishes the EPA study from earlier reports is that they did not include a "best guess" scenario in their analysis. This was a significant departure from previous studies. In addition, the EPA report went beyond earlier reports by attempting to use the ASF to rank policies in order of their effectiveness.

Still, the EPA report does have some shortcomings. For example: they did not analyze the economic and social costs or tradeoffs associated with specific policy choices, their analysis did not treat all of the major trace gases, and they did not address implementation issues. In addition the EPA report is similar to the report by Rose et. al in the sense that it includes an extensive discussion of technology options that could be used to reduce greenhouse gas emissions, yet it is unclear how this material was used in developing the EPA emissions scenarios. It is disappointing that the report's thorough and useful discussion of technologies is not explicitly used to give the reader a sense of why the EPA scenarios are plausible.

Using their scenario based analysis EPA concluded that:

> No single activity is the dominant source of greenhouse gases; therefore, no single measure can stabilize global climate. Many individual components, each having a modest impact on greenhouse gas emissions, can have a dramatic impact on the rate of climatic change when combined (EPA 1989, 32).

Given the interdependent nature of the climate change problem this is not a surprising conclusion.

Congressional Budget Office (1990)

In 1990 the Congressional Budget Office (CBO) published a report which looked at the effects of carbon charges—taxes on fossil fuels set according to their carbon content—on CO_2 emissions from the U.S. and globally (see CBO 1990). The study included both short-term and long-term analysis. The CBO's short-term analysis (for the next decade) was conducted using three models of the U.S. economy: the Energy Information Administration's PCAEO model, Data Resources Incorporated's quarterly econometric model of the U.S. economy, and Dale Jorgenson's Dynamic General Equilibrium Model. The CBO's long-term analysis (to the year 2100) was conducted using two global energy models: the ASF and the Manne-Richels model.

Combining the results from their short-term and long-term analysis the CBO concluded that in order to achieve substantial reductions in global CO_2 emissions multi-lateral carbon charges would be required. Unilateral charges by the U.S. would not be effective; however, applying multi-lateral charges rising to $300 per tonne of Carbon by 2100 might delay the doubling of CO_2 into the 22nd century (CBO 1990, 62). This result is different from the earlier study by Seidel and Keyes.

The CBO analysis is worth discussing because it used a number of models to look at the effects of carbon taxes on both short-term and long-term projections. Yet, it did not consider the uncertainty inherent in the model inputs. For example, the Edmonds et al. (1986) Monte-Carlo analysis found that the aggregate price elasticity of demand for energy was very important in determining CO_2 emissions. That is, a small change in the value chosen for price elasticity would have a large effect on the sensitivity of energy use to price changes. The CBO analysis does not try to justify its choice for price elasticity nor does it discuss the possible effects of a large carbon tax on the price elasticity itself.

Intergovernmental Panel on Climate Change (1990, 1992)

Recently two studies were published by the United Nations Intergovernmental Panel on Climate Change (see IPCC 1990a, 1990b, 1990c, 1991 and 1992). The emissions scenarios included in the studies were generated using the ASF. While the studies have been influential in the international policy process, the scenarios included in the studies have been very controversial. The next chapter (Chapter 5) discusses the details of the IPCC emissions scenarios and the controversy surrounding them.

5. Interpreting the IPCC Emissions Scenarios

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization and the United Nations Environment Programme during 1988. Initially the IPCC was charged with (1) assessing the scientific information related to the various components of the climate change issue, and (2) formulating realistic response strategies for the management of the climate change issue. To accomplish these tasks the IPCC formed three working groups. Working group 1 (WG1) was to assess the scientific information on climate change, working group 2 (WG2) was to determine the environmental and socioeconomic impacts of climate change, and working group 3 (WG3) was to formulate response strategies to climate change (IPCC 1990b).

Early on in the IPCC process it became clear that the three working groups needed to have a common set of emissions scenarios in order to be able to communicate their findings to each other and the outside world. As one participant in the process described it, "[the emissions scenarios] put us all on a common basis so we wouldn't be talking about different things." Thus when WG3 held its first meeting during January 1989—at the U.S. State Department in Washington, DC—the U.S. and the Netherlands were asked to develop preliminary net emissions profiles for several scenarios of the future. The "emissions scenarios" which came out of this process were used as a first basis for analyses by WG1 and WG2, and as an initial reference and guidance for the subgroups of WG3 (IPCC 1991, 13). Since the emissions scenarios represent important underlying assumptions about the future, which were used by all three working groups of the IPCC, they deserve further scrutiny.

This chapter discusses both the original IPCC scenarios and a new set of scenarios included in the 1992 IPCC supplement report. It looks at how the scenarios were specified, what role models played in developing the scenarios, and how the scenarios were interpreted by participants in the IPCC process. It draws on the results of interviews conducted with 14 participants in the IPCC process.

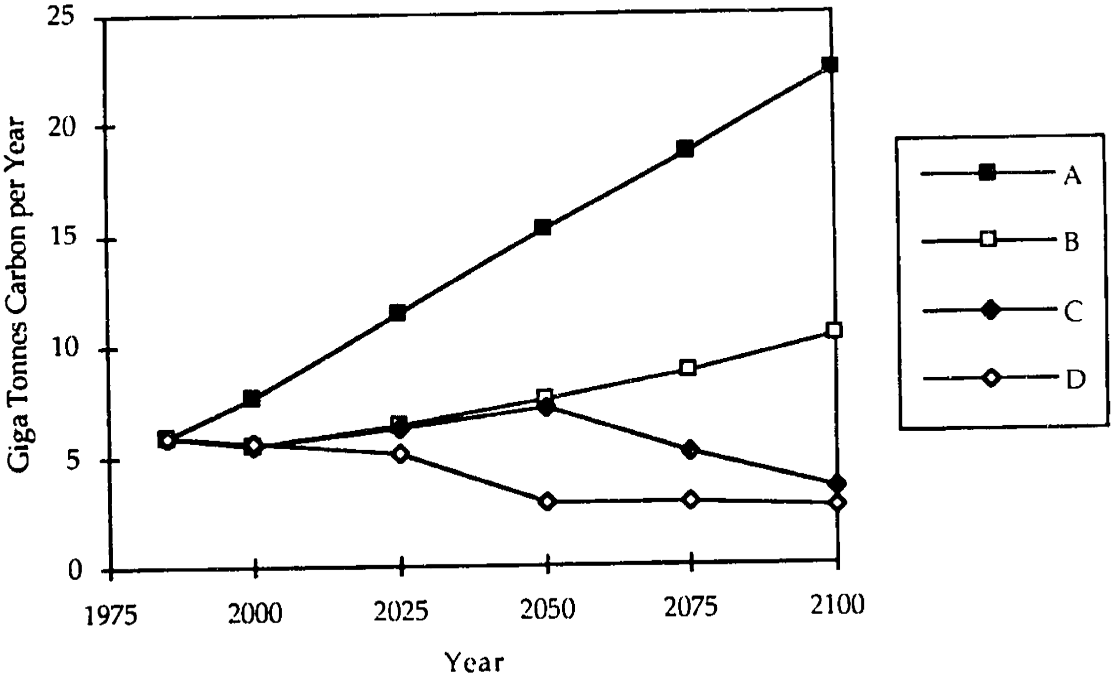
The interviewees included people who took part in the IPCC process from the U.S. government (the Environmental Protection Agency, the Department of Energy, the State Department, the Department of Justice and the President's Council of Economic Advisors); the IPCC itself (the Chairman of WG1, the Chairman of WG3 and the Chairman of the IPCC); Academia (Economists and Scientists); and Non-governmental organizations (NGO's). And they were from a number of countries including: Canada, England, the Netherlands, Sweden, the United States and Zimbabwe. Note that the interviews were conducted on the basis of non-attribution.

The interviewees played significant roles in defining, generating and using the scenarios, and they represented a broad range of perspectives on the IPCC process. The interviews focused on three main areas: how the participants thought about the models, how they interpreted the model results, and how they perceived the analysis underlying the model results. The questions used during the interviews are included in Appendix A.

Specification of the Scenarios

Initially WG1 requested that WG3 produce three scenarios: Scenario A would lead to a doubling of equivalent CO_2 concentrations by the year 2030, Scenario B to a doubling of equivalent CO_2 concentrations by the year 2060, and Scenario C to a doubling of equivalent CO_2 concentrations in the year

Figure 5-1: IPCC 1990 CO_2 Emissions Scenarios



Source: IPCC 1991, 26-29.

2090 with stabilization of atmospheric concentrations thereafter.[1] Later in the process the Netherlands and some other countries were not satisfied with the range of scenarios selected and consequently urged the addition of a fourth scenario: Scenario D which would lead to a stabilization of equivalent CO_2 concentrations well below the doubling level (Rotmans 1990, 195). The four 1990 IPCC CO_2 emission scenarios are shown in figure 5-1.

Clearly, the scenarios were defined in a restrictive manner. That is, the modelers were given target years for doubling of equivalent CO_2 concentrations, and then they constructed scenarios to meet the given targets

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[1] In the WG3 report "equivalent CO2 concentrations" is defined as "the concentration of CO2 that, by itself, would produce the increase in direct radiative forcing produced by all of the greenhouse gases" (IPCC 1991, 18).

though trial and error (i.e., by adjusting input assumptions). This approach to modeling is reminiscent of the mega-modeling example described in Chapter 3: Essentially the modelers were asked to produce a set of desired result in a consistent manner.

When discussing the scenarios with participants in the IPCC process it became clear that there was not a lot of analysis behind the choice of 2030, 2060, and 2090 as the equivalent CO_2 doubling dates. This was clearly articulated by one participant from the EPA. He described the meeting at which the scenarios were initially defined as follows:

> People said there should be a business as usual scenario, and that would mean that CO_2 would double around 2050, and then somebody else said, yeah but when you look at all the other gases it would happen sooner, and so they said well O.K., let's bracket 2060. And we ended up with 2030 and 2070 or something like that, and somebody said that's not a big enough gap so it became 2030 and 2090. Then primarily because the Dutch pushed for it at a subsequent meeting, with some other countries, they said we should have at least one scenario that stabilizes well below a doubling. And so the fourth scenario was added.

This quote illustrates that the scenarios were initially defined to provide reference scenarios, or different paths of emissions which would result in different impacts. That is, WG1 wanted a set of emissions scenarios which would lead to a range of impacts from very high to low.

In fact, originally there was a sense that A was a high scenario, B was a middle scenario, and C was a low scenario. In other words, originally the scenarios were intended to map out the variation that could occur in the future. They were not defined to be "policy scenarios." Further they were not intended to be interpreted as predictions of the future. The report by the "Expert Group on Emissions Scenarios" was very clear on this point. As stated in the Expert Group report, "These scenarios were not intended to be forecasts of possible development outcomes or of likely policy options, but would serve as a first step in the analysis of a plausible range of global climate change scenarios" (IPCC 1990a, 1).

Controversy Over Labeling the Scenarios

During the IPCC process the scenarios names were modified. Essentially the labels became Scenario A or Business As Usual (BAU) or 2030 High Emissions, Scenario B or 2060 Low Emissions, Scenario C or Control Policies, and Scenario D or Accelerated Policies. The label changes reflect how the interpretation of the scenarios changed throughout the process A member of the subgroup which developed the scenarios described how he felt about the transition as follows:

> When we did the scenarios originally, that is the first three scenarios, they weren't intended to be policy cases. They weren't called policy cases. But if you look at how they were developed, they were in some cases almost policy implementations, or things that could be considered to be policies that generated these results. Then they came back to do the final report and said, well gee these look a lot like policy cases. And they became policy cases, and there was a big brawl over that, because a lot of people didn't want them to be called policy cases. . . You could look at them and say in some sense that if you believed your assumptions in the business as usual scenario then you would have to have policies that got you [to lower emissions], that forced the deviation. In that sense they are policy scenarios .

This quote helps to illustrate that in one sense the struggle over what to name the scenarios reflects changing perceptions of the meaning of the scenarios throughout the process.

However, perhaps more importantly, since the scenarios are central to defining climate change as a political issue, the struggle is also about how to define climate change as a problem. For example, interpreting the IPCC emissions scenarios as a set of scenarios which cover a range of possible futures, including uncertainty yet independent of policies, says nothing about our ability to use policy responses to avoid climatic disruptions. The first interpretation only indicates that the future is highly uncertain. While the second interpretation, viewing the scenarios as representing business as usual and increasingly stringent policies scenarios, tells a very different causal story: Policies aimed at reducing emissions of GHG's can help us avoid major climatic disruptions.

As discussed in Chapter 2, in the policy world an issue is not a problem until someone thinks they have a solution. Thus participants in the policy process who want to see action taken on the climate change issue would like to interpret the scenarios as BAU and increasingly stringent policy scenarios. In other words, in the context of the political debate, they want to construct a convincing "causal story" linking policy intervention with reductions in climatic risks. On the other hand, there are participants in the policy process who want to interpret the scenarios simply as a range of possible futures. While they may believe that increasing the atmospheric concentrations of GHGs will result in significant climatic change, they may be skeptical about the effectiveness of policy intervention. In addition, there are participants in the policy process who would argue that there is not even a proven causal link between increased atmospheric levels of greenhouse gases and climatic change (see Lindzen 1992).

Probably the most controversial IPCC decision was to use the name "Business As Usual" for Scenario A. Here participants disagreed pointedly both about how they thought Scenario A should be interpreted and the meaning of the term "Business As Usual." For example, to some BAU means a projection of present trends into the future, while to others it means a prediction of the future in the absence of policy intervention. The difference in wording is subtle but the difference in meaning is very significant. This controversy was expressed in a number of different ways during interviews I conducted with participants in the process. For example, a representative to the IPCC from the State Department viewed the phrase BAU as being misleading:

> The phrase BAU was in and of itself misleading, because it did not take into account the changes that necessarily result as a consequence of new information and new technology development. In other words, if we did nothing between now and ten years from now, there would be more change than the BAU scenario allowed because of what is normal, because BAU is dynamic, it's not static. And the basic problem there was that they posited a proposition that BAU is static, that it's not dynamic, that it doesn't change. And it changes significantly, at least when forced by significant new information, significant new business opportunities, commercial development, etc. So the concept itself was misleading.

From this perspective since the name BAU implies a static future, it would probably lead to higher emissions than would be produced by a dynamic view of the future.

A representative to the IPCC from the Department of Energy expressed a similar view. He thought that the label BAU was inappropriate:

> They [the scenarios] were really miss-named. And that turned out to be important. They got miss-named in the sense that they got named 'Business As Usual,' and nobody really ought to believe that 2030 doubling is BAU, or else you don't believe that technology change occurs. . . I think this is a case where different parts of a government had different agendas within an administration, and so were able to push a more activist agenda with out the more conservative parts of the government catching on. . . As it appeared in the report it sounded like a projection. And that's absolutely what it is not. The reason why I could agree that night in Washington, was because it wasn't a projection. That's the reason I could agree to it. And the reason why we could go forward.

From this quote we see that some people in the IPCC process did not like the causal story implied by using the label BAU.

Contrastingly, there were participants in the IPCC process who thought that a "real" BAU scenario would lead to much higher emissions. One European representative expressed this view nicely:

> We were not very happy with that [the name change from Scenario A to BAU] because we think that a real BAU scenario, that involves a kind of attitude of doing nothing, would lead to higher emissions. . . We presented, in an article in *Climatic Change* our 'unrestricted' scenario: A scenario with no restrictions in it due to policy measures. That leads to a scenario in 2100 which is twice as high as the IPCC BAU scenario. In our case it leads to about 50 gigatonnes of carbon in 2100. That's very high but is indeed based on the attitude of taking no measures. I think that reflects the way we think in Western Europe about this. In general we are not as optimistic [as people the US].

In the middle of this controversy there were participants in the IPCC process who felt comfortable with the label BAU For example, a representative from the EPA thought that:

> . . . the labeling is probably appropriate given the analysis. Although the original mandate to generate the scenarios wasn't necessarily labeled that way. The labeling probably evolved to fit what the analysis showed. And I think that is probably right, that 2030 is more a BAU, and that the other scenarios probably do represent progressively more stringent policies.

