Climate Change Policy

Jason Shogren and Michael Toman

May 2000 • Discussion Paper 00–22

RESOURCES
FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202–328–5000
Fax: 202–939–3460
Internet: http://www.rff.org

Climate Change Policy

Jason Shogren and Michael Toman*

Abstract

Having risen from relative obscurity as few as ten years ago, climate change now looms large among environmental policy issues. Its scope is global; the potential environmental and economic impacts are ubiquitous; the potential restrictions on human choices touch the most basic goals of people in all nations; and the sheer scope of the potential response—a significant shift away from using fossil fuels as the primary energy source in the modern economy—is daunting. In this paper, we explore the economics of climate change policy. We examine the risks that climate change poses for society, the benefits of protection against the effects of climate change, and the costs of alternative protection policies. We organize our discussion around three broad themes: why costs and benefits matter in assessing climate change policies, as does the uncertainty surrounding them; why well-designed, cost-effective climate policies are essential in addressing the threat of climate change; and why a coherent architecture of international agreements is key to successful policy implementation. We conclude the paper with a summary of key policy lessons and gaps in knowledge.

Key Words: climate change, incentive-based policy, international environmental cooperation, benefit-cost analysis

JEL Classification Numbers: Q25, Q28, Q48

*Stroock Distinguished Professor of Natural Resource Conservation and Management, Department of Economics, University of Wyoming and Senior Fellow, Energy and Natural Resources Division, Resources for the Future, respectively.

Contents

Climate Change Policy[1]

Jason Shogren and Michael Toman

Introduction

Having risen from relative obscurity as few as ten years ago, climate change now looms large among environmental policy issues. Its scope is global; the potential environmental and economic impacts are ubiquitous; the potential restrictions on human choices touch the most basic goals of people in all nations; and the sheer scope of the potential response—a significant shift away from using fossil fuels as the primary energy source in the modern economy—is daunting. The magnitude of these changes has motivated experts the world over to study the natural and socioeconomic effects of climate change as well as policy options for slowing climate change and reducing its risks. The various options serve as fodder for often testy negotiations within and among nations about how and when to mitigate climate change, who should take action, and who should bear the costs.

In this paper, we explore the economics of climate change policy. We examine the risks that climate change poses for society, the benefits of protection against the effects of climate change, and the costs of alternative protection policies. We organize our discussion around three broad themes: why costs and benefits matter in assessing climate change policies, as does the uncertainty surrounding them; why well-designed, cost-effective climate policies are essential in addressing the threat of climate change; and why a coherent architecture of international agreements is key to successful policy implementation.

We consider first the state of knowledge about climate change and its effects, and developments in international and U.S. domestic policy. Next, we elaborate the first theme, stressing the importance of considering costs and benefits as well as uncertainty. Elaborating on the second theme, we discuss how to design climate change policies. Then, we consider the challenges to securing effective and economically sound international responses. We conclude the paper with a summary of key policy lessons and gaps in knowledge.

[1] This paper will appear as a chapter in the forthcoming second edition of the RFF book *Public Policies for Environmental Protection* (Paul Portney and Robert Stavins, eds.). The authors are very grateful to Larry Goulder for his extensive and constructive comments on an earlier draft of this paper, and to comments and advice provided by Sally Kane, Rob Stavins, Jonathan Wiener, and numerous other colleagues. Emily Aronow, Marina Cazorla, Sarah Cline and Jennifer Lee provided very capable research assistance in the preparation of the paper, and Kay Murphy provided excellent assistance in the preparation of the manuscript. Special thanks are due to Joel Darmstadter for his work in compiling the data for Tables 1 and 2. As usual, we take full responsibility for the contents of the paper.

A Brief Overview of Climate Change

Scientific Background

Life on Earth is possible partly because some gases such as carbon dioxide (CO_2) and water vapor, which naturally occur in Earth's atmosphere, trap heat—like a greenhouse. CO_2 released from use of fossil fuels (coal, oil, and natural gas) is the most plentiful human-created greenhouse gas (GHG). Other gases—including methane (CH_4),[2] chlorofluorocarbons (CFCs; now banned) and their substitutes currently in use, and nitrous oxides associated with fertilizer use—are emitted in lower volumes than CO_2 but trap more heat. Global GHG inventories are hard to calculate reliably. Tables 1 and 2 list U.S. emissions sources and energy consumption levels, respectively as of 1997. U.S. carbon emissions are roughly 25 percent of the global total in 1996 (U.S. EPA 1999).

Human-made GHGs work against us when they trap too much sunlight and block outward radiation. Scientists worry that the accumulation of these gases in the atmosphere has changed and will continue to change the climate. Potential climate risks include more severe weather patterns; hobbled ecosystems, with less biodiversity; changes in patterns of drought and flood, with less potable water; inundation of coastal areas from rising sea levels; and a greater spread of infectious diseases such as malaria, yellow fever, and cholera. On the plus side, climate change might benefit agriculture and forestry in certain locations by increasing productivity as a result of longer growing seasons and increased fertilization. Although climate change is not the same as day-to-day or even year-to-year fluctuations in the weather, the nature of these fluctuations could be altered by climate change.

Climate change is a historical fact, as illustrated by the ice ages. Part of the controversy today is the extent to which human activities are responsible for changes in the climate system. While acknowledging the many uncertainties about the precise nature and strength of the link between human activities and climate change, many scientists argue that the evidence points to an effect from people emitting too much CO_2 and other GHGs into the atmosphere.

Scientists reach this conclusion by looking at two trends. First, global surface temperature data show that Earth has warmed 0.5 °C (1 °F) over the past 100 years. At the same time, atmospheric concentrations of GHGs such as CO_2 have increased by about 30% over the past 200 years.

[2] Human-created sources of methane release include natural gas supply leaks, some coal mines, decomposition in landfills, and agricultural sources (for example, rice paddies and domestic animals).

Table 1. U.S. Sources of Greenhouse Gas Emissions, 1997

	Carbon equivalents (million metric tons)			
Sector	*CO_2*	*CH_4*	*Other*	*Total*
Energy	1,466	58	29	1,553
Other	22	122	117	261
Total	1,488	180	146	1,814

Sources: U.S. EPA (1999).

Table 2. U.S. Energy Consumption and CO_2 Emissions, 1997

Source or emitter	*Energy consumption (quads)*	*CO_2 emissions (million tons of carbon)*[a]
Energy source		
Fossil	80.5	1,466
Coal	20.9	533
Natural gas	22.6	319
Petroleum	37.0	613
Nonfossil	13.7	NA
Nuclear	6.7	NA
Hydro	3.9	NA
Other	3.1	NA
Total	94.2	1,466
Sector		
Fossil	80.5	1,466
Electric power	22.3	532
Industry	21.9	307
Transportation	24.7	446
Residential/commercial	10.9	168
Nonfossil	13.7	NA
Electric power	11.2	NA
Other	2.5	NA
Total	94.2	1,466

NA = Not applicable.

Notes: CO_2 emissions include small unallocable amounts emitted in U.S. territories (not shown separately) and exclude small amounts attributable to nonfossil (biogenic) resources. For the purpose of this presentation, the electric power sector is treated as a consumer of energy sources and emitter of CO_2. An alternative treatment would bypass the power sector and ascribe its energy use to ultimate consumers of electricity.

Sources: U.S. DOE (1998).

Scientists attempt to capture the interactions of a complex dynamic climate system and human activities that put additional GHGs in the atmosphere by developing complicated computer models to simulate how future climate conditions might change with, for example, double the preindustrial concentration of GHGs in the atmosphere. Critics of these efforts stress that correlation and causation should not be confused. They scientists also question the current ability to separate human-made changes from natural variability.

Although the causation between human actions and higher temperatures continues to be debated, the Intergovernmental Panel on Climate Change (IPPC) concluded in its Second Assessment Report that “the balance of evidence suggests that there is a discernible human influence on global climate” (IPCC 1996a). (This phrase has generated some controversy in its own right. The many uncertainties are characterized in Chapter 8 of the same report.) A recent report by the National Research Council (NRC 2000) found that evidence for a human contribution is rising. At the same time, however, the report found that scientists were becoming *less* confident in current quantitative forecasts of climate change.[3]

GHGs remain in the atmosphere for tens or hundreds of years. GHG concentrations reflect long-term emissions; changes in any one year’s emissions have a trivial effect on current overall concentrations. Even significant reductions in emissions made today will not be evident in atmospheric concentrations for decades or more. In addition, the major GHG emitters change over time. The industrialized world currently accounts for the largest portion of emissions. However, by the middle of the twenty-first century, developing countries with growing population and wealth probably will generate the largest share of emissions. Both of these factors affect climate policy design.

Potential Physical and Socioeconomic Consequences

The risk of climate change depends on the physical and socioeconomic implications of a changing climate. Climate change might have several effects:

- Reduced productivity of natural resources that humans use or extract from the natural environment (for example, lower agricultural yields, smaller timber harvests, and scarcer water resources).
- Damage to human-built environments (for example, coastal flooding from rising sea levels, incursion of salt water into drinking water systems, and damages from increased storms and floods).
- Risks to life and limb (for example, more deaths from heat waves, storms, and contaminated water, and increased incidence of tropical diseases).
- Damage to less managed resources such as the natural conditions conducive to different landscapes, wilderness areas, natural habitats for scarce species, and biodiversity. For

[3] Particularly vexing is the inability of models to better capture several factors: how climate change operates on a less than continental scale, in order to assess regional changes; how conventional pollutants such as very fine “aerosol” particles offset climate change by reflecting back sunlight; and how human activity on land can create “carbon sinks” to sequestere greenhouse gases in biomass (for example, reforestation).

example, rising sea levels could inundate coastal wetlands, and increased inland aridity could destroy prairie wetlands.

All of these damages are posited to result from changes in long-term GHG concentrations in the atmosphere. Very rapid rates of climate change could exacerbate the damage. The adverse effects of climate change most likely will take decades or longer to materialize, however. Moreover, the odds that these events will come to pass are uncertain and not well understood. Numerical estimates of physical impacts are few, and confidence intervals are even harder to come by. The rise in sea level as a result of polar ice melting, for instance, is perhaps the best understood, and the current predicted range of change is still broad. For example, scenarios presented by the IPCC (1996a) indicate possible increases in sea level of less than 20 cm to almost 100 cm by 2100 as a result of a doubling of Earth's atmospheric GHG concentrations. The uncertainty in these estimates stems from not knowing how temperature will respond to increased GHG concentrations and how oceans and ice caps will respond to temperature change. The risks of catastrophic effects such as shifts in the Gulf Stream and the sudden collapse of polar ice caps are even harder to gauge.

Unknown physical risks are compounded by uncertain socioeconomic consequences. Cost estimates of potential impacts on market goods and services such as agricultural outputs can be made with some confidence, at least in developed countries. But cost estimates for nonmarket goods such as human and ecosystem health give rise to serious debate.

Moreover, existing estimates apply almost exclusively to industrial countries such as the United States. Less is known about the adverse socioeconomic consequences for poorer societies, even though these societies arguably are more vulnerable to climate change. Economic growth in developing countries presumably will lessen some of their vulnerability—for example, threats related to agricultural yields and basic sanitation services would decline. But economic growth in the long term could be imperiled in those regions whose economies depend on natural and ecological resources that would be adversely affected by climate change. Aggregate statistics mask considerable regional variation: some areas probably will benefit from climate change while others lose (IPCC 1998).

In weighing the consequences of climate change, it is important to keep in mind that humans adapt to risk to lower their losses. In general, the ability to adapt contributes to lowering the net risk of climate change more in situations where the human control over relevant natural systems and infrastructure is greater. Humans have more capacity to adapt in agricultural activities than in wilderness preservation, for example. The potential to adapt also depends on a society's wealth and the presence of various kinds of social infrastructure, such as educational and public health systems. As a result, richer countries probably will face less of a threat to human health from climate change than poorer societies that have less infrastructure. For additional discussion about adaptation possibilities, see Rosenberg (1993), Smith and others (1996), Pielke (1998), Sohngen and Mendelsohn (1999), and Kane and Shogren (2000).

