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The Economics of Climate Change: A Primer

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Note

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Preface

A scientific consensus is emerging that rising atmospheric concentrations of greenhouse gases are gradually changing the Earth's climate, although the magnitude, timing, and effects of the alteration remain very uncertain. The prospect of long-term climate change raises a variety of domestic and international economic policy issues on which there is little accord. Considerable disagreement exists about whether to control greenhouse gas emissions, and if so, how and by how much; and whether to coordinate climate-related polices at the international level, and if so, through what mechanisms.

This Congressional Budget Office (CBO) study—prepared at the request of the Ranking Member of the House Committee on Science—presents an overview of issues related to climate change, focusing primarily on its economic aspects. The study draws from numerous published sources to summarize the current state of climate science and provide a conceptual framework for addressing climate change as an economic problem. It also examines public policy options and discusses the potential complications and benefits of international coordination. In keeping with CBO's mandate to provide impartial analysis, the study makes no recommendations.

Robert Shackleton of CBO's Macroeconomic Analysis Division wrote the study. CBO staff members Robert Dennis, Terry Dinan, Douglas Hamilton, Roger Hitchner, Arlene Holen, Kim Kowalewski, Mark Lasky, Deborah Lucas, David Moore, John Sturrock, Natalie Tawil, and Thomas Woodward provided valuable comments and assistance, as did Henry Jacoby of the Massachusetts Institute of Technology and Thomas Schelling of the University of Maryland at College Park. The comments of Chris Webster and John Reilly of the Massachusetts Institute of Technology and Mort Webster of the University of North Carolina at Chapel Hill were particularly helpful in developing the discussion of uncertainty.

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Douglas Holtz-Eakin
Director

April 2003

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1

Summary and Introduction

Human activities—mainly deforestation and the burning of fossil fuels—are releasing large quantities of what are commonly known as greenhouse gases. The accumulation of those gases is changing the composition of the atmosphere and is probably contributing to a gradual warming of the Earth's climate—the characteristic weather conditions that prevail in various regions of the world. Scientists generally agree that continued population growth and economic development over the next century will result in substantially more greenhouse gas emissions and further warming unless measures are taken to constrain those emissions.

Despite the general consensus that some amount of warming is highly likely, extensive scientific and economic uncertainty makes predicting and evaluating its effects extremely difficult. Because climate is generally a regional phenomenon, the effects of warming would vary by region. Moreover, some effects could be positive and some negative. Some could be relatively minor and some severe in their impact: warming could raise sea levels; expand the potential range of tropical diseases; disrupt agriculture, forestry, and natural ecosystems; and increase the variability and extremes of regional weather. There is also some possibility of unexpected, abrupt shifts in climate. Actual outcomes will probably be somewhere in the middle of the range of possibilities, but the longer that emissions grow unchecked, the larger the effects are likely to be.

A variety of technological options are available to restrain the growth of emissions, including improvements in the efficiency of people's use of fossil energy, alternative energy technologies such as nuclear or renewable power, methods for removing greenhouse gases from smokestacks, and approaches to sequestering gases in forests, soils, and oceans. But those alternatives are likely to be costly, and they are unlikely to be widely implemented unless measures are taken to lower their price or to raise the price of greenhouse gas emissions.

This Congressional Budget Office (CBO) study presents an overview of the issue of climate change, focusing primarily on its economic aspects. The study draws from many published sources to summarize the current state of climate science. It also provides a conceptual framework for considering climate change as an economic problem, examines public policies and the trade-offs among them, and discusses the potential complications and benefits of international coordination.

Common Resources: Addressing a Market Failure

The Earth's atmosphere is a global, open-access resource that no one owns, that everyone depends on, and that absorbs emissions from an enormous variety of natural and human activities. As such, it is vulnerable to overuse, and the climate is vulnerable to degradation—a problem known as the tragedy of the commons. The atmosphere's global nature makes it very difficult for communities and nations to agree on and enforce individual rights to and responsibilities for its use.

With rights and responsibilities difficult to delineate and agreements a challenge to reach, markets may not develop to allocate atmospheric resources effectively. It may therefore fall to governments to develop alternative policies for addressing the risks from climate change. And because the causes and consequences of such change are global, effective policies will probably require extensive cooperation among countries with very different circumstances and interests.

However, governments may also fail to allocate resources effectively, and international cooperation will be extremely hard to achieve as well. Developed countries, which are responsible for the overwhelming bulk of emissions, will be reluctant to take on increasingly expensive unilateral commitments while there are inexpensive opportunities to constrain emissions in developing countries. But developing nations, which are expected to be the chief source of emissions growth in the future, will also be reluctant to adopt policies that constrain emissions and thereby limit their potential for economic growth—particularly when they have contributed so little to the historical rise in atmospheric greenhouse gas concentrations and may suffer disproportionately more of the negative effects if nothing is done.

Balancing Competing Uses

The atmosphere and climate are part of the stock of natural resources available to people to satisfy their needs and wants over time. From an economic point of view, climate policy involves measuring and comparing the values that people place on resources, across alternative uses and at different points in time, and applying the results to choose a course of action. An effective policy would balance the benefits and costs of using the atmosphere and distribute those benefits and costs among people in an acceptable way.