As illustrated by the quotes above, the label BAU could be interpreted in a number of different ways. In the end, with some controversy remaining, the name of Scenario A was changed to "Business As Usual."[2]

Clearly there is a certain legitimacy to the controversy over using the name BAU instead of Scenario A. However, one could argue that the

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[2] The most widely read reports, the WG1 report (IPCC 1990b) and policy makers summery of the WG3 report (IPCC 1991), use the label "BAU". While the more technical reports, the chapter on the Emissions Scenarios of the WG3 report (IPCC 1991, Chapter 2) and the Expert Group on Emissions Scenarios Report (IPCC 1990a) use the label "2030 High Emissions" for Scenario A.

labeling debate was more political than substantive. Using the label BAU did effect how the IPCC reports read, but it did not really effect the substance of the reports. On the other hand, using the label BAU significantly influenced how the scenarios were perceived by people both inside and outside of the IPCC process.

The controversy over the names used for the emissions scenarios led to calls for the IPCC to define, more clearly, how the scenarios should be interpreted. For example, critics wanted to know if they were scenarios, predictions, projections or forecasts (Global Environmental Change Report 1991). This ultimately led to the creation of a new set of emission scenarios which were included in the 1992 IPCC Supplement Report (IPCC 1992). Before discussing the new set of scenarios, however, it is worthwhile to ask if the analysis underlying the original scenarios supported how they were interpreted.

The ASF Generated Scenarios

The main modeling tool used to generate the emissions scenarios was the Atmospheric Stabilization Framework (ASF).[3] As discussed in Chapter 4, the primary feature of a modeling framework, like the ASF, is that it enforces consistency. For example, in the ASF if you make assumptions about reducing emissions from the building sector by increasing conservation, then the model forces the system to tell you that less electric power will be generated, and so your ability to reduce emissions in the electric utility sector

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[3] Another model used by the IPCC was the Integrated Model for the Assessment of the Greenhouse Effect (IMAGE) which was developed by RIVM in the Netherlands. However, the Dutch did not independently design a set of emissions scenarios. Instead, they used IMAGE to confirm that the ASF generated emissions scenarios would lead to the requested atmospheric concentration levels. Also, IMAGE is very similar in structure to the ASF. In fact, IMAGE uses the Edmonds-Reilly model in its energy module (Rotmans 1990).

will be less than before. In other words, it keeps you from double counting and forces you to work within a framework which has fundamental constraints in it. This was the mode that the ASF was used in by the IPCC. Thus while the ASF was primarily used to get a consistent set of numbers, it also helped keep the political process from getting completely away from the constraints of reality.

For each of the four emissions scenarios (e.g., doubling by year X) two "detailed" scenarios were generated using the ASF: a higher economic growth scenario and a lower economic growth scenario. The reason, according to the expert group report, for generating two scenarios for each requested emissions scenario was to try to capture some of the uncertainty about the "many equally plausible yet divergent paths that the world could take to reach the equivalent CO_2 doubling levels" (IPCC 1990a, 1). Yet, in constructing the higher and lower growth scenarios the only parameter that was modified was the rate of economic growth. It is true that the future rate of economic growth is one of the most important variables influencing GHG emissions; however, there are other important, and uncertain, variables which influence GHG emissions significantly. For example, population growth rates will influence GHG emissions a great deal and are uncertain, yet the IPCC used a single population projection in all of its scenarios. Thus the higher and lower growth scenarios give a very limited sense of the possible "divergent paths."

After the eight higher and lower economic growth scenarios were created, they were used to generate four "average" emissions scenarios for <u>each</u> GHG. The average scenarios were simply an average of the higher and lower economic growth scenarios. Thus a total of twelve emissions scenarios for each GHG were created. The average emissions scenarios for CO_2 are shown in figure 5-1. The high, low and average growth CO_2 emissions scenarios are shown in Figure 5-2a-d.

Figure 5-2a: IPCC 1990 CO_2 Emissions: Scenario A

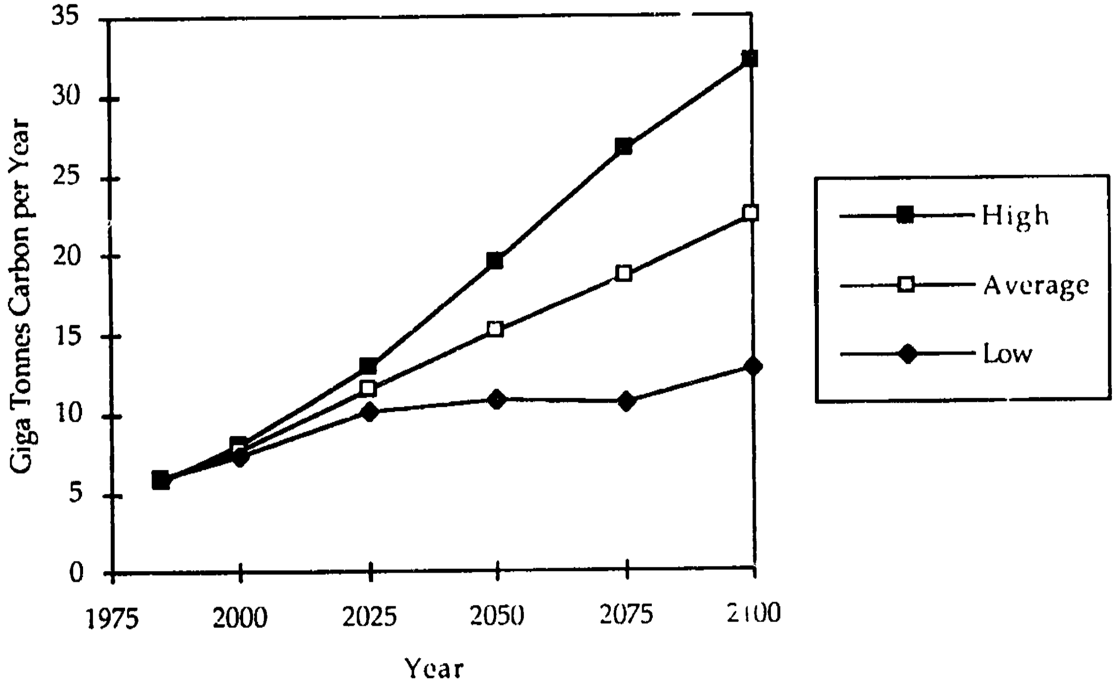


Figure 5-2b: IPCC 1990 CO_2 Emissions: Scenario B

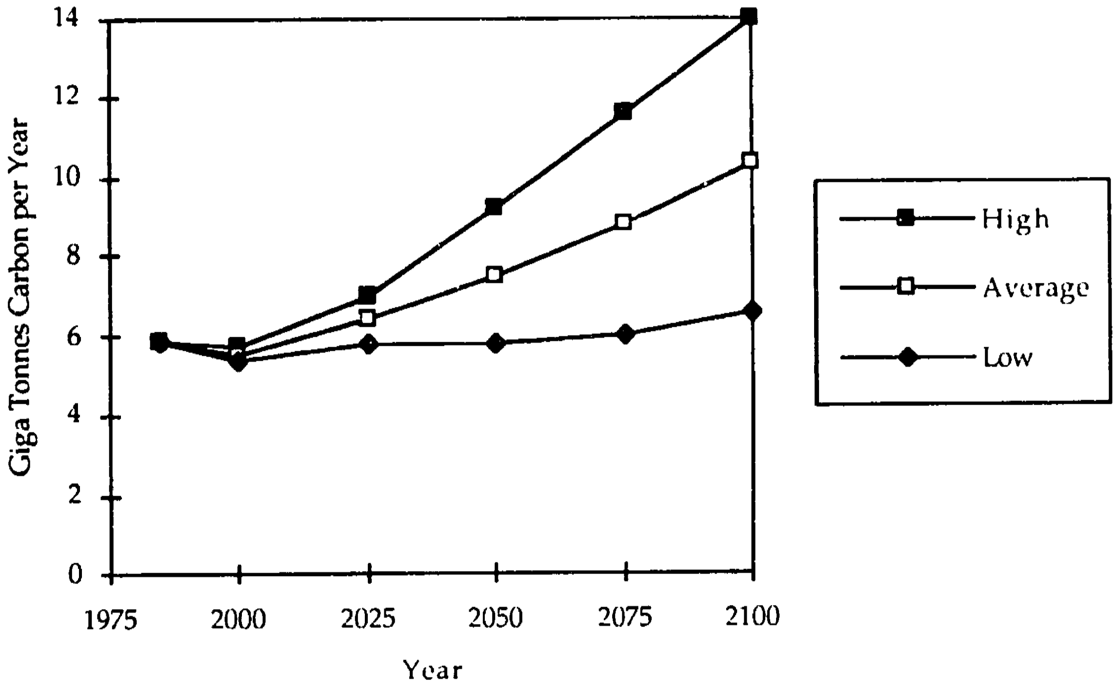


Figure 5-2c: IPCC 1990 CO_2 Emissions: Scenario C

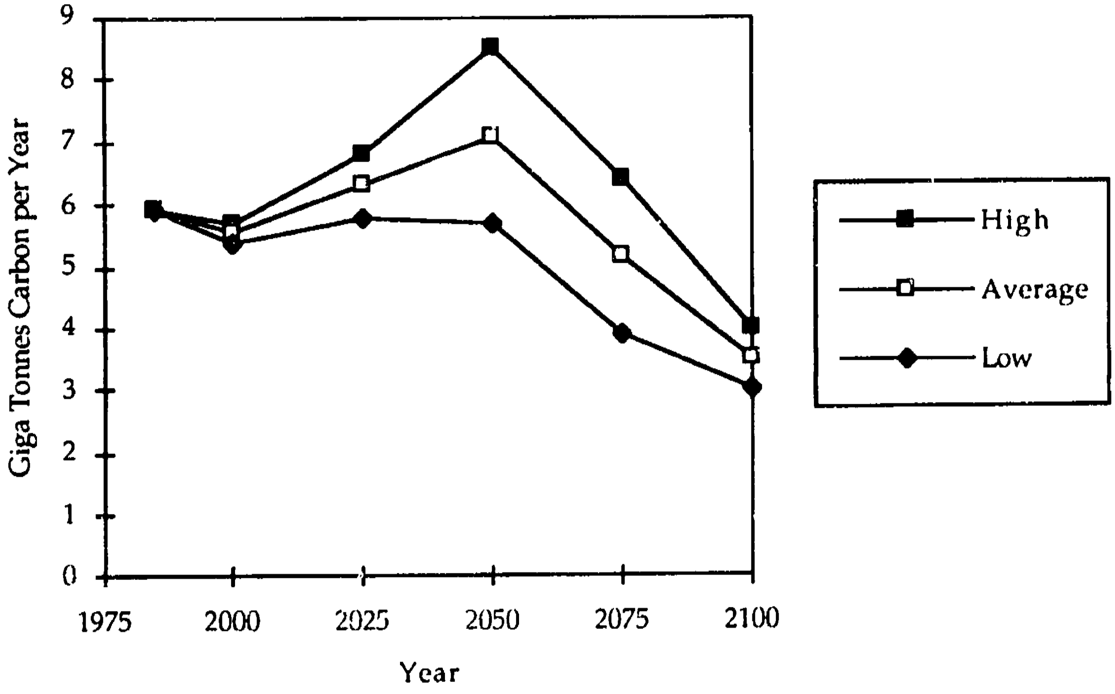
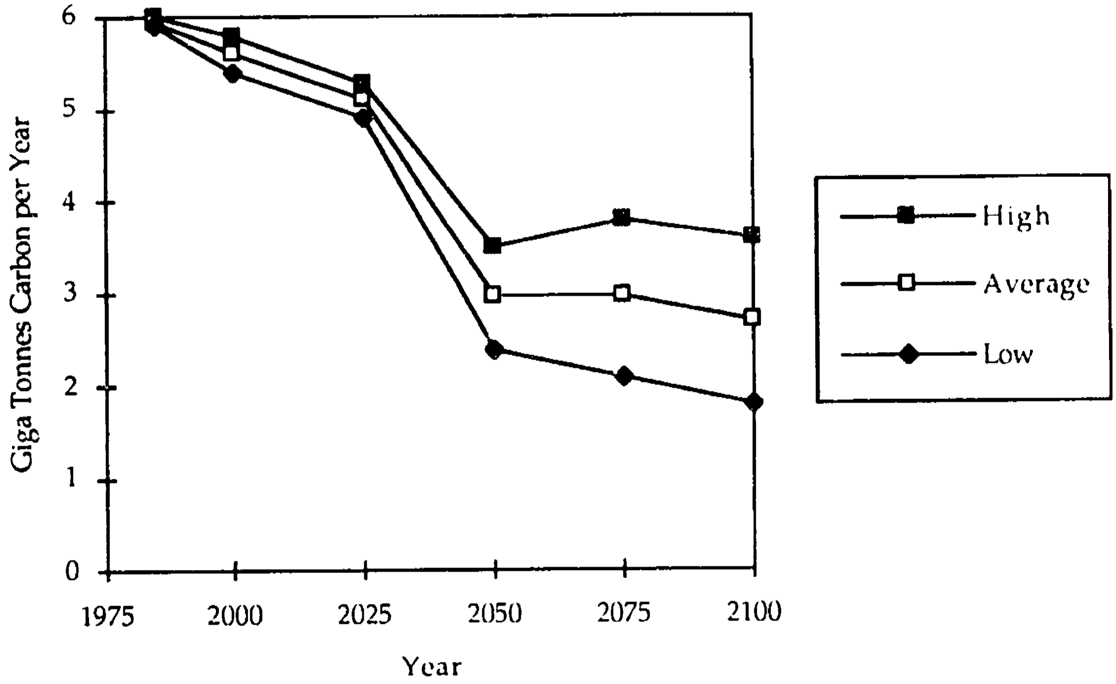


Figure 5-2d: IPCC 1990 CO_2 Emissions: Scenario D



Source: IPCC 1991, 26-29.

As discussed in Chapter 4, in addition to producing emissions scenarios, the ASF produces atmospheric concentration, forcing and warming scenarios. However, in the IPCC process only the ASF generated average emissions scenarios were used. The IPCC WG1 used these average emissions scenarios as inputs into their own models to calculate scenarios of trace gas concentrations, equivalent CO_2 concentrations, radiative forcing, warming and sea level rise. By using the average emissions scenarios WG1 essentially filtered out the uncertainty captured by the high and low growth scenarios.

Details of the Scenarios

In constructing the scenarios there were several key variables that were not manipulated (IPCC 1990a, 2). They included: the global population

Table 5-1: IPCC 1990 Scenario Assumptions

	Scenario A	Scenario B	Scenario C	Scenario D
Population	World Bank	World Bank	World Bank	World Bank
GNP	High/Low	High/Low	High/Low	High/Low
Energy Supply	Carbon Intensive	Gas Intensive	Non-Fossil Intensive	Early Non-Fossil Supply
Energy Demand	Moderate Efficiency	High Efficiency	High Efficiency	High Efficiency
Control Technology	Modest Controls	Stringent Controls	Stringent Controls	Stringent Controls
CFCs	Protocol/Low Compliance	Protocol/Full Compliance	Phase-Out	Phase-Out
Deforestation	Moderate	Reforest	Reforest	Reforest
Agriculture	Current Factors	Current Factors	Declining Factors	Declining Factors

Source: IPCC 1990a, 24.

growth rate, the extraction costs of fossil fuels, the size of the resource base for fossil fuels, the uncontrolled emission rates from energy production and consumption, the starting emission budgets for each greenhouse gas, the atmospheric response to changing greenhouse gas concentrations, and basic lifestyle preferences.

On the other hand, there were a number of key variables that were altered in order to obtain the target equivalent CO_2 levels (IPCC 1990a, 1). They included: the rate of economic growth, oil prices, energy supply, energy demand, energy efficiency, rates of deforestation and reforestation, CFC and halon production and use, and agricultural activities. Table 5-1, which is adapted from the Expert Group report, describes the major assumptions used to construct the scenarios. It is worth noting that in creating the IPCC "policy scenarios" three out of the five assumptions which were modified are related to energy policies.