Policymakers must address the perceived risks of climate change in the population, not only the risks indicated in scientific assessments. So far, climate change does not appear to be that salient an issue in the minds of many Americans. Although the public's understanding of the issue seems to be increasing, the topic still is not well understood; and so far, no dramatic climate change event has hit the media to give the issue a permanent place at the front of public attention.[4] Even if climate change becomes a more prominent issue in the United States, people may disregard the issue because they believe that the probability that severe results will come to pass is very low, so immediate action on their part is not required. For further general discussion of risk perception issues see Lichtenstein (1978), Camerer and Kunreuther (1989), Viscusi (1992), and Crocker and Shogren (1997).

In constructing a viable and effective risk-reducing climate policy, policymakers must address hazy estimates of the risks, the benefits from taking action, and the potential for adaptation against the uncertain but also consequential cost of reducing GHGs. Costs of mitigation matter, as do costs of climate change itself. One must consider the consequences of committing resources to reducing climate change risks that could otherwise be used to meet other human interests, just as one must weigh the consequences of different climatic changes.

We now consider how policymakers worldwide and in the United States have responded in the policy domain so far.

A Chronology of Policy and Institutional Responses

International Developments

Figure 1 summarizes some milestones in the evolution of global climate policy. The negotiation of the 1992 United Nations Framework Convention on Climate Change (UNFCCC 1999a) was a watershed in that process. Article 2 of the convention states that the objective is to stabilize GHG concentrations within a time frame that would prevent "dangerous" human damage to the climate system. Article 3 states that precautionary risk reduction should be guided by equity across time and wealth levels, as expressed in the concept of "common but differentiated responsibilities." Article 4 states that nations should cooperate to improve human adaptation and mitigation of climate change through financial support and low-emission technologies. Articles 3 and 4 also refer to the use of cost-effective response measures. In concert with the Framework Convention, advanced industrialized countries pledged to reduce emissions to 1990 levels by 2000. However, this pledge was not a legally binding international agreement.

[4] For additional discussion of these issues, see Morrisette and others (1991), Kempton and others (1995), Toman and others (1999), and Krosnick and others (forthcoming). Climate change has been a great concern in western Europe; for a summary of positions taken, see Grubb and others (1999). In most developing countries, climate change must compete with more immediate pressing environmental and poverty-related concerns.

Figure 1. Summary of Key Milestones in Climate Policy, 1979–99.

1979	•	First World Climate Conference
1990	•	First Assessment Report of the IPCC; initial evidence that human activities might be affecting climate, but significant uncertainty
1990	•	Second World Climate Conference; agreement to negotiate a "framework treaty"
1992	•	UNFCCC established at the UNCED (also known as the Earth Summit) in Rio de Janeiro, Brazil
	•	Annex I developed countries pledge to return emissions to 1990 levels by 2000
	•	United States ratifies UNFCCC later in the year
1993	•	Clinton administration publishes its Climate Change Action Plan, a collection of largely voluntary emission-reduction programs
1995	•	IPCC Second Assessment Report completed (published in 1996); stronger conviction expressed that human activities could be adversely affecting climate
1995	•	Berlin Mandate developed at the first COP (COP1) to the UNFCCC
	•	Agreement to negotiate *legally binding* targets and timetables to limit emissions in Annex I countries
1997	•	COP3 held in Kyoto Japan, leading to the Kyoto Protocol
	•	Annex I/Annex B countries agree to binding emission reductions averaging 5% below 1990 levels by 2008–12, with "flexibility mechanisms" (including emissions trading) for compliance; no commitments for emission limitation by developing countries
1997	•	U.S. Senate passes Byrd–Hagel resolution, 95 to 0, stating that the United States should accept no climate agreement that did not demand comparable sacrifices of all participants and calling for the administration to justify any proposed ratification of the Kyoto Protocol with analysis of benefits and costs
1998	•	COP4 held in Buenos Aires, Argentina; emphasis on operationalizing the "flexibility mechanisms" of the Kyoto Protocol
	•	IPCC Third Assessment begins
1999	•	COP5 held in Bonn, Germany; continued emphasis on operationalizing the flexibility mechanisms

IPCC = Intergovernmental Panel on Climate Change; UNFCCC = United Nations Framework Convention on Climate Change; UNCED = United Nations Conference on Environment and Development; COP = Conference of Parties. *Source: UNFCCC 1999c.*

The 1997 Kyoto Protocol of the Framework Convention (UNFCCC 1999b) was the next major milestone. The protocol states that the industrialized "Annex B" countries (known in the 1992 convention document as "Annex I" countries) agreed to legally binding reductions in net GHG emissions that would average about 5% below 1990 levels by 2008–12.[5] This

[5] Annex I nations were named after a list in an appendix to the Framework Convention. The agreed-to targets varied across countries; the United States agreed to a 7% reduction, whereas western Europe undertook an overall cut of 8% (divided unequally among E.U. members in subsequent negotiations) and Japan accepted a less steep reduction of 6%. Special provisions were made in defining the obligations of the industrialized countries of central and eastern Europe and the former Soviet Union, the emissions of which already are below 1990 levels. Annex I countries are Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, European Union, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland,

target was negotiated in a context wherein it was clear that almost all advanced industrialized countries would not achieve the pledged reduction of emissions to 1990 levels by 2000. Given expected business-as-usual emissions growth between 1990 and 2010, the actual emissions reductions needed for compliance are substantial (on the order of one-third of what otherwise would prevail in the United States, for example). No numerical targets for the emissions of developing countries were set in the protocol. In other words, the approach taken was "deep then broad"—a few countries are to make significant cuts early, with the hope of increased participation from other countries later—rather than the "broad then deep" strategy promoted by many critics of the Kyoto Protocol. For a critique of the Kyoto Protocol's deep-then-broad character, see Jacoby and others (1998) and Shogren (1999).

The Kyoto Protocol includes several flexibility mechanisms that allow nations some latitude as to how they will meet the targets and timetables. The details of how these mechanisms would operate was largely left for future negotiations. Individual Annex B countries are free to achieve their targets through any credible domestic policies they wish—domestic policies need not be coordinated. The protocol also provides for international "where flexibility" in which nations can reduce emissions through different forms of international trading of emissions quotas. The protocol further provides flexibility in that emissions targets can be met by reducing any of six different gases—not only CO_2—and via carbon sequestration through sinks such as forests. Non-CO_2 gas concentrations are compared with CO_2 concentrations by means of global warming potential equivalency factors that reflect the heat-trapping properties of different gases in the atmosphere.[6]

Post–Kyoto Protocol meetings continued the international debate, especially about the technical, legal, and moral foundations of the proposed flexibility mechanisms. This debate revealed sharp differences in opinion between the United States and some other industrialized countries versus the European Union and many developing countries. At issue was the extent to which reliance on international emissions trading could substitute for, or could only complement, domestic efforts to reduce energy use and CO_2 emissions. Although differences are beginning to be worked out, the ultimate fate of the flexibility mechanisms—and of the protocol itself—remain to be seen.

Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland, and United States of America.

[6] However, variations in long-term heat-trapping capacity do not immediately translate into variations in potential damage. For example, methane has a high heat-trapping potential but a shorter residence time in the atmosphere than CO_2; thus, if damages from climate change are growing over time because of greenhouse gas (GHG) accumulation generally, near-term methane releases will be less consequential than near-term CO_2 releases, whereas the opposite would be true if emissions occurred near the time of peak climate change and impacts (Reilly and Richards 1993; Schmalensee 1993; Hammitt and others 1996; Smith and Wigley 2000a, 2000b). Ideally, for policy purposes, different GHGs should be traded off against each other on the basis of their relative contribution to socioeconomic impacts, not only their chemical properties; however, there is no agreement on what damage-based equivalence factors should be.

U.S. Developments

A few key events trace out the broad outlines of U.S. climate change policy debates from the mid-1980s to the mid-1990s. The Reagan and Bush administrations were skeptical about the need for substantial reductions in carbon emissions. They advocated "actions which will have broad-ranging benefits" such as eliminating CFCs and other stratospheric ozone–depleting substances that are also GHGs (under the Montreal Protocol); implementing various pollution-control measures that also would promote energy efficiency (under the Clean Air Act); increasing forest sinks; encouraging energy efficiency in buildings, appliances, and lighting; and increasing the use of renewable and nonfossil sources of energy.[7]

The Clinton administration was more enthusiastic about GHG control policies, at least in rhetoric. They initially embraced voluntary technology-based measures promulgated in the 1993 Climate Change Action Plan (Clinton and Gore 1993). This approach was based on a firm conviction that substantial progress toward reducing GHG emissions could be achieved without adverse economic consequences; to the contrary, the administration touted the economic benefits of cleaner and more climate-friendly technology.

However, by 1996, it was clear that the United States would fail to achieve the goal of reducing emissions to 1990 levels by 2000. Reasons cited for the failure included less program funding than anticipated from a Republican Congressional majority and, more important, overoptimistic goals and a misspecified baseline (for example, oil prices did not rise as projected).

In 1996, the administration announced its willingness to accept legally binding, long-term emissions reductions goals in the international negotiations without spelling out which goals or policies it would support. As negotiations proceeded toward the 1997 Kyoto Protocol, the U.S. Senate passed by a vote of 95 to 0 a nonbinding resolution offered by Senators Robert C. Byrd and Chuck Hagel in the summer of 1997. The Byrd–Hagel resolution stated that the United States should accept no climate agreement that did not demand comparable sacrifices of all participants. The resolution was stimulated by concern about the effects of a climate agreement on the U.S. economy, but it conflicted with the idea of common but differentiated responsibilities for developed and developing countries espoused by the Climate Convention (UNFCCC 1999a), which the United States already had ratified. The resolution also required the administration to provide an economic justification of any climate change policy regime—a demonstration that the prospective benefits were worth the costs.

From 1996 through 2000, the Clinton administration pursued a public campaign to increase awareness of climate change risks. It also engaged in efforts to estimate the costs to the U.S. economy of GHG limitations while repeating much of its earlier rhetoric about the economic

---

[7] We appreciate the assistance of Jonathan Wiener in identifying these measures. The broad-ranging benefits included, in the judgment of some proponents, decreased foreign oil imports and increased use of U.S. energy sources and technologies as well as environmental benefits. It is also useful to keep in mind that the United Nations Framework Convention was ratified in 1992 (UNFCCC 1999a), during the Bush Administration.

benefits of GHG reduction. President Bill Clinton stated that the Kyoto Protocol would not be sent to the Senate for ratification until policymakers settled disputes about policies for flexibility in the means of compliance, costs of compliance, and "meaningful participation" by developing countries. Acrimonious debate erupted sporadically between the administration and Congress as well as among various nongovernmental stakeholders about budgetary priorities related to climate change and the consequences of climate policies for the U.S. economy.

Numerous studies were produced in and out of government to help fuel the controversy. Among the most noteworthy and controversial was a July 1998 report from the Clinton administration, prepared by the President's Council of Economic Advisers (CEA 1998). This report stated that under the most favorable policy circumstances, the effects on energy prices and the costs to the United States of meeting the Kyoto Protocol emissions target could be extremely small. It states that these costs are "likely to be modest if those reductions are undertaken in an efficient manner employing the [various international] flexibility measures for emissions trading."

By modest, the administration report means an annual GDP decrease of less than 0.5%—roughly, $10 billion dollars; no expected negative effect on the trade deficit; increases in gasoline prices of only about $0.05 a gallon; lower electricity rates; and no "significant aggregate employment effect."[8] A critical assumption in the administration scenario was a very high degree of success in implementing the Kyoto Protocol flexibility mechanisms, especially emissions trading with developing countries and the former Soviet Union. Essentially, a broad-and-deep baseline was built into the administration's cost estimates.

Critics labeled the report as unduly optimistic and out of step with mainstream economic analyses. These critics also savaged a study by a consortium of U.S. national laboratories (Interlaboratory Working Group 1997) in which it was concluded that large low-cost energy savings were possible in the United States. The critics claimed that the authors inadequately recognized the barriers to capturing these savings and the policies needed to reap them. Nevertheless, this idea continues to hold sway in the arguments of the Kyoto Protocol's advocates.

Economic studies that produced high cost estimates had their own set of critics. For example, a 1998 study by the Energy Information Administration (EIA 1998), which suggested that costs to meet the Kyoto Protocol with domestic policies would be very high, was criticized for assuming too little flexibility in energy use and for overstating the negative effects of energy price increases on the economy. A number of industry-sponsored studies that indicated high costs also were criticized, for similar reasons. These studies tended to show

[8] The pre-Kyoto Protocol results from the President's Interagency Analysis Team (IAT) are within this range as well (see Yellen 1998). One exception is that the IAT estimates that would reduce emissions to 1990 levels by 2010 would cost Americans 900,000 jobs by 2005 and 400,000 jobs by 2010.

substantial costs to the United States even with efficient domestic emission control policies: The trade deficit would increase by tens of billions of dollars, gasoline prices would increase by more than one-third, electricity prices would nearly double, and millions of U.S. jobs would disappear.

