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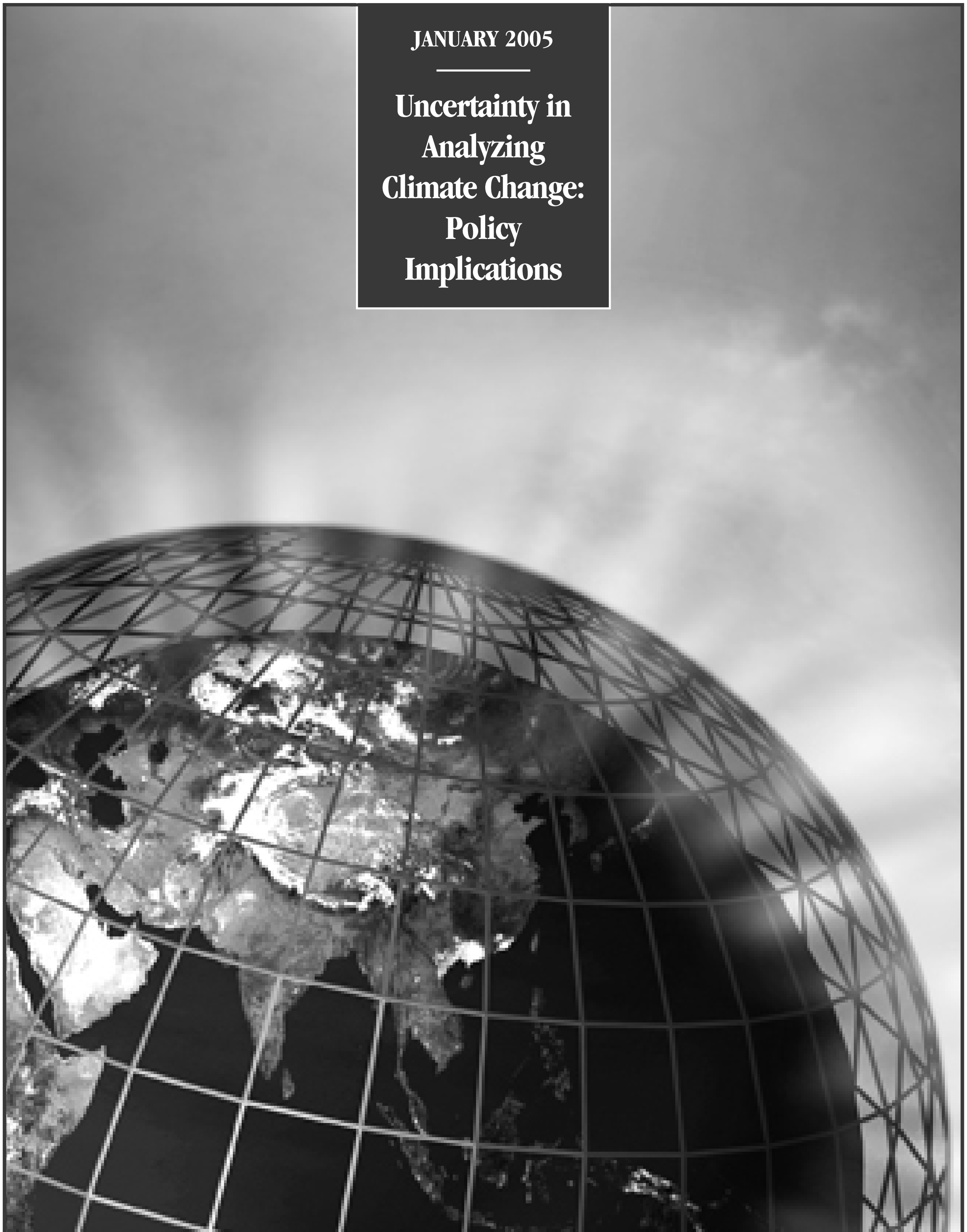
# Uncertainty in Analyzing Climate Change: Policy Implications



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# Uncertainty in Analyzing Climate Change: Policy Implications

January 2005

The Congress of the United States ■ Congressional Budget Office

# Note

Unless otherwise stated, prices are in current dollars.

# Preface

In addressing climate change, researchers and policymakers face various sources of uncertainty. The potential stakes in making policy choices are high: although emissions restrictions could impose significant costs, many experts believe that, if left unchecked, emissions could ultimately lead to costly damages.

This Congressional Budget Office (CBO) paper—prepared at the request of the Ranking Member of the Senate Committee on Environment and Public Works—provides an overview of the sources of uncertainty that limit the understanding of climate change and complicate the assessment of policies to address it. The paper provides examples of the different ways that analysts have addressed those uncertainties in formulating policy recommendations, illustrates the practical difficulties in doing so, and demonstrates the sensitivity of policy results to variations in assumptions about uncertain elements. Finally, it discusses the implications of uncertainty for three different types of policy responses: research and development, mitigation of greenhouse gas emissions, and adaptation to a warmer climate. In keeping with CBO's mandate to provide objective, nonpartisan analysis, this paper makes no recommendations.

Terry Dinan and Robert Shackleton, Jr., wrote the paper under the direction of Roger Hitchner and Robert A. Dennis. Douglas Hamilton, Arlene Holen, Mark Lasky, Angelo Mascaro, Chad Newcomb, and Elizabeth Robinson of CBO provided valuable comments, as did Peter J. Wilcoxen of Syracuse University, Henry Jacoby of the Massachusetts Institute of Technology, and William Pizer of Resources for the Future. (The assistance of external reviewers implies no responsibility for the final product, which rests solely with CBO.)

Christine Bogusz edited the paper, and John Skeen proofread it. Maureen Costantino prepared the paper for publication and designed the cover, Lenny Skutnik printed the initial copies, and Annette Kalicki and Simone Thomas produced the electronic versions for CBO's Web site (www.cbo.gov).

Douglas Holtz-Eakin
Director

January 2005

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# Summary

Since the 19th century, scientists have known that concentrations of carbon dioxide and other greenhouse gases in the atmosphere affect the Earth's climate.[1] Human activities—mainly deforestation and the burning of fossil fuels—are releasing large quantities of those gases. Because those gases, once emitted, affect atmospheric concentrations for centuries, researchers and policymakers are concerned about the impact of those emissions on the climate.

In assessing the potential risks from climate change and the costs of averting it, however, researchers and policymakers encounter pervasive uncertainty. That uncertainty contributes to great differences of opinion as to the appropriate policy response, with some experts seeing little or no threat and others finding cause for immediate, extensive action. Policymakers are thus confronted with a wide range of recommendations about how to address the risks posed by a changing climate—in particular, whether, how, and how much to limit emissions of greenhouse gases.

This Congressional Budget Office paper provides policymakers with an overview of the sources of uncertainty that limit the understanding and complicate the assessment of climate policies. It provides examples of the different ways that analysts have addressed those uncertainties in formulating policy recommendations, illustrates the practical difficulties in doing so, and demonstrates the sensitivity of policy results to variations in assumptions about uncertain elements. In addition, it discusses the implications of uncertainty for three different types of policy responses: research and development, mitigation of greenhouse gas emissions, and adaptation to a warmer climate. This paper primarily focuses on mitigation.

1. For more background information on climate change, see Congressional Budget Office, *The Economics of Climate Change: A Primer* (April 2003).

Because climate change is a global phenomenon—emissions from anywhere in the world mix in the atmosphere and affect regional climates everywhere—effective policies will require international cooperation and coordination. This paper discusses several different analyses that are based on the proposition that policies should maximize global net benefits—that is, expected global benefits minus expected global costs. Such analyses typically recommend policies that would motivate individuals and firms to make increasingly costly reductions in emissions up to the point at which the expected cost of the last reduction would be equal to its expected benefit. (Beyond that point, costs would exceed benefits, so additional reductions would not be worth the cost.) That approach provides a useful framework for assessing alternative policies. However, conducting such analyses in the face of uncertainties about both costs and benefits raises many issues.

## Scientific and Economic Sources of Uncertainty

Researchers who assess the costs and benefits of various policies to reduce greenhouse gas emissions must grapple with numerous gaps in scientists' understanding of the natural world as well as inherent difficulties in forecasting natural variability and human behavior. The uncertainties affecting benefits—that is, the future damages that would be avoided by limiting emissions today—are particularly large and pervasive.

### Uncertainty Affecting Benefits

Major scientific uncertainties complicate any assessment of the benefits of policies to reduce climate change. Those uncertainties include the following:

- How greenhouse gas emissions will accumulate in the atmosphere and how the resulting change in concentrations will affect the average global temperature;

- How changes in global temperature will be distributed across seasons and regions and how they will affect other variable characteristics of climate, such as rainfall, severity of storms, and sea level;

- How those changes in regional climates will affect natural and human systems, such as agricultural crops, property, species, and human health; and

- How short-term impacts will differ from the long-term impacts that will remain after natural and human systems have had time to adapt to the new climate.

One area of relatively recent concern is the potential for abrupt climate change—the possibility that the gradual buildup of greenhouse gases in the atmosphere could push the global climate system over a threshold, triggering an abrupt change to a new climate equilibrium. Scientists now realize that abrupt changes have occurred in the past (for example, a cold, dry, windy period lasting 1,600 years abruptly began about 12,800 years ago), and they have started to speculate whether human-induced changes in climate could trigger such changes in the future. An abrupt, unexpected shift—currently considered possible but very unlikely over the next century—could prove much more difficult for people and ecosystems to adapt to than a gradual change would be and, therefore, much more costly.

### Uncertainty Affecting Costs

The costs of policies to control greenhouse gas emissions will depend on the magnitude of future emissions: the lower emissions are in the absence of policy initiatives, the easier it will be to meet a given target (be it for temperature, emissions, or atmospheric concentrations) and the lower the cost will be. Yet future trends in emissions are uncertain—they depend on the pace of population and economic growth, the development and diffusion of technologies, and the demand for fossil fuels.

Furthermore, the cost of reducing emissions depends in large part on the efficiency of the policies that motivate those reductions. Provided that they are implemented effectively, policies that give individuals and firms an economic incentive to reduce emissions would probably achieve reductions at a lower cost than would command-and-control-style regulations that dictated specific methods for emissions reductions, locations for emissions reductions, or both.

Finally, the cost of reducing emissions is most accurately measured by the resulting price increases paid by consumers, the lower short-term profits made by producers, and the reduction in consumers' welfare that would result from changes in their purchasing patterns or behavior (for example, choosing to carpool). Focusing only on the cost of emissions-reduction technologies could considerably understate the total cost of adopting them. Even when the cost of emissions-reduction technologies is well understood, the challenges involved in estimating those broader economic impacts contribute to uncertainty about aggregate costs.

## Problems in Valuing Damages from Climate Change

In addition to the numerous scientific and economic uncertainties involved in determining climate-related damages, there are major questions about how those damages should be valued. Although there are many possible ways to define and measure value, economic analysis focuses on the value that individuals place on a particular good or service, as reflected in their willingness to forgo other goods and services to obtain it. For many goods, those individual valuations are reflected in market prices, which provide a standard of comparison across goods. When possible, economic analyses of climate policies use market prices to estimate the value people place on the damages that such policies would avoid.

Many of the damages from climate change, such as harm to ecosystems and adverse health effects for humans, would fall on entities, goods, and services that are not exchanged in markets. In the absence of market prices for certain goods and services, analysts face serious challenges in determining what people are willing to pay for them, adding another layer of uncertainty to policy analysis.

An additional problem is that many of the nonmarket damages—loss of species and ecosystems, for example—are to public goods, which are available to everyone for free. The value of a public good is the total of everyone's individual valuation. Researchers must therefore try to assess valuations for a large number of people to estimate the economic value lost when public goods are damaged.

Faced with those difficulties, analysts sometimes use arbitrary and controversial rules of thumb to estimate people's willingness to pay. One study, for instance, assumed that individuals in each region of the world would be willing to pay twice their annual income to avoid a premature loss of one year of life from an increase in disease resulting from a warmer climate. Some people object to such measures because they assign lower values to the adverse health effects or loss of life that are expected to occur in low-income countries than they apply to equivalent damages in high-income countries. That problem has no simple solution, however. Using a uniform global value for all lives saved (based on average global income) would result in a large disparity between the value placed on lives saved in low-income countries via climate change policies and the value (determined on the basis of countries' local economic resources) placed on lives saved via other policies, such as providing clean water or basic health care.

Based on such arbitrary and controversial valuations, the available damage estimates—and the policy prescriptions resulting from their use—should not be viewed as precise measures. Nevertheless, those valuations can provide a general sense of the magnitude of the damages from climate change and the relative benefits of alternative policies.

## Problems in Aggregating Costs and Benefits

Deciding on appropriate policies to address climate change is further complicated by the uneven distribution of costs and benefits across regions and over time.

### Controversy About the Weight to Attach to Future Damages

Even though the costs of policies to avoid climate-related damages would be incurred in the near term, the bulk of any damages from current emissions are expected to occur a century or more in the future. Analysts conventionally compare present costs and future benefits through present-value calculations, which discount future benefits at the market rate of interest. (That approach is based on the fact that the alternative to devoting resources to the policy being evaluated would be to invest them, allow the investment to compound over time, and derive significantly more income in the future.)

In the case of climate change, the choice of a discount rate is crucial because the very long time horizons involved make the results of cost-benefit analyses extremely sensitive to the discount rate that is used in the analysis. Different rates can lead to very different conclusions about the appropriate policy response, and that fact has led to a great deal of controversy about what rate to use.

Many analysts argue that the discount rate used in climate change analyses should reflect observed rates of return on long-term investments, adjusted for inflation and risk. According to that view, such returns represent the opportunities given up by investing resources in avoiding damages from climate change, as well as the opportunity to set aside resources today to compensate future generations for damages they may experience. Adjustment for uncertainty leads to a lower implicit discount rate, the farther in the future the benefits are expected to occur.

Some analysts, however, argue that distortions in saving and investment behavior resulting from taxes cause observed rates of return to be higher than they would be otherwise. According to that view, a lower rate of return would better reflect people's actual preferences between present and future costs and benefits. Applying a lower discount rate to the benefits of climate change policies would result in dedicating more resources to those policies.

Still other analysts argue that because costs and benefits are incurred by different generations, the valuation of future benefits should be viewed primarily as an equity decision (similar to providing foreign aid to developing countries) rather than as a traditional investment decision. According to that view, a discount rate can be thought of simply as a gauge of current generations' willingness to provide benefits to future ones—a willingness that need not be consistent with people's personal investment decisions. In general, proponents of such a view argue for discount rates that are lower than the rates of return on long-term investments.

### Problems in Determining the Appropriate Level of Risk Reduction

The choice of how stringent a policy to adopt is similar to a choice about insurance coverage: higher prices for emissions impose greater costs on households and businesses today but provide more protection against unpleasant surprises from damages in the future. People who are more averse to risk may prefer to implement a more stringent policy to control emissions (paying more up front in order to avoid or minimize risk in the future), whereas those who are less averse to risk may prefer a less stringent policy (paying less up front and incurring greater risk in the future). Such differences in risk aversion may contribute to differences of opinion over the appropriate level of policy stringency.

### Complications in Aggregating Benefits and Costs That Occur in Different Parts of the Globe

Determining the appropriate level of policy stringency is complicated by two other factors. First, some countries and regions could benefit from climate change while others would be worse off. For example, some researchers predict that India would experience a loss equal to about 5 percent of its total output if the global temperature rose by 2.5° Celsius, whereas Russia would benefit by an amount equal to about 0.65 percent of its total output. Because effects are aggregated, Russia's gains would offset India's losses, resulting in a less stringent policy than would be called for if only India's losses were taken into consideration. Second, countries that would bear a relatively large share of the costs of climate policies are not necessarily those that would receive a large share of the benefits. For example, under a policy determined by a global cost-benefit analysis, the United States would incur a substantial share of the costs but would receive a disproportionately small share of the benefits. Developing countries, in contrast, would incur a relatively small share of the costs but would receive a disproportionately large share of the benefits.

Under conventional methods of calculating net benefits, the gains by countries that would benefit from climate change policies would be deducted from the costs borne by countries that would be harmed. For policies whose benefits outweighed the costs, winners could compensate losers and still be better off. Given that such compensation is unlikely to occur, however, some observers find that logic unpersuasive.

## Policy Implications

The pervasive uncertainty inherent in many aspects of climate change presents researchers and policymakers with a challenge in attempting to develop appropriate policies. The potential stakes in making policy choices are high: emissions restrictions could impose significant costs, but many experts believe that, if left unchecked, emissions could ultimately lead to costly damages.