A comparison of the assumptions underlying the scenarios, as shown in table 5-1 , raises a fundamental question: Should changes in the values of key variables be interpreted as policy intervention or uncertainty about the future? A couple of examples will help illustrate the importance of asking this question:

- On the energy demand side essentially what varies between the scenarios are assumptions about the rate of improvement in energy intensity. But one could ask if these are just different assumptions about efficiency improvement rates or higher efficiency improvement rates achieved by implementing a particular set of policies. Note there is a great deal of disagreement about what the appropriate rates for autonomous energy efficiency improvements are in the absence of policy intervention.

- On the energy supply side in Scenario A there is a large increase in the use of coal in the future, while in Scenario B there is a large increase in the use of natural gas in the near future, some of which would have been uneconomic according to the model. But one could ask if the increased use of natural gas is due to an actual policy change or just a change in assumptions. Perhaps a range of assumptions should be used to reflect uncertainty about the size of the resource base and future costs of extraction.

- Scenarios C and D have large increases in the use of non-fossil sources. But one could ask if this is a result of policies or does it just reflect uncertainty about future technological developments. For example, some proponents of Photovoltaics claim that over the next 15 years low cost solar PV will become a viable options with or with out policy intervention.

Thus, how one interprets the changes in scenario assumptions (i.e., as specific policies or simply uncertainty), effects how one views the resulting scenarios (i.e., either as an uncertainty range or a policy range).

The text of the expert group report (IPCC 1990a) supports interpreting the changes in assumptions between Scenarios A and B as representing uncertainty about the future, and the changes in assumptions required in order to achieve Scenarios C and D as representing policy responses. The WG3 report also encourages this interpretation of the scenarios. For example, the WG3 report states that:

> The 2030 High Emissions and 2060 Low Emissions scenarios may be viewed as two different paths that global greenhouse gas emissions could follow over the next several decades. The latter case assumes sizable improvements in energy efficiency, which may only be possible with government action. The Control Policies and Accelerated Policies scenarios require deliberate actions by governments (e.g., phasing out of CFCs, increasing fossil energy prices or using other measures to ensure penetration by renewables) (IPCC 1991, 16).

Clearly this interpretation of the scenarios gives a false sense of certainty: it uses the average economic growth rates, a single population projection, and completely neglects the uncertainty of parameters endogenous to the model (for example price and income elasticity's for energy demand).

On the other hand, in the political process scenario A was interpreted as a "business as usual" scenario (i.e., a no policy forecast). At this point it should be clear that the analysis underlying the scenarios supports a different interpretation than the way they were generally interpreted in the process. It is worth asking how this could have happened.

Conflict Between Policymakers and Analysts

A basic source of confusion, when using model generated scenarios in a policy context, stems from conflict between what policymakers want and what modelers are capable of providing. As discussed in Chapter 3 a primary feature of models like the ASF is that while they may enforces consistency, they can not forecast the future accurately. However, policymakers prefer to be given forecasts, not internally consistent scenarios. One of the people I interviewed, who has been involved in a range of model driven policy debates, stated this concisely:

> Policymakers of course want forecasts, scenarios are not of great interest. To say 'if we do nothing this might happen' is not satisfying. The question is 'if we do nothing what is likely to happen?, what are the uncertainties?' So, you actually do want a forecast, I believe, for the BAU case. You want some baseline from which you can explore the effects of policies. Once you recognize that, then I think you want to describe it as a forecast, not try to hide it as a scenario, and indicate the level of uncertainty that attaches to it as a forecast.

However, even if an analyst presents model generated results as a forecast with a given level of uncertainty, it is still difficult to prevent policymakers from focusing on a single—best guess, mean or median—forecast. One of the modelers I interviewed expressed frustration about being in this situation as follows:

> When you present only one figure, with only one line, they [the policymakers] will always accept that line, but if you are uncertain of that it is always difficult presenting these cases. I demonstrated my model in the Dutch parliament, and I gave them three different scenarios: pessimistic, optimistic, and a moderate one. All the policymakers chose the middle one, the moderate one. That's always the kind of logic/attitude they have. They don't really believe in the optimistic and pessimistic ones.

Thus the conflict between what policymakers want to be given and what models are capable of providing, helps explain how the original IPCC scenarios were interpreted. As described above, in an attempt to include some uncertainty in their analysis, analysts created high and low growth scenarios for each of the four average scenarios. However, participants in the process focused almost exclusively on the average results of scenario A (i.e., the BAU scenario).

There are at least two important lessons we should learn from the IPCC experience: 1) modelers need to be more sensitive about how their results will be interpreted in the policy process, and 2) participants in the policy process need to move beyond trying to interpret every models generated result as a forecast. The challenge for modelers is to find a way to communicate the meaning of their analysis effectively. For example, when using scenario based analysis one option might be to refrain from giving a median or best guess scenario. Another possibility, for incorporating uncertainty into an analysis, would be to use probabilistic scenario analysis. This approach will be explored in detail in Chapter 6. However, approaches which generate results that explicitly incorporate uncertainty, are likely to make policymakers uncomfortable. One person I interviewed, who has been involved in energy modeling for over a decade, expressed this conflict succinctly:

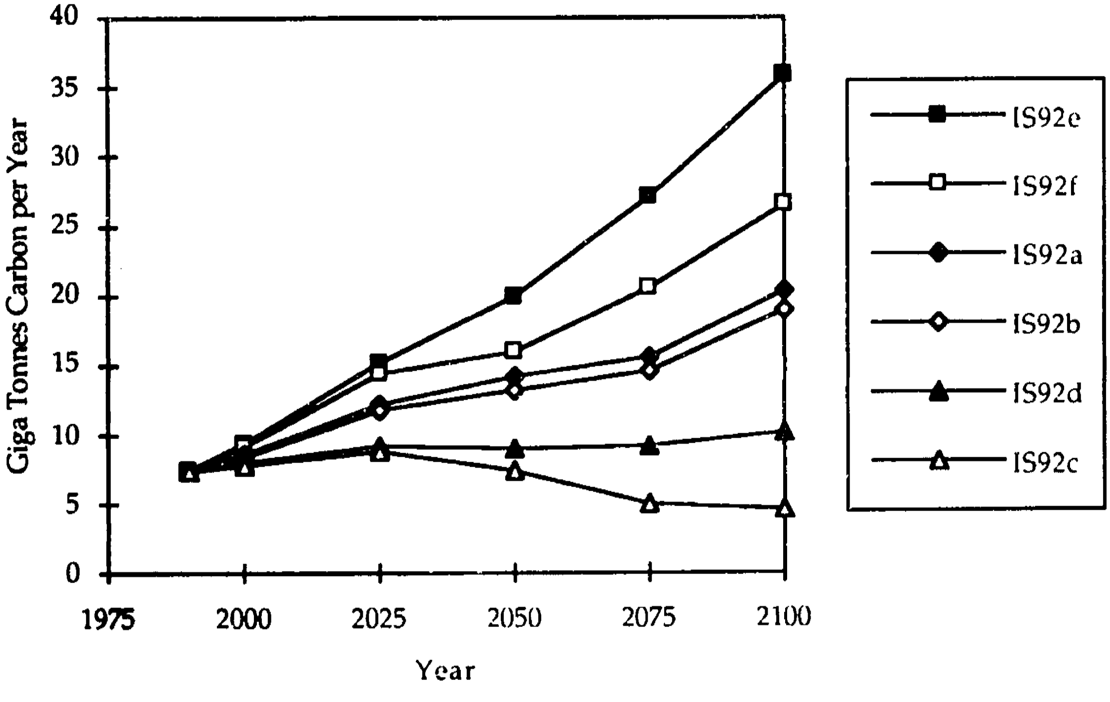
> Policymakers don't like to be told that between the 5th and 95th percentile there are about 2 orders of magnitude between what emissions can be in 100 years from now. Which makes perfect sense if your thinking about how different futures could turn out to be over the course of a century, and yet a policymaker doesn't want to know that.

However, since uncertainty is a central feature of climate change, it would be inappropriate to present results in a way that would encourage interpreting them as being more certain than they actually are. It was concern over this issue, in conjunction with the labeling controversy, which led to the creation of a new set of IPCC emissions scenarios.

The 1992 IPCC Update

The IPCC decided to "update" its original emissions scenarios at its fifth session held in Geneva during March 1991. At this meeting, the U.S. and the Netherlands were asked to co-chair the task-force to update the scenarios.[4] The result of this process was a set of six emission scenarios, which were included in the 1992 IPCC Supplement Report (IPCC 1992). The new set of emissions scenarios are shown in figure 5-3. Taken together the six new scenarios (IS92a-f) are intended to replace the original scenario A.

Figure 5-3: IPCC 1992 CO_2 Emissions Scenarios



Source: IPCC 1992, 16 & 18.

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[4] During its fifth session the IPCC decided to address six tasks in order to update its First Assessment Report. The six tasks included: assessment of net greenhouse gases emissions; predictions of the regional distributions of climate change and associated impact studies; issues related to energy and industry; forestry-related issues; vulnerability to sea level rise; and emissions scenarios (IPCC 1992).

The process of updating the scenarios created a lot of controversy within the IPCC. For example, one NGO representative described the situation after the emissions task-force met in the U.K. during July 1991 as follows:

> There was no consensus and I think a lot of people in IPCC now appreciate, whether it was intended or not, the value of having an initial target to shoot at because then some of these discussions become a lot less relevant. You know if you say, well, whatever the BAU scenario, however it is constructed, you have to end up doubling CO_2 equivalent in roughly 2030, then a lot of these other debates become less significant.

It is interesting that during the process of redefining the scenarios industry representatives, from the coal industry and World Energy Conference, vehemently argued that the energy demand and coal consumption, projected in the original BAU scenario, were much too high. They argued that the BAU scenario does not take into account a great deal of intrinsic energy efficiency that will happen in the absence of policies.

The supplement report points out that scenario IS92a is basically a modified version of original scenario A with a number of recent developments incorporated into it, such as: the London Amendments to the Montreal Protocol; revised population forecasts by the World Bank and United Nations; publication of the IPCC Energy and Industry Sub-group scenario of greenhouse gas emissions to 2025; political events and economic changes in the former USSR, Eastern Europe and the Middle East; re-estimation of sources and sinks of greenhouse gases; revision of preliminary FAO data on tropical deforestation; and new scientific studies on forest biomass (IPCC 1992, 14). Thus the updated scenario IS92a is described as if it is a new base case forecast. However, at the same time the supplement report states that the new scenario should not be interpreted as forecasts:

> Scenario outputs are not predictions of the future, and should not be used as such; they are inherently controversial because they reflect different views of the future. The results of short-term scenarios can vary considerably from actual outcomes even over short time horizons. Confidence in scenario outputs decreases as the time horizon increases, because the basis for the underlying assumptions becomes increasingly speculative. Considerable uncertainties surround the evolution of the types and levels of human activities (including economic growth and structure), technological advances, and human responses to possible environmental, economic and institutional constraints. Consequently, emission scenarios must be constructed carefully and used with great caution (IPCC 1992, 14).

This disclaimer is probably in response to complaints that the original scenarios were presented/interpreted as forecasts. It is odd that the supplement report both presents scenario IS92a as if it is a new base case forecast and yet claims that it is not a forecasts.

In addition to scenario IS92a, the supplement report includes five other scenarios (see figure 5-3). The additional scenarios were designed to incorporate a range of assumptions for population growth rates, economic growth rates, energy supplies, and restrictions on CFCs and other gases (IPCC 1992, 15). They were not designed as policy scenarios. Instead, they were developed with the recognition that there is considerable uncertainty about how future greenhouse gas emissions might evolve in the absence of policies (IPCC 1992, 14). However, the relative likelihood of the scenarios was not analyzed. Thus exactly what sort of uncertainty range the scenarios provide is unclear.

It is useful to compare the new set of scenarios to the original scenarios. As discussed above, the analysis underlying the original scenarios supports interpreting the changes in assumptions between scenarios A and B as representing uncertainty about the future. Additional uncertainty is captured by the high and low economic growth "detailed" scenarios. Thus, the range between the high economic growth scenario A and low economic growth scenario B (see figures 5-2a&b) could be viewed as the implicit uncertainty in the original scenarios. It is intriguing that the new scenarios span a range only slightly larger (4.6-35.8 GtC in 2100) than the range spanned between the high economic growth rate scenario A and low economic growth rate scenario B (6.6-32.0 GtC in 2100).

Going Beyond the IPCC Emissions Scenarios

The analysis underlying the first set of IPCC scenarios acknowledged that the future is uncertain, yet much of the uncertainty implicit in the analysis was filtered out during the political process. The interplay between analysts and policymakers, discussed above, highlights the need for modelers to be more sensitive about how their results will be interpreted in the policy process, and for participants in the policy process to move beyond trying to interpret every model generated result as a forecast.

The new set of scenarios in the 1992 IPCC supplement report responded to two distinct issues. First, the scenarios were intended to update the original BAU scenario: The new scenarios incorporated events and new information which had occurred since the completion of the 1990 IPCC reports. Second, the new scenarios responded to critics, who claimed that the original set of emissions scenarios were misleading. Thus the new scenarios were designed to explicitly included uncertainty about the future. However, the IPCC did not analyze the relative probability of the six new scenarios. In fact, the supplement reports states that the, "IPCC WG1 does not prefer any individual scenario" (IPCC 1992, 14). While this is a step forward, there is still the possibility that policymakers will be tempted to focus on a single scenario such as IS92a. In fact, when the supplement report discusses uncertainty in the climate system. it focuses on scenario IS92a.

In addition, while the new set of scenarios do incorporate uncertainty about the future, they do not include uncertainty endogenous to the model. In the next chapter, I will explore an approach for including both types of uncertainty when using energy, economic, environmental models in the climate change policy process. This approach—probabilistic scenario analysis—provides a method for moving beyond the IPCC emissions scenarios.

6. Exploring an Alternative Approach: Probabilistic Scenario Analysis

During the past 20 years expectations about future carbon dioxide (CO_2) emissions have changed dramatically. Early studies typically used time trend analysis to generate a single "best guess" or "business as usual" scenario, and predicted future CO_2 emission growth rates around 4.5% per year (Edmonds et al. 1986, 83). By the early 1980's the consensus had shifted downward significantly: In 1982 Clark reviewed a number of studies and found a consensus CO_2 emission growth rate of 2% per year (Clark 1982, 4). Even more recently the IPCC business as usual scenario had an average CO_2 emission growth rate of 1.4% per year (IPCC 1991, 26). As discussed in chapters 3 & 4, this downward shift in CO_2 emissions projections is closely linked to a downward shift in energy forecasts.

In addition, over the past 20 years, there have been a number of innovations in energy modeling/forecasting. Today the dominant mode of analysis has become "scenario analysis." As illustrated by the studies discussed in chapters 4 & 5, analysts have developed a number of approaches to scenario analysis. For example, one approach focuses on the effects of potential policy intervention on a "base case" or "business as usual" scenario. This approach was used by Edmonds and Reilly (1983), Rose et al. (1983), Chandler (1988), the CBO (1991), and the IPCC (1990).

Another approach focuses on the uncertainty in future energy use and CO_2 emissions. Different forms of this approach were used by Edmonds et al. (1984, 1986), Nordhaus and Yohe (1983) and the IPCC (1992). While these studies addressed uncertainty in future CO_2 emissions, they did not explore the effects of policies in the context of uncertainty.

This chapter uses the Edmonds-Reilly model to demonstrate an alternative approach for using energy-economic-environmental models when analyzing future CO_2 emissions. This approach—probabilistic scenario analysis—can be used to explore the effects of policies in the context of uncertainty. It builds specifically on the work by Nordhaus and Yohe (1983) and Edmonds et al. (1986).

The body of this chapter is divided into three main sections. I begin with a review of the Nordhaus and Yohe (1983) and Edmonds et al. (1986) studies. This review is intended to give the reader a general understanding of the probabilistic scenario analysis approach. Second, I describe the methodology used in my analysis. This section discusses both how input distributions for uncertain parameters were chosen and how scenarios were generated. And third, I present and discuss the results of six probabilistic policy experiments.