Other observers found moderate costs; that is, the Kyoto Protocol would not be painless but would not destroy national economies either. To better understand the context of these estimates, we next examine the assessment of costs and benefits of GHG control.

Evaluating the Costs and Benefits of Climate Change Risk Mitigation

The Importance of Considering the Costs and Benefits of Policy Intervention[9]

Although uncertain, climate change risks are real and need to be better understood so as to avoid unwanted consequences. Many observers characterize responding to the risks of climate change as taking out insurance; nations try to reduce the odds of adverse events occurring through mitigation, and to reduce the severity of negative consequences by increasing the capacity for adaptation once climate change occurs. The insurance analogy underscores both the uncertainty that permeates how society and policymakers evaluate the issue and the need to respond to the risks in a timely way.

Responding effectively to climate change risks requires society to consider the potential costs and benefits of various actions as well as inaction. By costs we mean the opportunity costs of GHG mitigation or adaptation—what society must forgo to pursue climate policy. Benefits are the gains from reducing climate change risks by lowering emissions or by enhancing the capacity for adaptation. An assessment of benefits and costs gives policymakers information they need to make educated decisions in setting the stringency of a mitigation policy (for example, how much GHG abatement to undertake, and when do it) and deciding how much adaptation infrastructure to create.

It is important to consider the costs and the benefits of climate change policies because all resources—human, physical, and natural—are scarce. Policymakers must consider the benefits not obtained when resources are devoted to reducing climate change risks, just as they must consider the climate change risks incurred or avoided from different kinds and degrees of policy response. *Marginal* benefits and costs reveal the gain from an incremental investment of time, talent, and other resources into mitigating climate risks, and the other opportunities forgone by using these resources for climate change risk mitigation. It is not a question of *whether* to address climate change but *how much* to address it.

---

9 For additional material and some contrasting views related to this discussion, see Heal and Chichilnisky (1993), Arrow and others (1996), Howarth (1996), Munasinghe and others (1996), Lind and Schuler (1998), and Portney (1998).

Critics object to a benefit–cost approach to climate change policy assessment on several grounds. Their arguments include the following:

- The damages due to climate change, and thus the benefits of climate policies to mitigate these damages, are uncertain and thus inherently difficult to quantify given the current state of knowledge. Climate change also could cause large-scale, irreversible effects that are hard to address in a simple benefit–cost framework. Therefore, the estimated benefits of action are biased downward.
- Climate mitigation costs are uncertain and could escalate rapidly from too-aggressive emission control policies. Proponents of this view are indicating a concern about the risk of underestimating mitigation costs.
- Climate change involves substantial equity issues—both among current societies and between current and future generations—that are questions of morality, not economic efficiency. Policymakers should be concerned with more than benefit–cost analysis in judging the merits of climate policies.

As these arguments indicate, some critics worry that economic benefit–cost analysis gives short shrift to the need for climate protection, whereas others are concerned that the results of the analysis will call for unwarranted expensive mitigation.

Both groups of critics have proposed alternative criteria for evaluating climate policies. These can be seen as different methods of weighing the benefits and costs of policies given uncertainties, risks of irreversibility, the desire to avoid risk, and distributional concerns. For example, under the "precautionary principle," which seeks to avoid "undue" harm to the climate system, cost considerations are absent or secondary. Typically, the idea is that climate change beyond a certain level simply involves too much risk, if one considers the distribution of benefits and costs over generations.

"Knee of the cost curve analysis," in contrast, seeks to limit emission reductions to a point at which marginal costs increase rapidly. Benefit estimation is set aside in this approach because of uncertainty. The approach implicitly assumes that the marginal damages from climate change (which are the flip side of marginal benefits from climate change mitigation) do not increase much as climate change proceeds and that costs could escalate rapidly from a poor choice of emissions target.

The benefit–cost approach can address both uncertainty and irreversibility. We do not mean to imply that estimates in practice are always the best or that how one evaluates and acts on highly uncertain assessments will not be open to philosophical debate.[10] But it is

[10] For example, as people become more informed about climate change, it is safe to presume that the importance they attach to the issue will change. Critics of the economic methodology argue that this process reflects in part a change in preferences through various social processes, not only a change in information. Moreover, in conditions of great uncertainty, the legitimacy of a policy decision may depend even more than normally on whether the processes used to determine it are deemed inclusive and fair, as well as on the substantive evidence for the decision.

fundamentally inaccurate to see analysis of economic benefits and costs from climate change policies as inherently biased because of uncertainty and irreversibility. Nor should benefit–cost analysis be seen as concerned only with market values accruing to developed countries. One great achievements in environmental economics over the past forty years has been a clear demonstration of the importance of nonmarket benefits, which include benefits related to the development aspirations of poorer countries. These values can be given importance equal to that of market values in policy debates.

Our advocacy that benefits and costs be *considered* when judging climate change policies does not mean we advocate a simple, one-dimensional benefit–cost test for climate change policies. In practice, decisionmakers can, will, and should bring to the fore important considerations about the equity and fairness of climate change policies across space and time. Decisionmakers also will bring their own judgments about the relevance, credibility, and robustness of benefit and cost information and about the appropriate degree of climate change and other risks that society should bear. Our argument in favor of considering both benefits and costs is that policy deliberations will be better informed if good economic analysis is provided. For additional discussion, see Toman (1998).

The alternative decision criteria advanced by critics also are problematic in practice. The definition of undue is usually heuristic or vague. The approach is equivalent to assuming a sharp spike, or peak, in damages caused by climate change beyond the proposed threshold. It may be the case, but not enough evidence yet exists to assume this property (let alone to indicate at what level of climate change such a spike would occur). With knee of the curve analysis, on the other hand, benefits are ignored so there is no assurance of a sound decision either.

Benefits and costs are unavoidable. How their impacts are assessed is what differentiates one approach from another. We maintain throughout this discussion that the assessment and weighing of costs and benefits is an inherent part of any policy decision.

Long-Term Equity and Fairness Issues

The fairness of climate change policies to today's societies and to future generations continues to be at the core of policy debates. These issues go beyond what economic benefit–cost analysis can resolve, though such analysis can help illustrate the possible distributional impacts of different climate policies. In this section we focus on intergenerational equity issues. Contemporaneous equity issues are addressed in a later section on the architecture of international agreements.

Advocates of more aggressive GHG abatement point to the potential adverse consequences of less aggressive abatement policies for the well-being of future generations as a moral rationale for their stance. They assert that conventional discounting—even at relatively low rates—may be inequitable to future generations by leaving them with unacceptable climate damages or high costs from the need to abate future emissions very quickly (see Howarth 1996, 1998). Critics also have argued that conventional discounting underestimates costs in the face of persistent income differences between rich and poor countries. Essentially, the argument is that because developing countries probably will not close the income gap over the next several decades, and because people in those countries attach higher incremental value to additional well-being than people in rich countries, the effective discount rate used to evaluate reductions in future damages from climate change should be lower than that applied to richer countries.

Supporters of the conventional approach to discounting on grounds of economic efficiency argue just as vehemently that any evaluation of costs and benefits over time that understates the opportunity cost of forgone investment is a bad bargain for future generations because it distorts the distribution of investment resources over time. These supporters of standard discounting also argue that future generations are likely in any event to be better off than the present generation is, casting doubt on the basic premise of the critics' concerns. For additional discussion of this view, see Schelling (1995) and Weitzman (1999).

Experts attempting to address this complex mixture of issues increasingly recognize the need to distinguish principles of equity and efficiency, even though there is as yet no consensus on the practical implications for climate policy. We can start with the observation that anything society's decisionmakers do today—abating GHGs, investing in new seed varieties, expanding health and education facilities, and so on—should be evaluated in a way that reflects the real opportunity cost, that is, the options forgone both today and over the long term. This answer responds to the critics who fear a misallocation of investment resources if climate policies are not treated similarly to other uses of society's scarce resources.

Moreover, as Weitzman (1998, 1999) pointed out, long-term uncertainty about the future growth of the economy provides a rationale for low discount rates on grounds of efficiency, not equity. The basic argument is that if everything goes well in the future, then the economy will be productive, the rate of return on investment will remain high, and the opportunity cost of displacing investment with policy today likewise also will be high. However, if things do not go so well and the rate of return on capital is low because of climate change or some other phenomenon, then the opportunity cost of our current investment in climate change mitigation versus other activities also will be low.

But economic efficiency only means a lack of waste given some initial distribution of resources. Specifically how much climate change mitigation to undertake is a different question, one that refers to the distribution of resources across generations. The answer to this question depends on how concerned members of the current generation are about the future generally, how much they think climate change might imperil the well-being of their descendants, and the options at their disposal to mitigate unwelcome impacts on future generations. For example, one could be very concerned about the well-being of the future but also believe that other investments—such as health and education—would do more to enhance the well-being of future generations. Not surprisingly, experts and policymakers do not agree on these points. For additional discussion, see the papers in Portney and Weyant 1999.

Estimating Benefits and Costs: Integrated Assessment Models

Analyzing the benefits and costs of climate change mitigation requires understanding biophysical and economic systems as well as the interactions between them. Integrated assessment (IA) modeling combines the key elements of biophysical and economic systems into one integrated system (Figure 2). IA models strip down the laws of nature and human behavior to their essentials to depict how more GHGs in the atmosphere raises temperature and how temperature increase induces economic losses. The models also contain enough detail about the drivers of energy use and interactions between energy and economy that one can determine the economic costs of different constraints on CO_2 emissions.[11]

Researchers use IA models to simulate a path of carbon reductions over time that would maximize the present value of avoided damages (that is, the benefits of a particular climate policy) less mitigation costs. As noted above, considerable controversy surrounds this procedure.

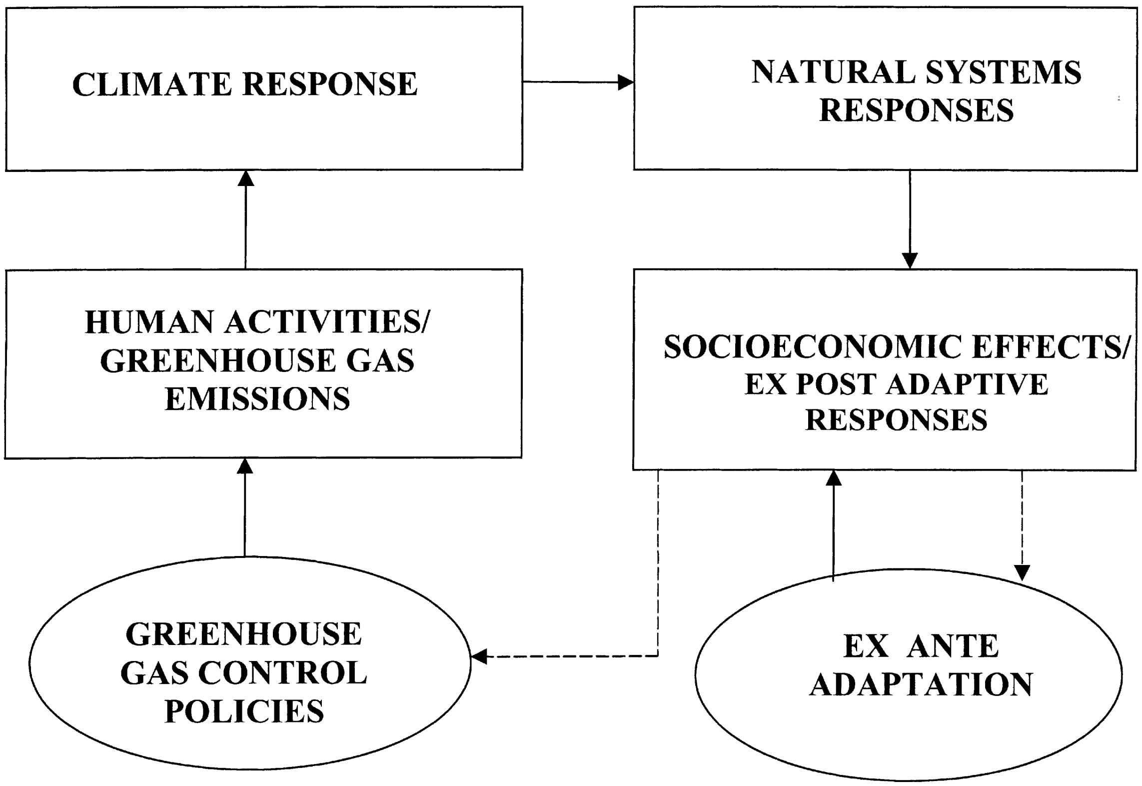
A striking finding of many IA models is the apparent desirability of imposing only limited GHG controls over the next 20 or 30 years. According to the estimates in most IA models, the costs of sharply reducing GHG concentrations today are too high relative to the modest benefits the reductions are projected to bring.