Although pursuing a strategy of waiting until uncertainties have been resolved and then implementing a single long-term "best" solution may sound appealing, uncertainty in the assessment of climate policy cannot be eliminated. Furthermore, greenhouse gas emissions that are released today will affect atmospheric concentrations for hundreds of years, potentially leading to damages that would only gradually appear and continue far into the future.

A more pragmatic climate policy will probably involve a sequence of decisions based on the gradual accumulation of information and the resolution of uncertainties. For such an approach, policies that can be easily modified over time would offer advantages. A flexible approach to dealing with climate change could include three different policy strategies:

- Researching the problem and developing technologies to address it,
- Restricting greenhouse gas emissions (mitigation), and
- Adapting to a warmer climate.

Determining the appropriate extent to which each of those strategies should be implemented and the balance among them is beyond the scope of this analysis. Instead, for each strategy, this analysis examines implications about policy design that can be drawn from an understanding of the uncertainties described above. This analysis primarily focuses on mitigation—the area for which existing research offers the most useful insights.

### Research and Development

Research is an essential part of any comprehensive strategy to address potential changes in the climate. Research is likely to provide benefits by helping to resolve uncertainties (including uncertainties about the physical damages that might result from climate change as well as the substantial uncertainties about how to evaluate those damages) and by leading to the development of technologies to make those cuts in emissions that prove advisable and to adapt to any climate changes that occur. If potential damages from climate change turned out to be large, such technologies could help reduce the cost of restricting greenhouse gas emissions and adapting to a warmer climate. If potential damages turned out to be relatively minor, the technologies need not be deployed.

### Mitigation

Analysts generally agree that economic incentives could limit several types of greenhouse gas emissions (including

**Summary Box 1.**

## Price- Versus Quantity-Based Economic Incentives

Economic incentives can be either price-based or quantity-based. A price-based economic incentive—such as a tax on emissions—would raise the cost of emitting greenhouse gases, thereby encouraging households and firms to cut their emissions as long as the cost of doing so was less than the tax. That approach would set an upper limit on the cost of emissions reductions (at the level of the tax) but would not ensure that any particular emissions target was met.

A quantity-based incentive—such as a cap-and-trade program—would set an overall limit on the level of greenhouse gas emissions but leave the decisions of where and how the necessary reductions should take place to households and firms. Under that approach, policymakers would establish an overall cap on emissions but allow regulated firms to trade rights to those emissions, called allowances. That trading would permit firms that could reduce their emissions most cheaply to sell some of their allowances to firms that faced higher costs to reduce their emissions. Such an approach would limit the overall level of emissions and achieve the emissions target at the lowest possible cost. It would not place any explicit limit on the cost of individual emissions reductions, however.

A third approach—a cap-and-trade program with a safety valve—would combine an overall cap on emissions with an upper price for allowances. Under that hybrid approach, policymakers would establish an overall cap and allow firms to trade allowances; in addition, they would determine an upper price—referred to as the safety-valve price—for allowances. If the price of allowances rose to the safety-valve price, the government would sell as many allowances as was necessary to maintain that price. Thus, if the safety valve was triggered, the actual level of emissions would exceed the cap. The cap would be met only if the allowance price never rose above the safety-valve price. (Another hybrid approach, involving a "circuit breaker" instead of a safety valve, would freeze a gradually declining cap on emissions if the allowance price rose above a predetermined level. Such a policy would not necessarily limit allowances to the trigger price, though.)

carbon dioxide emissions) more cost-effectively than command-and-control strategies could. Whereas command-and-control strategies specify where and how emissions should be reduced, economic incentives specify more-general restrictions and leave the where-and-how decisions to the market. Policymakers can choose between two general types of economic incentives: ones that set a price for emissions, such as emissions taxes, or ones that specify an aggregate limit or cap, such as cap-and-trade programs (see Summary Box 1).

**Given Current Uncertainties, Pricing Policies Have More Advantages Than Caps.** If policymakers had complete and accurate information on both the costs and benefits of various levels of emissions reductions, they could achieve the level of reductions that best balanced costs and benefits using either an emissions price or an emissions cap. With full information, policymakers could set the price or cap to the level at which the cost of the last reduction was equal to the benefit from that reduction.

However, neither the costs nor the benefits of restricting greenhouse gas emissions are known with certainty. For that reason, the best that policymakers can do is to choose the policy instrument that is most likely to minimize the cost of choosing the "wrong" level of control. Choosing policies that are too stringent (by setting too high a price or too tight a cap) would result in excess costs that are not justified by their benefits. Alternatively, choosing policies that are too lenient (by setting too low a price or too loose a cap) would result in forgone benefits that would have outweighed the cost of obtaining them.

Analysts generally conclude that under uncertainty, price instruments are much more efficient than quantity instruments for restricting carbon dioxide emissions—that is, they are much more likely to minimize the cost of getting it wrong. That conclusion follows from two observations: first, the expected benefits created by each additional reduction in emissions in a given year would probably be fairly constant; second, the costs would probably rise—perhaps steeply—with more abatement.[2] Thus, setting an emissions price equal to the expected benefits would result in the least-costly balancing of expected costs and benefits. If actual costs were greater than, or less than, anticipated, people would limit emissions less than, or more than, policymakers projected; yet emissions would be reduced up to the point at which the cost of doing so was equal to the expected benefits (as reflected in the emissions price). In contrast, a strict cap on emissions could result in actual costs that were far greater (or less) than expected—and that therefore exceeded or fell below the expected benefits.

Some observers have questioned the robustness of that logic, however, in light of recent evidence indicating that the buildup of greenhouse gases could push the climate system over a threshold, triggering an abrupt and costly shift to a new equilibrium. Current research suggests that the potential for catastrophic damages can indeed tilt the balance in favor of quantity controls, but only under restrictive conditions that do not currently exist: first, damages must be projected to rise very rapidly once a particular threshold (that is, a certain level of greenhouse gas concentrations or temperature) is reached; second, the level of the threshold must be known; and third, current emissions must be pushing the climate close enough to that threshold that policymakers would want to make very large cuts in current emissions in order to quickly stabilize the atmospheric stock of greenhouse gases. Currently, there is no consensus about whether such a threshold exists or where it lies. Under those circumstances, price instruments appear to be more cost-effective than quantity instruments for controlling emissions while minimizing the adverse consequences of choosing the wrong level of control.

2. Expected benefits are thought to be constant over the range of potential emissions reductions in a single year because those reductions will have only a small effect on the total stock of greenhouse gases in the atmosphere, and damages are a function of the size of that total stock. (Total emissions in a single year represent less than 1 percent of atmospheric emissions, so the *reduction* in emissions in a given year is likely to be a small fraction of 1 percent of atmospheric emissions.)

The superiority of price instruments could be reversed if accumulating information revealed a trigger temperature (or atmospheric concentration) that must be avoided and a level of emissions that would raise temperatures above the trigger. If so, policymakers might decide to switch to a quantity instrument as the potential for catastrophic effects became clearer. A hybrid policy, such as a cap-and-trade program with a safety-valve price (see Summary Box 1), would provide such flexibility. The safety valve would set an upper limit on the current cost of incremental emissions reductions. In effect, the hybrid policy would function as a tax if the safety valve was triggered. Should circumstances change, however, the safety valve could be phased out or eliminated altogether, transforming the trading program into one with a fixed cap on overall emissions.

**The Best Emissions Price Is Unclear.** If researchers conclude that current emissions will result in future damages and that the present value of those damages (after they are discounted) is greater than zero, then it is appropriate to set an emissions price that is greater than zero. However, given all the uncertainties associated with evaluating the costs and benefits of climate change policies, as well as the problems associated with aggregating them, accurately determining what price would best balance those costs and benefits is probably not a realistic goal. Even if scientists resolved uncertainties about physical damages, people would probably differ in their valuation of those damages, in the weight they attached to future effects, and in the level of risk they were willing to accept. Those differences would all result in differences of opinion as to the appropriate level of stringency in controlling emissions—and thus the best price to charge for emissions. Researchers agree, however, that the costs of such a pricing policy could be moderated by phasing in prices gradually, allowing the economy time to replace the existing fossil-fuel-burning capital stock at the lowest cost.

**International Coordination Could Greatly Reduce Costs.** Because the causes and consequences of climate change are global, the most cost-effective mitigation policies would require a coordinated international effort. The nature of the climate problem will make international agreement difficult to reach, however. The distribution of likely costs and benefits leaves countries and regions with considerably divergent interests. Furthermore, developing countries, which contributed a relatively small share of historical emissions but are expected to contribute a growing share of future ones, may object to having their development impeded by emissions restrictions. Finally, the challenges associated with enforcing a global solution may make some nations reluctant to participate, adding a source of uncertainty about how cost-effective the policies will be.

**Information on Underlying Uncertainties and Disaggregated Benefits Could Highlight Policy Trade-Offs.** While policymakers may derive important insights from assessments that attach monetary values to benefits and aggregate the expected costs and benefits of different mitigation policies, they may also profit from additional, more-detailed information, such as the following:

- Information that describes ranges of plausible outcomes for specific policies, measures of the probability that a given policy will achieve its objective, and acknowledgment of lingering uncertainties that cannot be quantified. That information may allow policymakers to more clearly see the risks associated with alternative policies.

- Information about important nonmarket benefits—such as health benefits or species preservation—in a disaggregated, nonmonetized form (for example, the decrease in number of species lost). That information would also allow policymakers to make their own judgments about people's willingness to pay for damages that are difficult to monetize.

- Information about the regional distribution of costs and benefits. That information could help policymakers understand the strength of other countries' and regions' interests in international negotiations.

## Adaptation

Although it has received relatively little attention from analysts and policymakers, adaptation is likely to be an important element of an effective climate strategy. Unlike mitigation policy, which could be implemented largely with a single instrument—for instance, a single emissions price or an aggregate emissions cap—efforts to promote adaptation are likely to be more diffuse, involving numerous policies in many different areas. Those policies could include the following:

- Promoting the efficient use of water resources (which are likely to become scarcer in some regions) through prices that reflect scarcity or through the establishment of markets for water;

- Encouraging the development of low-cost technologies for desalinating seawater;

- Encouraging the preservation of green corridors that would allow plant and animal species to migrate as their habitat changed;

- Facilitating the relocation of people living in low-lying areas of counties prone to increased flooding; and

- Encouraging the development and use of drought-resistant crops.

As the above list illustrates, many policies that could facilitate adaptation to a changing climate are likely to yield benefits even if climate change proved to be relatively benign.

CHAPTER

# 1

# Background and Introduction

The Earth's climate is driven mainly by solar radiation, which is absorbed into the atmosphere, ocean, and land and ultimately radiated back into space. Some of that outgoing radiation is trapped by naturally occurring greenhouse gases in the atmosphere and radiated back toward the surface, however, keeping it about 60° Fahrenheit (F), or 33° Celsius (C), warmer, on average, than it would be otherwise.[1]

Since the onset of the industrial revolution more than two centuries ago, people have released large and growing quantities of greenhouse gases into the atmosphere, raising the prospect of a gradual warming of the Earth's climate. Those emissions are associated primarily with the burning of fossil fuels—crude oil, coal, and natural gas—the world economy's primary source of energy. Measured in terms of warming potential, carbon dioxide from fossil fuels currently accounts for about 60 percent of greenhouse gas emissions. Carbon dioxide from deforestation accounts for another 15 percent or so, and the rest of the emissions are composed of a number of other greenhouse gases, largely methane from a wide variety of mainly agricultural sources.

Developed countries account for the bulk of emissions, especially those from fossil fuels. In 2000, for instance, 63 percent of carbon dioxide emissions from fossil fuels came from developed countries, even though those countries account for only 22 percent of the global population. Developing countries, with 78 percent of the population, were responsible for only 37 percent of fossil-fuel emissions. Over the next 20 years, developing countries are expected to account for roughly two-thirds of the growth in emissions as their populations and economies expand rapidly. Nevertheless, on a per-person basis, developing countries' emissions will remain far below those of developed countries. The typical developing country emits about 0.5 metric ton of carbon (mtc) per person every year; the typical developed country emits about 3 mtc per person, and the United States emits about 5.5 mtc per person.

Emissions have raised the atmospheric concentration of carbon dioxide by roughly one-third in the past two centuries and are currently raising it by about 0.4 percent per year. Concentrations of other greenhouse gases are increasing as well. Because the degree of warming depends on the total stock in the atmosphere rather than the flow of emissions alone, greenhouse gases are sometimes referred to as "stock pollutants."

The average surface temperature of the Earth has already risen by between 0.7°F and 1.4°F (0.4°C and 0.8°C) since the mid-19th century, with the warming trend most pronounced during the past decade and at higher latitudes. Scientists generally conclude that the warming trend is probably largely the result of human activities, although they cannot rule out the possibility that other natural forces may be playing a significant role.[2] Despite that uncertainty, scientists also expect emissions that have already occurred to gradually warm the climate further. Moreover, the accelerating pace of emissions is expected to contribute to a continuing warming trend, with highly uncertain but potentially serious and costly effects in at least some regions of the world.

1. For further background information on climate change, see Congressional Budget Office, *The Economics of Climate Change: A Primer* (April 2003).

2. The National Research Council concludes: "The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability." See National Research Council, Committee on the Science of Climate Change, *Climate Change Science: An Analysis of Some Key Questions* (Washington, D.C.: National Academy Press, 2001).

**Box 1-1.**

## Uncertainty and Natural Variability

The global climate is affected by long-term variations in the Earth's orbit and in solar radiation (as well as other external influences, such as eruptions of volcanic material into the atmosphere). Most of the variation in climate, however, involves internal interactions among the Earth's climate-related components: the atmosphere, oceans, glaciers, land surface, and biosphere.

Those interactions are complex and nonlinear, meaning that there is often no simple proportional relationship between a cause and its effects. Complexity and nonlinearity make climate patterns very sensitive to small perturbations—in technical terms, dynamically unstable or chaotic. That sensitivity greatly limits scientists' ability to accurately represent or predict the fluctuations of the climate system in great detail. Instead, climate forecasting is limited to estimating changes in the likelihood of different types of weather events, such as changes in average summer and winter temperatures or annual rainfall, or in the probability of different extremes of temperature or of severe storms or droughts in different parts of the world.

Much of the research to assess the potential processes and impacts of climate change (and policies to address it) makes use of numerical models. Those models represent complex entities (such as the atmosphere, the world's population, or total energy consumption) with relatively simple data and summarize complex interactions (such as the exchange of heat between the atmosphere and the ocean or the effect of a change in average global temperature on regional agriculture) with numerical relations called parameters. Because much of the information is of poor quality and many of the interactions are imperfectly understood, they can be modeled with only limited certainty.

In some cases, uncertainty results from a lack of information or knowledge that, in principle, could be overcome with further research. In other cases, however, it stems from inherent, natural variability that renders the processes being studied only roughly predictable, as with fluctuating weather patterns (see Box 1-1). In yet other cases—as with technological breakthroughs—uncertainty stems from processes that are essentially unpredictable. Levels of uncertainty can range from statistical uncertainty (when researchers can attach probabilities to different outcomes) to scenario uncertainty (when researchers can characterize a variety of plausible outcomes but do not understand the underlying processes well enough to provide probabilities) to recognized ignorance (when researchers lack sufficient understanding to develop plausible scenarios).

This Congressional Budget Office paper provides policymakers with an overview of the sources of uncertainty that limit the understanding and complicate the assessment of climate policies. It provides examples of the different ways that analysts have addressed those uncertainties in formulating policy recommendations, illustrates the practical difficulties in doing so, and demonstrates the sensitivity of policy results to variations in assumptions about uncertain elements. Finally, it discusses the implications of uncertainty for three different policy strategies:

- Research to resolve uncertainties about potential damages and to develop technologies that might cut the cost of reducing emissions or ease the adaptation to a warmer climate,
- Economic incentives to encourage low-cost emissions reductions today, with the expectation that more extensive reductions may be needed in the future, and
- Policies to help people adapt to any warming that does occur.

In illustrating the sources and implications of uncertainty, the paper discusses a number of analyses that are based on the proposition that policies should maximize global net benefits—that is, expected global benefits minus expected global costs—by inducing individuals and firms to make increasingly costly reductions in emissions up to the point at which the expected cost of the last reduction would be equal to its expected benefit. That proposition involves a number of assumptions about how to aggregate costs and benefits across countries and over time—assumptions that are controversial. Moreover, because the causes and consequences of climate change are global, such policies would require international cooperation and coordination—itself an uncertain possibility. Those and related complications are addressed in the following chapters.