Nordhaus and Yohe (1983) Probabilistic Scenario Analysis

The first formal probabilistic scenario analysis of future CO_2 emissions was performed by Nordhaus and Yohe in 1983. They developed a simple model of CO_2 emissions from energy use. The model included two types of energy: fossil (i.e., carbon emitting) and non-fossil (i.e., non-carbon emitting) energy. They used their model (1) to estimate the inherent uncertainty surrounding future CO_2 emissions and atmospheric concentrations, and (2) to determine which parameters were most important in producing the uncertainty.

Nordhaus and Yohe developed a set of probabilistic scenarios by assigning probability distributions to ten key input parameters.[1] As Nordhaus and Yohe point out, their approach does not try resolve current uncertainties but tries to represent them as accurately as possible and to integrate them into the modeling process in a consistent fashion (Nordhaus and Yohe 1983, 88). The distinct advantage of a probabilistic approach over a more qualitative one, like the approach included in the 1992 IPCC supplement report, is that it gives policymakers a sense of the relative likelihood of different outcomes.

Percentiles for carbon emissions from the Nordhaus and Yohe analysis are shown in figure 6-1. Figure 6-1 indicates that, based on Nordhaus and Yohe's analysis, in the absence of policy intervention for the year 2050 there is a 5% chance that carbon emissions will be below 5 GtC/yr, a 25% chance that carbon emissions will be below 8 GtC/yr, a 50% chance that carbon emissions will be below 15 GtC/yr, a 75% chance that carbon emissions will be below 17 GtC/yr, and a 95% chance that carbon emissions will be below 26 GtC/yr.

Nordhaus and Yohe also ranked parameters by their relative contribution to uncertainty. They found that the parameter representing the ease of substitution between fossil and nonfossil fuels was the most important parameter influencing the uncertainty in carbon emissions. The second most important parameter was the general productivity growth rate (a parameter which affects both energy and labor productivity). It is interesting that Nordhaus and Yohe found uncertainty about the population growth rate to rank relatively low on their list of importance.

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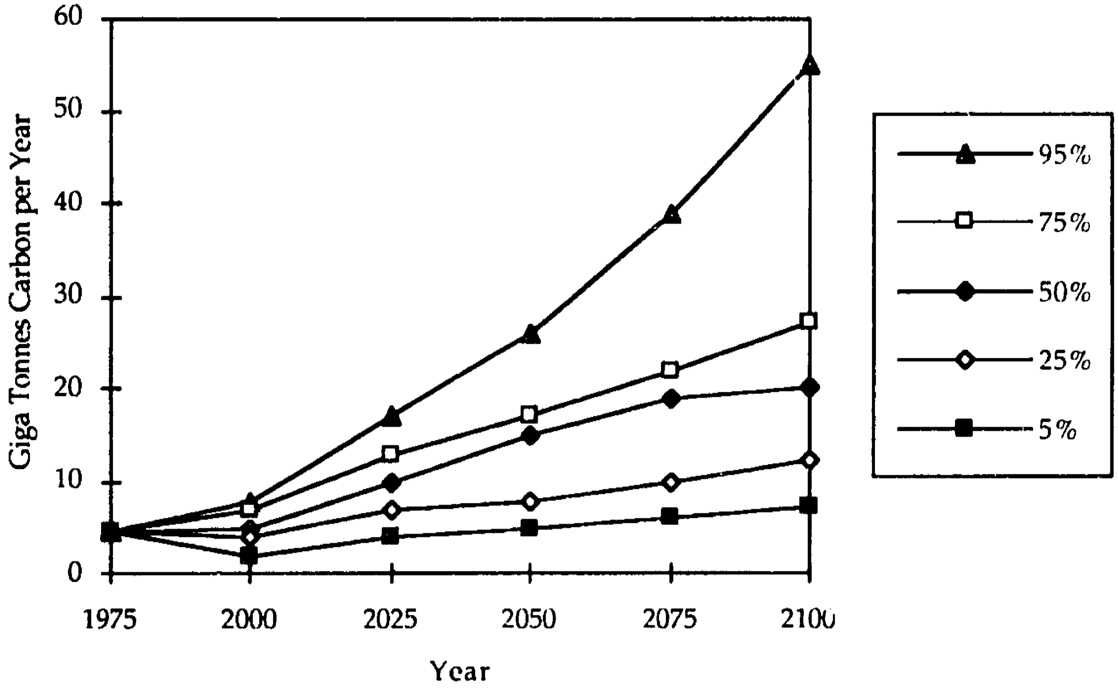
[1] For sampling purposes Nordhaus and Yohe discretized the distribution for each variable of the 10 uncertain variables into high, medium and low values. They did this in such a way as to make the variance of the discretized values equal to the variance of the continuous variable. They sampled 1000 of the possible 59,049 (=3^{10}) outcomes (Nordhaus and Yohe 1983, 90).

Figure 6-1: Carbon Emissions From Nordhaus and Yohe Probabilistic Scenario Analysis



Source: Nordhaus and Yohe 1983, 94.

Finally, Nordhaus and Yohe explored the effects of policies aimed at reducing carbon emissions from the energy sector by applying various levels of carbon taxes on fossil fuels. However, in their policy scenarios they set all ten uncertain parameters at their most likely values. Thus they did not explore the effects of carbon taxes in the context of uncertainty.

Edmonds et al. (1986) Uncertainty Analysis

Edmonds et al. conducted a similar uncertainty analysis in 1986. Like the Nordhaus and Yohe study, Edmonds et al. focused on representing uncertainty about various model parameters as accurately as possible. They did not attempt to resolve uncertainty. However they used a different model—the Edmonds-Reilly model—which has much more detail in its description of energy producing and consuming sectors than the model developed by Nordhaus and Yohe.

Edmonds et al. conducted a Monte-Carlo analysis using the Edmonds-Reilly model. First they defined uncertainty ranges for 79 input variables governing: population; economic growth; energy conservation; the resource base for fossil fuels, uranium, and biomass; technology descriptions for electric power generation, synfuel conversion, and solar power; environmental costs; and the effects of energy prices on overall economic activity. Then they used Monte-Carlo sampling to generate 400 scenarios. For each scenario they tracked 95 output variables. Finally, they determined the relative contributions of each of the input variables to the overall uncertainty of the output variables. Thus like Nordhaus and Yohe they produced an uncertainty range of future CO_2 emissions and ranked different parameters based on their contribution to output uncertainty.

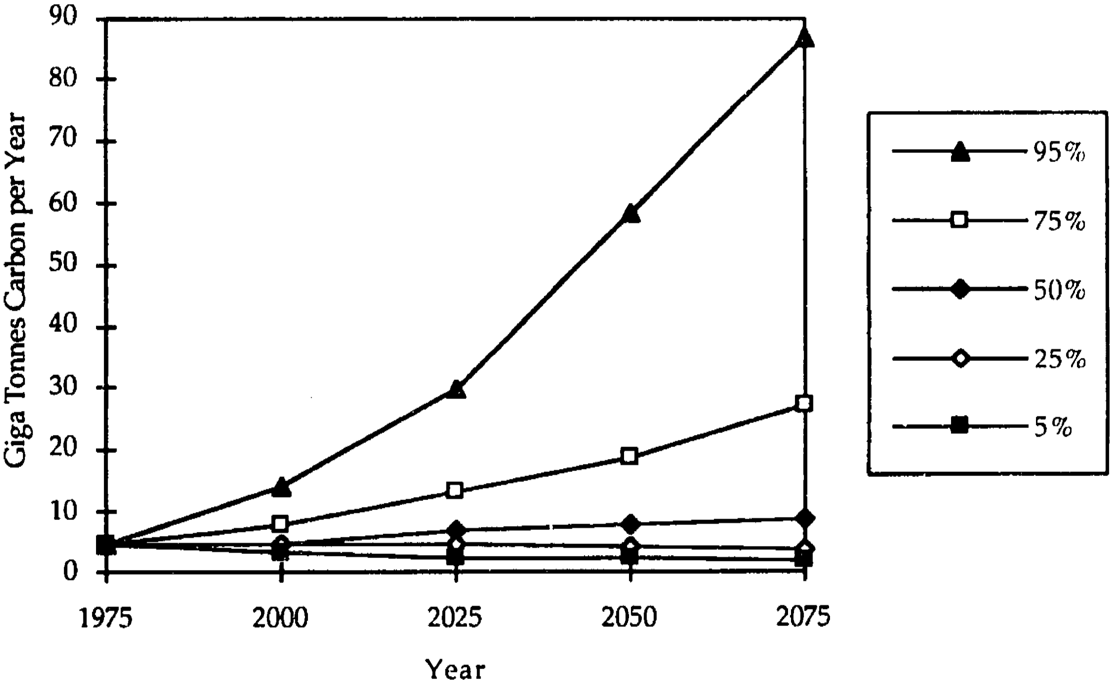
Edmonds et al. found that in the Edmonds-Reilly model four variables played dominant roles in determining CO_2 emissions:

- Labor productivity growth rate in developing countries,
- Labor productivity growth rate in developed countries.
- Exogenous energy end-use efficiency improvement rate, and
- Income elasticity of demand for aggregate energy in developing regions.

And that five additional factors were important in determining CO_2 emissions:

- Biomass costs,
- Environmental costs of coal extraction in developing regions,
- Income elasticity of demand for energy in the OECD,
- Aggregate price elasticity of demand for energy, and
- Rate of technological improvement of coal production.

Figure 6-2: Carbon Emissions from Edmonds et al. Uncertainty Analysis



Source: Edmonds and Darmstadter 1990a, 10.

It is interesting that the most important parameter in the Nordhaus and Yohe study, the interfuel substitution parameter, was not on the list of important parameters in the Edmonds et al. study. This difference is probably due to the increased detail included the Edmonds-Reilly model. For example, the Edmonds-Reilly model incorporates multiple sources of energy supply and allows for interfuel substitution options.

In their analysis Edmonds et al. concluded that future emissions of CO_2 from energy are highly uncertain. They found that a range for the average annual CO_2 emissions growth rate of 3 percent to -1.4 percent per year was needed to bracket 90 percent of the cases! Further roughly 25 percent of the cases resulted in constant or declining emissions. Percentiles for carbon emissions from their analysis are shown in figure 6-2.

Given the level of uncertainty in making long-term predictions it is not surprising that figure 6-2 includes a very wide range of possible future CO_2 emissions paths; however, the results of this analysis should still be viewed with caution. As stated in the report's executive summary, "The fact that uncertainty is described should not mislead the readers into concluding that whereas we do not know the future with certainty, we do know the uncertainty about the future with certainty." The results are still dependent on the accuracy of both the model and the input assumptions (including input variable distribution assumptions).

From the Edmonds et al. study, we learn that the model's structure is very important in determining the model's results and that changing the model's inputs can be equivalent to altering the model's structure. This is significant because it is not obvious which are the "right" values to use for key parameters identified in the analysis.

In sum, by systematically exercising their model Edmonds et al. were able to test the sensitivity of CO_2 emissions forecasts to changes in input assumptions, explore the behavior of the model under extreme and what are currently considered to be unlikely assumptions, assess the relative importance of alternative input assumptions and present their results in terms of a best guess with confidence intervals (Edmonds 1986, 3). On the other hand in their analysis Edmonds et al. looked only at uncertainty, they did not explicitly consider policies to control emissions of CO_2. This means that their analysis gives us more insight into the modeling framework than into the efficacy of various policy options.

A New Approach

The approach taken in this chapter uses the Edmonds-Reilly model and builds on the work by Nordhaus and Yohe (1983) and Edmonds et al. (1986) described above. First, five key uncertain parameters were chosen based on the results of Nordhaus and Yohe (1983) and Edmonds et al. (1986). The five parameters included in the analysis were:

- Population growth rate,
- Labor productivity growth rate,
- Exogenous energy end-use efficiency improvement rate,
- Income elasticity of demand for aggregate energy, and
- Aggregate price elasticity of demand for energy.

After choosing the parameters, probability distributions were defined for each parameter (see next section for detailed descriptions of the distributions). Then a computer program called PRISM (developed at Oak Ridge National Laboratory) was used to sample each input distribution and generate 100 sets of parameter values. Finally the Edmonds-Reilly model was run using the PRISM generated samples to set the appropriate input parameter values.

The result of this process was a set of 100 equally probable scenarios of future CO_2 emissions (and other data). However, unlike the previous studies by Nordhaus and Yohe (1983) and Edmonds et al. (1986), I took the analysis one step further. Instead of using the uncertainty analysis to gain insight into the relative importance of various input parameters on output uncertainty, I focused on <u>determining how various policies would affect the output distribution of CO_2 emissions</u>. Before discussing the results of this analysis it would be useful to discuss how the input distributions were chosen.

Defining Uncertainty Ranges for Input Parameters

One of the first steps in the analysis involved defining uncertainty distributions for the five key input parameters. This is a highly subjective process. For the purpose of illustrating how one might try to do this I chose to use triangular distributions.[2] As Morgan and Henrion (1990) point out there are two main reasons for choosing to represent a parameter's uncertainty with a triangular distribution: (1) using a triangular distribution implies that values toward the middle of the defined range are more likely to occur than values near either extreme, and (2) using a triangular distribution emphasizes the fact that the details of the shape of the distribution are not known precisely. However, the consequences of choosing to use triangular distributions are that one should not try to over-interpret or have a false sense of confidence in the subtle details of a model's results (Morgan and Henrion 1990, 96).

In order to specify a triangular distribution one needs to define three values: the minimum, the mode, and the maximum. Next I will briefly discuss how these values were chosen for each of the five input parameters. Also, I will provide histograms of the samples generated by PRISM for each parameter.

Population

Many recent analysts have utilized World Bank population projections provided by Zachariah and Vu (1988). For example, they have been used by the EPA (1989), the IPCC (1990), the Energy Modeling Forum (1991) and others. The World Bank estimate assumes that global population growth

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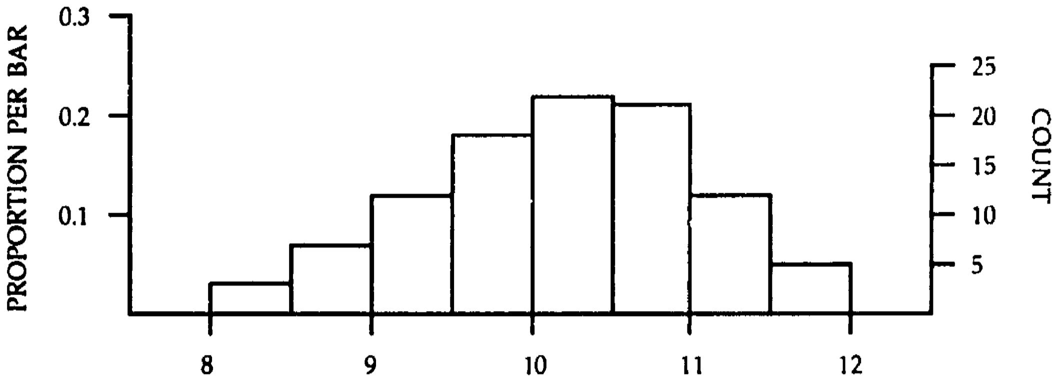
[2] Other possible distributions one could chose when using PRISM include: normal, log normal, uniform, loguniform, and logtriangular.

rates will slow down considerably after the year 2000, and that global population will stabilize around 10 billion after the year 2050. While this estimate may seem plausible, it is based on a set of highly subjective assumptions, and represents only one path that the world may evolve on. Thus in order to capture the inherent uncertainty about future population growth rates, in my analysis, I used the following triangular population distribution:

Population Stabilization Level (in 2075)

Region	Minimum	Mode	Maximum	
Global	8	10	12	Billion

Figure 6-3: Histogram of PRISM Generated Population Stabilization Level Samples



The histogram shown in figure 6-3 was generated from the actual PRISM samples for the population stabilization level. As shown in figure 6-3, dividing 100 samples into 8 classes yields a histogram which roughly approximates a triangle. The histogram would look more like a triangle if larger number of samples and narrower classes were used.