The benefit of reducing GHG concentrations in the near term is estimated in many studies to be on the order of $5–25 per ton of carbon (see for example Nordhaus 1998; Tol 1999). Only after GHG concentrations have increased considerably do the impacts warrant more effort to taper off emissions, according to the models.

Even more striking is the finding of many IA models that emissions should rise well into this century (see Manne 1996). In comparison, the models indicate that policies pushing for substantial near-term control, such as the Kyoto Protocol, involve too much cost, too soon, relative to their projected benefits. Critics react to these findings along the lines noted earlier. Specifically, they argue that IA models inadequately address several important elements of climate change risks: uncertainty, irreversibility and risk of catastrophe. Assessing the weight

[11] For additional discussion of this modeling approach, see Nordhaus (1993, 1994a), Tol (1995), Peck and Teisberg (1996), Weyant and others (1996), and Kolstad (1998).

Figure 2. Climate Change and Its Interaction with Natural, Economic, and Social Processes



Key components of an integrated assessment model are illustrated. Solid lines represent physical changes; broken lines represent policy changes. *Source*: Darmstadter and Toman (1993).

of these criticisms requires us to explore the influences on the economic benefits and costs of climate protection.

Influences on the Benefits

The IPCC Second Assessment Report (IPCC 1996b, 1996c) concluded that climate change could pose some serious risks. The IPCC presented results of studies showing that the damaging effects of a doubling of GHG concentrations in the atmosphere could cost on the order of 1.0–1.5% of GDP for developed countries and 2.0–9.0% of GDP for developing countries (Pearce and others 1996; see also Frankhauser and others 1998). Reducing such losses is the benefit of protecting against the negative effects of climate change.

Several factors affect the potential magnitude of the benefits. One is the potential scale and timing of damages avoided. Although IA models differ greatly in detail, most have economic damage representations calibrated to produce damages resulting from a doubling of atmospheric GHG concentrations roughly of the same order as the IPCC Second Assessment. This point is worth keeping in mind when evaluating the results. The models increasingly contain separate damage functions for different regions (see Nordhaus and Yang 1996; Tol 1995). Generally, the effects in developing countries are presumed to be worse than in the developed world, again as in the IPCC Second Assessment. For the most part, these costs would be incurred decades into the future. Consequently, the present value of the costs would be relatively low today.

Assumptions about adaptation also affect estimates of potential benefits. Some critics of the earlier IPCC estimates argue that damages likely will be lower than predicted because expected temperature increases from a doubling of atmospheric GHG concentrations probably will be less than projected, ecosystems seem to be more resilient over the long term than the estimates suggest, human beings can adapt more than was supposed, and damages are not likely to increase proportionally with GDP (see for example Mendelsohn 1999; Mendelsohn and Neumann 1999). The implication is that the optimal path for GHG control (in a present value sense) should be even less aggressive than the IA results indicate. These new assessments remain controversial.[12]

A third factor affects benefits: Damage costs not only are uncertain but also involve a chance of a catastrophe (see Cline 1992; Yohe 1993; Tol 1995; Pizer 1999; Roughgarden and Schneider 1999). However, a general finding from IA models is that GHG reductions should be gradual, even if damages are larger than conventionally assumed. A risk of catastrophe provides a rationale for more aggressive early actions to reduce GHG concentrations; however, the risk has to be very large to rationalize near-term actions as aggressive as those

[12] One ongoing question concerns the cost of adjusting to a changing climate versus the long-term cost of a changed climate. Another is whether the effects of climate change (for example, in encouraging the spread of human illness through a greater incidence of tropical diseases, reducing river flows that concentrate pollutants, and increasing the incidence of heat stress) are being underestimated.

envisioned in the Kyoto Protocol in a present-value IA framework (see Peck and Teisberg 1993, 1996; Manne 1996; Gjerde and others 1999; Pizer 1999; a survey of experts by Nordhaus 1994b on climate change risks provides much of the grist for this ongoing debate). Part of the reason for this finding is that the outcome with the lowest cost also is the most likely to occur. IA models also do not incorporate risk-averse attitudes, which would provide a stronger rationale for avoiding large costs. Moreover, discounting in the models reduces the effective impact of all but the most catastrophic costs after a few decades.

Irreversibility of GHG emissions is yet another factor influencing the benefits of GHG abatement. Because GHG emissions persist in the atmosphere for decades, even centuries, the resulting long-term damages strengthen the rationale for early and aggressive GHG control (see Narain and Fisher 1999). Moreover, given that some damage costs from adjusting to a changed climate depend on the *rate* of climate change, immediate action also might be valuable. To date, however, the importance of this factor has not been conclusively demonstrated; the gradual abatement policies implied by the IA models do not seem likely to increase the speed of further climate change that much.

Finally, policies that reduce CO_2 also can yield ancillary benefits in terms of local environmental quality improvement—such as reduced human health threats or damage to water bodies from nitrogen deposition. The magnitudes of these ancillary effects remain fairly uncertain. They are lower to the extent that more environmental improvement would occur anyway, in the absence of GHG policy. They also depend on how GHG policies are implemented (for example, a new boiler performance mandate that encouraged extending the lives of older, dirtier boilers would detract from the environment). For additional discussion, see Burtraw and others (1999) and Lutter and Shogren (1999).

Influences on the Costs

Estimates of the cost of mitigating GHG emissions vary widely. Some studies suggest that the United States could meet its Kyoto Protocol target at negligible cost; other studies claim that the United States would lose at least 1–2% of its GDP each year. A study by the Energy Modeling Forum helped explain the range of results in assessing the costs to meet the Kyoto Protocol policy targets (Weyant and Hill 1999). For example, the carbon price (carbon tax or emissions permit price) needed to achieve the Kyoto Protocol emissions target in the United States with domestic policies alone ranges from about $70 per metric ton of carbon to more than $400 per ton (in 1990 dollars) across the models. The corresponding GDP losses in 2010 range from less than 0.2% to 2.0% relative to baseline.[13] Carbon prices are put in perspective by relating them to prices for common forms of energy, as listed in Table 3.

[13] The percentages of GDP are not reported in Weyant and Hill (1999) but are inferred from graphs presented there.

Table 3. Implications of a Carbon Tax for Gasoline and Coal Prices

		Price (US$)	
Commodity	*1997 U.S. average*	*With $100/ton carbon tax*	*With $400/ton carbon tax*
Bituminous coal	26.16	87.94	273.28
Motor gasoline	1.29	1.53	2.26

Note: Coal price is national average annual delivered price per ton to electric utilities; gasoline price is national average annual retail price per gallon.

Sources: U.S. DOE (1999a), U.S. DOE (1999b).

The results reported by Weyant and Hill (1999) and previous assessments of GHG control costs (Hourcade and others 1996a, 1996b) reflect different views about three key assumptions that drive the estimated costs of climate policy: stringency of the abatement policy, flexibility of policy instruments, and possibilities for development and diffusion of new technology. First, as one would expect, the greater the degree of CO_2 reduction required (because the target is ambitious, baseline emissions are high, or both), the greater the cost.

Costs of GHG control depend on the speed of control as well as its scale. Wigley and others (1996) showed that most long-term target GHG concentrations could be achieved at substantially lower present value costs if abatement were increased gradually over time, rather than rapidly, as envisaged under the Kyoto Protocol. Subsequent elaboration of this idea has shown that, in principle, cost savings well in excess of 50% could be achieved by using a cost-effective strategy for meeting a long-term concentration target versus an alternative path that mandates more aggressive early reductions (see Manne and Richels 1997). These cost savings come about not only because costs that come later are discounted more but also because less existing capital becomes obsolete prematurely. Kolstad (1996) points out that an irreversibility problem is associated with premature commitment to a form and scale of low-emissions capital, just as irreversibility is associated with climate change. The former irreversibility implies lower costs with a slower approach to mitigation.

Another important factor in assessing the costs of CO_2 control is the capacity and willingness of consumers and firms to substitute alternatives for existing high-carbon technologies. Substitution undertaken depends partly on the technological ease of substituting capital and technological inputs for energy inputs and partly on the cost of lower-carbon alternatives. Some engineering studies suggest that 20–25% of existing carbon emissions could be eliminated at low or negligible cost if people switched to new technologies such as compact fluorescent light bulbs, improved thermal insulation, efficient heating and cooling systems, and energy-efficient appliances (see IPCC 1996b, 1996c; NAS 1991; OTA 1991; Interlaboratory Working Group 1997). Economists counter that the choice of energy technology offers no free lunch. Even if new technologies are available, many people are unwilling to experiment with new devices at current prices. Factors other than energy efficiency also matter to consumers, such as quality, features, and the time and effort required to learn about a new technology and how it works. People behave as if their time horizons are short, perhaps reflecting their uncertainty about future energy prices and the reliability of the technology.

In addition, the unit cost of GHG control in the future may be lower than in the present, as a consequence of presumed continuation in trends toward greater energy efficiency in developed and developing countries (as well as some increased scarcity of fossil fuels). These trends will be enhanced by policies that provide economic incentives for GHG-reducing innovation. Kolstad (1996) argued that the cost associated with premature commitment to irreversible long-lived investments in low-emissions technologies is likely to be more important in practice than climatic irreversibility, at least over the medium term. The reason is that sunk investments cannot be undone if climate change turns out to be less serious than might be expected, whereas society can accelerate GHG control if it learns that the danger is greater than estimated. The strength of this point depends in part on how irreversible low-GHG investment is and on the costs of irreversible climate change (Narain and Fisher 1999).

Other analysts have argued that without early action to reduce GHG emissions, markets for low-emission technologies would not develop and societies would lock in to continued use of fossil fuel–intensive energy systems (Grubb and others 1995; Grubb 1997; Ha-Duong and others 1997). When knowledge is gained through basic research and development (R&D), the optimal time path moves in the direction of maintaining current emissions levels and increasing future reductions to take advantage of accumulated knowledge (Goulder and Mathai 2000). However, when knowledge is gained through "learning by doing" there is a stronger case for earlier action.[14]

Still another important factor is the flexibility and cost-effectiveness of the policy instruments imposed, both domestically and internationally. For example, Weyant and Hill (1999) showed that the flexibility to pursue CO_2 reductions anywhere in the Annex I group of countries through some form of international emissions trading system could lower U.S. costs to meet the Kyoto Protocol target by roughly 30–50%. Less quantitative analysis has been done of alternative domestic policies. Nevertheless, it can be presumed from studies of the costs of abating other pollutants that cost-effective policies will lower the cost of GHG abatement, perhaps significantly. In contrast, constraints on the use of cost-effective policies—for example, the imposition of rigid technology mandates in lieu of more flexible performance standards—will raise costs, perhaps considerably.[15] This factor often is neglected in analyses of domestic abatement activity that consider only the use of cost-

[14] Goulder and Schneider (1999) note that opportunity costs may be associated with inducing more technical innovation in greenhouse gas mitigation: To the extent that fewer research and development resources are made available in the economy as a whole for other innovation activities, productivity growth in the economy as a whole would be lower than otherwise.

[15] More flexible approaches are more cost-effective when abatement costs in the economy are heterogeneous because such approaches allow more abatement to be carried out by those actors with the lowest costs, using the most effective technologies. Thus, for example, an abatement policy that relies in part on automobile fuel efficiency standards may impose excessive costs if the incremental cost of greenhouse gas abatement is lower in the power sector.

effective policies such as emissions permit trading, although use of such policies is hardly foreordained. Ignoring this factor means that the costs reported in the economic models probably understate the costs societies will actually incur in GHG control. By the same reason, studies of international policies that assume ideal conditions of implementation and compliance are overoptimistic.