CHAPTER

# 2

# Scientific and Economic Sources of Uncertainty

Uncertainty permeates people's understanding of the potential for and the consequences of climate change. This chapter provides an overview of the many sources of uncertainty that arise because of gaps in scientific understanding—how the climate functions, how species will respond to climate change, and so forth—and because of inherent difficulties in forecasting human behavior—for instance, how population growth and energy use will change over time. (Other important complications, discussed in the following chapters, have to do with valuation: how to value impacts, how to balance values over time, and how to aggregate values across individuals.)

## Uncertainty Affecting Costs

The costs of policies to reduce greenhouse gas emissions will depend in large part on the magnitude of those emissions: the lower that emissions are expected to be in the absence of policy changes—that is, in the "baseline"—the fewer reductions will be needed to meet a given target and the lower the costs will be. The magnitude of emissions will depend on driving forces such as population, the demand for energy, and the reliance on fossil fuels (which, in turn, will depend on the prices of alternative energy sources). Uncertainty about those forces compounds into a very wide range of uncertainty for emissions projections that grows larger as the time horizon lengthens.

Despite such uncertainty, many assessments simply incorporate point estimates of key variables and relationships to produce "best guesses" of how human activity will affect the global climate. For example, a pair of related models, the Dynamic Integrated model of Climate and the Economy (DICE-99) and the Regional Dynamic Integrated model of Climate and the Economy (RICE-99), project that in the absence of policies to restrict them, annual carbon dioxide emissions will rise by roughly a factor of two between 2000 and 2100 to approximately 13 billion metric tons of carbon.[1] Some point estimates are considerably higher: the best-known emissions scenario from the early 1990s, referred to as IS92a, projects carbon dioxide emissions of nearly 20 billion mtc in 2100.[2]

Although the best-guess approach is relatively manageable, it fails to provide a sense of how likely a best-guess estimate actually is, how wide the range of plausible outcomes around it may be, or how robust recommended policies are likely to be in the face of the full range of possible outcomes. Those insights require an alternative approach that explicitly acknowledges the underlying uncertainties.

One alternative—the scenario approach—provides a sense of the rate of possible outcomes by analyzing several different scenarios, each based on a different set of plausible guesses.[3] In one such exercise, the International Panel on Climate Change (IPCC) developed six different groups of emissions scenarios, with each group incorporating a different set of assumptions about the forces that

1. For a description of those models, see William D. Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (Cambridge, Mass.: MIT Press, 2000), p. 5. Many analysts have used the models to examine policy options for climate change.

2. K.P. Shine and others, "Radiative Forcing of Climate," in J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds., *Climate Change: The IPCC Scientific Assessment* (Cambridge, England: Cambridge University Press, 1990), pp. 41-68.

3. A specialized type of scenario analysis—bounding analysis—involves taking the largest and smallest plausible estimates of values and parameters, which produces the most optimistic and most pessimistic plausible outcomes.

drive emissions.[4] For 2100, projected annual emissions vary by roughly an order of magnitude, from less than 3 billion metric tons of carbon—less than half of today's emissions—to 35 billion metric tons.[5]

By allowing policymakers to consider a range of possible cases, a scenario approach may help them develop robust policies that perform well under a range of outcomes. However, that approach does not provide a sense of how likely any particular scenario is or whether some scenarios are more likely than others. The experts who developed the IPCC scenarios felt that they lacked sufficient information to assess their relative probabilities.

Another approach—the Monte Carlo method—overcomes that limitation by incorporating probability distributions for model parameters. Researchers have developed estimates of the likelihood that parameters would take on different values and have used those estimates to undertake Monte Carlo analyses. That technique involves running a model many times with parameter values randomly drawn from their probability distributions.[6] A large enough set of such simulations reveals the range of possible outcomes and the likelihood of those different outcomes. Applied to economic and climate models, the Monte Carlo method yields ranges of emissions that are similar to those of the IPCC but suggests that the highest and lowest emissions projections are relatively unlikely.[7]

The cost of reducing those projected emissions will depend not only on their magnitude but also on what (and when) alternative technologies become available, the cost of those technologies, and the potential for behavioral, institutional, cultural, and political barriers to impede the adoption of those technologies.[8] Technologies that might be used to reduce emissions range from proven methods with reasonably well-known costs to others that are not likely to be developed for many years and whose costs can only be guessed. As an emissions-reduction target becomes more stringent, the number and cost of the technologies that may come into play increase—as does the uncertainty about that cost. Uncertainty about all of those factors feeds into uncertainty in the projection of mitigation costs.

The cost of reducing emissions also will depend on how efficient the policies are that motivate those reductions. In many cases, a given reduction in emissions can be obtained at a lower cost using economic incentives, which leave the specifics of where and how to reduce emissions to individuals and firms, rather than by command-and-control policies that specify where and how such reductions must take place. The feasibility of using economic incentives for controlling various greenhouse gases is discussed below.

Finally, the cost of reducing carbon emissions is appropriately measured not by the cost of emissions-reduction technologies alone—as is often done in engineering studies—but by the costs that society as a whole bears as a result of decreasing carbon emissions.[9] Those costs include higher prices paid by consumers, lower short-run profits made by producers (both of which, in turn, depend on

4. See Intergovernmental Panel on Climate Change, *Emissions Scenarios* (Cambridge, England: Cambridge University Press, 2000), p. 4, Box SPM-1. The scenarios differ in terms of the rapidity of economic growth in different regions as well as the rates at which different regions converge economically, their populations stabilize, various kinds of technology become available, and so forth.

5. Ibid., p. 7.

6. Ideally, those distributions are estimated using appropriate data and statistical tools, but if those are not available, researchers may develop distributions using expert opinion, rough guesses, or other techniques. Where appropriate, researchers may account for correlation among parameters. For example, analysis may suggest that slower population growth tends to be associated with more rapid productivity growth. In that case, very little weight would be placed on scenarios with rapid population and productivity growth.

7. See, for example, Mort Webster and others, "Uncertainty Analysis of Climate Change and Policy Response," *Climatic Change*, vol. 61, no. 3 (December 2003), pp. 295-320. Analyses vary in the number of input parameters that are treated as uncertain: in some cases, researchers have characterized probability distributions for only a handful of variables and parameters; in other cases, they have introduced distributions for a relatively large number. An assessment may treat only growth rates and climate parameters as uncertain, while using point estimates for damages. Alternatively, it may treat growth rates and climate parameters as certain, but include a wide uncertainty range for damage estimates. No analyses have estimated the most appropriate policy given ranges of uncertainty for growth rates, emissions, climate responses, damage valuations, and mitigation costs.

8. See Intergovernmental Panel on Climate Change, *Emissions Scenarios*, p. 11.

9. For a discussion of the near-term costs of reducing emissions in the United States, see Mark Lasky, *The Economic Costs of Reducing Emissions of Greenhouse Gases: A Survey of Economic Models,* CBO Technical Paper No. 2003-03 (May 2003), available at www.cbo.gov/Tech.cfm.

the cost of technologies), and the reduction in consumers' welfare that would result from changes in their purchasing patterns or behavior (for example, choosing to carpool).[10] Even when the cost of emissions-reduction technologies is well-understood, the challenges involved in estimating the economic impacts of adopting those technologies contribute to uncertainty about aggregate costs.

## Uncertainty Affecting Benefits

The benefits of climate change policies—that is, the potential future damages avoided by reducing emissions today—are even more uncertain than the costs. Major scientific and economic uncertainties are involved in assessing the following factors:

- How greenhouse gas emissions will accumulate in the atmosphere and how the resulting change in concentrations will affect the average global temperature;
- How changes in global temperature will be distributed across seasons and regions and how those changes will affect other climate characteristics, such as rainfall, severity of storms, and sea level; and
- How any changes in regional climates will affect natural and human systems, such as agricultural crops, property, species, and human health.

### Changes in Climate

Several scientific uncertainties complicate attempts to forecast the effects on global and regional climates of a change in atmospheric concentrations of greenhouse gases.[11] Among the most important uncertainties are these:

- The role of the world's oceans in absorbing heat and carbon dioxide from (and releasing them into) the atmosphere;
- The role of different types of aerosols, which in their pure form act as cooling agents but, when contaminated by soot, may also contribute to warming;
- The role of clouds, which have both warming and cooling effects, and which can have very different effects on projections of regional climate depending on how the clouds are modeled;
- The role of glaciers;
- The potential for unpredictability in the global weather system; and
- The potential for abrupt shifts in the global climate.

**An Increase in the Average Global Temperature.** Models based on the IPCC emissions scenarios have produced projections of increases in the average global temperature ranging from less than 1.5°C to more than 5.5°C, depending on the model and the emissions scenario used as an input to the model—although without any estimate of the relative likelihoods of those outcomes.[12] Using Monte Carlo simulations to characterize that uncertainty statistically, other researchers estimate that the increase in the mean global temperature between 1990 and 2100 will most likely lie between 1°C and roughly 4.9°C, with a mean increase of 2.4°C, which is nearer to the low end

10. For a discussion of this point, see Paul R. Portney, "Applicability of Cost-Benefit Analysis to Climate Change," in William D. Nordhaus, ed., *Economics and Policy Issues in Climate Change* (Washington, D.C.: Resources for the Future, 1998), pp. 121-122. In addition, by raising prices—and thus lowering real returns on capital and labor—carbon-reduction policies may exacerbate the discouraging effects that existing taxes on capital and labor have on economic activity—a connection known as the tax-interaction effect. A full accounting of the cost of carbon-reduction policies should take into account that potentially costly secondary effect. For a good survey of the literature on the tax-interaction effect, see A. Lans Bovenberg and Lawrence H. Goulder, "Environmental Taxation and Regulation," in Alan Auerbach and Martin Feldstein, eds., *Handbook of Public Economics*, vol. 3 (Amsterdam: Elsevier/North-Holland, 2002), pp. 1471-1545. For a discussion of the tax-interaction effect in the context of a cap-and-trade policy for reducing carbon emissions, see Terry M. Dinan and Diane Lim Rogers, "Distributional Effects of Carbon Allowance Trading: How Government Decisions Determine Winners and Losers," *National Tax Journal*, vol. 55, no. 2 (June 2002), pp. 199-221.

11. For more details on this subject, see Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, England: Cambridge University Press, 2001). Box 1 (on p. 24) and Box 3 (on p. 48) are particularly helpful.

12. Ibid., p. 555. Average global temperature is used as a summary statistic to describe climate developments and is often used as an input in rough calculations of the aggregate impacts of climate change. However, impacts would be determined mainly by regional changes in seasonal temperatures, which are related to global changes but are subject to much greater uncertainty.

of their range than to the high end.[13] (In contrast, the DICE-99 model, incorporating a set of best-guess parameters, projects a 2.0°C increase in the average global temperature between 2000 and 2100.[14])

**A Rise in Sea Level.** Warming of the earth's atmosphere and oceans would cause a gradual but uncertain rise in sea level, mainly from thermal expansion of the oceans but also from the melting of sea ice.[15] For the IPCC scenarios discussed previously, predictions of the average rise in sea level globally between 1990 and 2100 range from as little as 9 centimeters (cm) to as much as 88 cm, with a mean value of 48 cm (or about a foot and a half). That is two to four times the increase estimated to have occurred over the 20th century.[16] Researchers from the Massachusetts Institute of Technology (MIT) project a similar range, but with a mean value slightly under 40 cm.[17]

**Changes in Precipitation and Extremes in Weather and Climate.** Scientists expect a warmer world to be a wetter one: on average, rising temperatures will lead to more evaporation, humidity, and rainfall. The IPCC predicts increases in climate extremes as well, with higher daily minimum temperatures, more hot days, and heat waves "more likely" (but fewer frost days and cold days "likely") over nearly all land areas.[18] However, the relationship between increases in average temperatures and changes in extreme weather events is very uncertain. Warming could also change the frequency of thunderstorms and tornados, but the IPCC considered the data insufficient to make even general projections of trends for those weather events.

**Regional Differences in Effects.** Climate change would not be uniform: some regional changes in climate are expected to be much more pronounced than changes in the global average, and others less so. For example, the IPCC predicts that winter warming for all high-latitude northern regions will exceed the global mean by more than 40 percent.[19] In addition, a recent report on the impact of climate change on the Arctic concluded that "the Arctic is now experiencing some of the most rapid and severe climate change on Earth."[20] Furthermore, the IPCC predicts that changes in rainfall will vary greatly around the world, with rainfall increasing in high-latitude regions but decreasing in Australia, Central America, and southern Africa. Even the rise in sea level is expected to vary across regions, with nearly all models projecting a greater-than-average rise in the Arctic Ocean and a less-than-average rise in the Southern Ocean.[21]

**The Potential for Abrupt Changes.** One area of growing concern is the potential for the gradual buildup of greenhouse gases to push the global climate system over a threshold, producing an abrupt change to a different, stable, and irreversible equilibrium.[22] Scientists realize that

13. See Webster and others, "Uncertainty Analysis of Climate Change and Policy Response." The authors estimate that there is only a 1-in-20 chance that the temperature increase will lie outside that range.

14. That calculation comes from the spreadsheet version of the model.

15. For a more complete discussion, see Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis*, p. 31, Box 2. Sea level is also affected by various factors not related to climate change. Those factors include changes in terrestrial water storage (from factors such as the extraction of groundwater and building of reservoirs); vertical land movements caused by natural geological processes, such as slow movements in the Earth's mantle and tectonic displacements of the crust; and changes in atmospheric and ocean dynamics.

16. Ibid., p. 75.

17. See Webster and others, "Uncertainty Analysis of Climate Change and Policy Response."

18. See Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis*, p. 72.

19. In summer, warming in excess of 40 percent of the mean change globally is predicted for central and northern Asia. Ibid., pp. 67 and 69.

20. See the statement of Robert W. Corell, Chair, Arctic Climate Impact Assessment, before the Senate Committee on Commerce, Science, and Transportation, November 16, 2004, p. 3, available at www.acia.uaf.edu/PDFs/Testimony.pdf.

21. A higher rise in the Arctic sea level may result from an increase in freshwater, which reduces salinity and density and requires a rise in sea level to maintain pressure gradient at depth. See Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis*, pp. 75 and 673-674.

22. The National Research Council defines abrupt climate change as occurring when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause. Chaotic processes in the climate system may allow the cause of such an abrupt climate change to be undetectably small. Because crossing the threshold pushes the system into a new equilibrium, the system does not return to its original state, even when the pressure on it is relieved. See National Research Council, *Abrupt Climate Change: Inevitable Surprises* (Washington, D.C.: National Academy Press, 2002), pp. 13-14; and R.B. Alley and others, "Abrupt Climate Change," *Science*, vol. 299 (March 28, 2003), pp. 2005-2010.

abrupt changes have occurred in the past, especially during periods when external forces (such as changes in the Earth's orbit) were already causing relatively rapid changes in the climate system. Both the degree and the rapidity of warming are thought to affect the potential for an abrupt change in the climate.[23] An abrupt, unexpected shift could prove much more difficult for people and ecosystems to adapt to and, therefore, much more costly.

Scientists do not currently understand the processes that cause abrupt changes well enough to quantify the likelihood of such changes. (See Box 2-1 for a discussion of the scientific understanding of abrupt climate change.) The National Research Council has placed a high priority on obtaining rational estimates of the likelihood of abrupt shifts that may be of low probability but that could have very significant impacts.[24]

### Damages to Natural and Human Systems from Climate Change

To estimate the benefits of averting any changes in climate, analysts must determine how predicted patterns of change might affect natural and human systems—and, furthermore, how those effects would be mitigated by policies that reduced the magnitude and rate of climate change. Effects could include the initial transient impacts that would occur as the world first experienced the effects of a changing climate, as well as long-term impacts that would remain if temperature and greenhouse gas concentrations were stabilized and the world adjusted to the new equilibrium. For example, forests in some regions of the world could die off as temperatures rose, and new forests that had adapted to the new climate would take time to grow. In the long run, the effects of the change might be relatively modest, but the transition might be much more disruptive.