Labor Productivity Growth Rate

The nine regions of the Edmonds-Reilly model were combined into two aggregate regions when calculating labor productivity growth rates: North (N. America, Europe, USSR, Japan and Australia) and South (Asia, Africa, L. America and Middle East). Edmonds et al. (1986) used a similar aggregation for labor productivity growth rate in their uncertainty analysis. In the studies conducted by the EPA (1989) and the IPCC (1990) labor productivity growth rate assumptions were extrapolated from World Bank (1987) projections for 1986-1995. Both the EPA (1989) and the IPCC (1990) used the same set of "high growth" and "low growth" labor productivity growth rate assumptions. In all of the EPA (1989) and IPCC (1990) scenarios the growth rate decreases after 2000 by approximately 0.5% per 25 years.

In contrast when running the Edmonds-Reilly model the labor productivity growth rate is held constant during each model run. The growth rates I chose were designed to include the high and low growth assumption of the EPA (1989) and IPCC (1990). In my analysis I used the following triangular labor productivity growth rate distribution:

Labor Productivity Growth Rate

Region	Minimum	Mode	Maximum	
North	0.0	1.5	2.5	% per year
South	1.0	2.5	3.5	% per year

Figure 6-4a: Histogram of PRISM Generated Labor Productivity Growth Rate Samples for the North

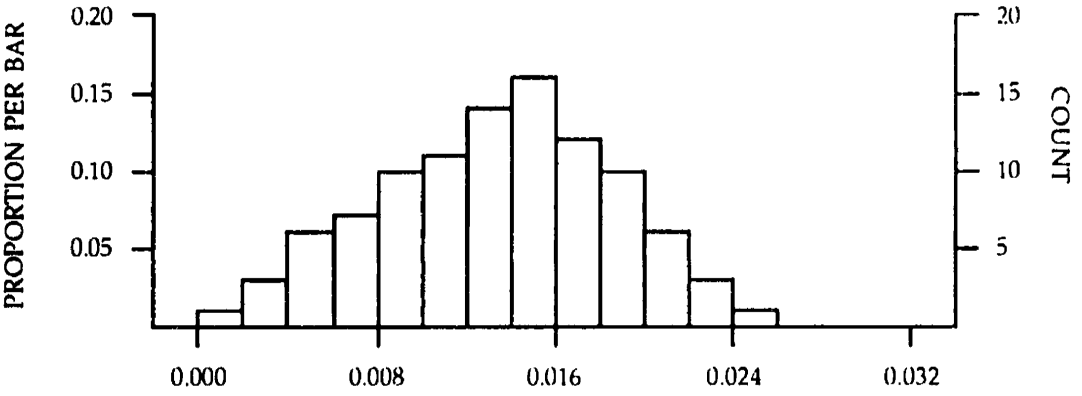
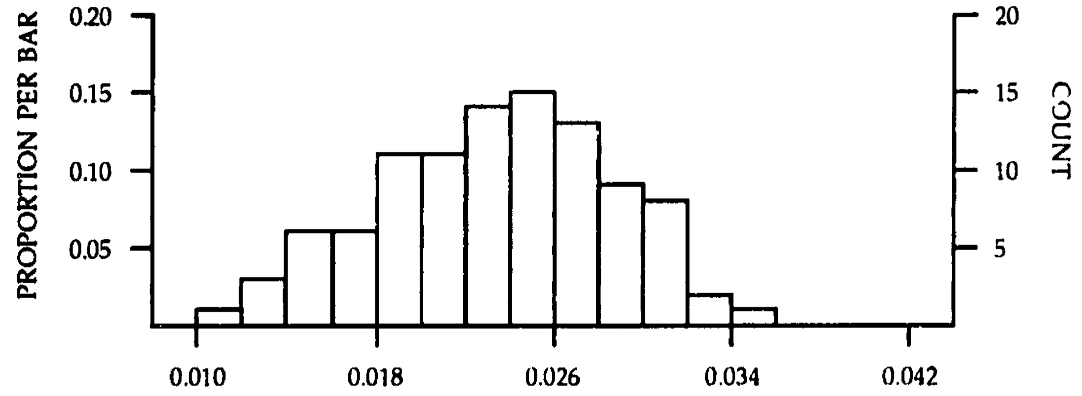


Figure 6-4b: Histogram of PRISM Generated Labor Productivity Growth Rate Samples for the South



Exogenous Energy End-Use Efficiency Improvement Rate

In the Edmonds-Reilly model the exogenous energy end-use efficiency improvement rate represents the rate at which energy use per unit output declines over time as a consequence of technological change. It is a rate of technical improvement which is independent of population, GNP and prices. Model results are very sensitive to small changes in its value (see Edmonds et al. 1986, Edmonds and Barns 1991). As illustrated by a series of articles on CO_2 emission limits in *The Energy Journal* (Hogan 1990; Manne and Richels 1990a&b; Lave 1990; Perry 1990; and Williams 1990) there is a great deal of controversy over what is an appropriate value to use for this parameter. Analysts can not even agree on what the historical value has been. For example, Manne and Richels (1990a) and Hogan (1990) argue that there is no evidence for an exogenous energy end-use efficiency improvement rate in the post-1947 historical record. On the other hand, Williams (1990) argues that the historical rate between 1920 and 1973 averaged 0.9%.

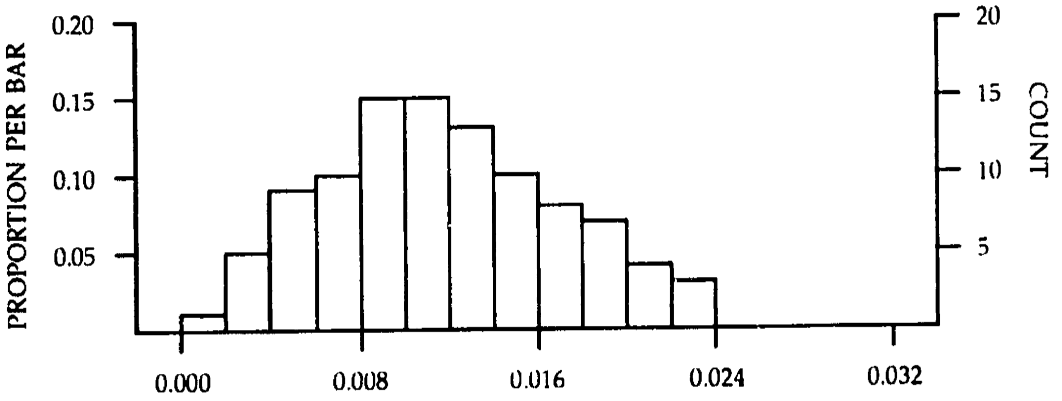
There is also a great deal of disagreement about whether on not policies can be used to increase the rate of exogenous energy end-use efficiency improvements in the future. This parameter is at the heart of the technical optimist vs. pessimist debate, and the economic vs. technological modeling approaches. It is sometimes treated as a policy parameter; however, it is not really a policy parameter. Instead is can be argued that there are policy changes which could affect it such as: regulatory changes in the electric power sector, increases in CAFE standards, appliance efficiency standards, increased government funding of energy efficiency R&D, etc.

In my analysis I defined the exogenous energy end-use efficiency improvement rate distribution based largely on work by Edmonds et al. (1986) and Edmonds and Barns (1991). I used the following triangular distribution for exogenous energy end-use efficiency improvement rate:

Exogenous Energy End-Use Efficiency Improvement Rate

Region	Minimum	Mode	Maximum	
Global	0.0	1.0	2.5	% per year

Figure 6-5: Histogram of PRISM Generated Exogenous Energy End-Use Efficiency Improvement Rate Samples



Income and Price Elasticities of Demand for Aggregate Energy

Typically values chosen by analysts for price and income elasticities are treated as if they are defined constants. In reality they are empirical functions with a great deal of uncertainty associated with them. Uncertainty about income and price elasticities arise primarily from subjective judgment and disagreement about how much the future is likely to be like the past. In my analysis using the Edmonds-Reilly model, income elasticity is aggregated into North and South (same as labor productivity) while price elasticity is set globally. Both parameters are held constant during each model run.

In my analysis I defined the elasticity distributions based largely on work by Edmonds et al. (1986) and Edmonds and Barns (1991). I used the following triangular distributions for income and price elasticities:

Income Elasticity of Demand for Aggregate Energy

Region	Minimum	Mode	Maximum
North	0.5	1.0	1.3
South	0.6	1.2	2.0

Figure 6-6a: Histogram of PRISM Generated Income Elasticity of Demand for Aggregate Energy Samples for the North

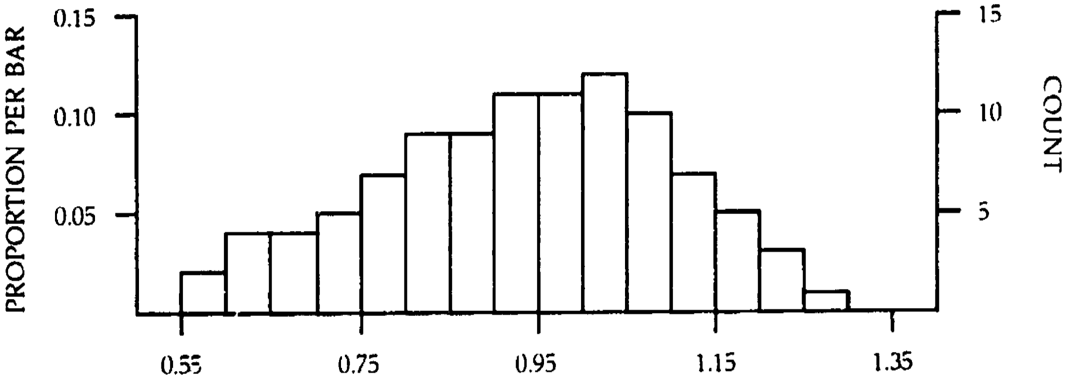
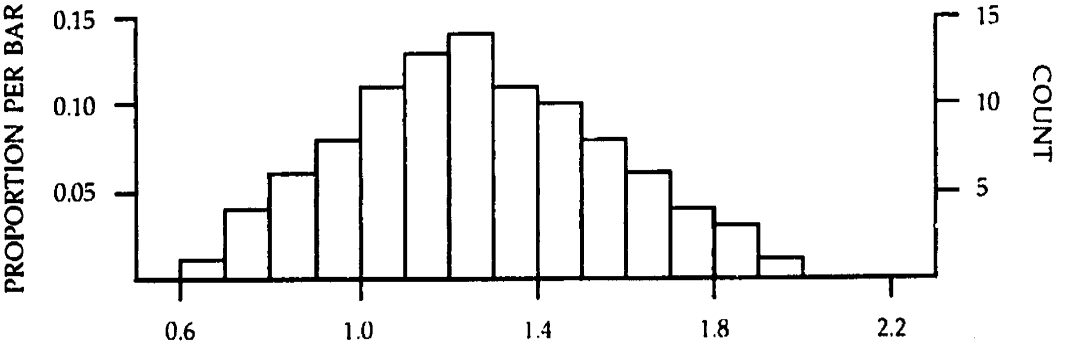


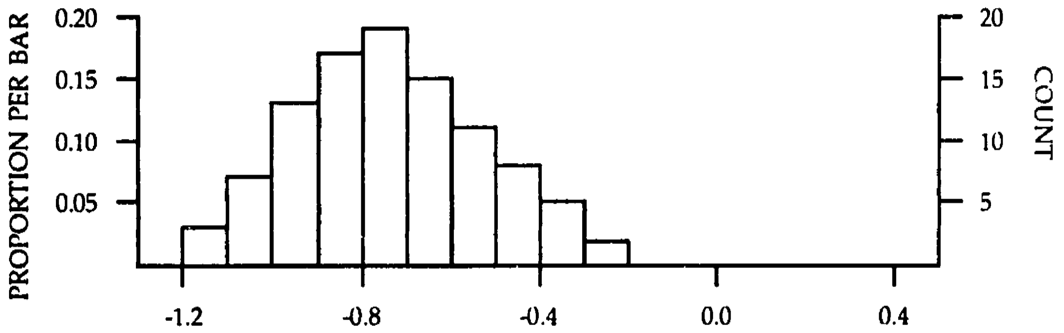
Figure 6-6b: Histogram of PRISM Generated Income Elasticity of Demand for Aggregate Energy Samples for the South



Aggregate Price Elasticity of Demand for Energy

Region	Minimum	Mode	Maximum
Global	-1.2	-0.8	-0.2

Figure 6-7: Histogram of PRISM Generated Aggregate Price Elasticity of Demand for Energy Samples



Generation of Samples Using PRISM

After defining the input distribution as described above PRISM was used to generate samples to be used when running the Edmonds-Reilly model. The technique for generating samples used by PRISM is called Latin-Hypercube sampling. In Latin-Hypercube sampling, to generate *n* samples, each input distribution is divided up into *n* equiprobable intervals. Then a single value is sampled (at random) from within each of the intervals. Thus for each input distribution a sample of *n* values is produced that is more uniformly distributed than random sampling. Then *n* sets of samples are generated by selecting one value at random from each of the input samples, without replacement. The result is *n* sets of samples, in which each value from each input is used only once (Morgan and Henrion 1990, 204-5). In my analysis I set *n* equal to 100. Thus PRISM was used to generate 100 sets of samples.

Base Output Distribution

I ran the Edmonds-Reilly model with the PRISM generated sets of samples and produced a set of 100 scenarios.[3] The 100 scenarios are shown in Figure 6-8. I will refer to them as my "base output distribution." Figure 6-9 shows the percentiles for carbon emissions in a similar format to Nordhaus and Yohe (figure 6-1) and Edmonds et al. (figure 6-2).[4] My results fall between the results of these two earlier studies.

In 2075 the Edmonds et al. (1986) study shows a range of 2 to 87 GtC/yr for the 5th to 95th percentiles, and a range of 4 to 27 GtC/yr for the 25th to 75th percentiles; meanwhile, in 2075 my base output distribution shows a range of 1.6 to 40 GtC/yr for the 5th to 95th percentiles, and a range of 4.6 to 19 GtC/yr for the 25th to 75th percentiles. It is not surprising that my results span a narrower range than the results presented by Edmonds et al., because Edmonds et al. were varying 79 variables in their analysis while I was varying 5 variables. In fact it is interesting how much of the uncertainty is produced by the 5 variables I chose to vary.[5]

In comparison to the Nordhaus and Yohe study, in 2100 my base output distribution shows a range of 1.4 to 52 GtC/yr for the 5th to 95th

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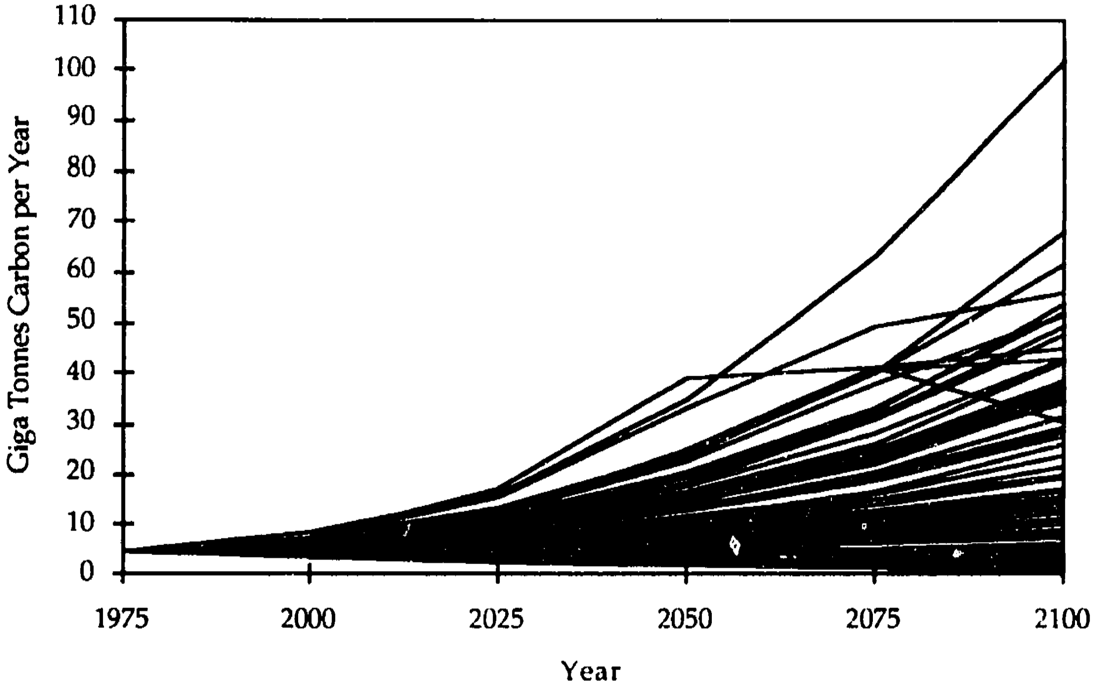
[3] I modified version 2.50 of the Edmonds-Reilly model to automatically run 100 times using the PRISM generated data file. The modified version of the Edmonds-Reilly model and PRISM were both run on the Energy Lab's Micro Vax 3400 using Vax/VMS V 5.4-3.