Uncertainty about the scientific aspects of climate change and about its potential effects complicates the challenge of developing policy by making it difficult to estimate or balance the costs of restricting greenhouse gas emissions and the benefits of averting climate change. (Some of the risks involved, moreover, may be effectively impossible to evaluate or balance in pecuniary terms.) Nevertheless, assessments of the potential costs and benefits of a warming climate typically conclude that the continued growth of emissions could ultimately cause extensive physical and economic damage. Many studies indicate significant benefits from undertaking research to better understand the processes and economic effects of climate change and to discover and develop new and better technologies to reduce or eliminate greenhouse gas emissions.

At the same time, such studies typically find relatively small net benefits from acting to reduce greenhouse gas emissions in the near term. In balancing alternative investments, they conclude that if modest restrictions on emissions were implemented today, they would yield net benefits in the future; however, more-extensive restrictions would crowd out other types of investment, reducing the rate of economic growth and affecting current and future generations' material prosperity even more than the averted change would. As income and wealth grow and technology improves, the studies say, future generations are likely to find it easier to adapt to the effects of a changing climate and to gradually impose increasingly strict restraints on emissions to avoid further alteration.

Those conclusions greatly depend, among other things, on how one balances the welfare of current generations against that of future generations. In assessments of costs and benefits occurring at different points in time, that process of weighting is typically achieved by using an interest, or discount, rate to convert future values to present ones. But there is little agreement about how to discount costs and benefits over the long time horizons involved in analyzing climate change.

Whatever weighting scheme is chosen, consistency calls for applying it to all long-term investment alternatives. For example, applying a lower discount rate to give more weight to the welfare of future generations implies that society should reduce its current consumption and increase its overall rate of investment in productive physical and human capital of all kinds—not only those involved in ensuring a beneficial future climate.

Government policies that deal with use of the atmosphere inevitably affect the distribution of resources. Inaction benefits people who are alive today while potentially harming future generations. Reducing emissions now may benefit future generations while imposing costs on the current population and may benefit countries at relatively higher risk of adverse effects from warming while hurting those that stand to gain from it. Restraints on emissions would impose costs on nearly everyone in the global economy, but they would affect energy-producing and energy-intensive industries, regions, and countries much more than they would others. However, many studies of the costs and benefits of climate change fail to highlight the extent to which differences in geographic and economic circumstances complicate the balancing of interests.

Policy Options

Governments may respond to climate change by adopting a "wait-and-see" approach, by pursuing research programs to improve scientific knowledge and develop technological options, by regulating greenhouse gas emissions, or by engaging in a combination of research and regulation. The United States has invested in research and subsidized the development of carbon-removal and alternative energy technologies. Furthermore, some programs that were intended to achieve other goals, such as pollution reduction, energy independence, and the limitation of soil erosion, also discourage emissions or encourage the removal of greenhouse gases from the atmosphere. However, other programs have opposing effects.

Should a government decide to control emissions, it may choose from a broad menu of regulatory approaches. One option is direct controls, which set emissions standards for equipment and processes, require households and businesses to use specific types of equipment, or prohibit them from using others. A government could also adopt more indirect, incentive-based approaches, either singly or in combination—for example, by restricting overall quantities of emissions through a system of permits or by raising the price of emissions through fees or taxes. Incentive-based approaches are generally more cost-effective than direct controls as a means of regulating greenhouse gas emissions.

Uncertainty about the costs and benefits of regulation affects the relative advantages of different incentive-based approaches. Some research indicates that such uncertainty gives a system of emissions pricing economic advantages over a quota system that fixes the quantity of emissions. Those advantages stem from two facts: both the costs and benefits of reducing greenhouse gas emissions are uncertain; and the incremental costs—the additional costs of reducing an additional ton of emissions—can be expected to rise much faster than the incremental benefits fall. Under those circumstances, the cost of guessing wrong about the appropriate level of taxes—and, perhaps, of failing to reduce emissions enough in any given year—is likely to be fairly low. But the cost of miscalculating the appropriate level of emissions—and perhaps imposing an overly restrictive and hence expensive limit—could be quite high.

A system of emissions pricing has several other advantages over one of emissions quotas. Pricing could raise significant revenues that could be used to finance cuts in distortionary taxes—such as those on income—that discourage work and investment. Moreover, emissions pricing more effectively encourages the development of technologies that reduce or eliminate emissions than direct controls or strict limits on emissions do.

Restricting greenhouse gas emissions would tend to reduce emissions of some conventional pollutants as well, yielding a variety of ancillary benefits, such as improvements in health from better-quality air and water. Those additional benefits would partly offset the costs of greenhouse gas regulations, particularly in developing countries that have significant problems with local pollution.