The degree of damage to both human and natural systems also would depend on the amount of adaptation that occurred, creating another source of uncertainty in predicting damages. For example, the damage from coastal flooding would be less severe if the threat of increased flooding was recognized and, as a result, development in coastal areas was limited. Similarly, the damage to agriculture would be less extensive if farmers raised different crops in response to the changed climate than if they continued to try to grow the same crops as they did in the past. One study estimated that without adaptation, global welfare losses in today's agricultural food sector would be between $0.2 billion and $84 billion if carbon dioxide concentrations were suddenly doubled, but potential adaptation could reduce the upper bound on losses to $52 billion or even result in a gain of $10 billion.[25]

Despite the potential for adaptation in at least some regions, the IPCC projects a number of adverse effects on human systems:[26]

- A general reduction in potential crop yields in most tropical and subtropical regions from most projected temperature increases;
- Decreased availability of water in many dry regions, particularly in the subtropics;[27]
- An increase in the number of people exposed to water-borne diseases such as cholera, diseases like malaria that are spread by arthropods (such as ticks and mosquitos), and an increase in heat-stress mortality;
- A widespread increase in the risk of flooding for many human settlements; and
- Increased energy demand for space cooling because of higher summer temperatures.

23. See Alley and others, "Abrupt Climate Change," p. 2008.
24. See National Research Council, *Abrupt Climate Change: Inevitable Surprises,* p. 116.
25. See John Reilly, N. Hohmann, and S. Kane, "Climate Change and Agricultural Trade: Who Benefits, Who Loses?" *Global Environmental Change*, vol. 4, no. 1 (March 1994), pp. 24-36.
26. See Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (Cambridge, England: Cambridge University Press, 2001), p. 5.
27. Climate modelers at Princeton University also reached a similar conclusion. They modeled a quadrupling of atmospheric carbon dioxide above preindustrial levels. Their results found that freshwater would be significantly less available in regions that are already relatively dry. See Syukuro Manabe and others, "Century-Scale Change in Water Availability: $CO_2$-Quadrupling Experiment," *Climatic Change*, vol. 64, no. 1-2 (May 2004), pp. 59-76.

**Box 2-1.**

## Scientific Understanding About Abrupt Climate Change

The current scientific emphasis on abrupt climate change is motivated by accumulating evidence of extreme and rapid climate changes in the past.[1] An important example is the abrupt onset of a cold, dry, windy period—referred to as the Younger Dryas—about 12,800 years ago, as the world was emerging from the previous Ice Age, and its equally abrupt end about 1,600 years later.[2] A less dramatic, shorter, but equally abrupt cold snap occurred about 8,200 years ago.

Scientists believe that those two episodes were probably triggered when large amounts of freshwater from melted glaciers broke through ice dams and flowed into the North Atlantic Ocean.[3] Those flows decreased the salinity of the ocean's surface water, slowing down a system of deep ocean circulation known as the thermohaline circulation, or THC.[4] (The THC helps transfer a great deal of tropical heat to higher latitudes, affecting weather patterns throughout the world, and is largely responsible for the relatively mild climate of large parts of Europe.[5]) Historical changes in the THC are believed to have caused significant changes in climate around the globe.

1. See R.B. Alley and others, "Abrupt Climate Change," *Science,* vol. 299 (March 28, 2003), p. 2008.
2. See National Research Council, *Abrupt Climate Change: Inevitable Surprises* (Washington, D.C.: National Academy Press, 2002), p. 24.
3. Wallace S. Broecker, "Future Global Warming Scenarios," *Science*, vol. 304 (April 16, 2004), p. 388.
4. Recent modeling indicates that the atmosphere-ocean system during the last glaciation was very close to a threshold, so relatively small increases in freshwater could have triggered abrupt changes in the THC. However, other factors, such as unknown periodic forcings and instabilities in ice sheets, also could have played a role. The basic question of the origin of the abrupt change in the THC is not resolved, but to date, models point to the key role of the freshwater balance in the Atlantic Ocean. See Peter U. Clark and others, "The Role of the Thermohaline Circulation in Abrupt Climate Change," *Nature,* vol. 415, no. 6874 (February 21, 2002), p. 866.
5. See National Research Council, *Abrupt Climate Change*, p. 76.

Recently, some observers have expressed concern that global warming could trigger a disastrous slowdown of the THC, and they have argued that such a possibility may justify aggressive actions to limit greenhouse gas emissions immediately. However, although experts do not fully understand the causes of previous slowdowns of the THC, they generally consider such a development highly unlikely over the next century, in large part because there are no sufficiently large sources of freshwater near the North Atlantic Ocean that could be released suddenly.[6]

Scientists are also studying less dramatic but equally abrupt changes in climate that occurred during the Holocene period, the name given to the past 11,000 years of the Earth's history. Such abrupt changes include rapid shifts in the magnitude and frequency of regional rainfall, hurricanes, and typhoons as well as global changes in temperature and precipitation patterns.[7] Because they occurred in a climate much like today's, such shifts may be particularly helpful in understanding what could unfold in the future. (Models used to simulate changes in climate are not yet sophisticated enough to project the likelihood of abrupt climate shifts in the future.) The National Research Council notes that "we know that droughts unprecedented in the last 150 years have occurred in the last 2,000 years and so could occur in the future, [but] we do not have the scientific understanding to predict them or to recognize their onset."[8] Although human actions did not cause those historical abrupt changes, scientists seek to understand how human-induced changes in climate could affect the likelihood of future abrupt changes.

6. The National Research Council concludes that predictions of dire near-term consequences are unfounded. In addition, one expert—the scientist who first discovered the link between the THC and the abrupt cooling—argues that the effect of global warming on sea ice formation in the North Atlantic could decrease the likelihood of a THC slowdown. See Broecker, "Future Global Warming Scenarios."
7. Changes in temperature and rainfall patterns around the globe can be triggered by El Niño or La Niña events, which are characterized by, respectively, unusually warm or cold temperatures in the Equatorial Pacific. See http://www.pmel.noaa.gov/tao/elnino/la-nina-story.html.
8. See National Research Council, *Abrupt Climate Change*, p. 44.

However, the IPCC reports that climate change could have some beneficial impacts on human systems as well:[28]

- Higher potential crop yields in some regions at mid-latitudes from increases in temperature of a few degrees Celsius or less;
- A potential increase in the global timber supply from appropriately managed forests;
- Increased availability of water for populations in some relatively dry regions—for example, in parts of southeast Asia;
- Reduced winter mortality at mid- and high latitudes; and
- Reduced energy demand for space heating because of higher winter temperatures.

Finally, any change in climate could affect natural systems as well as human systems. Potential changes include:

- Changes in the distribution, population size, population density, and behavior of wildlife and plants;[29]
- Reduction in habitat for cold- and cool-water fishes and gains in habitat for warm-water fishes; and
- Increases in erosion, accelerated loss of wetlands and mangroves, and seawater intrusion into freshwater sources as a result of increases in flooding.

The increased risks of climate change appear to be particularly great for species that are already rare or endangered and for species whose habitat would probably disappear and who therefore cannot easily migrate. For example, some species are adapted to isolated habitats on top of mountains in the tropics; others species are endemic to the temperate climate of the southern tip of Africa. If the climate changes in those regions, mountaintop species cannot move farther uphill; nor can southern African species migrate farther south.

The damaging effects of global warming on species would probably be exacerbated by human encroachment on natural habitats from population growth. While some species would be likely to disappear, the number or percentage of species in danger is extremely uncertain.

Differences in baseline climate conditions, changes in climate, initial vulnerability, and capacity for adaptation give rise to substantial differences in potential damages among regions. Predicting regional damages is further complicated by the fact that climate models do not yet yield reliable, detailed projections of regional changes. As a consequence, substantial uncertainty surrounds predictions of regional damages stemming from any particular degree or rate of climate change.

On the basis of analysts' current understanding, it appears that in general, regions with the fewest resources—in terms of wealth, infrastructure, technology, and education—would be likely to suffer the greatest losses, including damage to both human and natural systems. For example, the IPCC found that, to date, damages as a share of gross domestic product (GDP) from climate extremes have been substantially greater in developing countries than in developed countries.[30] In part, that discrepancy results because the economies of some developing countries are relatively heavily dependent on climate-sensitive industries, such as agriculture or fisheries.[31] In addition, developing countries typically have fewer resources to adapt to climate change and would therefore experience greater losses.[32]

28. See Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, p. 6.

29. For example, a recent report on the Arctic predicted that changes in climate could have "devastating" consequences for polar bears. See statement of Robert W. Corell, November 16, 2004.

30. See Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, p. 8

31. Ibid., p. 14

32. Ibid., p. 8.

CHAPTER

# 3

# Problems in Valuation

In addition to the numerous scientific and economic uncertainties involved in determining potential damages from climate change, it is very difficult to value such damages. The following discussion illustrates those challenges and controversies by describing the approach and results presented in a book by Yale University researchers William Nordhaus and Joseph Boyer.[1] Although the problems discussed below arise in any attempt to measure the costs and benefits of climate policies, Nordhaus and Boyer's work is particularly useful for illustrating them, in part because those researchers have made a comprehensive analysis of the potential economic impacts of climate change throughout the world, providing point estimates for many different types of economic impacts of climate change in many different regions.[2] Furthermore, they have incorporated their damage estimates in a relatively transparent, publicly available set of models. The availability of those models has allowed other analysts to understand how differences in assumptions influence policy recommendations. It also has allowed them to extend Nordhaus and Boyer's framework to analyze how the recommended policies change when they account for uncertainty in the model's parameter estimates. [3]

Nordhaus and Boyer attempted to follow the conventional economic approach to valuing benefits, which is to determine what people are willing to pay for them—that is, the value they place on particular goods or services, as reflected in their willingness to forgo other goods and services to obtain them.[4] Where goods and services are traded, their market prices provide some indication of what individuals would be willing to pay to avoid dam-

1. See William D. Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (Cambridge, Mass.: MIT Press, 2000).

2. Most researchers, in contrast, have tended to focus on only parts of the problem. However, other comprehensive estimates are available in William R. Cline, *The Economics of Global Warming* (Washington, D.C.: Institute for International Economics, 1992); Samuel Fankhauser, *Valuing Climate Change: The Economics of the Greenhouse* (London: Earthscan, 1995); Richard S.J. Tol, "Estimates of the Damage Costs of Climate Change, Part I: Benchmark Estimates," *Environmental and Resource Economics*, vol. 21, no. 1 (January 2002), pp. 47-73; and Richard S.J. Tol, "Estimates of the Damage Costs of Climate Change, Part II: Dynamic Estimates," *Environmental and Resource Economics*, vol. 21, no. 2 (February 2002), pp. 135-160.

3. For instance, Klaus Keller and others have extended the Dynamic Integrated model of Climate and the Economy to examine the policy implications of a possible collapse in the thermohaline circulation; see Klaus Keller and others, "Preserving the Ocean Circulation: Implications for Climate Policy," *Climatic Change*, vol. 47, no. 1-2 (October 2000), pp. 17-43. William Pizer has extended the model to explicitly incorporate probability distributions for various parameters; see William A. Pizer, "Optimal Choice of Policy Instrument and Stringency Under Uncertainty: The Case of Climate Change," *Resource and Energy Economics*, vol. 21 (1999), pp. 255-287. Tim Roughgarden and Stephen Schneider have reformulated the model to reflect an alternate estimate of the potential damages from climate change; see Tim Roughgarden and Stephen H. Schneider, "Climate Change Policy: Quantifying Uncertainties for Damages and Optimal Carbon Taxes," *Energy Policy*, vol. 27, no. 7 (July 1999), pp. 415-429. William Cline has adapted the model to examine different assumptions about economic growth, rates of warming, and preferences between present and future consumption; see William R. Cline, "Meeting the Challenge of Global Warming," in Bjorn Lomborg, ed., *Global Crises, Global Solutions* (Cambridge, England: Cambridge University Press, 2004), available at www.copenhagenconsensus.com/Files/Filer/CC/Papers/Climate_Change_300404.pdf. Richard Howarth has extended the model to consider the interests of several different overlapping generations; see Richard B. Howarth, "Climate Rights and Economic Modeling," in Darwin C. Hall and Richard B. Howarth, eds., *The Long-Term Economics of Climate Change: Beyond a Doubling of Greenhouse Gas Concentrations* (Amsterdam: Elsevier Science, 2001), pp. 315-326.

4. Alternatively, benefits may be measured by people's willingness to accept compensation for losing them. Willingness-to-accept measures are generally found to be higher than willingness-to-pay measures.

ages. In a flood zone, for instance, property prices indicate the value that could be lost from unexpected severe flooding. Similarly, in cases in which an environmental good is directly linked to the consumption of a marketed good, researchers can impute values for the environmental good by observing behavior in related markets. For example, they may estimate the value of clean air by measuring the variation in housing prices in areas with different levels of air quality.

Determining people's willingness to pay for an environmental good is particularly difficult when it is not bought or sold in a market and when its consumption is not directly linked to a marketed good. In that case, it is difficult to determine whether and how people are willing to trade environmental goods for other goods. Researchers may ask people directly what they are willing to pay for an environmental good, such as preserving species and their habitats (for example, the polar bear or the Great Barrier Reef), but that approach has been controversial, with some analysts questioning whether individuals can provide meaningful answers about the values that they would attach to such goods.[5]

A further difficulty is that many of the nonmarket damages—for example, habitat destruction and species extinction—that could result from climate change are damages to public goods, which, once provided, are available to everyone for free. The total value of the damages to a public good typically is taken to be the sum of the valuations of those damages across all people—valuations that could, in principle, vary from very positive to very negative. Thus, even if individuals could provide meaningful willingness-to-pay values, an extremely large sample size would be required to accurately assess that measure of total value.

Lacking empirical evidence on the actual value that individuals place on preventing damage from global warming, Nordhaus and Boyer used proxy data, rules of thumb, and expert opinion to construct estimates of people's willingness to pay to avoid damages in 13 regions of the world, for six major areas of impact: agriculture, sea levels, other market sectors, health, nonmarket amenities, and human settlements and ecosystems. Furthermore, they assessed the expected aggregate global damages from a catastrophic change in climate.[6] Importantly, the researchers implicitly assumed that people in each region place no value on damages in any other region.

The following discussion focuses on potential damages in three of those areas—agriculture, health, and human settlements and ecosystems—and on the estimate of expected catastrophic damages to highlight the challenges and controversies involved. A final section discusses the usefulness of such arbitrary and subjective valuations.

## Agriculture: Data Gaps Remain

Researchers have devoted much effort to estimating the potential impacts of climate change on the agricultural sector. Assessing the value of damages to agriculture is relatively straightforward because agricultural goods are sold in markets and their prices are easily determined. As a result, estimates of potential agricultural impacts are probably more reliable than those for any other sector.

Nevertheless, evaluating potential damages in the agricultural sector presents serious challenges. In addition to facing scientific uncertainty about projections of global and regional changes in climate, researchers face economic uncertainty in projecting many variables:

- How the economy will develop over time,
- How agricultural technologies might change,
- How agriculture's share of the economy might change, and

5. See Henry D. Jacoby, "Informing Climate Policy Given Incommensurable Benefits Estimates," *Global Environmental Change: Human and Policy Dimensions*, vol. 14, no. 3 (October 2004), pp. 287-297.

6. For a complete discussion of the assessment of willingness to pay in each of those six areas and of the estimate of catastrophic damages, see Nordhaus and Boyer, *Warming the World*, pp. 71-89.

- How farmers could adapt by adjusting their crop mix to a change in regional climate.[7]

The last consideration is particularly important. Although a change in climate might make it impossible to grow the same crops in a particular region, it might favor the cultivation of other crops, with little net economic impact.

A further complication is that present data limitations make it nearly impossible to estimate potential agricultural losses for many low-income and middle-income countries. For those countries, the researchers simply relied on estimates of the share of agricultural output lost for the "rest of the world" by other researchers and made assumptions about how agriculture's share of income differed among countries on the basis of their level of wealth.[8]

## Health: Questions About Valuing Lives Saved

Nordhaus and Boyer's damage estimates for the health sector illustrate the additional complications involved in estimating the value of damages to nonmarketed goods and services.[9] Finding no comprehensive studies of the potential health effects from climate change, they relied on estimates of the actual global incidence of diseases and years of life lost as a result of them, identifying a subset of those diseases that they believed to be climate-related. The authors derived a very rough estimate of how much more prevalent those diseases might become with a 2.5°C increase in the average global temperature, and they used that estimate to determine how many additional years of life could be lost in each region.[10]

To assign an economic value to their calculation of potential years of life lost, Nordhaus and Boyer estimated that people's willingness to pay to avoid an additional year of life lost would be twice the annual per capita income in the region. That controversial assumption implies that the value of life depends on the current distribution of income and thus is proportionately greater in a high-income country than in a low-income country. In other words, the lower a person's income, the less he or she would be able and willing to pay to avoid a premature death.