[4] The percentiles are determined from the actual sampling distribution. In other words, they are derived from the output distribution which is generate by the set of parameter input distributions described above. Determining percentiles for a set of 100 scenarios involves a straight forward procedure. First sort the carbon emissions in each period, then by definition the 5th, 25th, etc. sample from each ordered set corresponds to the 5th, 25th, etc. percentile.

[5] The 5 variables I chose to vary include 6 out of 9 of the variables found to be most important in terms of contributing to uncertainty in the 1986 Edmonds et al. study.

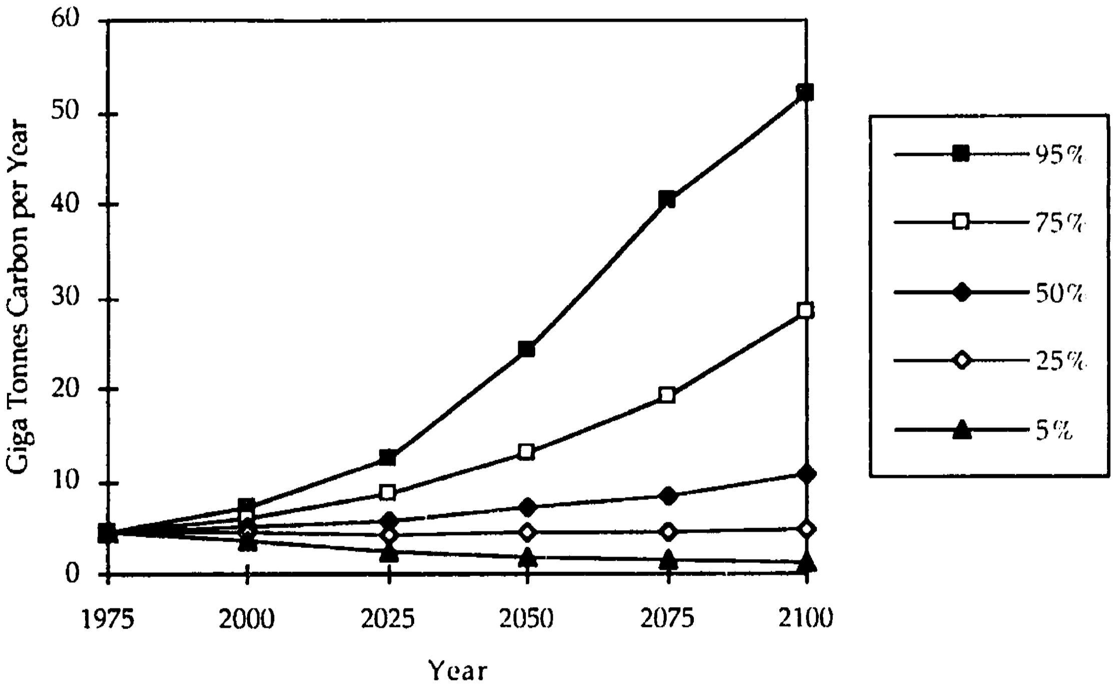
Figure 6-8: Carbon Emissions for 100 Base Output Scenarios



percentiles, and a range of 4.9 to 28 GtC/yr for the 25th to 75th percentiles; meanwhile, the Nordhaus and Yohe (1983) study shows a range of 7.2 to 55 GtC/yr for the 5th to 95th percentiles, and a range of 12 to 27 GtC/yr for the 25th to 75th percentiles.

Thus my base output distribution is in line with previous work done by Edmonds et al. (1986), and Nordhaus and Yohe (1983). However, these two previous studies focused their uncertainty analysis on defining base output distributions. In contrast, I extended the probabilistic approach by also conducting probabilistic policy experiments with the Edmonds-Reilly model.

Figure 6-9: Carbon Emissions Percentiles for Base Output Scenarios



Implementing Policies in the Context of Uncertainty

The use of probabilistic scenario analysis explicitly acknowledges that there is uncertainty in a model's structure and in parameters which drive a model. These two inherent uncertainties mean that a model's output will also be uncertain. This is true when using a model to generate a base output distribution, as described above, and when conducting policy experiments with a model. In fact as pointed out in chapter 4, because of the inherent uncertainty in model generated results, instead of testing policy options on a single future it makes sense to investigate the effectiveness of various policy options across an entire set of possible futures. After all, what we really ought to be concerned about is how a particular set of policies will effect the distribution of possible futures instead of how they will effect a specific future.

I used the Edmonds-Reilly model to conduct 6 probabilistic policy experiments: 3 experiments used different levels of carbon taxes based on a fuel's carbon content; 1 experiment applied a carbon tax levied as a fixed rate; and 2 experiments explored the effects of changing the input distribution for the exogenous energy end-use efficiency improvement rate. Thus 7 sets of scenarios (1 base and 6 policy) were generated using the Edmonds-Reilly model. Since each set of scenarios contains 100 individual scenarios, a total of 700 scenarios were generated. Next I will discuss both how each policy was implemented and the results of each probabilistic policy experiment.

Carbon Tax Based on a Fuel's Carbon Content

The most commonly discussed policy with respect to climate change is a carbon tax based on a fuel's carbon content. Typically, such a tax is only applied to fossil fuels and is based on the carbon emission coefficients for each fuel. Table 6-1 shows typical values for carbon emission coefficients.

Table 6-1: Carbon Emissions Coefficients

Fuel	Carbon Emissions
Liquids	19.2 TgC/EJ
Gases	13.7 TgC/EJ
Solids	23.8 TgC/EJ
Carbonic Rock Mining	27.9 TgC/EJ

Source: Edmonds and Barns 1991.

Using the emission coefficients shown in table 6-1 would imply that a \$100/tC tax would be equivalent to a \$1.92/gJ tax on oil, \$1.37/gJ tax on gas, \$2.38/gJ tax on coal, and \$2.79/gJ tax on shale oil (from carbonic rock).[6] Thus a \$100/tC

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[6] All prices in this chapter are in 1990 prices unless other wise noted.

tax applied in 1990 would have increased the cost of minemouth coal by almost 250%, crude oil by over 70% and wellhead natural gas by about 80% (DOE 1991, 63).[7]

During the past couple of years, analysts have explored a wide range of carbon taxes. For example, Montgomery (1991) reviewed the results of 4 studies using different energy models (Global 2100, Jorgenson-Wilcoxen, Edmonds-Reilly, and DRI) and found that taxes ranging from $60/tC to $427/tC were required in order to stabilize carbon emissions in 2020 at 80% of 1988 levels (Montgomery 1992, 11). In my analysis I looked at carbon taxes up to $300/tC.

The Edmonds-Reilly model does not contain a parameter for taxes based on carbon content. However, the model does contain a parameter for the "Environmental Cost of Energy." I used this parameter to simulate a carbon tax. This is a reasonable approach since the environmental cost parameter is applied as an add on cost to all grades of a given fuel (i.e., it is equivalent to a tax). Thus using the carbon emission coefficients given in table 6-1, I was able to translate a given carbon tax into equivalent environmental costs for oil, gas, coal, and shale oil.

I ran the model with 3 different levels of carbon taxes: $100/tC, $200/tC, and $300/tC. The trajectories for how these taxes were applied over time are shown in figure 6-10. In all cases the carbon tax started at $0/tC and increased linearly to its final value in 2050. After 2050 the tax remained constant. Thus the taxes were phased in over a 75 year period. This is a very long phase in time for a tax. One could argue that it would be possible to

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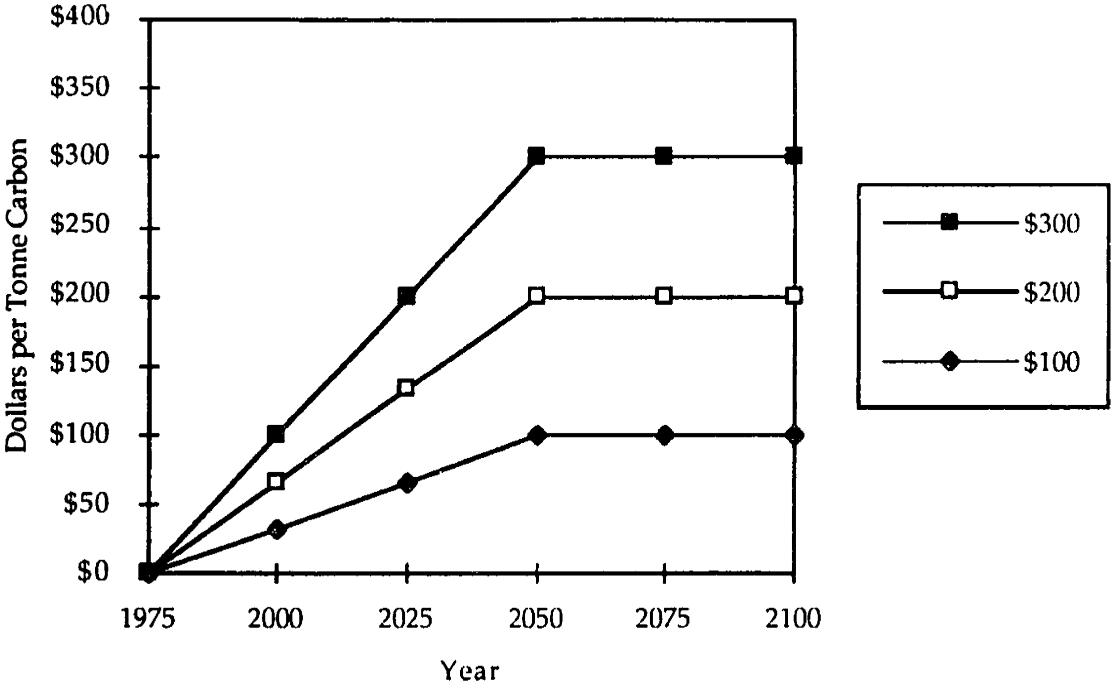
[7] Assumes a base cost, in 1989$, for coal of $23.02/short ton, for oil of $16.81/bbl, and for natural gas of $1.81/tcf (DOE 1991, 63).

Figure 6-10: Carbon Tax Trajectories for Various Tax Levels



phase in a carbon tax (even a very large one) over a much shorter time period, say 20 or 25 years.

Percentile graphs of the results for a $100/tC tax, $200/tC tax, and $300/tC tax are shown figures 6-11, 6-12, and 6-13. Note that the scales are not the same on each of these figures. Also, in order to be able to compare the results more easily, a box plot of carbon emissions in 2075 for the base output distribution, and the three tax levels is shown in figure 6-14. Table 6-2 contains a basic description of how to interpret box plots.

As expected larger carbon taxes lead to lower carbon emissions. Thus a $100/tC tax keeps carbon emissions nearly constant for the 50th percentile through 2100, a $200/tC tax stabilizes carbon emissions for the 75th percentile by 2075, and a $300/tC tax comes very close to stabilizing carbon emissions for the 95th percentile by 2075. These results show that imposing a carbon tax based on carbon content can have a significant effect on carbon emissions.