The distributional effects of emissions regulations would depend on the type and stringency of the regulations and could be very large relative to how much the policy improved people's well-being. Those potential effects might spur the affected parties to engage in rent-seeking—vying for regulatory provisions that would provide them with tax exemptions, access to permits, and so on. An emissions pricing system (based either on taxes or on auctioned permits) would benefit different groups in different ways, depending on how the government returned the receipts to the economy. Certain ways of using the revenues could offset some—but probably not all—of the costs of regulation. (For example, if the government issued permits free of charge, even permit recipients who were heavily regulated could benefit from the regulation.)

International Coordination

Because the causes and consequences of climate change are global in nature, effective policies to deal with it will probably require extensive international coordination among countries with very different circumstances and interests. Coordination may involve formal treaties or nonbinding agreements and could range from modest commitments to engage in research to more-extensive programs to restrict emissions, monitor compliance, and enforce penalties.

Effective international agreements typically involve straightforward commitments and distribute costs in a way that is acceptable to participating countries. Binding commitments with explicit penalties may be more likely than nonbinding ones to ensure compliance, but nonbinding agreements may also significantly affect a nation's actions. Many factors will influence the effectiveness of international cooperation, particularly the size and distribution of the costs and benefits of mitigating climate change and the strength of conflicting interests. Successful cooperation would entail frequent interaction among national representatives and link discussion of climate issues with that of related problems.

An international system of emissions controls could draw on the same set of options that domestic regulation employs—direct controls, emissions taxes or permits, or a hybrid system—or it could allow each country to choose its own independent system. Much of the international debate in recent years has focused on strictly limiting emissions through national quotas, with or without the international trading of emissions rights. However, quantitative limits are likely to prove more costly than approaches that affect emissions indirectly by raising their price. And because there are low-cost opportunities to reduce emissions throughout the world and because fossil fuels can be transported relatively easily, a system that raised the price of emissions everywhere would probably be more cost-effective than one that applied only to a limited set of countries.

International cooperation on the issue of climate change has been developing since the Intergovernmental Panel on Climate Change was created in 1988. And nearly all nations, including the United States, are signatories to the United Nations Framework Convention on Climate Change, which commits them to undertake research and prevent dangerous changes in the Earth's climate. In 1997, negotiators signed the Kyoto Protocol (a draft treaty) to the convention, under which developed countries agreed to limit emissions while developing countries remained exempt from restrictions. However, subsequent negotiations collapsed in 2000 over details of implementation, and the United States withdrew from the talks in 2001. Ironically, that withdrawal made some of the positions that the United States had advocated much more attractive to the remaining parties and helped them reach agreement on nearly all outstanding implementation issues. The European Union and Japan ratified the protocol in mid-2002; it will go into force if Russia follows suit.

The protocol's implementation would establish a complex set of emissions rights for a limited set of developed countries for the period 2008 through 2012. It would also put into place institutions to oversee international financial transfers amounting to several billion dollars per year for the purchase of emissions allowances, mainly among the developed countries. However, the protocol would limit participating countries' overall emissions by only a small amount and would have essentially no effect on the growth of emissions in the United States and in developing countries.

Analysts have proposed a variety of alternatives to the provisions of the Kyoto Protocol to try to improve the potential effectiveness of international cooperation and broaden its appeal. Each alternative simultaneously addresses the problems of limiting emissions and distributing the burden of regulation, which remain the crucial sources of disagreement. Each option reflects a distinct interpretation of the available evidence about the net benefits of averting climate change in different regions and for different generations, as well as practical concerns about how climate policy would affect the global economy.

Some analysts argue for a laissez-faire approach because they believe that the amount of warming is likely to be small and its effects largely benign, or that near-term action is unwarranted in the light of scientific uncertainty. Other researchers have proposed systems of emissions taxes or tradable emissions permits that would be auctioned at fixed prices. In general, the permits would apply to developed countries and exempt developing nations on the grounds of equity. Still other analysts have proposed complex systems that are intended to impose roughly uniform emissions prices throughout the world yet ensure that developed countries bear most of the cost.

CHAPTER

2

The Scientific and Historical Context

Scientists have gradually realized that a variety of human activities are changing the composition of the atmosphere and may significantly affect the global climate.[1] During the past decade, scientific research has greatly improved the state of knowledge about climate change, but substantial uncertainty about critical aspects of climate science remains and will persist in spite of continued progress. That uncertainty contributes to differences of opinion within the scientific community about the potential for significant climate change and about its possible effects.

The Greenhouse Effect, the Carbon Cycle, and the Global Climate

As the Earth absorbs shortwave radiation from the Sun and sends it back into space as longwave radiation, naturally occurring gases in the atmosphere absorb some of the outgoing energy and radiate it back toward the surface (*see Figure 1*). That phenomenon, which is called the "greenhouse" effect, currently warms the surface by an average of about 60º Fahrenheit (F), or 33º Celsius (C), creating the conditions for life as it exists on Earth. Water vapor is by far the most abundant greenhouse gas and accounts for most of the warming effect. However, several other trace gases also play a pivotal role in maintaining the current climate because they not only act as greenhouse gases themselves but also enhance the amount of water vapor in the atmosphere and thus amplify the effect. Those trace gases include carbon dioxide, methane (which also contains carbon), and nitrous oxide, as well as the man-made halocarbons, which contribute to the breakdown of stratospheric ozone and which, molecule for molecule, are very powerful greenhouse gases.[2]