A subtle but important influence on the cost of GHG control is whether emission-reducing policies also raise revenues (such as a carbon tax) and what is done with those revenues. When the revenue generated by a carbon tax or other policy is used to reduce other taxes, this revenue recycling offsets some of the negative effect on incomes and labor force participation of the increased cost of energy. However, it may be more effective at stimulating employment and economic activity in countries with chronically high unemployment than in the United States. The issue of revenue recycling applies also to policies that would reduce CO_2 through carbon permits or caps. If CO_2 permits are auctioned, then the revenues can be recycled through cuts in existing taxes; freely offered CO_2 permits do not allow the possibility of revenue recycling. The difference in net social costs of GHG control in the two cases can be dramatic. The analysis by Parry, Williams, and Goulder (1999) finds that reducing CO_2 emissions with auctioned permits and revenue recycling can have net costs less than the benefits of GHG control indicated by the IA models. In contrast, with a system of freely provided CO_2 permits, *any* level of emissions reduction yields environmental benefits (according to the IA models) that fall short of society’s costs of abatement.

Most cost analyses presume that the relevant energy and technology markets work reasonably efficiently (other than the commonly recognized failure of private markets to provide for all the basic R&D that society wants, because this is a kind of public good). This assumption is more or less reasonable for most developed industrial economies. Even in these countries, one can identify problems such as direct and indirect energy subsidies that encourage excessive GHG emissions. Problems of market inefficiency are far more commonplace in the developing countries and in countries in transition toward market systems; accordingly, one expects incremental CO_2 control costs to be lower (even negative) in those countries (Jepma and others 1996; Lopez 1999). However, the institutional barriers to accomplishing GHG control in these economic systems may negate the potential efficiency gains.

Thus far, we have concentrated on CO_2 control. Because CO_2 is only one of several GHGs, and because CO_2 emissions can be sequestered or even eliminated by using certain technologies, emissions targets related to climate change can be met in several ways. Some recent analyses suggest that the costs of other options alternatives compare very favorably with the costs of CO_2 reduction. For example, counting the results of forest-based sequestration and the reduction of non-CO_2 gases toward total GHG reduction goals could lower the cost to the United States of meeting its Kyoto Protocol emissions target by roughly 60% (Reilly and others 1999). But care is needed in interpreting some of the cost estimates. In particular, low estimates for the cost of carbon sequestration may not adequately capture all the opportunity cost of different land uses (see Sedjo and others 1997; Newell and Stavins forthcoming).

Uncertainty, Learning, and the Value of New Information

Another key factor in choosing the timing and intensity of climate change mitigation is the opportunity to learn more about both the risks of climate change and the costs of mitigation. Several studies show that the value of more and better information about climate risks is substantial (see Manne and Richels 1992; Peck and Teisberg 1993; Chao 1995; Kolstad 1996). This value arises because one would like to avoid putting lots of resources into mitigation in the short term, only to find out later that the problems related to climate change are not serious. However, one also would like to minimize the risk of doing too little mitigation in the short term, only to find out later that very serious consequences of climate change will cost much more to avert because of the delay. Manne and Richels (1992) showed that it generally pays to do a little bit of abatement in the short run under these conditions—to hedge against the downside without making too rapid a commitment. One virtue of some delay in emissions control is that it allows us to learn more about the severity of the risk of climate change and the options for responding to it. If the risk turns out to be worse than expected, mitigation can be accelerated to make up for lost time. To be sure, the strength of this argument depends on how costly it is to accelerate mitigation and on the degree of irreversibility of climate change. Analysts will continue to debate these points for some time to come.

In this section, we have explained that benefits and costs matter, for both efficiency and equity reasons, and that benefits and costs must and can be considered in the context of the uncertainties that surround climate change. Economic analyses provide several rationales for pursuing only gradual abatement of GHG emissions. Because damages accrue gradually, catastrophes are uncertain and off in the future, and unit mitigation costs are likely to fall over time (especially with well-designed climate policies), it makes sense to proceed slowly. To the extent that innovation is slower than desired with this approach, government programs targeted at basic R&D can help. The IA models indicate that rapid abatement does not maximize the present value of all society's resources.

We have not argued that current benefit–cost analyses are the last word on the subject. Opportunities certainly exist to improve the measurement of benefits and costs and to track the incidence of costs and risks across groups and over time. In practice, policy decisions will turn on a broader set of considerations that a single expected benefit–cost ratio. However, the arguments in favor of purposeful but gradual reduction in GHGs seem strong.

Whatever climate change policy goals are agreed upon, it makes sense to adopt cost-effective policies. Doing so means not committing excessive resources to meeting the climate policy goals, but preserving greater resources for other worthy goals, such as education and health. We discuss this topic in more detail in the next section.

Designing Climate Policy Instruments

Good climate change policies reflect the inherent trade-off between the stringency of a target (however defined) and the flexibility to meet this goal. Different policy tools can inflate or attenuate the costs of hitting any given target. Inflexible, inefficient policies will inflate costs without additional reductions in climate risk. Well-designed policies will lower the cost of achieving any particular targets and thereby make more stringent targets affordable. In this section, we emphasize economic policy tools that work cost-effectively by creating incentives for GHG mitigation while maintaining flexibility in the means used.

Creating Economic Incentives: Taxing and GHGs Trading

Economic tools help cut the costs of achieving a GHG emissions target because they generate a market price for GHG emissions, which are otherwise treated as a free good. This price creates tangible financial reasons to reduce carbon emissions while providing flexible means to do so at low cost. Emissions taxes and GHG permit trading are economists' favorite incentives. Consumers respond to the price signals that these policies represent by switching to less-carbon-intensive fuels (for example, natural gas for coal); increasing energy efficiency per unit of output by using less-energy-intensive technologies; adopting technologies to reduce the emissions of other GHGs (assuming they are covered in the tax program); reducing the production of what become high-cost, carbon-intensive goods; increasing the sequestration of carbon through reforestation; and developing and refining new technologies (for example, renewable energy resources) for avoiding GHG emissions.

Carbon can be taxed indirectly by taxing fossil fuels. Taxing fossil fuels works because their carbon content is easily ascertained, and no viable option for end-of-pipe carbon abatement (for example, scrubbing) currently exists. A fossil fuel tax could be collected in several ways: as a severance tax on domestic fossil fuel output, plus an equal tax on imports; as a tax on primary energy inputs levied on refineries, gas transportation systems, and coal shippers; or as a tax downstream, on consumers of fossil fuels. However, the farther upstream the tax is levied (that is, closer to the producers of fossil fuels), the less carbon leaks out through uncovered activities such as oil field processing. Implementing such a tax would be relatively straightforward in the United States and most other developed countries, given existing tax collection systems, but more challenging in developing countries that have less effective institutions for levying taxes and monitoring behavior.

Carbon trading is somewhat more complicated than a carbon tax. One has to decide where to assign property rights for carbon: downstream, upstream, or some combination of the two. In principle, a downstream approach encompasses all emissions. In practice, however, all people in the United States who heat their homes with fossil fuel and/or drive a car would be required to buy and sell carbon permits. Operating and overseeing such a market would be an administrative nightmare. In contrast, an upstream system would be easier to administer because the number of market actors is smaller. Comprehensive policy would have to account for imported refined products as well as domestic fossil energy supplies and to address noncombustion uses of fossil fuels (for example, chemical feedstocks). One possibility is a system in which emissions of large sources are regulated directly and small sources are regulated through limits on their fossil fuel supplies. Or, a carbon tax could be levied on the energy used by smaller sources.

Questions about how to distribute permits also complicate carbon trading. A government could sell permits to the highest bidders in an auction-style system, hand them out gratis according to some formula such as grandfathering (that is, the government assigns permits to existing emitters relative to a historical base year), or combine the two approaches somehow.

The choice forces policymakers to address trade-offs among goals of economic efficiency, distributional equity, and political feasibility. Efficiency increases with greater auctioning because the revenues can be used to offset existing distortionary taxes. Gratis permit allocation can target the distribution of a valued commodity toward the people most adversely affected by the policy (for example, low-income households and coal miners) or to those wielding the greatest political influence over the distribution of trading profits and losses. This option no doubt could increase the political feasibility of a trading policy. Bovenberg and Goulder (forthcoming) provide some simulation analyses that suggest that the cost of compensating fossil fuel–producing companies and their shareholders for losses resulting from reduced sales under a carbon-trading system is not very large. The cost increases, of course, if policy also seeks to compensate fossil fuel–intensive industries and the affected workers.

Which GHGs to address beyond CO_2 is another issue that both trading and taxation policies must address. For instance, the appropriate tax on natural gas entering the pipeline system could account for leakage and the greater relative potency of methane. Levies also could be placed on methane releases from coal mines and landfills and on human-manufactured gases on the basis of their expected venting to the atmosphere through sources such as automobile air conditioners. Some gases will be more difficult than others to control. A prime example is how to capture decentralized sources of agricultural methane that would be costly to measure.

Tax or trading systems also could be extended to carbon sequestration activities such as reforestation programs, which could earn tax credits or garner additional emissions permits. The challenge is to define a credible baseline to measure the amount of carbon sequestered by the forest. For example, one does not want a system that rewards carbon sequestration that would have occurred anyway as part of forest rotation practices, or a system that encourages deforestation so that landowners could then claim credit for replanting trees. For additional discussion about carbon sequestration, see Sedjo and others (1997).

Rules for banking and borrowing carbon permits are another key component of a trading system. Banking lowers costs by allowing traders to hedge against risks in emissions patterns (for example, a colder than average winter), and to smooth out fluctuations in abatement costs over time. With borrowing, traders have more flexibility to respond to unexpected short-term increases in abatement costs, thereby spreading the economic risk of compliance across time. The Kyoto Protocol provides a very limited amount of such flexibility by allowing Annex I countries to average their emissions over a five-year commitment period (2008–12).

Banking and borrowing raise the more fundamental issue of how to set credible long-term targets while facilitating short-term adjustments. In principle, policy could set a long-term GHG concentration target and let private actors reach the target most cost-effectively by adjusting their abatement strategies to minimize costs over time (see Kosobud and others 1994; Peck and Teisberg 1998). But critics doubt the credibility of such long-term targets. They also argue that a firm's natural tendency to delay emissions control to the future could impose unacceptable future climate change costs and make targets unenforceable(see Leiby and Rubin 2000).

This issue may be overwhelmed by the larger question: When should GHG reduction take place—now or later? As indicated earlier, many analyses suggest substantial cost savings from a more gradual path of emissions control than is envisaged in the Kyoto Protocol (however, some critics question how compelling these findings are). Even critics of intertemporal GHG trading need to address the possibility of policy targets with more flexibility over time and more gradual controls.

International Implementation of GHG Trading

GHG trading can be extended around the globe. Theory says that global trading can generate mutual gains by allowing low-cost abaters to profit from selling permits to grateful high-cost abaters. The Kyoto Protocol allows for both formal GHG trading among the Annex I developed countries and bilateral trading through the Clean Development Mechanism (CDM). Under the CDM, emissions reduction activities in noncapped, non-Annex I nations can generate emission reduction credits for Annex I nations. Annex I trading could involve tying together domestic emissions trading programs or a project-level approach in which participants can generate emission credits from emission-reducing actions in other Annex I countries (so-called joint implementation).[16] These various endeavors could be organized and financed by Annex I investors, the developing countries themselves, and international third parties.

The CDM could generate both low-cost emissions reductions for developed countries and tangible benefits to the host country through the transfer of efficient, low-carbon technology. However, many obstacles remain. The key immediate question is how to design a credible monitoring and enforcement system that does not impose such high transaction costs that it chokes off CDM trades. People will not start a project if the time, effort, and financial outlays needed to search out, negotiate, and obtain governmental approvals are too onerous. For additional discussion, see Goldemberg (1998), Grubb and others (1999), Jepma and van der Gaast (1999), and Haites and Yamin (forthcoming).

The United States has been a strong advocate for international trading in international negotiations. Other countries, notably in Western Europe and the developing world, have been cooler toward decentralized private-sector emission trading. Some nations like trading, but only if strict rules are imposed, which in a sense may ultimately be self-defeating. European negotiators have advocated trading limits which restrict the degree to which Kyoto Protocol targets could be met through international flexibility mechanisms. Such "supplementarity" constraints (as they are termed in the debates) have been stoutly resisted by the United States for fear that they would unduly restrict opportunities for cost-effective emissions control and delay the evolution of effective GHG permit markets.