Although that approach reflects the real income constraints that countries face, it is perceived by some people as inequitable. Using any other approach, however, would present other problems. People in poor countries with very low incomes cannot, and do not, spend a great deal to reduce their risk of death. A climate policy that valued their years of life as highly as those of people in high-income countries would create a disparity between the value placed on potentially extending lives by means of climate change policies and the value placed on doing so via other policies—such as providing clean water or basic health care—that are funded by limited local resources. It also would place a disproportionate value on risk reduction from climate change policies and the value attached to other public goods and services that residents in poor countries might wish to have resources spent on, such as the building of roads or the provision of electricity. (The reverse problem would arise if a policy was adopted that valued years of life of high-income people as little as those of people in low-income countries.) In sum,

7. On the basis of available data, Nordhaus and Boyer estimated that in 1995, the negative impact on U.S. agriculture of a 2.5°C increase in the average global temperature would have been about $4 billion—or about 0.065 percent of total output—in the U.S. economy. They concluded that the United States would be willing to pay 0.065 percent of its total output to avoid the damage to agriculture that a 2.5°C increase in the average global temperature would be expected to bring about in today's economy. They made adjustments to reflect the expected timing of the warming, which they assumed would occur in 2100, and the changes in the economy that they projected would have taken place by then.

8. See Nordhaus and Boyer, *Warming the World*, pp. 74-75. Countries for which information is extremely poor include those in Africa, the group of countries classified as lower middle income in the Regional Dynamic Integrated model of Climate and the Economy (for example, Thailand, Mexico, and Peru), and those classified as low income (for example, Indonesia, Bangladesh, and Bolivia).

9. Ibid., pp. 78-82.

10. Nordhaus and Boyer used three alternative methods to provide a rough estimate of the increase in those diseases that might occur with a 2.5°C increase in the average global temperature. Method A assumes that half of the years of life lost (YLLs) because of climate-related diseases estimated by the researchers for the 1990-2020 period will be lost as a result of a 2.5°C warming. Method B adjusts the change in YLLs for each region to approximate the difference among subregions that is related to climate. Method C uses econometrics to determine the relationship between differences in climate-related YLLs in various regions and differences in climate. The authors take the average of those three methods to estimate the additional years of life lost from climate change in each of the regions identified in their model.

setting priorities among alternative policies becomes very difficult if some policies have willingness-to-pay benefit estimates that reflect a country's actual income constraint and others do not.[11]

## Human Settlements and Ecosystems: Valuing Damages to Nonmarketed Goods and Services

Nordhaus and Boyer highlight the importance and difficulty of evaluating the effects—particularly the nonmarket damages—that climate change might have on human settlements (for example, losses due to water intrusion in low-lying cities or countries, such as Venice or Bangladesh) and on natural systems (for example, the loss of species that have limited ranges or the destruction of complex ecosystems). Faced with no meaningful valuations, the authors developed rough estimates of the capital value of climate-sensitive human settlements and natural ecosystems in each region—ranging from 5 percent to 25 percent of regional output—and assumed that each region would be willing to pay roughly 1 percent of that capital value annually to prevent the damage that it might incur as a result of a 2.5°C increase in the average global temperature. For the United States, they estimated that the capital value of climate-sensitive human and natural settlements was 10 percent of national output, or $500 billion, and that Americans would be willing to pay $5 billion per year to protect that value.[12]

11. For an extensive discussion, see Paul R. Portney, "Applicability of Cost-Benefit Analysis to Climate Change," in William D. Nordhaus, ed., *Economics and Policy Issues in Climate Change* (Washington, D.C.: Resources for the Future, 1998), pp. 122-123. Portney presents the argument somewhat differently, stating that using a global average value for all lives saved would lead developing countries to concentrate all of their attention on programs that saved lives in the short term and to pay little or no attention to climate change policies. However, the real problem stems not from the time frame of the policies but from evaluating some policies with willingness-to-pay estimates that reflect a domestic budget constraint and evaluating others using a global budget constraint.

12. Nordhaus and Boyer assumed that this estimate of willingness to pay would be sensitive to changes in income. As countries' incomes grew, their willingness to pay to prevent damages to human settlements and natural ecosystems would increase as well. For additional detail, see Nordhaus and Boyer, *Warming the World*, pp. 85-87.

## Catastrophic Damages: Expert Opinions Vary Widely

To provide a rough estimate of the potential for catastrophic damages from climate change—as well as their possible magnitude—Nordhaus surveyed a group of natural scientists, environmental economists, and other social scientists about their expert assessments of the probability that a temperature increase of either 3°C or 6°C by 2095 would lead to catastrophic damages, which he defined as a 25 percent reduction in global world product (GWP).[13]

Nordhaus used the survey responses to develop a set of "certainty-equivalent" damages, which convert low-probability catastrophic losses into certain losses of lower value. Nordhaus assumed risk neutrality in those conversions; under that assumption, a 1 percent chance of losing $100 is equivalent to a certain loss of $1. (Under an assumption of risk aversion, it would be equivalent to more than $1.) Using that approach, Nordhaus converted the experts' varying assessments of the likelihood of a 25 percent loss of GWP into a certain loss of 0.36 percent of GWP for a warming of 2.5°C and 2.04 percent of GWP for a 6°C warming.[14]

Nordhaus also asked the experts to provide their best guesses of the magnitude of the damages that might result from a 3°C or 6°C increase in average global temperature by 2095. The experts' estimates ranged from 0.3 percent to 21 percent of GWP for the value of damages from a 3°C increase and from 0.8 percent to 62 percent of GWP for a 6°C increase.[15] The experts also provided estimates

13. See William D. Nordhaus, "Expert Opinion on Climate Change," *American Scientist*, vol. 82, no. 1 (January-February 1994), pp. 45-51.

14. See Nordhaus and Boyer, *Warming the World*, pp. 87-89. Nordhaus adjusted the certainty-equivalent calculations to account for information about the potential shutdown of the Atlantic Ocean's thermohaline circulation that became available after his survey was done (see Box 2-1). He assumed that the probability of a catastrophic loss with a 2.5°C temperature increase was double the experts' estimated probabilities for a 3°C warming and that the probability associated with a 6°C warming was double the experts' estimates.

15. Best guesses are defined as 50 percentile estimates—the point at which the expert surveyed believed that there was a 50 percent chance that actual damages could lie either above or below that level. For an analysis of those survey results, see Roughgarden and Schneider, "Climate Change Policy: Quantifying Uncertainties for Damages and Optimal Carbon Taxes."

of the probability ranges around those best guesses: at least one expert felt that there was a 10 percent chance that the damage from a 3°C rise in average global temperature could exceed 31 percent of GWP; at the other extreme, at least one expert thought that there was only a 10 percent chance that the damage resulting from a 3°C rise could exceed 0.6 percent of GWP.

The experts' damage estimates seem to depend on their particular area of knowledge: natural scientists tended to predict larger losses than social scientists did, with the bulk of the expected losses consisting of damages to nonmarketed goods and services rather than the types of goods and services that are measured in standard national economic accounts. Thus, much of the variance in damage estimates appears to come from divergent views about either the extent of damage to the natural world, the value of that damage, or both.

Other researchers have applied the responses from Nordhaus's survey to develop policy recommendations that reflect the uncertainty associated with potential damages. Those analyses are discussed in Chapter 5.

## The Usefulness of Subjective Estimates

The lack of meaningful data on the value of many potential damages from climate change leads researchers to use arbitrary rules of thumb to determine values. In at least some cases, the rules of thumb and the predicted damages are highly speculative and probably inaccurate measures that provide only very rough guidance at best in the development of policy. However, such efforts may be helpful in providing some sense of the likely magnitude of damages and, thus, some general sense about the desirability of alternative policies. As discussed in Chapter 5, clarifying the process by which those values are determined (and describing how the use of alternative values affects policy prescriptions) may be as useful in informing policymakers as the estimates themselves.

CHAPTER

# 4

# Problems in Aggregation

The evaluation of climate policy is further complicated by the fact that benefits and costs would occur at widely different times and could occur in different parts of the world. For both of those reasons, climate change—and policies to avert it—would probably yield gains for some regions and countries and losses for others. That fact raises complicated problems about how to aggregate and balance gains and losses over time and across locations.

## Problems in Comparing Present Costs and Future Damages

The damages associated with climate change are expected to occur many years from now—with most researchers estimating that the bulk of damages from current emissions may occur a century or more in the future. In contrast, the cost of policies enacted to avoid damages would be incurred in the near term. As a consequence, analysts and policymakers must consider trade-offs between the costs that climate policies impose on people today and the benefits that they are projected to yield for future generations. Although many analysts adopt the conventional economic approach to evaluating long-term benefits, others argue for an alternative approach.

### The Conventional Approach to Discounting

The conventional "opportunity-cost" approach to comparing the current costs and the future benefits of policies is to convert future values to present values using market interest rates. The approach is based on the fact that resources devoted to a policy also could be invested at current market interest rates and allowed to compound over time, yielding significantly more income in the future. Following that logic, the conventional approach is to weigh policy costs against the investment opportunities forgone by undertaking the policy.

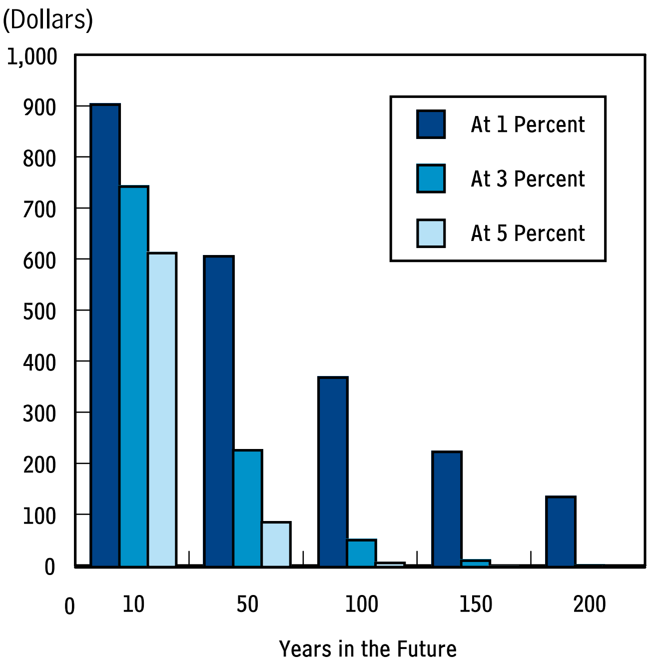
Suppose, for example, that current generations were considering a policy that they expected would yield $1,000 worth of climate benefits to people living a century from now. An alternative would be to provide those future generations with $1,000 worth of inflation-adjusted income. The amount of income to set aside today for that purpose depends on the expected rate of return on investments: if the rate was expected to be 3 percent, the current generation would have to invest about $52 to make sure that $1,000 was available a century hence. In other words, at a 3 percent interest (or discount) rate, the present value of $1,000 one century from now is $52 today. Because the present cost of providing $1,000 to future generations through a conventional investment is $52, analysts conclude that at a 3 percent discount rate, $52 is the present value of $1,000 of any sort of benefit a century from now.

If the rate was expected to be lower—say, 1 percent—the current generation would have to put aside more income to yield $1,000 in a century—nearly $370. At a higher rate—say, 5 percent—the current generation could put aside much less income—about $8. The farther in the future the income is needed, the smaller the initial investment can be, because it has longer to compound and grow: the present value of $1,000 two centuries from now is about $137 at a 1 percent rate of return but less than $3 at a 3 percent rate and only six cents at a 5 percent rate (see Figure 4-1). Although present-value calculations may seem to dramatically devalue future damages from climate change, they simply reflect the fact that alternative long-term investments can and do yield positive rates of return.

A related way of thinking about the problem of comparing present and future values—one that leads to the same conclusion—is in terms of compensation: if current generations are producing emissions that will impose dam-

**Figure 4-1.**

## The Present Discounted Value of $1,000




Source: Congressional Budget Office.

ages on future generations, they may set aside income today to compensate future generations for the damages they are expected to incur. To provide compensation, people can invest income today and allow it to grow, yielding the appropriate amount of compensating income in the future.

The same logic can be applied to setting the level of a price on greenhouse gas emissions. An appropriately set tax on carbon would lead current generations to eliminate those emissions that were more costly to compensate future generations for than to forgo, but to continue those emissions that would cost more for current generations to eliminate than the discounted damages that they caused and the compensation that they could, in principle, pay to future generations.

According to the opportunity-cost approach, then, the present value of all future benefits, including climate damages, depends on the market rate of interest. However, analysts encounter a serious problem in implementing that approach for very-long-term policies: there are no financial markets in which to make centuries-long investments and from which to determine very-long-term interest rates. Some observers argue that the absence of such rates calls the opportunity-cost approach into question, but most analysts use rates on long-term government bonds as a rough proxy for such very-long-term rates of return.[1]

To derive a discount rate for present-value calculations from such market rates, analysts must adjust the rates to eliminate compensation for expected inflation and various forms of risk.[2] Furthermore, adjusting for the uncertainty about rates of return on long-term bonds yields an implicit rate of return that is lower than the average rate—and one that declines the farther in the future the values are converted to present ones. That adjustment can considerably increase the weight attached to long-term benefits, compared with simply applying a constant average discount rate based on the returns on long-term bonds. According to recent research, that adjustment increases the present value of one estimate of future climate-related damages over the next four centuries by 7 percent to 95 percent, depending on the initial interest rate and the assumed reasons for the variability.[3]

1. For example, funds continuously reinvested in 10-year U.S. Treasury bonds from 1789 to the present would have earned an average inflation-adjusted return of slightly more than 3 percent a year.

2. Interest rates typically reflect the riskiness of the relevant investment: the riskier an investment, the less likely it will be to pay a return, and the greater the rate of return that investors will demand as a condition for accepting the risk of failure. Similarly, interest rates typically include an upward adjustment that reflects expectations about the risk of future inflation. Adjusting for risk does not imply that future damages should be considered certain, but rather that the comparison of present and future values should be distinguished from calculations of risk—an issue discussed in the next section.

3. See Richard G. Newell and William A. Pizer, *Discounting the Benefits of Climate Change Mitigation: How Much Do Uncertain Rates Increase Valuations?* (Arlington, Va.: Pew Center on Global Climate Change, December 2001). When the future real interest rate is uncertain, the value of a future benefit, discounted by that interest rate, could be high or low; and the expected value of that future benefit today is the average of the possible outcomes. Because interest rates compound over time, the difference between higher and lower discounted values of a given benefit gets larger the farther out in the future the benefit occurs. The net effect of that divergence between higher and lower discounted values is to generate an expected benefit that is much closer to the value implied by the low rate than the one implied by the high rate.

The opportunity-cost approach thus allows analysts to convert future values into present ones in a way that is consistent with the ability to convert present income into future income and that can be adjusted for many kinds of uncertainty. If analysts believe that past variability in such market rates does not fully reflect the potential for variability in future returns—perhaps because of the potential for disasters even greater than those that have occurred during the period for which long-term government bond rates exist—they can assume a greater degree of future variability when calculating the implicit discount rate, yielding a lower set of rates.

## The Prescriptive Approach to Discounting

Despite the flexibility of the conventional approach and its general acceptance by economic analysts, some analysts have argued for a "prescriptive" approach that uses lower discount rates to convert future values into present ones.[4] The main argument usually cited for doing so is that society does not save and invest sufficiently—in terms of physical capital, technology, or a beneficial climate—to provide for future generations. Market distortions are one source of the problem, particularly taxes on capital that drive a wedge between pretax and after-tax returns on investments. Some analysts argue further that pure impatience or "time preference" leads people to undervalue the future in their personal financial behavior.