The geologic record reveals dramatic fluctuations in greenhouse gas concentrations and in the Earth's climate, on scales as long as millions of years and as short as just a few years. The record suggests a complicated relationship between greenhouse gas concentrations and the Earth's climate. Warmer climates have usually been associated with higher atmospheric concentrations of greenhouse gases and cooler climates with lower concentrations. (*Figure 2* illustrates how carbon dioxide concentrations and the antarctic climate have varied together over roughly the past half-million years.) However, the climate has oc-

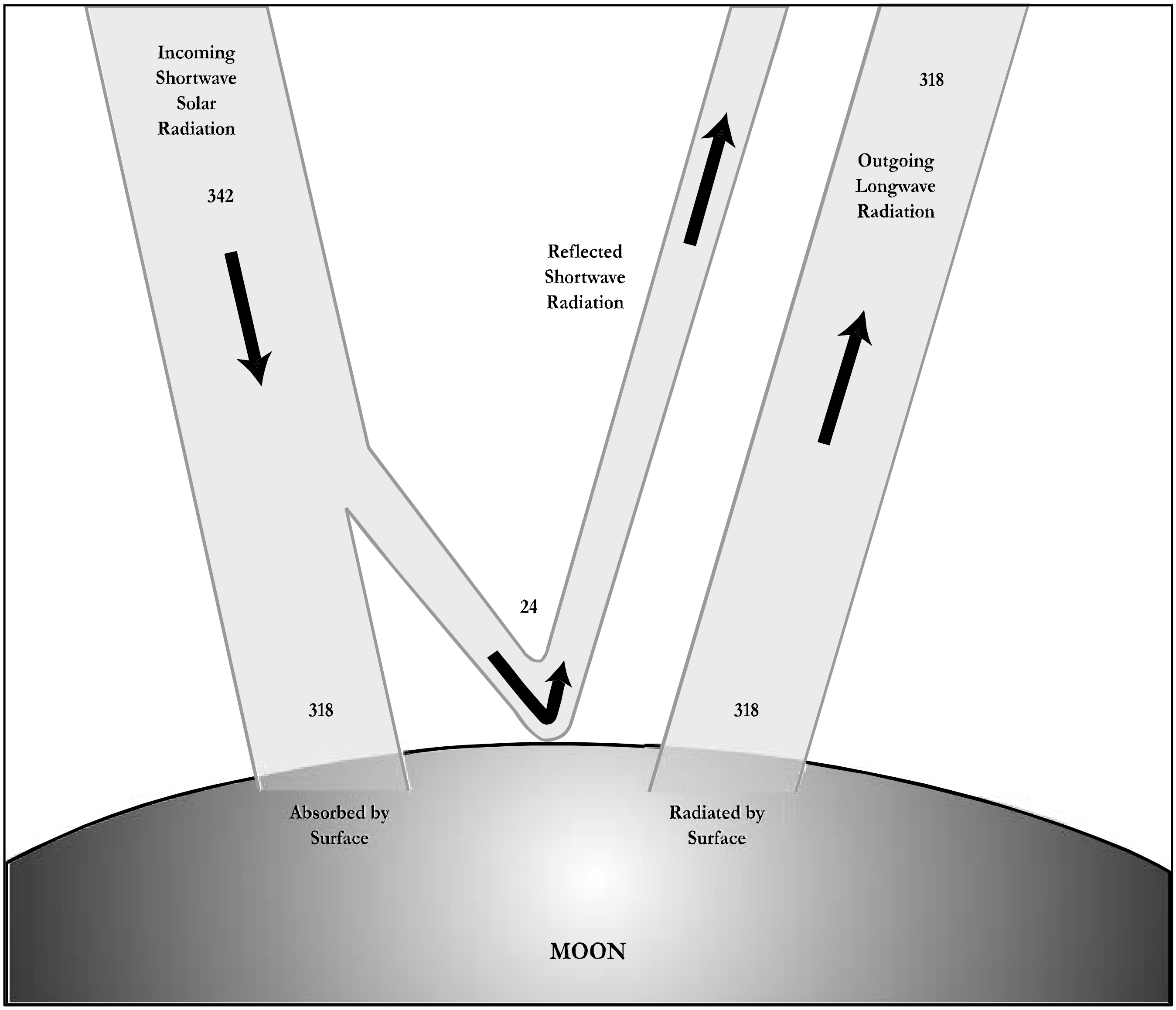
1. The discussion in this chapter is drawn mainly from a series of reports prepared by the Intergovernmental Panel on Climate Change, which summarize the current state of scientific and technical knowledge in that area. The most recent set of reports, which are cited in detail in the reference list beginning on page 57, are Houghton and others (2001); McCarthy and others (2001); Metz and others (2001); and Watson and others (2001). Other sources are specifically noted. The Congressional Research Service (2001) provides another summary. For a short history of scientific research on climate change, see Weart (1997).