---

[16] Hahn and Stavins (1999) describe the practical difficulties of operating a transaction-specific, credit-based joint implementation program internationally with heterogeneous domestic greenhouse gas measures. They point out the trade-off between international cost-effectiveness and domestic policy sovereignty that it engenders.

Trade-offs between Taxing and Trading GHGs

Choosing between taxing and trading GHGs requires consideration of several key trade-offs. First, a tax generates revenue for the government, which need not be the case with permit trading. Second, taxes fix the price and allow the emissions levels to vary, putting the risk on the environment, because the firms knows the cost of emission reduction, whereas permits fix the emission target and allow the price to vary, putting the risk on the regulated firms, because the firm no longer knows the cost of a permit with certainty. As such, a permit system fits more naturally into the Kyoto Protocol (UNFCCC 1999b), which focuses on fixed emissions targets and timetables.

A downside to GHG trading is that society does not know what the actual abatement cost will be for a fixed quantity of emissions. When costs are uncertain and potentially severe, society may be better off with a tax-based approach that caps the cost of emissions control but does not ensure hitting a specific emissions target (Weitzman 1974; Pizer 1997; Newell and Pizer 1998). The exception would be cases in which a strong reason exists to limit GHG concentrations below a certain limit because of the risk of catastrophic damages. But no solid evidence exists at this time on which to base such a judgment. It is also possible to adopt a hybrid policy based on emissions trading but with a safety valve in case costs go too high. In practice, this policy would involve the government issuing additional permits if the price went beyond some predetermined level (which could change over time).[17]

Technology and Market Reform Policies

Incentive-based policies such as taxing and GHG trading work to encourage the diffusion of existing low-carbon technology and the development of new technology. They beg the question of whether additional nonprice policies are necessary to promote climate-friendly technology advances and investment. Proponents of such policies argue that economic incentives are inadequate to change behavior to a degree sufficient to reduce climate risk. They advocate public education and demonstration programs; institutional reforms, such as changes in building codes and utility regulations; and technology mandates, such as fuel economy standards for automobiles and the use of renewable energy sources for power generation.

No one doubts that such approaches eventually might reduce GHG emissions. At issue is the cost-effectiveness of such programs. Advocates of technology mandates often argue that the subsequent costs are negligible because the realized energy cost savings more than offset the initial investment costs. But as we noted earlier, this view does not address several factors that impinge on technology choices, and it implies a widespread lack of rational decisionmaking by energy users.

---

[17] A version of this idea is sketched in Pizer (1997), and a policy for U.S. implementation is suggested in Kopp and others (1999). If permits are internationally traded, regulations would have to prevent entities in the United States from selling off all their "base" permits to trigger the safety valve.

The economic perspective emphasizes searching for real inefficiencies that impede low-cost choices as opposed to barriers that reflect unavoidable direct or hidden costs, such as the capacity of technology to predictably meet the needs of its users. Most economic analysis recognizes that energy use suffers from inefficiencies but remains skeptical that such large no-regret gains actually exist. Economic analyses also acknowledge a role for government when consumers have inadequate access to information or if existing regulatory institutions are poorly designed. This role can include subsidies to basic R&D to compensate for an imperfect patent system; reform of energy sector regulation and reduction of subsidies that encourage uneconomic energy use; and provision of information about new technological opportunities. For additional discussion and competing perspectives on these issues, see Geller and Nadel (1994), Jaffe and Stavins (1994), Metcalf (1994), Levine and others (1995), and Jaffe and others (1999).

Finally, in developing countries, barriers in the energy sector stall the diffusion of cost-effective technology. These barriers often are compounded by other economy-wide policy and infrastructure problems. When barriers to technology diffusion exist, the most effective solution typically is not found in regulatory mandates or ill-focused rules for technology adoption. Rather, solutions are found in institutional or broader market reforms, such as greater availability of information, expansion of financing opportunities, and reforms in energy sector pricing and other areas. For additional discussion, see Blackman (1997) and Lopez (1999).

Coherent International Architecture Matters

Good domestic policy will be only as effective as the stability of an international agreement that defines a common purpose across nations. As such, the third factor that matters for climate change policy is a coherent international architecture. Speaking about the Rio negotiations, Prime Minister Gro Bruntland said, “We knew the basic principles on which we needed to build: cost-effectiveness, equity, joint implementation, and comprehensiveness. But not how to make them operational” (as quoted in Schmalensee 1996).

Because the source of the risk is widespread, responsibility for resolving the problem ultimately must be shared. But the more widespread the responsibility, the greater the challenge of maintaining a stable agreement, because nations have more incentive to free ride on the actions of other nations. This challenge is compounded by national differences related to income, vulnerability to climate change, and capacities to respond. Two related elements of cooperative and noncooperative economic behavior underlie the numerous intricacies of international diplomacy aiming to design and implement a climate agreement: the paradox of international agreements and the engagement of developing nations.

The Paradox of International Agreements

The problem of achieving effective and lasting agreements can be stated simply: A self-enforcing deal is easiest to close when the stakes are small, or when no other option exists (a clear and present risk). Nations have a common interest in responding to the risk of climate change, yet many are reluctant to reduce GHG emissions voluntarily. They hesitate because climate change is a global public good—no nation can be prevented from enjoying climate protection, regardless of whether it participates in a treaty. Each nation's incentive to reduce emissions is thus limited because it cannot be prevented from enjoying the fruits of other nations' efforts. This incentive to free ride reflects the divergence between national actions and global interests.

No global police organization exists to enforce an international climate agreement. As such, an agreement must be voluntary and self-enforcing—all sovereign parties must have no incentive to deviate unilaterally from the terms of the agreement. But a self-enforcing agreement is hardest to achieve in the gray area between low and infinite stakes. By free riding, some nations can be better off refusing an agreement. The greater the global net benefits of cooperation, the stronger the incentive to free ride; therefore, a self-enforcing agreement is harder to maintain. A self-enforcing agreement is most easily maintained when the global net benefits are not much bigger than no agreement—hence, the paradox. For more discussion see Hoel (1992), Carraro and Siniscalco (1993), Barrett (1994), and Bac (1996).

If self-enforcement is insufficient, signatories who have ongoing relationships can try to alleviate free riding on climate change policy by retaliating with threats such as trade sanctions (see Chen 1997). But the force of linkage and deterrence is blunted in several respects. A nation's incentive not to participate in reducing GHG emissions depends on the balance between short-term gains from abstaining relative to the long-term cost related to punishment. Participating nations must see a gain in actually applying punishment, otherwise their threats of retaliation will not be credible. Credibility problems arise when, for example, retaliation through trade sanctions damages both the enforcer and the free rider. Moreover, because many forms of sanctions exist, nations would need to select a mutually agreeable set of approaches—probably another involved negotiation process. For an illustration, see Dockner and van Long (1993).

Even if a self-enforcing agreement involved only two or three big emitting markets (for example, the United States and the European Union) and many small nations refused to agree, total emissions probably would remain higher than global targets. For their part, many decisionmakers in industrialized countries worry about the consequences to their economies of reducing emissions while developing countries face no limits. This situation could adversely affect comparative advantages in the industrialized world, whereas leakage of emissions from controlled to uncontrolled countries would limit the environmental effectiveness of a partial agreement. Estimates of this carbon leakage vary from a few percent to more than one-third of the Annex B reductions, depending on model assumptions regarding substitutability of different countries' outputs and other factors (Weyant and Hill 1999).

Designing Climate Agreements to Draw In Developing Nations

Developing nations have many pressing needs, such as potable water and stable food supplies, and less financial and technical capacity than rich countries to mitigate or adapt to climate change. These nations have less incentive to agree to a policy that they see as imposing unacceptable costs. The international policy objective is obvious, but elusive:

finding incentives to motivate nations with strong and diverse self-interests to move voluntarily toward a collective goal of reduced GHG emissions.

Equity is a central element of this issue, because differences in perceptions about what constitutes equitable distributions of effort complicate any agreement. No standard exists for establishing the equity of any particular allocation of GHG control responsibility. Simple rules of thumb, such as allocating responsibility based on equal per capita rights to emit GHGs (advantageous to developing countries) and allocations that are positively correlated to past and current emissions (advantageous to developed countries) are unlikely to command broad political support internationally. The same problem arises with dynamic graduation formulas, which seek to gradually increase the control burden of developing countries as they progress economically. However, these dynamic approaches do offer more negotiating flexibility (see Burtraw and Toman 1992; Rose and Stevens 1993; Manne and Richels 1995; Schelling 1995; Rose and others 1998; Yang 1999).

Direct side payments through financial or low-cost technical assistance can increase the incentive to join the agreement. Incentive-based climate policies can help by reducing the cost of action for all countries. In particular, both buyers and sellers benefit from trade in emissions permits. Emissions trading also allows side payments through the international distribution of national emissions targets. More reluctant countries can be enticed to join with less stringent targets while other countries meet more stringent targets to achieve the same overall result. These points often are lost when critics argue that emissions trading will weaken international agreement because a seller country can fail to meet its domestic target and export “phony” emissions permits.

Side payments through emissions trading result when countries are given national quotas in excess of their expected emissions, an allocation sometimes called “headroom.” Such an allocation was provided to Russia and Ukraine in the Kyoto Protocol and came to be called “hot air” by critics, who feared it would slow international progress by giving advanced industrial countries such as the United States a cheap way out of cutting their own emissions. But had this cost-reducing option not been part of the package, it is unclear whether the United States and other countries would have agreed to the protocol or could achieve its goals in practice (see Wiener 1999). Nevertheless, international reallocations of wealth in permit trading give rise to broader domestic political debates. Imagine, for instance, the domestic debate if the United States administration decided to transfer many billions of dollars annually to Russia, or perhaps China in a subsequent agreement, for emissions permits (see Victor and others 1998).

Critics claim that tradable permits have a Catch-22 that threatens the future of the Kyoto Protocol and longer-term agreements. Without trading, mitigation costs are too high to be politically acceptable; with trading, the distribution of these costs is too unfair to be politically acceptable. So, some observers promote individually administered national carbon taxes as the only reasonable option (Cooper 1998). However, this approach is not a panacea for distributional concerns, in that the initial allocation of rights and responsibilities is implicit in *any* international control agreement, including taxes. Moreover, the argument for taxes rests on the willingness of the developing world to implement substantially higher energy taxes than exists today. Although developing countries theoretically would reap some advantages of increasing energy taxes (for example, more reliable revenue than from income taxes), it is unclear whether the advantages are so compelling in practice. (Wiener 1999 offers several efficiency and political economy arguments in favor of a quantity-based over a tax-based approach.) Without such participation, the tax approach becomes an inefficient partial agreement like the Kyoto Protocol.

Concluding Remarks

Climate change poses risks to society. We have reviewed what researchers know about these risk and have discussed the benefits and costs of different protection strategies. Several lessons emerge that underscore the similarities and differences between climate change and other environmental issues. As with other issues—though perhaps to a greater degree in some cases—efficiency and complex equity issues must be addressed. Economic incentives are necessary for cost-effective and credible policies. Policymakers need to better understand the political and economic trade-offs between flexibility and stringency in the design of climate policies, and people need to recognize and account for the serious uncertainties that exist. In addition, international participation is necessary to effectively address climate issues, and significant challenges exist to establishing agreements that are substantial in their aims and credible in their implementation.

We also have identified several gaps between what the economics of climate change would tell us about policy and the actual direction of U.S. and international policy debates. In terms of the three themes we have followed through this paper, economic analysis would suggest the following benefits and costs matter, as does uncertainty.

- There needs to be some balance of concern between the irreversible consequences of climate change and the costs of misplaced mitigation investment.
- A gradual approach to the implementation of GHG control targets to take advantage of cost savings and opportunities for learning is desirable.
- Well-designed, cost-effective climate policies are essential.
- Incentive-based mechanisms warrant a warm embrace, both domestically and internationally.
- A greater emphasis is needed on price-based approaches over strict quantity targets in the short to medium term to manage the risk of uncertain response costs.
- Targeted efforts to compensate the greatest losers with the least waste for political expediency should be undertaken.
- Climate policies should be coupled to broader economic reform opportunities to maximize win–win opportunities.
- Coherent international architecture is key to success.
- Serious discussion is needed of common ground for common but differentiated participation of developed and developing countries based on shared burdens and mutual benefit.