Figure 6-11: Percentiles of Edmonds-Reilly Model Runs With a $100/tC Tax

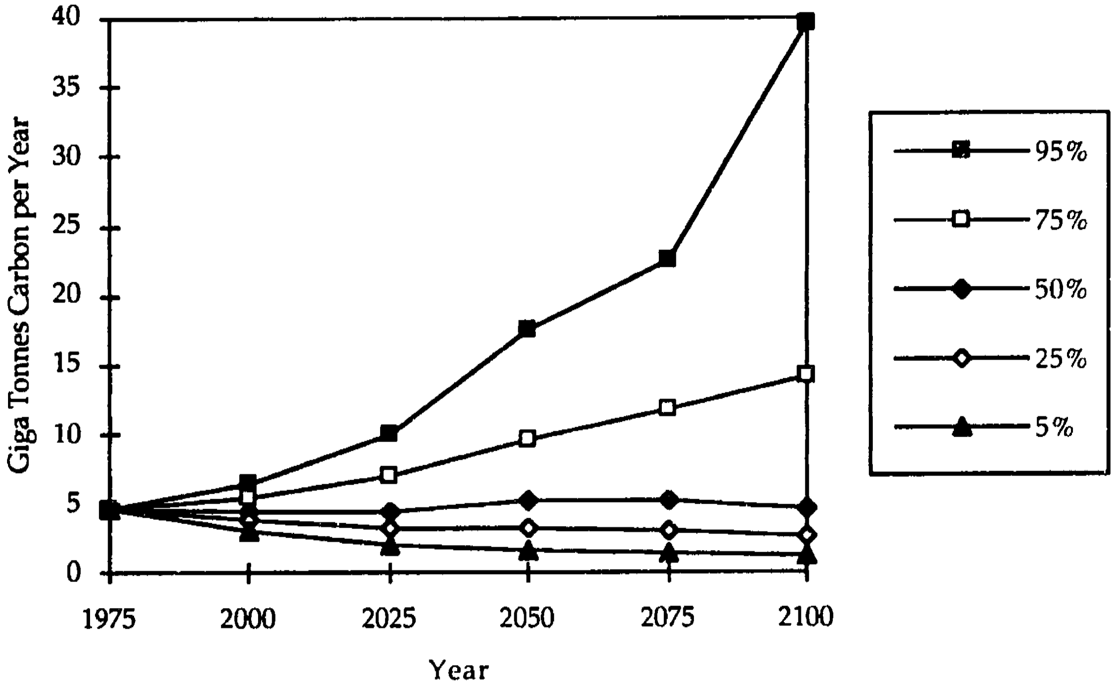


Figure 6-12: Percentiles of Edmonds-Reilly Model Runs With a $200/tC Tax

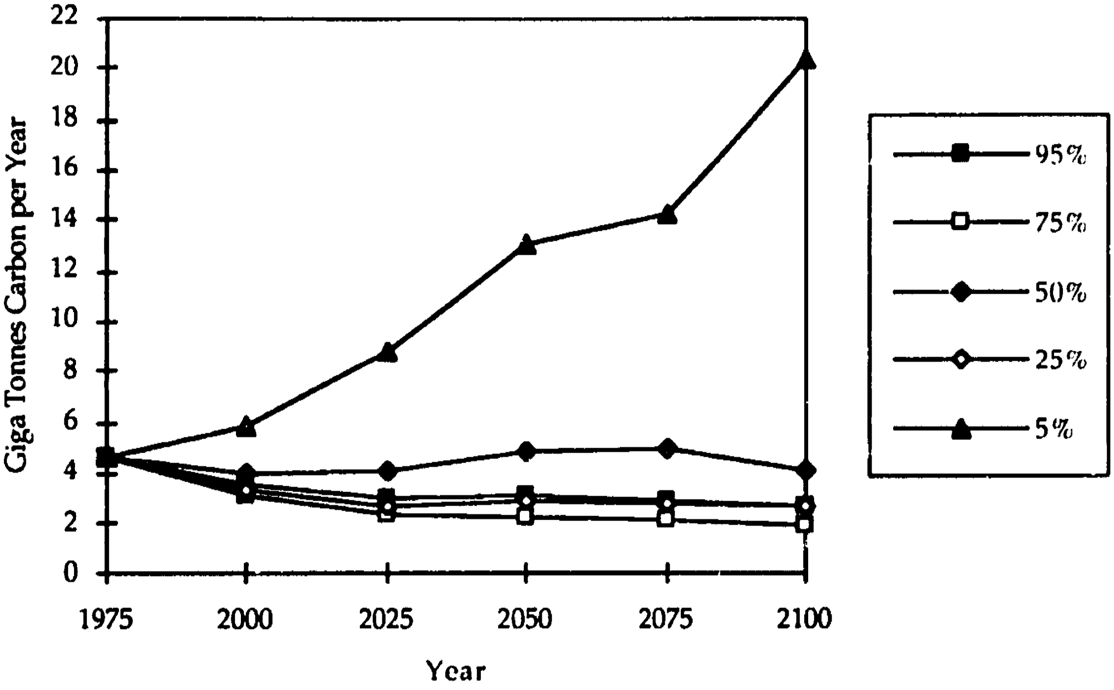


Figure 6-13: Percentiles of Edmonds-Reilly Model Runs With a $300/tC Tax

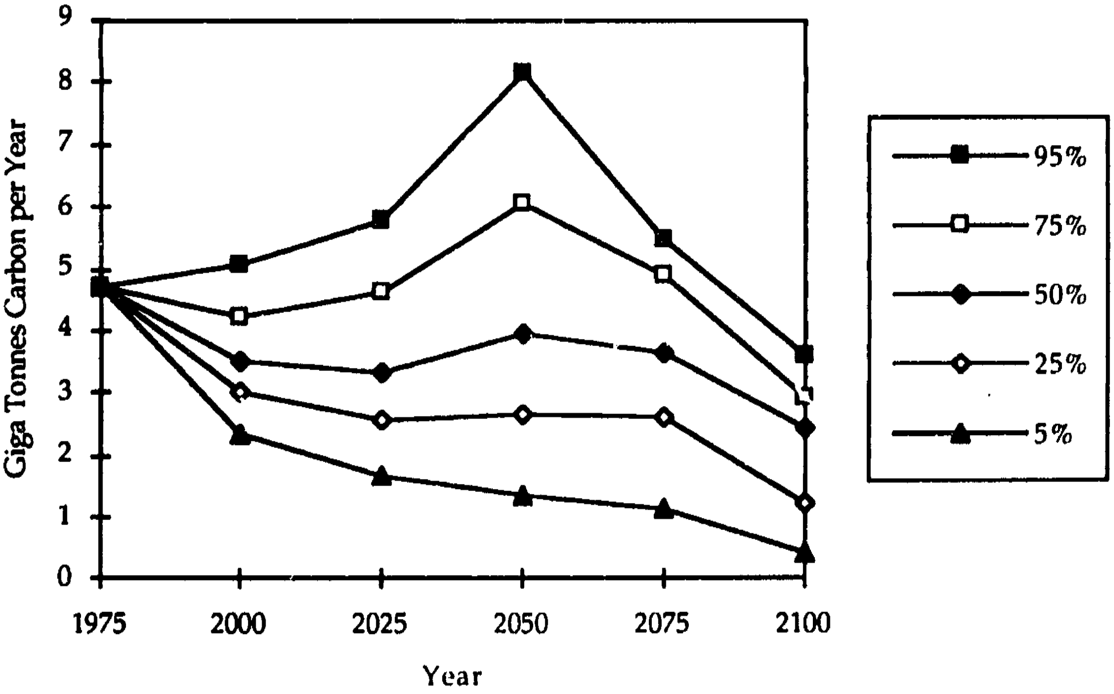


Figure 6-14: Box Plot for Base Output Distribution, and Three Tax Levels (in 2075)

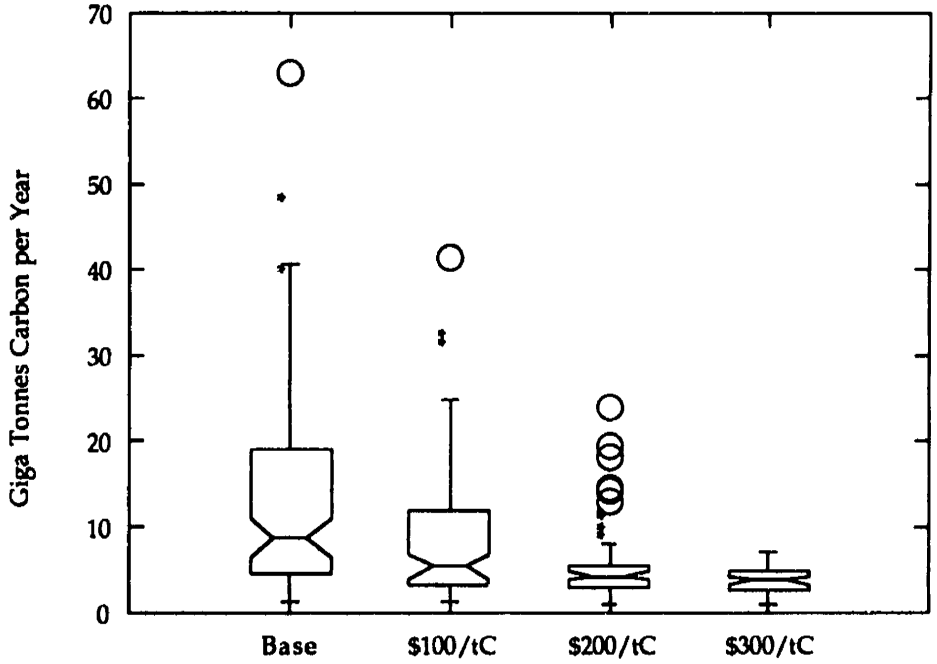


Table 6-2: Interpreting Box Plots

- The line in the middle of each box is the median value (i.e., the 50th percentile).
- The edges of each box are defined as the upper and lower hinges (i.e., the 75th and 25th percentiles respectively).
- Hspread is defined as the difference between the upper and lower hinges (i.e., the interquatile range).
- The inner fences are defined as:
  lower inner fence = lower hinge - (1.5Hspread), and
  upper inner fence = upper hinge + (1.5Hspread).
  The lines from each end of a box to the upper and lower inner fences are called whiskers. Values outside the inner fences are plotted with asterisks.
- The outer fences are defined as:
  lower outer fence = lower hinge - (3Hspread), and
  upper outer fence = upper hinge + (3Hspread).
  Values outside the outer fences are plotted as empty circles.
- Boxes are notched at the median and return to full width at the upper and lower confidence intervals.

Source: Wilkinson 1989, 182-6.

Carbon Tax Levied as a Rate

An alternative to a carbon tax based on carbon content is a carbon tax levied as a fixed rate. There are two central features to a carbon tax levied as a fixed rate: (1) each fuel's price is raised by fixed percentage, and (2) the percentage increase is proportional to a fuel's carbon content. For example, using the carbon emission coefficients in table 6-1, placing a 10% tax on coal would lead to a 8.1% tax on oil and a 5.8% tax on gas.

This approach might be used to try to avoid the excessive shifts in relative fuel prices produced by a tax based on carbon content. As Kaufmann (1992) points out, a carbon tax imposed as a rate based on relative carbon emissions, would ensure that the slope of the budget line for fuel purchases would shift according to the relative rates of carbon emissions. Thus it would encourage a shift towards less carbon intensive fuels, i.e. from coal to oil and gas, and from oil to gas.

The Edmonds-Reilly model contains a set of parameters for "Energy Taxes on Final Consumption by Fuel, Region and Period." I used this set of parameters to implement a carbon tax as a rate. I ran the model with one set of carbon tax rates. The trajectories for how these tax rates were applied over time are shown in figure 6-15. For each of the fuels the tax rate started at 0% and increased linearly to its final value in 2050. As shown in figure 6-15 the rate was set to double the price of coal by 2050.

The percentile graph of the results for this tax rate is shown in figure 6-16. In addition, a box plot of carbon emissions in 2075 for the base output distribution, fixed rate tax, and $100/tC tax based on carbon content is shown in figure 6-17. As shown in figures 6-16 & 17 the percentiles shift down somewhat relative to the no tax results, but not as much as a $100/tC tax based on carbon content. However, as mentioned above a $100/tC tax would increase the current price of coal by almost 250%, oil over 70% and natural gas by about 80%. Thus, we would not expect the tax applied here to have as much of an effect on carbon emissions as a $100/tC tax based on carbon content.

Figure 6-15: Trajectories for Taxes on Final Consumption of Fossil Fuels

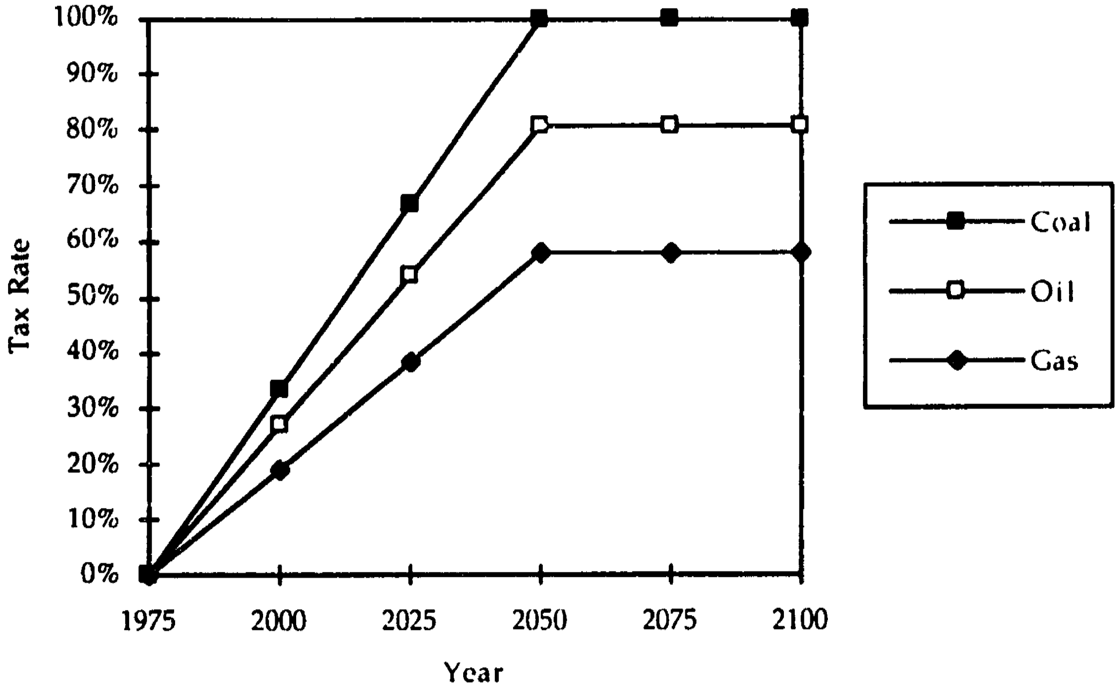


Figure 6-16: Percentiles of Edmonds-Reilly Model Runs With a Carbon Tax Reaching 100% on Coal, 81% on Oil, and 58% on Gas by 2050

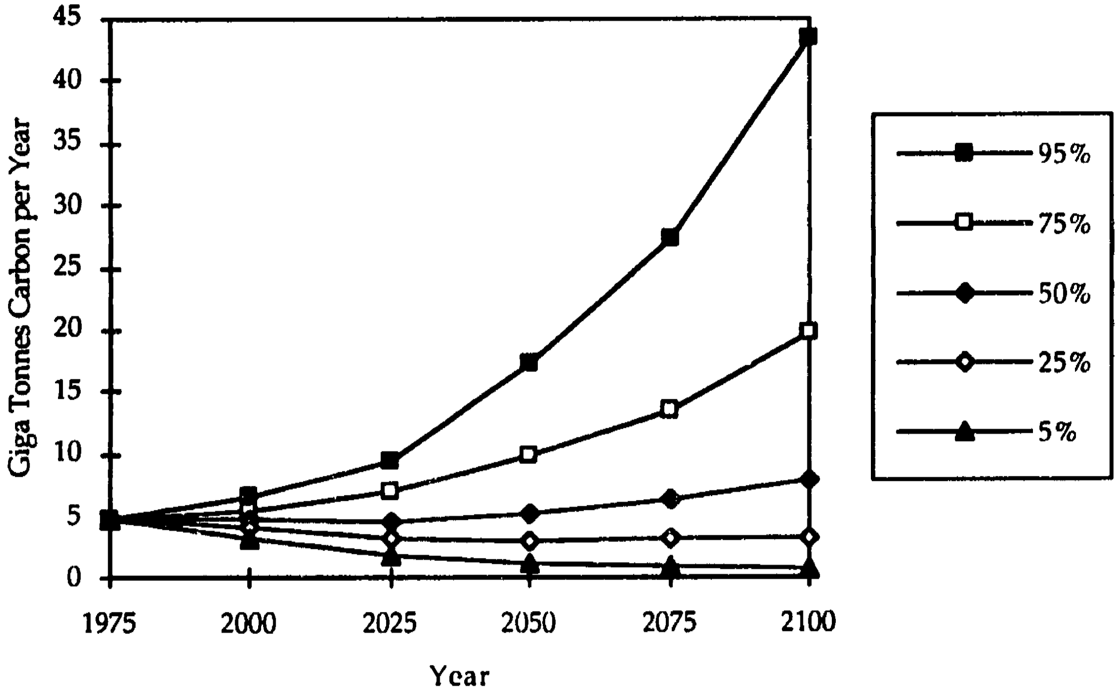
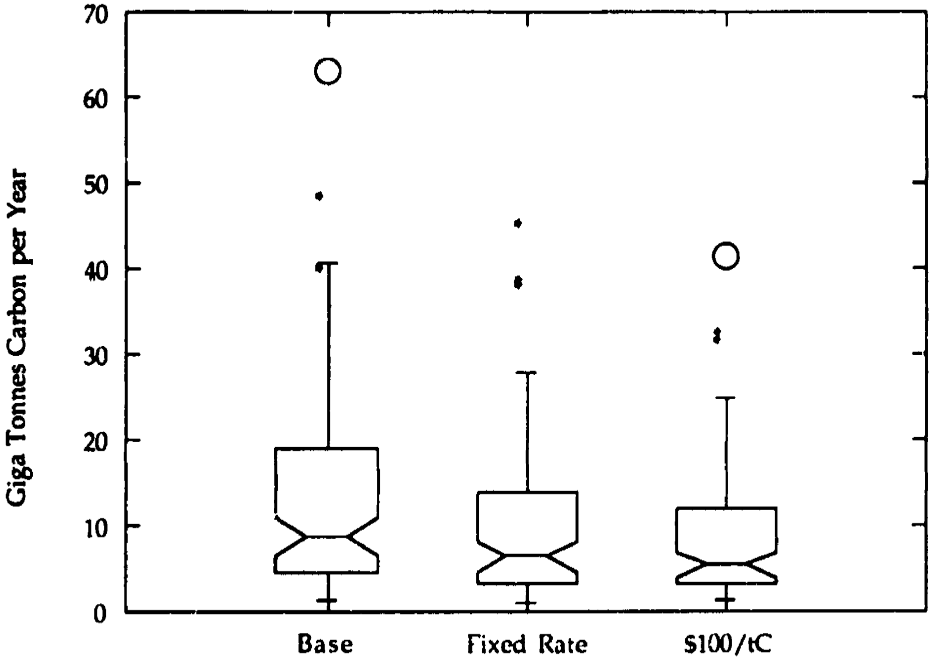


Figure 6-17: Box Plot for Base Output Distribution, Fixed Rate Tax and $100/tC Tax (in 2075)