2. Greenhouse gases differ in their ability to trap energy; they interact with each other, and they stay in the atmosphere for different and varying lengths of time. By convention, scientists apply a standard metric to the gases by comparing their 100-year global warming potentials, or GWPs (the amount of warming that an incremental quantity of a given gas would cause over the course of a century), with that of carbon dioxide. The convention is somewhat rough because the GWP of each gas is affected by the quantity of other gases, but it is used in international negotiations because of its simplicity. GWPs range from 1 for carbon dioxide to many thousands for halocarbons. Using 100-year GWPs, scientists convert quantities of other greenhouse gases to metric tons of carbon equivalent, or mtce.

Figure 1.

The Atmospheric Energy Budget and the Greenhouse Effect

Without Greenhouse Effect

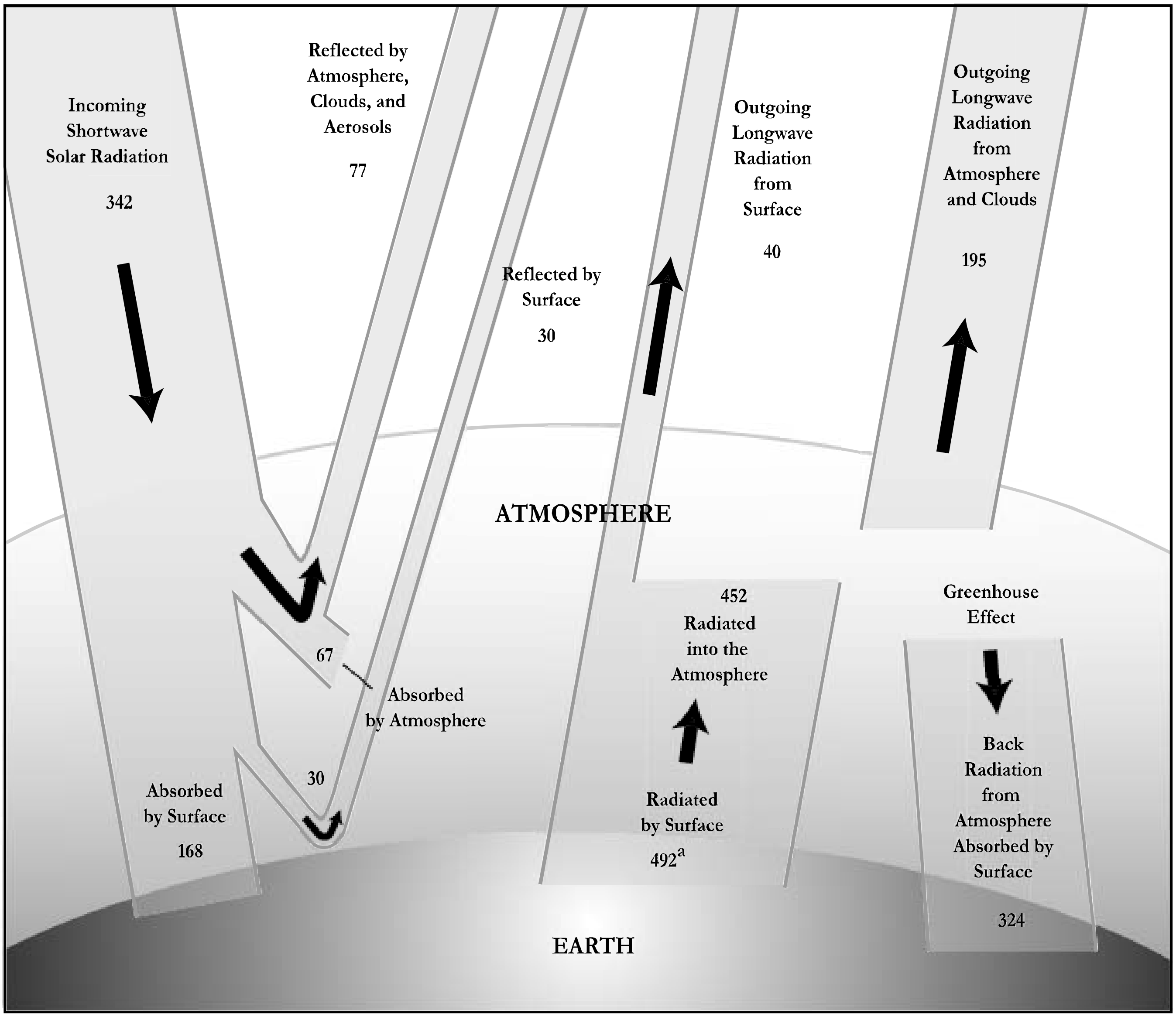


Source: Congressional Budget Office adapted from J.T. Houghton and others, eds., *Climate Change 2001: The Scientific Basis* (Cambridge, U.K.: Cambridge University Press, 2001).

Figure 1.