In practice, the policy debate has tended to emphasize climatological and socioeconomic damage risks over risks related to economic response costs. It has focused on strict and ambitious quantitative emissions targets for a subset of countries, without a clear path for implementing or broadening the agreement, and has been somewhat dismissive of those who see their own self-interest as not aligned with the emissions control targets being advocated. The debate has downplayed the importance of response costs by emphasizing potential "free lunch" opportunities in the technological arena, has sought to limit the operation of cost-reducing incentive-based systems (especially outside the United States), and has played up the tensions between developed and developing countries.

Some of these contrasts might be rationalized on the basis of factors such as strong aversion to risk of climate change, concerns about credible implementation of policies in practice, and honest disagreements in assessing the costs of GHG control. But a great deal of the difference, as we see it, reflects the politics of the issue. It remains to be seen how these political issues will play out, particularly whether the Kyoto Protocol or a successor agreement will be successfully ratified and implemented.

- Finally, many uncertainties remain that affect climate policy design. To reduce the related uncertainties and improve the feasibility of future policy, policymakers need to better understand several points:
- The risks of climate change from a socioeconomic as well as a scientific perspective.
- The nature of public concern about climate change risks.
- The trade-offs between adaptation and emissions control, and the importance of different forms of infrastructure (especially in developing countries) for enhancing the capacity for adaptation.
- The costs of GHG control in an international context, accounting for trade and financial flows under different patterns of participation in international abatement efforts.
- How large the "energy efficiency gap" is in practice, and the consequences for assessing the cost of GHG abatement.
- The incentives for technical progress created by different climate policies, and the opportunity costs of inducing innovation toward GHG control versus other applications.
- The processes of international negotiation and coalition formation as they apply to climate agreements, in theory and practice.
- Better practical understanding of the distributional impacts of different policy regimes.

Most of these questions will persist well beyond a third edition of this book. Starting to address them now can only increase the economic soundness and ultimately the reliability of climate change policy into the future.

References

Arrow, Kenneth J., and others. 1996. Intertemporal Equity, Discounting, and Economic Efficiency. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: University of Cambridge Press, 125–44.

Azar, Christian, and Thomas Sterner. 1996. Discounting and Distributional Considerations in the Context of Global Warming. *Ecological Economics* 19:169–84.

Bac, Mehnet. 1996. Incomplete Information and Incentives to Free Ride on International Environmental Resources. *Journal of Environmental Economics and Management* 30(3):301–15.

Barrett, Scott. 1994. Self-Enforcing International Environmental Agreements. *Oxford Economic Papers* 46:878–94.

Blackman, Allen. 1997. The Economics of Technology Diffusion: Implications for Greenhouse Gas Mitigation in Developing Countries. RFF Climate Issues Brief No. 5, October. Washington, DC: Resources for the Future.

Bovenberg, A. Lans, and Lawrence H. Goulder. Forthcoming. Neutralizing the Adverse Industry Impacts of CO_2 Abatement Policies: What Does It Cost? In *Behavioral and Distributional Effects of Environmental Policies: Evidence and Controversies*, edited by Carlo Carraro and Gilbert Metcalf. Chicago, IL: University of Chicago Press.

Burtraw, Dallas, and Michael A. Toman. 1992. Equity and International Agreements for CO_2 Containment. *Journal of Energy Engineering* 118(2):122–35.

Burtraw, Dallas, Alan Krupnick, Karen Palmer, Anthony Paul, Michael Toman, and Cary Bloyd. 1999. Ancillary Benefits of Reduced Air Pollution in the U.S. from Moderate Greenhouse Gas Mitigation Policies in the Electricity Sector. RFF Discussion Paper 99-51. September. Washington, DC: Resources for the Future.

Camerer, Colin F., and Howard Kunreuther. 1989. Decision Processes for Low Probability Events: Policy Implications. *Journal of Policy Analysis and Management* 8(4):565–92.

Carraro, Carlo, and Dominico Siniscalco. 1993. Strategies for the International Protection of the Environment. *Journal of Public Economics* 52(3):309–28.

Chao, Hung-po. 1995. Managing the Risk of Global Climate Catastrophe: An Uncertainty Analysis. *Risk Analysis* 15(1):69–78.

Chen, Zhiqi 1997. Negotiating an Agreement on Global Warming: A Theoretical Analysis, *Journal of Environmental Economics and Management* 32(2):170–88.

Cline, William R. 1992. *The Economics of Global Warming.* Washington, DC: Institute for International Economics.

Clinton, William J., and Al Gore. 1993. *Climate Change Action Plan*. Washington, DC: Executive Office of the President.

Cooper, Richard. 1998. Toward a Real Global Warming Treaty. *Foreign Affairs* 77(2, March/April):66–79.

Council of Economic Advisers. 1998. *The Kyoto Protocol and the President's Policies to Address Climate Change: Administration Economic Analysis.* July. Washington, DC: Executive Office of the President.

Crocker, Thomas D., and Jason F. Shogren. 1997. Endogenous Risk and Environmental Program Evaluation. In *Environmental Program Evaluation: A Primer*, edited by Gerrit Knaap and Tschangho J. Kim. Urbana, IL: University of Illinois Press, 255–69.

Darmstadter, Joel, and Michael A. Toman, eds. 1993. *Assessing Surprises and Nonlinearities in Greenhouse Warming: Proceedings of an Interdisciplinary Workshop.* Washington, DC: Resources for the Future.

Dockner, Englebert, and Ngo Van Long. 1993. International Pollution Control: Cooperative versus Noncooperative Strategies. *Journal of Environmental Economics and Management* 24:13–29.

Energy Information Administration (EIA). 1998. *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*. Washington, DC: EIA.

Frankhauser, Samuel, Richard S. J. Tol, and David W. Pearce. 1998. Extensions and Alternatives to Climate Change Impact Valuation: On the Critique of IPCC Working Group III's Impact Estimates. *Environment and Development Economics* 3(Part 1):59–81.

Geller, Howard, and Steven Nadel. 1994. Market Transformation Strategies to Promote End-Use Efficiency. *Annual Review of Energy and the Environment*. 19:301–46.

Gjerde, Jon, Sverre Greppud, and Snorre Kuendakk. 1999. Optimal Climate Policy under the Possibility of a Catastrophe. *Resource and Energy Economics* 21(3–4):289–317.

Goldemberg, Jose. 1998. *Issues and Options: The Clean Development Mechanism.* New York: United Nations Development Programme.

Goulder, Lawrence H., and Koshi Mathai. 2000. Optimal CO_2 Abatement in the Presence of Induced Technological Change. *Journal of Environmental Economics and Management* 39(1):1–38.

Goulder, Lawrence H., and Stephen H. Schneider. 1999. Induced Technological Change and the Attractiveness of CO_2 Abatement Policies. *Resource and Energy Economics* 21(3–4):211–53.

Grubb, Michael J. 1997. Technologies, Energy Systems and the Timing of CO_2 Emissions Abatement: An Overview of Economic Issues. *Energy Policy* 25(2):159–72.

Grubb, Michael J., T. Chapuis, and H. D. Minh. 1995. The Economics of Changing Course: Implications of Adaptability and Inertia for Optimal Climate Policy. *Energy Policy* 23(4/5):417–32.

Grubb, Michael J., Christiaan Vrolijk, and Duncan Brack. 1999. *The Kyoto Protocol: A Guide and Assessment.* London: Royal Institute of International Affairs.

Ha-Duong, M., Michael J. Grubb, and Jean-Charles Hourcade. 1997. Influence of Socioeconomic Inertia and Uncertainty on Optimal CO_2 Emission Abatement. *Nature* 390:270–73.

Hahn, Robert W., and Robert N. Stavins. 1999. What Has Kyoto Wrought? The Real Architecture of International Tradeable Permit Markets. March. RFF Discussion Paper 99-30. Washington, DC: Resources for the Future.

Haites, Erik., and F. Yamin. Forthcoming. The Clean Development Mechanism: Proposals for Its Operation and Governance. *Global Environmental Change*.

Hammitt, James K., Atul K. Jain, and John L. Adams. 1996. A Welfare-Based Index for Assessing Environmental Effects of Greenhouse Gas Emissions. *Nature* 381:301–3.

Heal, Geoffrey, and Graciela Chichilnisky. 1993. Global Environmental Risks. *Journal of Economic Perspectives* 7(4):65–86.

Hoel, Michael. 1992. International Environmental Conventions: The Case of Uniform Reductions of Emissions. *Environmental and Resource Economics* 2(2):141–59.

Hourcade, Jean-Charles, and others. 1996a. A Review of Mitigation Cost Studies. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: University of Cambridge Press, 263–96.

Hourcade, Jean-Charles, and others. 1996b. A Review of Mitigation Cost Studies. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: University of Cambridge Press, 297–306.

Howarth, Richard H. 1996. Climate Change and Overlapping Generations. *Contemporary Economic Policy* 14:100–111.

——. 1998. An Overlapping Generation Model of Climate–Economy Interactions. *Scandinavian Journal of Economics* 100(3):575–91.

IPCC (Intergovernmental Panel on Climate Change). 1996a. *Climate Change 1995: The Science of Climate Change*. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

——. 1996b. *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analysis.* Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

——. 1996c. *Climate Change 1995: Economic and Social Dimensions of Climate Change.* Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

——. 1998. *The Regional Impacts of Climate Change: An Assessment of Vulnerability*. New York: Cambridge University Press.

Interlaboratory Working Group (IWG). 1997. *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond*. September. Report LBNL-40533 and ORNL-444. Berkeley, CA, and Oak Ridge, TN: Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory.

Jacoby, Henry, Ronald Prinn, and Richard Schmalensee. 1998. Kyoto's Unfinished Business. *Foreign Affairs* 77(4, July/August):54–66.

Jaffe, Adam B., and Robert N. Stavins. 1994. The Energy-Efficiency Gap: What Does It Mean? *Energy Policy* 22(1):804–10.

Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins. 1999. Energy-Efficient Technologies and Climate Change Policies: Issues and Evidence. December. RFF Climate Issue Brief No. 19. Washington, DC: Resources for the Future.

Jepma, Catrinus J., and Wytze van der Gaast, eds. 1999. *On the Compatibility of Flexibility Instrument.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Jepma, Cristinus J., and others. 1996. A Generic Assessment of Response Options. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: University of Cambridge Press, 225–62.

Kane, Sally, and Jason Shogren. Forthcoming. Adaptation and Mitigation in Climate Change Policy. *Climatic Change*.

Kempton, Willett, James S. Boster, and Jennifer A. Hartley. 1995. *Environmental Values in American Culture.* Cambridge, MA: MIT Press.

Kolstad, Charles D. 1996. Learning and Stock Effects in Environmental Regulation: The Case of Greenhouse Gas Emissions. *Journal of Environmental Economics and Management* 31:1–18.

——. 1998. Integrated Assessment Modeling of Climate Change. In *Economics and Policy Issues in Climate Change*, edited by W. Nordhaus. Washington, DC: Resources for the Future, 263–86.

Kopp, Raymond J., Richard Morgenstern, William Pizer, and Michael Toman. 1999. A Proposal for Credible Early Action in U.S. Climate Policy (Feature). *Weathervane* (http://www.weathervane.rff.org/features/feature060.html).

Kosobud, Richard, Thom Daly, David South, and Kevin Quinn. 1994. Tradable Cumulative CO_2 Permits and Global Warming Control. *Energy Journal* 15(2):213–32.

Krosnick, John A., Holbrook, A. L., and P. S. Visser. Forthcoming. The Impact of the Fall 1997 Debate about Global Warming on American Public Opinion. *Public Understanding of Science*.

Leiby, Paul., and Jonathan. Rubin. 2000. Bankable Permits for the Control of Stock Pollutants: The Greenhouse Gas Case. February 2. Draft paper. Orono, Maine: University of Maine.

Levine, Mark D., Jonathan G. Koomey, James E. McMahon, Alan H. Sanstad, and Eric Hirst 1995. Energy Efficiency Policy and Market Failures. In *Annual Review of Energy and the Environment* 19:535-55.

Lichtenstein, Sarah., and others. 1978. The Judged Frequency of Lethal Events. *Journal of Experimental Psychology* 4(6):551–78.