According to the prescriptive approach, taxes and impatience both may induce people to save and invest less than they would otherwise, leaving pretax interest rates higher than they would be in an ideal world in which the tax system was not so distortionary and people were not so impatient. Proponents of that view argue that public policies that address long-term problems should offset the effects of market distortions and impatience by evaluating projected future damages using discount rates that are lower than market rates.[5]

The effect of the prescriptive approach is to place a higher value on climate-related damages (and other damages evaluated using lower rates) than is placed on comparable future benefits that are evaluated using market rates. To illustrate that point, consider the example presented earlier. If climate-related damages are expected to be $1,000 a century from now, applying a lower discount rate—say, 1 percent instead of a 3 percent market rate—increases the present value of those damages from $52 to $370 and thus leads to a recommendation to undertake more mitigation today. However, that $370 could be invested today and could be expected to yield much more than $1,000 in income in a century, even at a very uncertain market interest rate—so long as the rate ranged around the long-run historical average of about 3 percent. Therefore, as long as most investments are undertaken at market rates, the recommendation to apply a lower discount rate has the effect of valuing future climate damages more highly than comparable benefits from most other investments.[6]

The only way to compare all future benefits on an equal basis is to evaluate them using a similar set of discount rates. Thus, the only way for policies evaluated at lower-than-market rates to be compared on an equal basis with

4. The distinction between the prescriptive and conventional (or "descriptive") approach is discussed in K.J. Arrow and others, "Intertemporal Equity, Discounting, and Economic Efficiency," in James P. Bruce, Hoesung Lee, and Erik F. Haites, eds., *Climate Change 1995: Economic and Social Dimensions of Climate Change* (Cambridge, England: Cambridge University Press, 1996), pp. 125-144. A particularly well-known version of the prescriptive argument is made by William R. Cline, "Discounting for the Very Long Term," in Paul R. Portney and John P. Weyant, eds., *Discounting and Intergenerational Equity* (Washington, D.C.: Resources for the Future, 1999), pp. 131-140.

5. Under the prescriptive approach, future generations' well-being may be discounted to some extent—for instance, because of risk aversion or because they are likely to have much greater wealth than current generations to offset a climate-related loss of well-being—but not by as much as is implied by market interest rates. Interestingly, some research also indicates that people may approve of public policies that place more emphasis on benefits in the distant future than they do in their own personal saving and investment behavior. For further discussion, see Maureen L. Cropper, Sema K. Aydede, and Paul R. Portney, "Preferences for Life Saving Programs: How the Public Discounts Time and Age," *Journal of Risk and Uncertainty*, vol. 8, no. 3 (1994), pp. 243-265.

6. Skeptics of the opportunity-cost approach sometimes object that the proposed alternative investment could not serve as adequate compensation for climate-related damages. That, too, is another way of saying that the climate-related damages should be given not just a higher present value but also a higher future value. Another argument presented for using a lower discount rate for environmental benefits such as averting damages from climate change is that future generations are likely to enjoy higher income, so they may value those benefits more highly than current generations do and would be willing to pay more for them. That argument is also, in effect, a way of placing a higher future value on future damages. (William Nordhaus and Joseph Boyer, taking that consideration into account, incorporate the effect of rising income on willingness to pay in their valuation of climate-related damages; thus, the argument would not apply to their estimates.)

other policies would be for society as a whole to increase its investment to the point at which the rate of return on investments was driven down to the same lower rate. At that point, the opportunity-cost approach and the prescriptive approach would yield the same evaluation for any proposed policy or investment. Because that is not the case in reality, the prescriptive approach drives a wedge between the present value of typical market investments and that of policies evaluated at below-market rates.

All of the difficulties described above—uncertainty about the future rate of return, the valuation of future damages, market distortions, and concerns about how to value different types of benefits and the welfare of future generations—complicate the balancing of present and future costs and benefits. The discount rate chosen can dramatically affect conclusions about the appropriate stringency of policy today. In one application of the Dynamic Integrated model of Climate and the Economy, for instance, the present value of future climate-related damages, at a 4 percent discount rate, is about $8 per ton of carbon emitted but nearly $29 per ton at a 2 percent rate.[7]

## Problems in Determining the Appropriate Level of Risk Reduction

Given the many uncertainties associated with climate change, the choice of policy stringency is similar to a choice about insurance coverage: higher emissions prices impose higher costs on households and businesses today but provide more protection against unpleasant surprises from damages in the future. Yet another potential source of controversy, therefore, is that people vary in their aversion to risk: although a person who views risk neutrally may value a 1 percent probability of sustaining $100,000 in damage at $1,000—and therefore would be willing to pay up to $1,000 to avoid it—another person who is very averse to risk may be willing to pay considerably more.

Differences in risk aversion can thus lead people to differ in the level of policy stringency they prefer, even if they agree on all the other scientific, economic, and valuation uncertainties. Because of the formidable difficulties in evaluating uncertain costs and benefits assuming risk aversion, however, very little research has been done in that area. The cost-benefit assessments discussed in previous chapters all assume risk neutrality and therefore provide little guidance to policymakers on how to evaluate potential costs and benefits under different risk preferences.

## Problems in Aggregating Costs and Benefits Across Regions

Just as problems arise in balancing present and future costs and benefits, complications arise in aggregating costs and benefits across individuals, regions, and countries. As discussed in Chapter 3, one source of controversy is that estimates of benefits reflect the affected people's willingness to pay to avoid potential damages—and therefore are linked to their income. Thus, equivalent damages receive greater weight if they occur in high-income countries than in low-income ones.

A second source of controversy, discussed in Chapter 2, is that the effects of climate change are likely to be very unevenly distributed: according to one estimate, for example, India would experience an annual loss equal to about 5 percent of its total output if the average global temperature rose by 2.5° Celsius, whereas Russia would benefit by an amount equal to about 0.65 percent of its total output.[8] An aggregation of potential damages would conflate India's losses and Russia's gains, yielding a single value for net losses, regardless of whether Russia used any of its gains to compensate India for its losses.

A third source of controversy is that countries that are expected to bear a large share of the cost of mitigation policies, such as the United States, may receive only a small share of the benefits. At the same time, developing countries, which may bear a relatively small share of the mitigation costs, are expected to receive a large share of the benefits. The assumption implicit in analyses that maximize global net benefits is that countries that benefit could theoretically compensate those that bear the cost—making all countries better off—yet few observers expect such compensation to occur.

Finally, benefits and costs can be aggregated only if they can be translated into common units—for instance, a monetary value such as constant dollars. However, as dis-

7. Newell and Pizer, *Discounting the Benefits of Climate Change Mitigation.*

8. See William D. Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (Cambridge, Mass.: MIT Press, 2000), p. 91.

cussed in Chapter 3, assigning monetary values to avoided damages for nonmarketed goods and services is extremely difficult. Furthermore, many of those damages are to public goods, and their valuation requires some method of aggregating people's different evaluations of the same phenomena.

Those complications in aggregating benefits are not the same as scientific uncertainties about the radiative forcing value for different greenhouse gases or the response of species to changes in habitat. However, they are important factors contributing to differences of opinion about how aggressively to pursue any climate policy.

CHAPTER

# 5

# Policy Implications

Large uncertainties are inherent in estimating the costs and benefits of any policy to address the possible risks associated with climate change; yet the stakes in making policy choices are high. Although reducing greenhouse gas emissions could impose significant costs on nations around the globe, some experts believe that those emissions, if left unrestrained, could lead to costly damages.

Climate policy will probably involve a sequence of decisions based on the gradual accumulation of information and the resolution of uncertainties.[1] Waiting until all uncertainties are resolved and then implementing a single long-term "best" solution may not be a pragmatic approach, for three reasons. First, uncertainty in the assessment of climate policy can be decreased but not eliminated. Second, greenhouse gases that are emitted today will contribute to a gradual long-term warming, the full effects of which will become apparent only over many decades. Third, reducing the global economy's reliance on fossil energy would be a slow process.

Actions taken over the next decade are likely to have relatively little impact on the extent of any climate change a century from now, since long-term climate change will depend on the path of the global economy and policies pursued over the whole century. However, current actions might lay the groundwork for potentially large reductions in emissions in the future, should research indicate the need for them. That possibility suggests a flexible strategy that could be easily modified over time and that could include several elements:

- Research to resolve uncertainties about potential damage and to develop technologies that might cut the cost of reducing emissions or be helpful in adapting to a warmer climate;

- Economic incentives to encourage inexpensive reductions in emissions today, with the expectation that more-extensive reductions may be merited in the future; and

- Policies that would facilitate adaptation, thus lowering the cost of any warming that did occur.

Determining the appropriate magnitude of each of those strategies or the balance among them is beyond the scope of this paper. Instead, the paper examines implications about policy formation that can be drawn from an understanding of the uncertainties described in previous chapters, focusing on mitigation—the area for which existing research offers the most useful insights.

## Research and Development

Research would be an essential part of a comprehensive approach to addressing climate change. Research may even yield economic benefits if it helps resolve uncertainty about elements of the problem, thus reducing the likelihood of taking unnecessarily expensive measures or not taking actions that would have proved beneficial. (However, as it has in the past, research may also uncover new elements of the problem whose importance had previously gone unrecognized. In that respect, greater knowledge may not necessarily reduce the overall range of uncertainty about the risks of climate change.)

1. That sequence is sometimes referred to as an "act, then learn, then act" process. A seminal discussion of that approach is provided in A.S. Manne and R.G. Richels, *Buying Greenhouse Insurance: The Economic Costs of $CO_2$ Emission Limits* (Cambridge, Mass.: MIT Press, 1992). Another useful discussion is found in L. James Valverde A. Jr., Henry D. Jacoby, and Gordon M. Kaufman, "Sequential Climate Decisions Under Uncertainty: An Integrated Framework," *Journal of Environmental Modeling and Assessment*, vol. 4, no. 2-3 (1999), pp. 87-101.

One team of analysts has estimated that research to reduce uncertainty about those risks is likely to have the biggest payoff if it is directed at improving knowledge about the value of potential damages (for example, the monetary value of health damages or reductions in species) and the cost of reducing emissions.[2] In contrast, they found a somewhat lower payoff from obtaining a better understanding of the climate system or of the future growth of emissions. An important limitation of that study, however, is that it measures only the expected benefits of research and not what the required research would cost.

Research could also play a key role in developing technologies to reduce the cost of making more dramatic emissions reductions in the future, should they be warranted, or to reduce the cost of adapting to a warmer climate, should it become necessary. The availability of such technologies would make the transition away from reliance on fossil energy (or the sequestration of fossil-fuel-related emissions) or the adaptation to a warmer climate less expensive than it would otherwise have been. If potential damages do not indicate a need for those technologies, the development cost would represent insurance against a risk that did not ultimately materialize.

## Mitigation

Policymakers may choose to limit emissions by using a variety of command-and-control strategies—those that specify firm-specific emissions reductions or technology requirements—or by using policies that provide broad economic incentives to reduce emissions.[3] When economic incentives can be successfully applied, they are generally less costly than command-and-control approaches. Command-and-control policies that dictate explicit methods for reducing emissions are unlikely to prescribe the best technology in every application, and they may easily overlook cost-effective solutions. Likewise, government regulators are unlikely to know which firms can cut emissions most cheaply. For that reason, experts believe that broad-based economic incentives, which provide firms with much more leeway in where and how to reduce emissions, are likely to result in more cost-effective emissions reductions than are command-and-control regulations.

Experts generally agree that economic incentives could be successfully applied to regulate carbon dioxide emissions from the burning of fossil fuels, nitrous oxide emissions from industrial sources, and methane emissions from landfills. Those types of emissions are relatively easy to measure and monitor, making the administrative cost of implementing and enforcing an incentive-based policy relatively low.[4] In contrast, greenhouse gas emissions that come from agricultural and forestry activities are much more difficult to monitor, complicating the application of incentive-based policies.

When monitoring and enforcement considerations allow the use of economic incentives, policymakers must decide between two general forms—incentives that limit the overall level of emissions (so-called quantity instruments) or incentives that reduce emissions by raising their price (so-called price instruments). Cap-and-trade programs offer a way to set an aggregate limit on the level of greenhouse gas emissions while relying on economic incentives to determine where and how those emissions reductions take place. Under such a program, policymakers would establish an overall cap on emissions but allow regulated firms to trade rights (or allowances) to those emissions. Trading would allow firms that could reduce their emissions most cheaply to do so in order to sell some of their allowances to firms that faced higher costs to reduce their emissions. Furthermore, the price increases that resulted from the cap would encourage households to consume less fossil fuel, thus leading to lower carbon emissions. That approach would achieve the emissions target at the

2. See William Nordhaus and David Popp, "What Is the Value of Scientific Knowledge? An Application to Global Warming Using the PRICE Model," *Energy Journal*, vol. 18, no. 1 (1997), pp. 1-45.

3. Command-and-control policies can include policies that set specific emissions limits (or standards) that firms must make but do not specify how those limits must be met. For example, corporate average fuel economy standards specify an average fuel economy standard that each auto manufacturer's fleet must meet but do not specify how manufacturers must meet that standard. Although such policies provide manufacturers with some degree of flexibility, they provide much less flexibility than cap-and-trade programs.

4. Fossil fuels are produced by a relatively small number of firms, and the carbon content of those fuels is well known; the other emissions also come from a relatively small number of sources that, for the most part, are already monitored for other types of pollution emissions. The removal and sequestration of emissions from large sources—such as electric power plants and industrial boilers—would also be relatively easy to monitor and measure.

lowest possible cost, but it would not necessarily balance that cost against the benefits achieved by the target.

Taxing greenhouse gas emissions, in contrast, would boost the cost of those emissions, thereby encouraging households and firms to cut emissions as long as the cost of doing so was below the tax. (Households and firms could reduce emissions by using less fossil fuel or by relying on fossil fuels yielding relatively few emissions.) That price-based approach would establish an upper bound on the cost of individual emissions reductions—the level of the tax—but would not ensure that any particular emissions target was met. Such an approach would balance benefits and costs only if the tax was set equal to the benefit resulting from incremental reductions in emissions.

A cap-and-trade program with a "safety valve" combines an aggregate cap on total emissions with a ceiling on the allowance price. Under that hybrid approach, policymakers would establish an overall cap and allow firms to trade allowances, but they would also set an upper price for allowances, referred to as the safety-valve price. If the price of allowances rose to the safety-valve price, the government would sell as many allowances as was necessary to maintain that price. Thus, if the safety valve was triggered, the actual level of emissions would exceed the cap. The cap would be met only if the price of allowances never rose above the safety-valve price.[5]

## Given Current Uncertainties, Pricing Policies Better Balance Costs and Benefits Than Emissions Caps

If policymakers could be sure of the costs and benefits of limiting emissions, they could set either an emissions cap or an emissions price at exactly the right level to achieve the largest net benefits (benefits minus costs). Either approach could induce households and firms to reduce emissions up to the point at which the cost of the most expensive reduction in emissions was equal to the benefit that it would yield. Because the cost of emissions reductions would rise as successively costly cuts were undertaken, each reduction in emissions prior to that point would produce a benefit that exceeded the cost of achieving it, and each reduction after that point would have a benefit that fell below its cost.

In reality, of course, neither potential benefits nor potential costs are certain. As a consequence, policymakers cannot be sure that a policy designed to maximize *expected* benefits minus *expected* costs would maximize *actual* benefits minus *actual* costs: benefits, costs, or both are likely to end up being different than anticipated. Setting an excessively high price or too tight a cap would impose costs that were not justified by their benefits. Conversely, setting too low a price or too loose a cap would result in forgone benefits that outweighed the cost of obtaining them.

Most analysts believe that for greenhouse gas emissions that can be regulated through economic incentives, a policy that sets emissions prices is much more likely to minimize the adverse consequences of making a wrong choice than a policy that sets a strict limit on emissions.[6] The reasons, discussed below, are related to characteristics of the costs and benefits of controlling stock pollutants.

**Why Are Price Instruments More Efficient than Emissions Caps?** If the costs of policies to restrict emissions could be accurately determined and only the benefits of those policies were uncertain, then the choice be-

5. Another hybrid approach includes a "circuit breaker" rather than a safety valve. Under that approach, the cap would gradually decline as long as the price of allowances stayed below a predetermined trigger price. If the allowance price increased to the level of the trigger, the cap would be frozen. Once that happened, the price of allowances could remain above the trigger—which would be likely to occur, because the frozen cap would be harder to meet as the economy grew. Thus, a circuit breaker would not cap costs in the manner of a safety valve.