Continued

With Greenhouse Effect

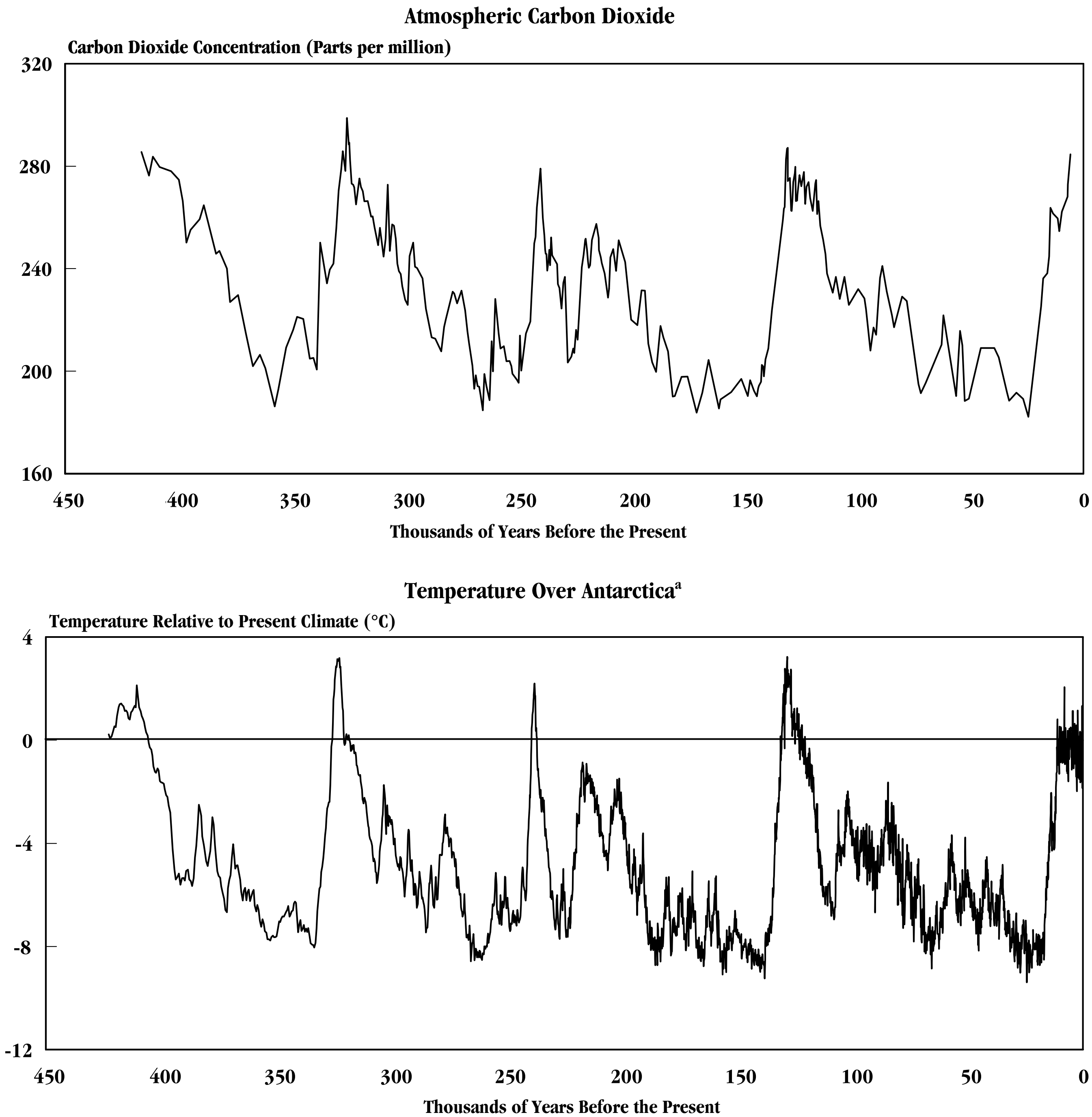


Note: Numbers represent watts per meter squared (W/m^2). With an atmosphere, 492 W/m^2 (instead of 318 W/m^2) reach the Earth's surface because the atmosphere absorbs radiation from the Earth and radiates it back. That process constitutes the greenhouse effect.

a. Includes thermals and evapotranspiration.

Figure 2.

Carbon Dioxide and Temperature



Source: Congressional Budget Office based on J. M. Barnola, C. Lorius Raynaud, and N.I. Barkov, "Historical CO_2 Record from the Vostok Ice Core," and J.R. Petit and others, "Historical Isotopic Temperature Record from the Vostok Ice Core," in Department of Energy, Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center, *Trends: A Compendium of Data on Global Change* (2003), available at http://cdiac.esd.ornl.gov/trends/trends.htm.

a. Variations in antarctic temperatures are roughly double average global variations.

casionally been relatively warm while concentrations were relatively low and cool while they were high. Moreover, climate change has occurred without alterations in greenhouse gas concentrations. Nevertheless, significant changes in concentrations appear to be nearly always accompanied by changes in climate.[3]

The link between greenhouse gases and climate is greatly complicated by a variety of physical processes that obscure the direction of cause and effect. Variations in the Sun's brightness and the Earth's orbit affect the climate by changing the amount of radiation that reaches the Earth. Clouds, dust, sulfates, and other particles from natural and industrial sources affect the way radiation filters in and out of the atmosphere. Snow, ice, vegetation, and soils control the amount of solar radiation that is directly reflected from the Earth's surface. And the Earth's vast ocean currents, themselves partly driven by solar radiation, greatly influence climate dynamics. Moreover, the climate system exhibits so-called threshold behavior: just as a minor change in balance can flip a canoe, relatively small changes sometimes can abruptly trigger a shift from one stable global pattern to a noticeably different one (Alley and others, 2003).