Lind, Robert C., and Richard E. Schuler. 1998. Equity and Discounting in Climate-Change Decisions. In *Economics and Policy Issues in Climate Change*, edited by William. Nordhaus. Washington, DC: Resources for the Future, 59–96.

Lopez, Ramon. 1999. Incorporating Developing Countries into Global Efforts for Greenhouse Gas Reduction. January. RFF Climate Issue Brief 16. Washington, DC: Resources for the Future.

Lutter, Randall, and Jason Schogren. 1999. Reductions in Local Air Pollution Restrict the Gain from Global Carbon Emissions Trading. November 22. AEI Working Paper. Washington, DC: American Enterprise Institute.

Manne, Alan S. 1996. Hedging Strategies for Global Carbon Dioxide Abatement: A Summary of the Poll Results EMF 14 Subgroup—Analysis for Decisions under Uncertainty. In *Climate Change: Integrating Science, Economics, and Policy,* edited by Nebojsa Nakicenovic and others. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Manne, Alan S., and Richard Richels. 1992. *Buying Greenhouse Insurance: The Economic Costs of* CO_2 *Emission Limits.* Cambridge, MA: The MIT Press.

——. 1995. The Greenhouse Debate: Economic Efficiency, Burden Sharing, and Hedging Strategies. *The Energy Journal* 16(4):1-37.

——. 1997. On Stabilizing CO2 Concentrations-Cost-Effective Emission Reduction Strategies. Environmental Modeling & Assessment 2(4): 251-265.

Mendelsohn, Robert. 1999. *The Greening of Global Warming*. Washington, DC: AEI Press.

Mendelsohn, Robert, and James E. Neumann, eds. 1999. *The Impact of Climate Change on the United States Economy*. Cambridge, U.K.: Cambridge University Press.

Metcalf, Gilbert E. 1994. Economics and Rational Conservation Policy. *Energy Policy* 22(10):819–25.

Morrisette, Peter M., Joel Darmstadter, Andrew J. Plantinga, and Michael A. Toman. 1991. Prospects for a Global Greenhouse Gas Accord. *Global Environmental Change* 1(3):209–23.

Munasinghe, Mohan, and others. 1996. Applicability of Techniques of Cost–Benefit Analysis to Climate Change. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: University of Cambridge Press, 145–77.

Narain, Urvashi, and Anthony Fisher. 1999. Irreversibility, Uncertainty, and Catastrophic Global Warming. Gianni Foundation Working Paper 843. Berkeley, CA: University of California, Department of Agricultural and Resource Economics.

NAS (National Academy of Sciences). 1991. *Policy Implications of Greenhouse Warming.* Washington, DC: National Academy Press.

Newell, Richard G., and William A. Pizer. 1998. Regulating Stock Externalities under Uncertainty. RFF Discussion Paper 99-10. Washington, DC: Resources for the Future.

Newell, Richard G., and Robert N. Stavins. (2000). Climate Change and Forest Sinks: Factors Affecting the Costs of Carbon Sequestration. *Journal of Environmental Economics and Management*.

Nordhaus, William D. 1993. Rolling the "DICE": An Optimal Transition Path for Controlling Greenhouse Gases. *Resource and Energy Economics* 15(1):27–50.

——. 1994a. *Managing the Global Commons: The Economics of Climate Change*. Cambridge, MA: MIT Press.

——. 1994b. Expert Opinion on Climatic Change. *American Scientist* 82:45–51.

——. 1998. *Roll the DICE Again: The Economics of Global Warming.* December 18. New Haven, CT: Yale University.

Nordhaus, William D., and Zili Yang. 1996. A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies. *American Economic Review* 86(4):741–65.

NRC (National Research Council). 2000. *Reconciling Observations of Global Temperature Change.* Washington, DC: National Academy Press.

OTA (Office of Technology Assessment). 1991. *Changing by Degrees: Steps to Reduce Greenhouse Gases*. OTA-0-482. Washington, DC: U.S. Government Printing Office.

Parry, Ian W. H., Roberton C. Williams III, and Lawrence H. Goulder 1999. When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets. *Journal of Environmental Economics and Management* 37:52–84.

Pearce, David, and others. 1996. The Social Cost of Climate Change: Greenhouse Damage and the Benefits of Control. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Cambridge, U.K.: Cambridge University Press.

Peck, Stephen C., and Thomas J. Teisberg. 1993. Global Warming Uncertainties and the Value of Information: An Analysis Using CETA. *Resource and Energy Economics* 15(1):71–97.

_____. 1996. Uncertainty and the Value of Information with Stochastic Losses from Global Warming. *Risk Analysis* 16:227–35.

_____. 1998. A Property Rights Approach to Climate Change Mitigation. Unpublished manuscript, June 16. Palo Alto, CA: Electric Power Research Institute.

Pielke, Roger A. Jr. 1998. Rethinking the Role of Adaptation in Climate Policy. *Global Environmental Change* 8(2):159–70.

Pizer, William A. 1997. Prices vs. Quantities Revisited: The Case of Climate Change. RFF Discussion Paper 98-02. Washington, DC: Resources for the Future.

——. 1999. The Optimal Choice of Climate Change Policy in the Presence of Uncertainty. *Resource and Energy Economics* 21(3–4):255–87.

Portney, Paul. 1998. Applicability of Cost–Benefit Analysis to Climate Change. In *Economics and Policy Issues in Climate Change*, edited by William D. Nordhaus. Washington, DC: Resources for the Future, 111–27.

Portney, Paul R., and John P. Weyant, eds. 1999. *Discounting and Intergenerational Equity*. Washington, DC: Resources for the Future.

Reilly, John M., and Kenneth R. Richards. 1993. Climate Change Damage and the Trace Gas Index Issue. *Environmental and Resource Economics* 3(1):41–61.

Reilly, John M., Ronald Prinn, J. Harrisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melillo, P. Stone, A. Sokolov, and C. Wang. 1999. Multi-Gas Assessment of the Kyoto Protocol. *Nature* 401:549–55.

Rose, Adam, and Brandt Stevens. 1993. The Efficiency and Equity of Marketable Permits for CO_2 Emissions. *Resource and Energy Economics* 15(1):117–46.

Rose, Adam, Brandt Stevens, Jae Edmonds, and Marshall Wise. 1998. International Equity and Differentiation in Global Warming Policy: An Application to Tradeable Emission Permits. *Environmental and Resource Economics* 12:25–51.

Rosenberg, Norman J. 1993. *Towards an Integrated Assessment of Climate Change: The MINK Study*. Boston, MA: Kluwer Academic Publishers.

Roughgarden, Tim, and Schneider, Stephen H. 1999. Climate Change Policy: Quantifying Uncertainties for Damages and Optimal Carbon Taxes. *Energy Policy* 27:415–29.

Schelling, Thomas C. 1995. Intergenerational Discounting. *Energy Policy* 23:395–401.

Schmalensee, Richard. 1993. Comparing Greenhouse Gases for Policy Purposes. *Energy Journal* 14(1):245–55.

——. 1996. Greenhouse Policy Architectures and Institutions. November 13. Report. Cambridge, MA: MIT Joint Program on the Science and Policy of Global Change.

Sedjo, Roger A., R. Neil Sampson, and Joe Wisniewski, eds. 1997. *Economics of Carbon Sequestration in Forestry*. New York: CRC Press.

Shogren, Jason. 1999. *The Benefits and Costs of Kyoto*. Washington, DC: American Enterprise Institute.

Smith, J. B., N. Bhatti, G. V. Menzhulin, R. Benioff, M. I. Budyko, M. Campos, B. Jallow, and F. Rijsberman, eds. 1996. *Adapting to Climate Change: Assessments and Issues.* New York: Springer-Verlag.

Smith, Steven. J., and Thomas M. L. Wigley. 2000a. Global Warming Potentials: 1. Climatic Implications of Emissions Reductions. *Climatic Change* 44:445–57.

——. 2000b. Global Warming Potentials: 2. Accuracy. *Climatic Change* 44:459–69.

Sohngen, Brent, and Robert Mendelsohn. 1999. The U.S. Timber Market Impacts of Climate Change. In *The Impacts of Climate Change on the United States Economy*, edited by Robert Mendelsohn and James E. Neumann. Cambridge, U.K.: Cambridge University Press, Chapter 5.

Tol, Richard S. J. 1995. The Damage Costs of Climate Change Toward More Comprehensive Calculations. *Environment and Resource Economics* 5:353–74.

——. 1999. The Marginal Costs of Greenhouse Gas Emissions. *Energy Journal* 20(1):61–81.

Toman, Michael A. 1994. Economics and “Sustainability”: Balancing Trade-offs and Imperatives. *Land Economics* 70(4):399–413.

——. 1998. Sustainable Decision-Making: The State of the Art from an Economics Perspective. In *Valuation and the Environment: Theory, Method and Practice*, edited by Martin O’Connor and Clive Spash. Northampton, MA: Edward Elgar, 59–72.

Toman, Michael A., Richard D. Morgenstern, and John Anderson. 1999. The Economics of “When” Flexibility in the Design of Greenhouse Gas Abatement Policies. *Annual Review of Energy and the Environment* 24:431–60.

UNFCCC (United Nations Framework Convention on Climate Change). 1999a. *Convention on Climate Change.* UNEP/IUC/99/2. Geneva, Switzerland: Published for the Climate Change Secretariat by the UNEP’s Information Unit for Conventions (IUC). http://www.unfccc.de.

——. 1999b. *The Kyoto Protocol to the Convention on Climate Change.* UNEP/IUC/99/10. France: Published by the Climate Change Secretariat with the Support of UNEP's Information Unit for Conventions (IUC). http://www.unfccc.de.

____. 1999c. Guide to the Climate Change Negotiation Process. http://www.unfcc.de/resource.

U.S. DOE (Department of Energy). 1998. *Annual Energy Review 1997.* July. Washington, DC: U.S. DOE, Energy Information Administration.

——. 1999a. *Annual Energy Review 1998.* July. Washington, DC: U.S. DOE, Energy Information Administration.

——. 1999b. *Annual Energy Outlook 2000.* December. Washington, DC: U.S. DOE, Energy Information Administration.

U.S. EPA (Environmental Protection Agency). 1999. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–1997.* March. Washington, DC: U.S. EPA.

Victor, David G., Nebojsa Nakicenovic, and Nadejda Victor. 1998. The Kyoto Protocol Carbon Bubble: Implications for Russia, Ukraine, and Emissions Trading. Interim Report IR-98-094. Laxenburg, Austria: International Institute for Allied Systems Analysis.

Viscusi, W. Kip 1992. *Fatal Tradeoffs*. Cambridge: Oxford University Press.

Weitzman, Martin L. 1974. Prices vs. Quantities. *Review of Economic Studies* 41(4):477–91.

——. 1998. Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate. *Journal of Environmental Economics and Management* 36(3):201–8.

——. 1999. Just Keep Discounting, but …. In *Discounting and Intergenerational Equity*, edited by Paul R. Portney and John P. Weyant. Washington, DC: Resources for the Future.

Weyant, John P., and J. Hill. 1999. Introduction and Overview. *The Energy Journal* Special Issue: vii–xiiv.

Weyant, John, and others. 1996. Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results. In *Climate Change 1995: Economic and Social Dimensions of Climate Change*, edited by James P. Bruce, Horsang Lee, and Erik F. Haites. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. New York: University of Cambridge Press, 366–439.

Wiener, Jonathan B. 1999. Global Environmental Regulation: Instrument Choice in Legal Context. *Yale Law Journal* 108(4):677–800.

Wigley, Thomas M. L., Richard Richels, and James A. Edmonds. 1996. Economic and Environmental Choices in the Stabilization of Atmospheric CO_2 Concentrations. *Nature* 379(6562):240–43.

Yang, Zili. 1999. Should the North Make Unilateral Technology Transfers to the South? North–South Cooperation and Conflicts in Responses to Global Climate Change. *Resource and Energy Economics* 21(1):67–87.

Yellen, Janet. 1998. The Economics of the Kyoto Protocol. March 5. Statement before the Committee on Agriculture, Nutrition, and Forestry, U.S. Senate.

Yohe, Gary W. 1993. Sorting Out Facts and Uncertainties in Economic Response to the Physical Effects of Global Climate Change. In *Assessing Surprises and Nonlinearities in Greenhouse Warming: Proceedings of an Interdisciplinary Workshop,* edited by Joel Darmstadter and Michael Toman. Washington, DC: Resources for the Future, 109–32.