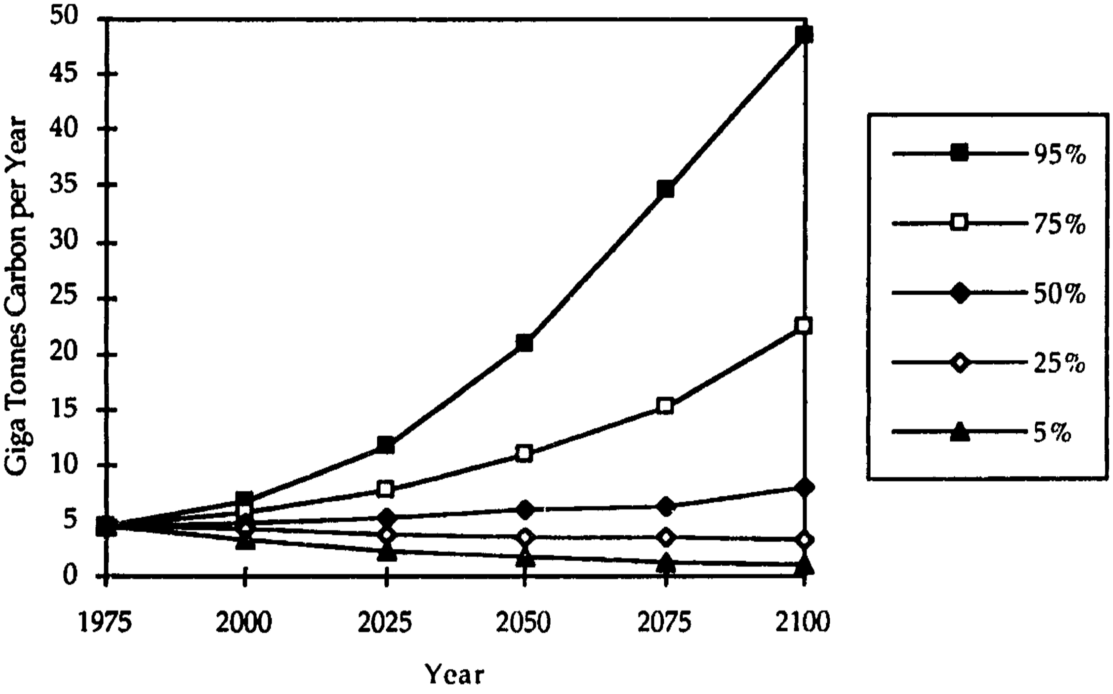


Changing Efficiency Assumptions

Typically, as above, policy experiments using energy models focus on the use of carbon taxes to reduce future carbon emissions. In this study, in addition to looking at the effects of carbon taxes, I explored how changing the exogenous energy end-use efficiency improvement rate assumptions would effect the base output distribution. In order to simulate higher efficiency improvement rates I conducted two experiments: (1) I shifted the mode of the input distribution +0.5% (to 1.5%), and (2) I shifted the entire input distribution +0.5% (mode and end points). PRISM was used to generate two new sets of samples, and the samples were used to run the Edmonds-Reilly model.[8]

The percentile graphs of the results are shown in figure 6-18 & 19. In addition, figure 6-20 shows a box plot of carbon emissions in 2075 for the base output distribution, the mode of the efficiency distribution shifted +0.5%, and the entire efficiency distribution shifted +0.5%. All three of these graphs show relatively small shifts downward, from the base distribution, in carbon emissions. As expected shifting the entire distribution leads to a larger decrease than shifting only the mode of the distribution.

Figure 6-18: Percentiles of Edmonds-Reilly Model Runs Shifting the Mode of the Efficiency Improvement Rate +0.5%



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[8] In order to ensure that the efficiency improvement rates were the only parameters to change, I used the same random number seed when re-running PRISM.

Figure 6-19: Percentiles of Edmonds-Reilly Model Runs Shifting the Entire Efficiency Improvement Rate Distribution +0.5%

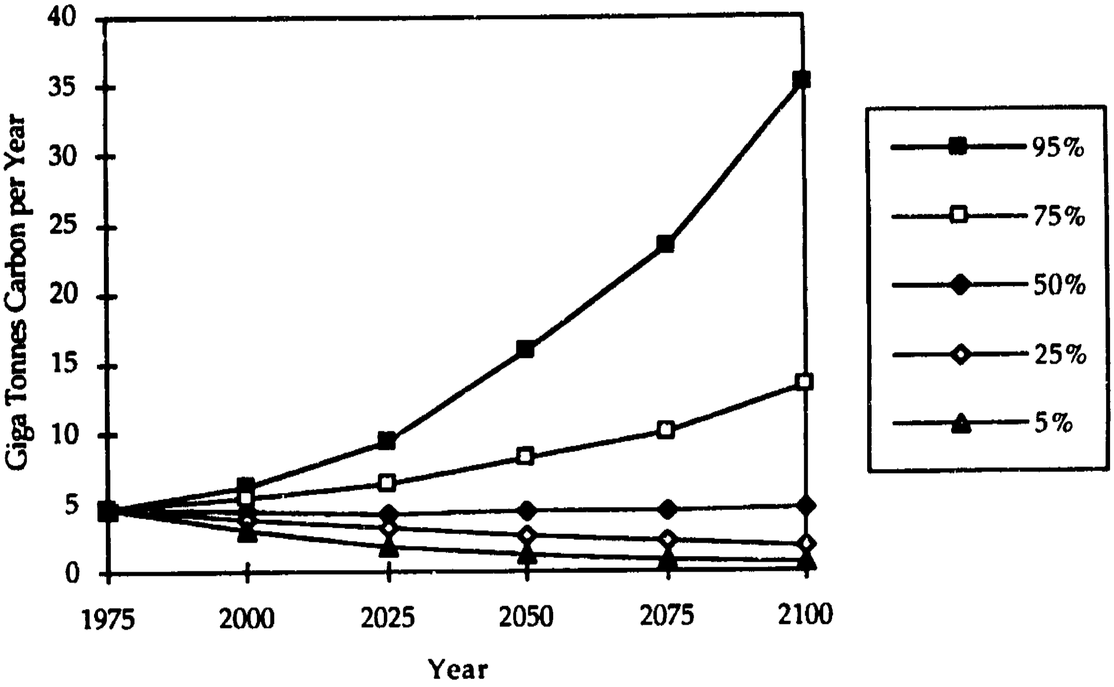
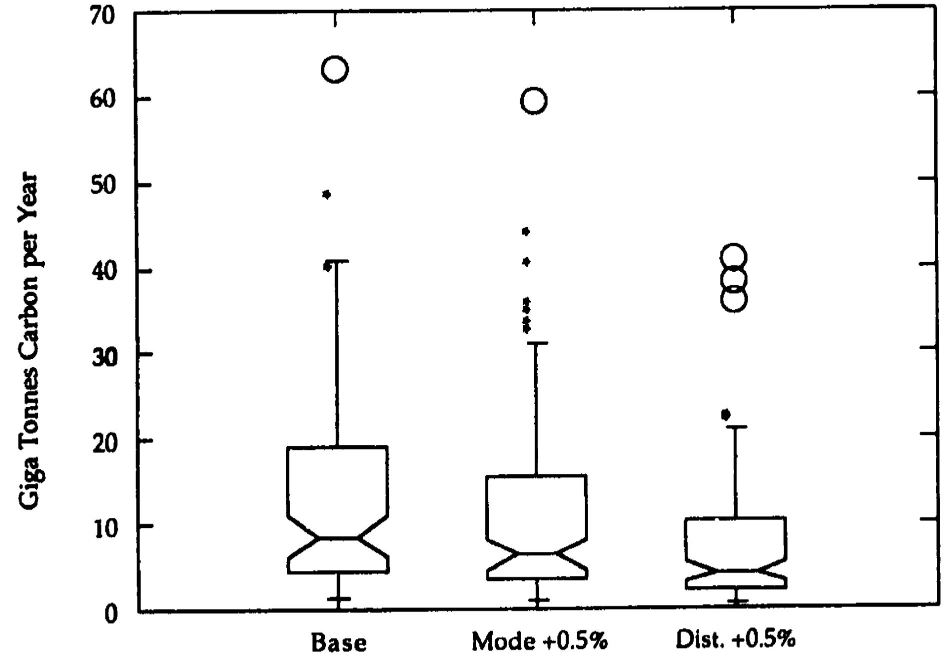


Figure 6-20: Box Plot for Base Output Distribution, Efficiency Mode Shifted +0.5%, and Efficiency Distribution Shifted +0.5% (in 2075)



These experiments were not intended to determine whether on not policies aimed at increasing efficiency improvement rates would be effective; instead, they were intended to highlight some of the issues that arise when trying to model policies other than carbon taxes. For example, in the first experiment I shifted the mode of the distribution, but not the end points. This was done to highlight the fact that there is uncertainty in implementing policies aimed at increasing efficiency improvement rates. In fact, the relationship between policies (such as R&D spending) and efficiency improvement rates is very uncertain.

Finally, these two experiments highlight the need to design models with "policy levers" that translate potential policies, other than carbon taxes, into model inputs in a clear and defensible manner. This is a difficult task because the relationship between policy actions and changes in a model's parameters are often unclear.

Summary

The analysis described above develops a methodology for using long-term energy-economic-environmental models for evaluating the effects of policies in the context of uncertainty. It builds on the previous studies conducted by Nordhaus and Yohe (1983) and Edmonds et al. (1986). Since the analysis focuses on methodology its numerical results should not be taken too seriously. Further, it is important to understand that using a probabilistic scenario analysis to explore the effectiveness of various policies on reducing future carbon emissions from energy use is a significant departure from the types of scenario analyses discussed in chapters 4 & 5. However, given the inherent uncertainty in any long-term energy-economic-environmental model's structure and parameters, these more traditional scenario analyses can be misleading.

7. Conclusions & Recommendations for Future Research

Conclusions

This thesis has taken a close look at how energy-economic-environmental models have been used in the climate change policy process. The experience of energy modeling during the past two decades, of energy-economic-environmental modeling during the past decade, and most recently of the Intergovernmental Panel on Climate Change (IPCC) suggest a number of lessons for using energy-economic-environmental models in the climate change policy process in the future:

Uncertainty in long-term energy-economic-environmental models is more fundamental than simply lacking detailed knowledge about future values of various model parameters. In fact, when using a long-term energy-economic-environmental model, in the climate change policy process, analysts should include two types of uncertainty in their analysis: (1) uncertainty in parameters which drive the model (i.e., the future), and (2) uncertainty inherent in the model's structure. This means that even in the absence of policy intervention there is a wide range of possible future GHG emission scenarios. Both analysts and policymakers need to acknowledge this.

Analysts should use energy-economic-environmental models to explore the effects of various policy options in the context of uncertainty. Only by testing policy options over a range of uncertain futures can analysts help policymakers form their own judgments about the relative merits of various policy options. A methodology for doing this, called probabilistic scenario analysis, was demonstrated in Chapter 6. The probabilistic approach involves both creating a base output distribution and conducting probabilistic policy experiments.

Analysts need to try to communicate uncertainty in their results more effectively. The discussion in Chapter 5 about the IPCC emissions scenarios illustrates that, even when analysts include uncertainty in their analysis, effectively communicating uncertainty to policymakers is very difficult. As shown in Chapter 6, one approach for trying to communicate uncertainty to policymakers is to use percentile charts and box plots.

Analysts need to avoid using energy-economic-environmental models simply to produce a desired set of results in a consistent manner. If analysts use this mode of analysis it can lead to a situation where policymakers interpret their results in a manner that is not supported by the underlying analysis. For example, as discussed in Chapter 5, the 1990 IPCC scenarios were designed as an internally consistent set of plausible scenarios; meanwhile, in the IPCC process the scenarios were generally interpreted as forecasts.

Policymakers need to be more open to thinking about the future as being uncertain. Even when analysts present their results to policymakers as being uncertain, policymakers can still filter out uncertainty by focusing on a mean, median or some other percentile result.

Using a probabilistic approach, as demonstrated in Chapter 6, offers both analysts and policymakers an opportunity to move beyond arguing about which is the "right" best guess scenario. Using this approach can be somewhat humbling for analysts because it forces them to admit that they have limited knowledge. However, it enables policymakers to consider a full range of possible futures along with each one's likelihood. Thus by using a probabilistic approach, policymakers can concentrate on the real questions at the heart of the climate change issue:

- Should we focus our attention on narrowing the range of uncertainty?
- Should we minimize the risk of following a set of undesirable future paths? Or,
- Should we act based on expected value?

In essence, by using a probabilistic approach analysts can focus on using energy-economic-environmental models to help participants in the policy process learn about how different components of the overall energy-economic-environmental system interact with each other, gain insight into the limitations of the models themselves, identify important uncertainties in the models, and evaluate potential policy options over a range of possible futures.

Recommendations for Future Research

There are a number of areas where it would be useful to conduct future research on how to use energy-economic-environmental models and their results in the climate change policy process. For example, the probabilistic policy experiments described in Chapter 6 could be expanded by using a wider range of carbon taxes, different time trajectories for phasing in carbon taxes, and/or other types of policies. Also, one could look at model output parameters other than CO_2 emissions. Additional output parameters that might be interesting to look at include energy use, energy prices, shifts in energy supply, changes in GNP, etc.

An other area where future research would be useful is in developing a base output distribution. For example, one could investigate how correlating various input parameters would effect the base output distribution. In Chapter 6 it was assumed that the input variables were independent.

However, one could argue that there is a correlation between population growth and economic growth, energy efficiency improvements and economic growth, etc. These input parameters are not really independent of each other.

Developing policy levers which can be used, in energy-economic-environmental models, to translate potential policies into model inputs in a clear and defensible manner is an important area where future research needs to be conducted. The difficulty of going beyond policies such as carbon taxes was illustrated, in Chapter 6, by conducting probabilistic policy experiments where the input distribution for energy efficiency improvements were changed.

Finally, another important area where future research needs to be done is in linking various models together in order to be able to analyze the overall uncertainty in the climatic system. Going beyond an understanding of the uncertainty in GHG emissions is important because the climate change policy process is ultimately concerned with the potential social and environmental consequences of climate change. Thus, in order to be able to provide useful information to the climate change policy process, a distribution of GHG emissions scenarios must be translated into atmospheric concentration levels. Then atmospheric concentration levels need to be translated into changes in climate, such as shifts in regional temperatures, dryness, etc. And finally climate change needs to be translated into effects on society and the environment, such as changes in air quality, agricultural productivity, water supply, biodiversity, etc.

Appendix A: Interview Questions

1) Models: How energy-economic-environmental models and their results were used throughout the IPCC process.

1a) Do you think the models were used to ask the proper questions?

1b) What do you think the proper role of models/model results should have been in the IPCC process?

1c) How do you think the models (the way they present results, etc.) might be modified to make them more useful in the process?

2) The Model Results (Scenarios):

2a) How were the model results presented to you?

2b) How familiar are you with the Emissions Scenarios? (unfamiliar, some what familiar, familiar, very familiar)?

2c) How did you interpret the emission scenarios? What did the scenarios tell you? What was the information content of the scenarios? Did they tell you that it would be easy/ hard, feasible/infeasible, expensive/cheap to achieve them?

2d) Do you think that the emission scenarios affected the way the participants thought about the issues? How?

2e) What information did you want but found that you did not get from the emission scenarios? (i.e.: specific policy proposals, discussion of uncertainty, costs)

2f) How did you think about the uncertainty in the scenario numbers? Did you have any ideas/feelings for the level of uncertainty in the scenario numbers, cost, etc.? (completely uncertain, uncertain, some what certain, very certain).

2g) In your discussions with other people did you talk about the scenarios, how they were derived, their meaning?

3) Analysis Underlying the Emission Scenarios:

3a) Are you familiar with the analysis underlying the emission scenarios?

3b) What did you think about the analysis? ASF? IMAGE?

4) Is there anything else you think I might be interested in?

Other Questions (if there is extra time):

Process:

- In general how did/do you feel about the IPCC process?
- What do you feel was useful that came out of the IPCC process?
- What do you think the IPCC working groups did well?
- Where did you see areas of substantial misunderstanding?
- How was the IPCC process structured to accommodate dissenting views and different cultural views?

Future:

- Where do you think attention should be focused in the future?
- What do you think the IPCC working groups could have done better?
- What do you think was misunderstood in the three IPCC reports?
- Where do you think the IPCC needs to do more work?

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