Fluctuations in those physical processes affect the complex balance among the reservoirs of carbon dioxide and methane in the atmosphere and the larger reservoirs of carbon in the biosphere—which comprises soils, vegetation, and creatures—and in the oceans. Large quantities of carbon flow back and forth between those reservoirs, regulated by the seasons, winds, and ocean currents.[4] The flows maintain a rough equilibrium among the reservoirs, which all gradually adjust to other influences—and to influxes of carbon—over periods of decades to centuries. Other greenhouse gases, such as nitrous oxide, are part of similarly complex cycles.

In the absence of human activity, other, even larger reservoirs of carbon adjust only over thousands to millions of years. They include fossil deposits of coal, oil, and natural gas, which hold 10 to 20 times as much carbon as the atmosphere; deposits of methane hydrate in the ocean floors, which contain perhaps 12 times as much carbon; and rocks that contain much more carbon than all of the surface reservoirs, or "sinks," combined (*see Figure 3*).

Over the past million and a half years, the Earth has experienced a period of "ice ages"—hundred-thousand-year cycles of cooling and warming that are governed mainly by variations in the Earth's orbit around the Sun. That period, which is unusual in geologic history, has been accompanied by changes in greenhouse gas concentrations that interact with and magnify the effects of the orbital variations (Shackleton, 2000). Geologically speaking, the most recent ice age just ended: less than 20,000 years ago, large parts of North America and Eurasia were covered by huge glaciers. Atmospheric concentrations of carbon dioxide were only half of what they are today; average global temperatures were roughly 7°F to 9°F (4°C to 5°C) lower; and the global climate was apparently drier and much more variable (Broecker and Hemming, 2001; Crowley, 1996; and Ganopolski and Rahmstorf, 2001). In addition, the trees and soils of the biosphere held perhaps one-third less carbon than they do now; tropical forests were much less extensive; and sea level was hundreds of feet lower.

All of recorded human history, as well as the development of agriculture, has occurred during a temporary interglacial period that began about 12,000 years ago and that has been warmer and unusually stable by comparison with the preceding cold period. Even during that stable interval, however, minor climatic changes have had substantial effects on preindustrial economies throughout the world. (For an extensive description of the effects of climate change over history, see Lamb, 1995.)

Historical Emissions and Climate Change

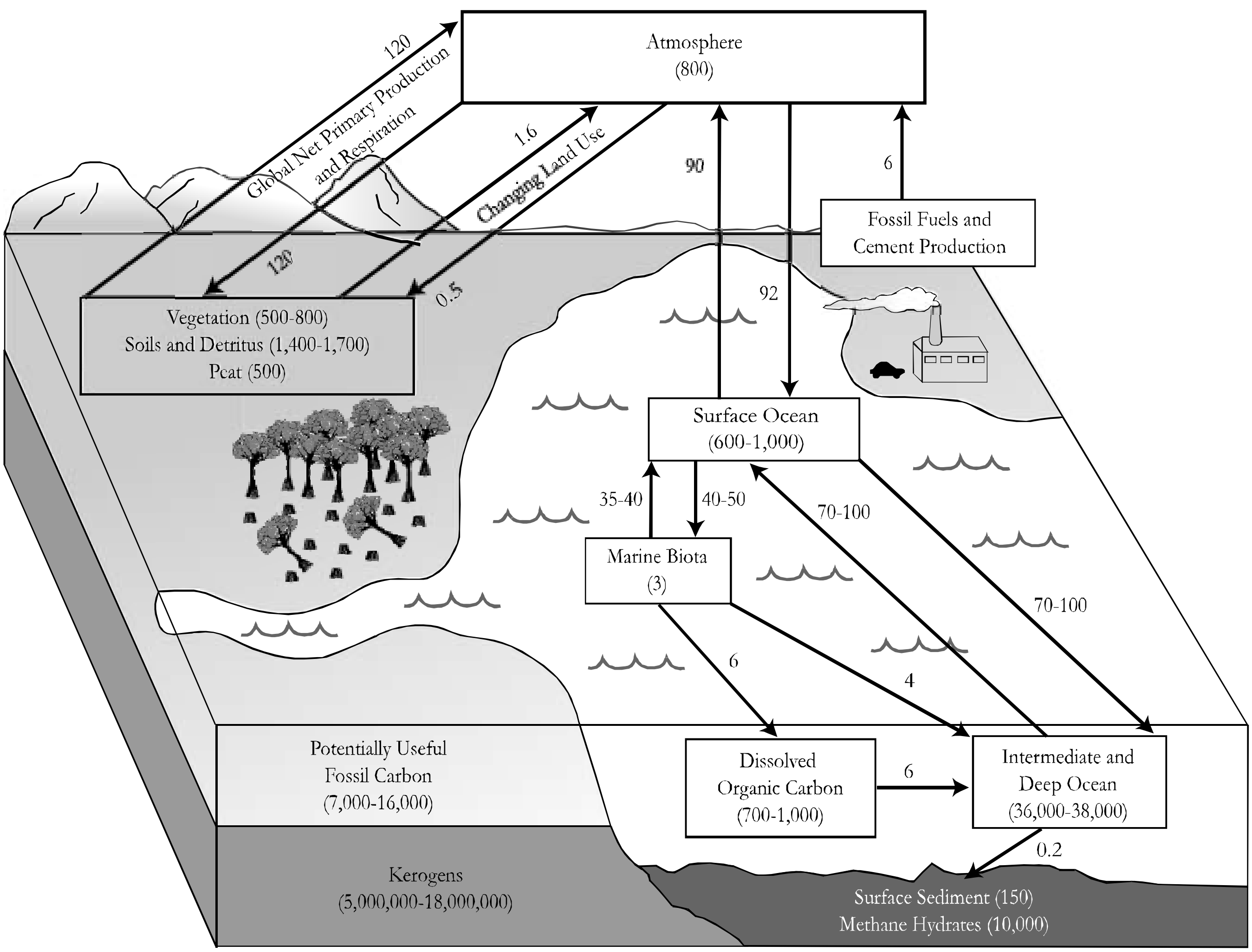
With the onset of the industrial revolution more than two centuries ago, people have begun to change the carbon cycle significantly, increasing the amount of carbon dioxide in the atmosphere by about a third, or from roughly