6. One researcher found that under certain conditions (including a perfect trading market and a lack of random shocks to allowance prices that do not stem from shocks in abatement costs), a tradable-allowance policy could cause firms to make greater investments in abatement technologies than an emissions price that produced the same level of emissions in the initial year. See Jinhua Zhao, "Irreversible Abatement Investment Under Cost Uncertainties: Tradable Emission Permits and Emissions Charges," *Journal of Public Economics*, vol. 87, no. 12 (December 2003), pp. 2765-2789. In contrast, emissions charges could offer a substantial advantage if the revenue generated from the charges was used to reduce existing taxes that cause distortions in the economy, such as taxes on capital and labor. The economic benefits of decreasing those distortionary taxes could substantially reduce the costs of the policy. A cap-and-trade program could offer a similar advantage, but only if the allowances were sold to firms rather than given away for free. For a discussion of that issue, see Ian Parry, *Revenue Recycling and the Costs of Reducing Carbon Emissions*, Climate Issue Brief No. 2 (Washington, D.C.: Resources for the Future, 1997); and Ian W.H. Parry, Roberton C. Williams III, and Lawrence H. Goulder, "When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets," *Journal of Environmental Economics and Management,* vol. 37, no. 1 (January 1999), pp. 52-84.

tween policies that specified emissions limits or emissions prices would be irrelevant. Policymakers could set either an emissions price or an emissions limit at the point at which the expected cost of the last reduction in emissions was equal to the expected potential benefit that it would produce. If benefits ended up being lower than expected, the policy would end up being too stringent; if benefits were greater than expected, the policy would be too lenient. Either way, however, the adverse consequences of having chosen the wrong policy—the gap between costs and benefits—would be the same. The fact that the actual benefits were different than expected would have no effect on people's response to the policy. Those responses would be determined either by the cap on emissions or the price, both of which were based on expected benefits. Thus, the actual emissions reductions—and the costs and benefits of those reductions—would be the same under either policy instrument.

When the costs of restricting emissions are also uncertain, however, the two policy instruments may result in very different levels of actual emissions—and different costs and benefits—even if both are set to yield the same expected level of emissions. Under a price instrument, households and firms will adjust their level of emissions reductions in a way that will keep actual costs roughly in balance with expected benefits—something they cannot do if faced with a strict limit on emissions.[7] The advantage of a price instrument is particularly great when regulators are very uncertain about the costs of reducing carbon emissions—either because they have less information about those costs than firms do or because those costs will ultimately depend on factors that neither firms nor policymakers know at the present time (such as the development of new technologies).

The illustrative example in Table 5-1 demonstrates that point. Despite the uncertainty surrounding the marginal benefit of reducing emissions, this example arbitrarily assumes that the value is $10 per metric ton of carbon. Furthermore, the example assumes that firms would minimize their compliance costs—either by equating their marginal cost of reducing emissions to the emissions price (under a tax) or to the allowance price (under a cap-and-trade policy).[8] The example shows outcomes for two domestic policies (a price on emissions and a cap on emissions) that are designed to produce the same level of emissions reductions (and thus, the same expected costs and benefits). If policymakers charged a tax of $10 per ton on carbon (based on the expectation that the benefits of reducing a ton of carbon emissions is $10) and if the cost of reducing emissions was what they had anticipated, the $10 tax would result in a reduction of 29 million metric tons of carbon in the first year of the policy and provide a net benefit of $143 million.

If, however, the cost of reducing emissions by that amount was 50 percent lower than anticipated, firms would find it advantageous to undertake additional low-cost reductions—nearly twice as many—in lieu of paying the tax on those emissions. As a result of the unexpectedly low cost and the subsequent adjustment in emissions reductions, actual net benefits would be $280 million, which is $137 million greater than anticipated. Similarly, if costs were 50 percent higher than anticipated, firms would make fewer cuts in emissions—19 million mtc instead of 29 million mtc. The level of net benefits also would be lower than expected—but not as low as it would have been if firms had not had the flexibility to make fewer reductions and had been forced to make the full cut as was originally expected. Furthermore, given that reductions would be made up to the point at which the actual cost of the last reduction was equal to the expected benefit (because the tax had been set equal to that expected benefit), actual net benefits would be maximized, regardless of whether the costs were higher or lower than anticipated.

Suppose, in contrast, that policymakers set an emissions cap that they believed would reduce emissions by the same amount as the $10 tax—29 million metric tons of carbon. The cap would be met regardless of the cost. If the marginal cost of meeting that cap turned out to be 50 percent lower than expected, then actual net benefits, at

7. Martin L. Weitzman first showed that a government policy that set a price on pollution would lead to higher expected net benefits than a policy that limited the level of pollution. See Martin L. Weitzman, "Prices vs. Quantities," *Review of Economic Studies*, vol. 41, no. 4 (October 1974), pp. 477-491.

8. If this assumption did not hold, then the potential cost savings of an economic incentive policy would not be realized. For example, if firms chose to pay the tax rather than to undertake emissions reductions that could be made at a lower cost, firms' costs (including tax payments) would be higher—and emissions reductions would be lower—than estimated in this example. Likewise, if firms did not make potentially cost-saving allowance trades, then the cost of meeting an emissions cap would be higher than estimated.

**Table 5-1.**

## An Example of the Advantage of Using a Tax, Rather Than a Cap, to Reduce Carbon Emissions

| | | Actual Outcomes | |
|---|---|---|---|
| | Expected Outcomes | If the Cost of Reducing Emissions Was 50 Percent Lower Than Expected | If the Cost of Reducing Emissions Was 50 Percent Higher Than Expected |
| | | **Set a Tax of $10 per Ton of Carbon** | |
| Marginal Cost (Dollars) | 10 | 10[a] | 10[b] |
| Emissions Reduction (Millions of metric tons) | 29 | 56 | 19 |
| **Net Benefit (Millions of dollars)** | **143** | **280** | **96** |
| | | **Set a Cap to Reduce Carbon Emissions by 29 Million Metric Tons** | |
| Marginal Cost (Dollars) | 10 | 5 | 15 |
| Emissions Reduction (Millions of metric tons) | 29 | 29 | 29 |
| **Net Benefit (Millions of dollars)** | **143** | **215** | **72** |
| **Memorandum:** Percentage Increase in Net Benefit from a Tax Rather Than a Cap | n.a. | 30 | 34 |

Source: Congressional Budget Office.

Notes: This example arbitrarily assumes that the benefit of reducing carbon emissions is $10 per metric ton. It examines the net benefits that would result in the first year of each policy, assuming that the policy would apply only to the United States, that the initial year would be 2010, and that the policy would have been announced 10 years earlier. The cost of firms' emissions reductions (and the response to various taxes) is derived from Mark Lasky, *The Economic Costs of Reducing Emissions of Greenhouse Gases: A Survey of Economic Models,* CBO Technical Paper No. 2003-03 (May 2003), available at www.cbo.gov/Tech.cfm.

n.a. = not applicable.

a. The actual marginal cost of reducing 29 million metric tons (mmt) of carbon is $5, but the tax induces reductions up to 56 mmt, at a marginal cost of $10.

b. The actual marginal cost of reducing 29 mmt of carbon is $15, but the tax induces fewer reductions (19 mmt instead of 29 mmt), up to a marginal cost of $10.

$215 million, would be significantly greater than expected—but still lower than the $280 million in net benefits from the tax, which would induce firms to make additional beneficial emissions reductions (that is, reductions that would cost less than the benefits that they created). The cap, in contrast, would not induce firms to make any such adjustment.

Likewise, if the cost of meeting the cap was higher than anticipated, firms would still be required to reduce emissions by 29 million mtc, even though emissions reductions beyond 19 million mtc (the amount induced by a $10 tax) would cost more than the benefits that they created. As a consequence of that inflexibility, the net benefits from the cap would be 34 percent lower than the net benefits from the tax.[9]

An important assumption in this example is that the expected benefit of *each* emissions reduction is roughly constant—at about $10 per ton—across the range of possible emissions reductions in a given year. The fact that carbon dioxide is a stock pollutant, with damages determined by the total amount in the atmosphere, makes that assumption plausible. In the year in which this example is assumed to take place—2010—the policy-induced reductions in emissions constitute only 1 percent to 3 percent of total projected U.S. carbon dioxide emissions, which themselves will only amount to far less than 1 percent of the total stock of carbon dioxide in the atmosphere. Thus, the reductions would yield extremely small changes in the stock—a few hundredths of a percent at most. Over such a small range, the incremental benefit associated with each ton of reductions is expected to be roughly constant. That is not to say that the damages from a ton of emissions are zero, and it has nothing to do with the fact that the damages are very uncertain. The logic is simply that the incremental damage from each additional ton of emissions is essentially the same as the damage from each of the preceding tons in that year.[10]

The less information policymakers have about the cost of meeting a particular emissions cap, the greater the advantage offered by a price instrument. As discussed in Chapter 2, the cost of meeting a given cap is likely to be difficult to estimate for at least three reasons. First, the cost of meeting a future cap would vary significantly with the amount of growth in baseline carbon emissions. Those emissions are difficult to predict: they are a function of numerous factors, including population trends, economic growth, and energy prices. Second, policymakers have less information about the cost of reducing emissions than do the regulated firms. Third, the cost of meeting the future cap would depend on the technologies that were developed to reduce carbon dioxide emissions and the economic consequences of adopting those technologies—neither of which can be predicted with certainty.

**Are Price Instruments Still Preferred When the Potential for Abrupt Climate Change Is Taken into Account?** Intuitively, the case for emissions caps would appear to be much stronger if there were evidence that temperature increases above a certain threshold would cause catastrophic damages—especially given the inertia of the climate system and the long adjustment to changes in concentrations. (See Box 2-1 on page 10 for a discussion of the scientific understanding about the potential for catastrophic damages.) That possibility might seem to call for a cap on emissions to avoid crossing the threshold. Current research supports that intuition, but only under a very restrictive set of circumstances:[11]

- There must be a trigger temperature that, if exceeded, results in a steep increase in damages;
- Policymakers must have clear information about the location of the trigger temperature—for instance, if scientists uncovered evidence that an abrupt change that would be economically catastrophic would definitely occur at a temperature increase of 4.0° Celsius (C); and
- The threshold must be sufficiently near so that policymakers would want to virtually shut down emissions—regardless of the cost—to avoid, or delay, crossing it.

Under those circumstances, either a price instrument or an emissions cap (appropriately set) would probably yield very large benefits, but the expected benefits from using an emissions cap would be greater.

If there is uncertainty about either the existence or the level of a trigger temperature—as is currently the case—the potential advantages of emissions caps decline. Under those circumstances, it is no longer clear whether, or at what level, to set a cap to avoid a catastrophic outcome.

9. Those results are based on a very simplified example of a domestic emissions reduction policy in force for one year. In a more rigorous analysis that used the Dynamic Integrated model of Climate and the Economy and accounted for numerous sources of uncertainty, Resources for the Future researcher William Pizer found that a price instrument could generate expected net benefits that were up to five times as high as those resulting from a cap. See William A. Pizer, "Choosing Prices or Quantity Controls on Greenhouse Gases," in Michael A. Toman, ed., *Climate Change Economics and Policy: An RFF Anthology* (Washington, D.C.: Resources for the Future, 2001), pp. 99-107.

10. See Henry D. Jacoby and A. Denny Ellerman, *The Safety Valve and Climate Policy*, Report No. 83 (Cambridge, Mass.: MIT Joint Program on the Science and Policy of Global Change, July 2002).

11. See William A. Pizer, *Climate Change Catastrophes*, Discussion Paper 03-31 (Washington, D.C.: Resources for the Future, May 2003).

Thus, setting an upper limit on the incremental cost of reducing emissions via a price instrument (even though that limit may be high) becomes relatively more important.[12]

Similarly, price instruments are generally superior if damages are expected to grow large, but at a gradual rate of increase (rather than increasing very rapidly beyond a known temperature threshold). Under those circumstances, being able to control emissions precisely is less critical (because there is less concern about passing a trigger point).

Finally, price instruments are preferred if modest emissions reductions are called for. If policymakers wished to slow the growth of the existing stock (or stabilize it, but only after a period of several decades), then there would be considerable leeway as to how reductions could be allocated across time. Costs would be minimized by making cuts when it was least costly to do so. A price instrument would allow for such flexibility in timing, whereas short-term emissions caps would not. Such caps would become desirable only if extremely large cuts in current emissions were required to quickly stabilize the atmospheric stock in order to avoid crossing a threshold.[13]

In sum, price-based policy instruments appear to be superior to caps, at least for the present—when uncertainty about the potential for catastrophic effects is large, the temperature increase that could trigger catastrophic outcomes is unknown, and the emissions reductions being contemplated fall substantially short of a complete shutdown. However, the choice of instrument could be revisited as information and circumstances change. Policymakers could switch from a price instrument to an emissions cap if possible future damages became more imminent and certain or if the potential for catastrophic effects became clearer. A hybrid cap-and-trade program with a safety-valve price could be easily transformed into an emissions cap simply by eliminating the safety valve.

## The "Best" Emissions Price Is Unclear

If the expected marginal benefits of reducing emissions are greater than zero, the corresponding price on emissions will be greater than zero. A recent survey of the marginal benefits of reducing carbon emissions found 88 estimates in 22 studies, authored by 12 independent teams of researchers.[14] That survey found a wide range of estimates, with values very sensitive to the discount rate used in the analysis (lower rates led to higher marginal benefit values). The author concluded that "using standard assumptions about discounting and aggregation, the marginal cost of carbon dioxide emissions [that is, the marginal benefit of emissions reductions] is unlikely to exceed $50 per ton and is probably much smaller."[15] The Regional Dynamic Integrated model of Climate and the Economy (constructed by William Nordhaus and Joseph Boyer and described in this paper) estimates that the best price for a policy beginning in 2005 would be $12 per ton.[16]

The wide range of marginal benefit estimates (and thus recommendations about the best price) stems from the fact that determining the appropriate price requires long-term projections of uncertain economic and climate developments, valuation of uncertain impacts, and the balancing of competing interests and attitudes toward risks. Given that there is a wide range of valid opinions about those numerous factors, general agreement on a best price is highly unlikely.

Regardless of the level of stringency desired, costs could be moderated by phasing in prices gradually. A gradual phase-in would allow the economy to replace the existing capital stock at minimal cost to adjust to restrictions on fossil-fuel use. Prices could be increased over time as fu-

12. Furthermore, the uncertainty between carbon emissions and temperature change forces emissions caps to overcontrol emissions to make sure that the temperature threshold is not crossed. In that way, emissions caps become more like price instruments, which must overcontrol to account for the uncertainty in the relationship between increases in the price of carbon and the resulting reduction in carbon emissions. See Pizer, *Climate Change Catastrophes*.

13. For further discussion, see Pizer, "Choosing Prices or Quantity Controls on Greenhouse Gases."

14. Richard S.J. Tol, "The Marginal Costs of Carbon Dioxide Emissions" (presentation from an International Seminar on the Social Cost of Carbon sponsored by the U.K. Department for Environment, Food, and Rural Affairs, July 7, 2003, draft dated August 24, 2003), available at www.defra.gov.uk/environment/climate change/carbonseminar/tol.pdf

15. Ibid., abstract.

16. See William D. Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (Cambridge, Mass.: MIT Press, 2000), p. 133. Numbers have been updated from 1990 dollars to 2005 dollars using a GDP deflator.

ture damages became more certain or took on more weight (as they became more imminent) or if information revealed that damages were likely to be greater than anticipated. If damages were projected to become sufficiently serious and imminent, a hybrid cap-and-trade program with a safety-valve price could be converted to a fixed cap by eliminating the safety valve.

### The Most Efficient Policies Would Require International Coordination

Any effective mitigation policy would require international cooperation. Inexpensive opportunities to reduce emissions exist around the world, so costs would be minimized only if all countries imposed similar price-based emissions controls. The policy analyses discussed in this paper are based on the assumption that nations would cooperate to maximize global net benefits. However, some rapidly developing countries, such as China and India, may be reluctant to adopt lower-carbon technologies that could increase their cost of economic development, particularly in light of the fact that developed countries incurred no such penalty during the early phases of their industrialization. At the same time, developing countries will contribute a growing share of carbon emissions over time, and the infrastructure that they put in place today will affect carbon emissions for decades in the future. Finally, the requirements associated with enforcing a global solution might make some nations reluctant to participate and add a source of uncertainty about how effective and cost-effective the policies would be. (See Box 5-1 for a discussion of the current state of international coordination on climate policy.)

A further difficulty is that, as discussed in Box 5-1, international negotiations have focused on developing a set of national emissions allowance quotas or caps. Under that approach, nations might be able to minimize the cost of achieving the overall global emissions cap by trading allowances at the international level, but they would not necessarily do so at a marginal cost that was equal to the expected marginal benefit. That goal could be achieved by introducing a safety-valve price—set equal to the expected marginal benefit—that each country would agree to maintain by selling allowances at that price. Under a policy that incorporated an international safety valve, permits would be traded at the international level only if the market price was below the level of the safety valve.

Effectively implementing any international solution would require a means of monitoring emissions and ensuring enforcement. Monitoring would be easier if policies were limited to emissions of carbon dioxide from fossil fuels: nearly all fossil fuels are traded in commercial markets; information on countries' fuel consumption is readily available; and the carbon content of different fuels is well understood.[17] Significantly greater challenges arise in monitoring carbon emissions from (as well as uptake in to) forests and soils and in monitoring flows of other greenhouse gases from almost all sources.[18]

Even with a monitoring system in place, enforcing emissions restrictions would present a series of challenges. International environmental laws might be enforced through dispute resolution, unilateral actions such as economic sanctions, and the use of nongovernmental organizations, such as environmental groups.[19] Advocates of an international cap-and-trade program for carbon dioxide emissions have also considered the possibility that international enforcement could be achieved by making either the seller or the buyer of allowances liable for the allowances' integrity. A complete discussion of the pros and cons, and likely effectiveness, of those various approaches is beyond the scope of this paper; however, the ability to enforce such a global system of economic incentives to reduce greenhouse gases remains an important aspect of the problem—and an important source of uncertainty about costs.[20]

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17. See David G. Victor, *The Collapse of the Kyoto Protocol and the Struggle to Slow Global Warming* (Princeton, N.J.: Princeton University Press, 2001), pp. 56-57. Victor notes that some on-site inspection could be needed for countries, such as Russia, that have poor fossil-fuel accounting systems and that consume a large percentage of the fossil fuels they produce.

18. Ibid., p. 59.

19. For example, environmental groups have played prominent roles in enforcing international agreements to protect wildlife, such as panda bears, elephants, and tigers. Ibid., p. 66.

20. Ibid., pp. 63-74.

**Box 5-1.**

## International Cooperation on Climate Policy

International cooperation to address the prospect of climate change began with the creation of the Intergovernmental Panel on Climate Change in 1988. Four years later, most of the world's nations signed the United Nations Framework Convention on Climate Change, committing to undertake extensive research to better understand the climate system and, ultimately, to stabilize atmospheric concentrations of greenhouse gases at levels that would prevent dangerous climate change.

In 1997, following several years of negotiations, participating countries adopted the Kyoto Protocol to the convention. The Kyoto Protocol limits greenhouse gas emissions from 38 developed countries to generally somewhat below their 1990 levels but exempts developing countries from restrictions altogether. The restrictions are scheduled to take effect during the so-called First Budget Period, from 2008 to 2012, with no restrictions specified after that period. Ratification by Russia in late 2004 allowed the Kyoto Protocol to be officially accepted by enough countries to come into force in early 2005.

Countries that have accepted restrictions on emissions under the protocol will probably be able to meet their commitments at little cost. They are allowed a significant degree of flexibility, including the right to trade allowances to emit greenhouse gases, the option to receive some credit for carbon sequestered in growing forests, and the option to receive credits by financing projects to reduce emissions in countries that are not subject to emissions limits. Moreover, a few countries—notably Russia and the Ukraine—are expected to have substantial amounts of surplus emissions allowances during the 2008-2012 period. Other countries will be able to fulfill their commitments in part by buying surplus allowances and forestry credits at relatively low cost and thus will not have to undertake extensive emissions reductions domestically.

Although countries' costs of meeting their commitments are expected to be relatively low, experts generally agree that the cost of reducing emissions will probably vary considerably among countries, despite the option of trading allowances at the international level. Moreover, the actions taken by countries with commitments will be more than offset by the growth of emissions elsewhere and therefore will do little to moderate the growth in global emissions.

Even if fully implemented, the Kyoto Protocol is expected to have only a small impact on temperature increases. One research team projects that permanently complying with the emissions limits outlined in the protocol would reduce the 2.53° Celsius (C) increase in the average global temperature that is predicted to occur over the next century in the absence of policy initiatives by 0.03°C to 0.04°C.[1]

Having effectively withdrawn from negotiations in 2001, the United States has not undertaken any commitments under the Kyoto Protocol. The next round of international negotiations, over what steps to take after 2012, will begin later this year.

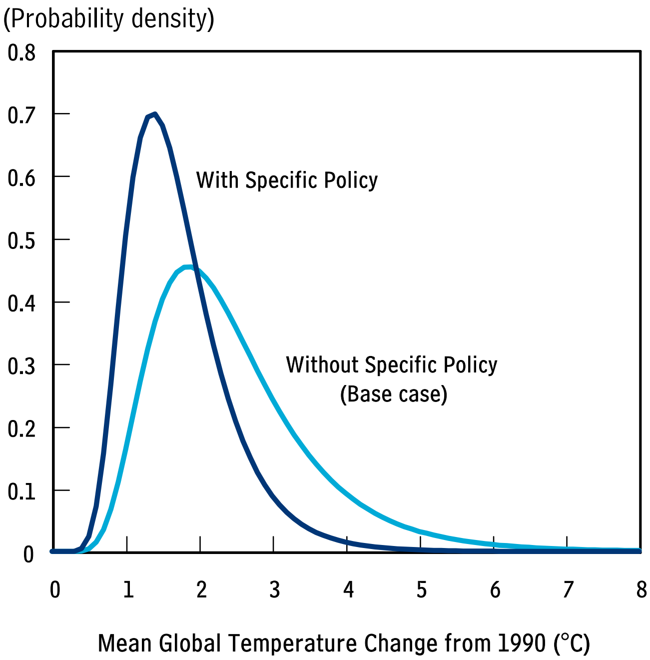
1. See William D. Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (Cambridge, Mass.: MIT Press, 2000), p. 153.

### Information on Underlying Uncertainties, Nonmarket Benefits, and Distributional Effects Could Highlight Policy Trade-offs

While policymakers may derive important insights from assessments that attach monetary values to expected benefits and that aggregate the expected costs and benefits of mitigation policies, they may also profit from supplemental information that reveals the underlying uncertainties, reports key nonmarket benefits in natural units (such as the number of species lost), and reveals distributional effects.

**Figure 5-1.**

## Projected Change in Temperature in 2100 from a Specific Policy




Source: Congressional Budget Office adapted from Figure 1(B) in Mort Webster and others, "Uncertainty Analysis of Climate Change and Policy Response," *Climatic Change,* vol. 61, no. 3 (December 2003), p. 310.

Note: The specific policy illustrated in this figure is to stabilize carbon dioxide concentrations in the atmosphere at 550 parts per million.

**Revealing Information About the Uncertainty of Policy Effects.** Policy recommendations that take the form of point estimates can be useful, but they mask the enormous uncertainty underlying such estimates as well as the trade-off between higher current costs and greater protection from the risks of future damages. Although some studies have demonstrated how changes in a small subset of uncertain parameters can affect policy outcomes, no existing model is capable of simultaneously addressing all of the relevant uncertainties. Explicitly revealing uncertainty about costs and benefits could provide a more meaningful range of potential policy options and a better understanding of the probability that a given policy would actually balance future benefits and current costs.[21] Policymakers may be able to make more-informed decisions about how to insure against those risks if they have a sense of the full range of potential risks rather than certainty-equivalent point estimates based on that range.

One way of conveying uncertainty about the effects of a given policy is to present graphs that illustrate the likelihood of different outcomes, or tables that report several different points in the distribution of outcomes. Figure 5-1, adapted from a policy analysis from the Massachusetts Institute of Technology, illustrates how a specific policy might affect the average global temperature, taking into account uncertainty about future emissions, their rate of accumulation in the atmosphere, and the response of the climate.

The figure shows two distributions of temperature increases in 2100: one represents a "base" case; the other a policy designed to stabilize carbon dioxide concentrations in the atmosphere at 550 parts per million.[22] (The higher the curve is above a particular temperature increase, the more likely that increase is to occur.) In the base case, the expected mean temperature increase in 2100 is 2.4°C, but there is a 1-in-40 chance (5 percent) that the increase will exceed 4.9°C. Under the specific policy, the expected increase is 1.7°C, which is 0.7°C less than in the base case, and there is an exceedingly small chance that the increase will exceed 4.9°C. However, there is still a 1-in-7 chance (about 14 percent) that the temperature increase would exceed 2.4°C (the mean increase predicted in the

21. Similar recommendations are made by S.H. Schneider, K. Kuntz-Duriseti, and C. Azar in "Costing Non-Linearities, Surprises, and Irreversible Events," *Pacific and Asian Journal of Energy,* vol. 10, no. 1 (June 2000), pp. 81-106; and by Henry D. Jacoby, "Informing Climate Policy Given Incommensurable Benefits Estimates," *Global Environmental Change: Human and Policy Dimensions,* vol. 14, no. 3 (October 2004), pp. 287-297. Simultaneously accounting for all of the uncertainties involved in calculating the costs and benefits of climate change policies would be intractable. Nevertheless, analysts could focus on developing probability distributions for key parameters and on revealing the uncertainty about which policy that results from those underlying distributions would be best.

22. See Figure 1(B) in Mort Webster and others, "Uncertainty Analysis of Climate Change and Policy Response," *Climatic Change*, vol. 61, no. 3 (December 2003), p. 310.

base case) and a 1-in-40 chance that it would be greater than 3.2°C.[23]

Those distributions do not imply that there is a chance that the policy would not restrain the temperature increase at all; rather, they imply that the exact outcome cannot be predicted in either case. The lesson for policymakers is that policies are more accurately viewed as changing the distribution of potential future temperatures rather than as achieving specific targets.

Another method of revealing the uncertainty associated with alternative policies is to provide several point estimates that correspond to outcomes that have different likelihoods of occurring. A demonstration of that technique is provided by Stanford University researchers Tim Roughgarden and Stephen Schneider, drawing on a survey by William Nordhaus (discussed in Chapter 3). That survey revealed widely divergent views about the potential damages—and the value of those damages—that would result from a 3°C or 6°C temperature increase in 2095. Roughgarden and Schneider carried out a Monte Carlo analysis (see Chapter 2 for a description of that technique) to determine the range of possible "best" prices. In that analysis, each of 1,000 runs of the simulation model selected random damages from the probability distribution of potential damages based on the full set of experts' estimates in Nordhaus's survey.[24]

Roughgarden and Schneider estimated that the mean "best" price (which would balance benefits and costs) would be $53 per ton of carbon in 1995 and $145 in 2105. At the same time, there is the possibility that damages could be very large and that the true optimal price could be very high: the researchers calculated a 5 percent chance that the optimal price could be at least as high as $255 per ton of carbon in 1995 and $683 in 2105.

The probabilities and damage estimates underlying that analysis are based on experts' best guesses and should not be considered scientifically determined. Despite those limitations, the analysis offers a valuable lesson: recommended emissions prices can vary depending on policymakers' aversion to the risks from climate change.[25] If risk-averse policymakers wanted to choose a policy that would be optimal if experts predicting large damages were correct, then they should set a very high emissions price—and accept the cost that such a high price would impose on economic growth.

Although characterizing the uncertainty associated with policy outcomes can be useful, such attempts can create a false sense of precision. Analysts should be careful to acknowledge the lingering uncertainties that cannot be meaningfully quantified in their analyses.

**Revealing Information About Nonmarket Benefits.** As discussed in Chapter 3, there is no clear-cut method for attaching monetary values to many of the nonmarket damages that would result from climate change. Policymakers could therefore profit from additional information on the benefits derived from nonmarketed goods and services that underlie policy recommendations.[26] For example, policy outcomes could include predictions of reductions in the number of species lost, premature deaths avoided, or land area lost because of a rise in sea level and could indicate the values that were used for them in the analysis. That approach would allow policymakers to determine whether the weights used in the

23. Matters get even more complicated when all greenhouse gases are included in the analysis, because of uncertainties about how powerful their greenhouse effects are and how long they stay in the atmosphere. See Marcus C. Sarofim and others, *Stabilization and Global Climate Policy,* Report No. 110 (Cambridge, Mass.: MIT, July 2004).

24. See Tim Roughgarden and Stephen H. Schneider, "Climate Change Policy: Quantifying Uncertainties for Damages and Optimal Carbon Taxes," *Energy Policy,* vol. 27, no. 7 (July 1999), pp. 415-429. Numbers are in current dollars. Also note that this study examined uncertainty only in damages, using best estimates for all of the other inputs to the analysis, such as mitigation costs, the degree of climate change, and the discount rate.

25. William Nordhaus used the experts' responses to develop a set of certainty-equivalent damages (see Chapter 3). Using that certainty-equivalent damage function in a climate policy model, Nordhaus estimated that costs and benefits would be best balanced by a carbon tax that started at $8 per ton in 1995 and rose to $89 per ton in 2105 (numbers are in current dollars). While that expected-value method of determining damages provides some insights into a price that might result in a balancing of benefits and costs, it conceals the considerable amount of uncertainty about which price would actually accomplish that goal. That is, it does not reveal the probability that the actual best price could prove to be higher or lower; nor does it calculate the price that would balance uncertain costs and benefits if people were more averse to risk.

26. Ideally, the probability distributions underlying such predictions could be reported as well. For a more detailed discussion of this recommendation and others discussed in this section, see Jacoby, "Informing Climate Policy Given Incommensurable Benefits Estimates."

analysis were consistent with their own or their constituents' preferences.

**Revealing Information About Distributional Effects.** Since the costs and benefits of climate policies are not expected to be evenly distributed across the globe, information on the regional distribution of costs and benefits associated with alternative policies could help policymakers understand the strength of other countries' and regions' interests in international negotiations. To the extent that nonmarketed goods are a key component of the benefits of a given policy, reporting those nonmarket benefits on a regional basis could be helpful. Given the current level of knowledge, however, predictions of outcomes at the regional level are likely to be particularly speculative.

## Adaptation

The world is committed to some degree of warming from emissions that have already occurred, and even very aggressive emissions restrictions are unlikely to halt the growth of concentrations for many years to come.[27] In light of the potential for future temperature increases, adaptation could play an important role in any effective climate strategy.

Unlike mitigation policy, which could be implemented largely with a single instrument—for instance, a single emissions price, or an aggregate emissions cap—policies to promote adaptation are likely to be more diffuse, involving numerous policies in many different areas and involving different levels of government. Potential adaptations could be facilitated through various policies, including: [28]

- Promoting the efficient use of water resources (which would become scarcer in a warmer world) through prices that reflect scarcity or the establishment of markets for water;
- Encouraging the development of low-cost technologies for desalinating seawater;
- Instituting vaccination programs to prevent the spread of diseases transmitted by arthropods, such as ticks or mosquitos;
- Encouraging the preservation of green corridors that would allow plant and animal species to migrate as their habitat changed;
- Developing early-warning systems to alert people to potential flooding, developing more appropriate building standards and design codes for buildings in flood-prone areas, and facilitating the relocation of people living in low-lying areas in counties prone to increased flooding; and
- Encouraging the development and use of drought-resistant crops.[29]

Local, state, and federal governments could be involved in such efforts. For example, local governments could institute early-warning systems, enact building codes, or restrict development in flood-prone areas. The federal government could fund research, develop education programs, and subsidize immunization programs. International organizations could also play an important role in adaptation efforts, as when the World Bank established a Disaster Management Facility in 1998 to facilitate a more strategic response to disaster emergencies and to integrate policies to reduce the risk of disasters into development activities.[30] As the above list illustrates, many policies that could facilitate adaptation to a changing climate are likely to yield benefits even if climate change proves to be relatively benign.

27. For example, William Nordhaus and Joseph Boyer provide a best-guess projection that limiting global carbon dioxide emissions to 1990 levels would reduce the expected temperature increase in 2100 from 2.53°C to 2.02°C. See Nordhaus and Boyer, *Warming the World*, p. 141. Researchers at MIT projected that a policy designed to stabilize carbon concentrations in the atmosphere at 550 parts per million would reduce the expected average global temperature increase from 2.4°C to 1.7°C. See Webster and others, "Uncertainty Analysis of Climate Change and Policy Response."

28. See Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (Cambridge, England: Cambridge University Press, 2001), p. 88.

29. Ibid., pp. 885-886.

30. See Ajay Mathur, Ian Burton, and Maarten van Aalst, eds., *An Adaptation Mosaic: A Sample of the Emerging World Bank Work in Climate Change Adaptation* (Washington, D.C.: World Bank Global Climate Change Team, February 2004).