3. See Falkowski and others (2000); Veizer, Godderis, and François (2000); Crowley and Berner (2001); and Zachos and others (2001).

4. Quantities of carbon in gases and elsewhere are measured in metric tons of carbon, or mtc. Mtc differs from mtce, which measures warming potential rather than quantities of carbon.

Figure 3.

The Carbon Cycle



Source: Congressional Budget Office adapted from D. Schimel and others, "Radiative Forcing of Climate Change," Chapter 2 in J.T. Houghton and others, eds., *Climate Change 1995: The Science of Climate Change* (Cambridge, U.K.: Cambridge University Press, 1996). The figure draws on data from Mustafa Babiker and others, *The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results*, Report no. 71 (Cambridge, Mass.: Massachusetts Institute of Technology Joint Program on the Science and Policy of Global Change, 2001); Department of Energy, Energy Information Administration, *Annual Energy Review 2000*, DOE/EIA-0384(2000) (November 2001); P. Falkowski and others, "The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System," *Science*, vol. 290, no. 5490 (October 13, 2000), pp. 291-296; J.T. Houghton and others, eds., *Climate Change 2001: The Scientific Basis* (Cambridge, U.K.: Cambridge University Press, 2001); R.A. Houghton and David L. Skole, "Carbon," in B.L. Turner II and others, eds., *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years* (Cambridge, U.K.: Cambridge University Press, 1990), pp. 393-408; Keith A. Kvenvolden, "Potential Effects of Gas Hydrate on Human Welfare," *Proceedings of the National Academy of Sciences*, vol. 96 (March 1999), pp. 3420-3426; Bert Metz and others, eds., *Climate Change 2001: Mitigation* (Cambridge, U.K.: Cambridge University Press, 2001); Edward D. Porter, *Are We Running Out of Oil?* Discussion Paper no. 81 (Washington, D.C.: American Petroleum Institute, December 1995); and World Energy Council, *Survey of Energy Resources*, 19th ed. (London: World Energy Council, 2001), available at www.worldenergy.org/wec-geis/publications.

Note: Reservoirs of carbon are in billions of metric tons (shown in parentheses); flows of carbon (shown as arrows) are in billions of metric tons per year.

600 billion to 800 billion metric tons of carbon (mtc)—the highest amount in at least 400,000 years.[5] About 30 percent of the increase has come from cutting timber and clearing land for agriculture; the rest stems from extracting coal, oil, and natural gas from the fossil reservoir and burning them.[6] Atmospheric concentrations of methane and nitrous oxide have also risen over the past two centuries—by about 150 percent and 16 percent, respectively—as a result of various agricultural and industrial activities. More recently, halocarbons have begun to accumulate as well. The combined effect of these additions to the atmosphere has been to enhance the greenhouse effect slightly by raising the amount of radiation at the Earth's surface by about 0.5 percent—with perhaps half of that impact offset by the effects of other human activities, such as the cooling influence of sulfate emissions.

Current evidence indicates that since the mid-19th century, the average surface temperature of the Earth has risen by between 0.7ºF and 1.4ºF (0.4ºC and 0.8ºC). The warming trend has been most pronounced during the past decade and in higher latitudes. Ocean temperatures are also rising, expanding the volume of water, and that expansion, combined with water from melting glaciers, has raised global sea level by about four to 10 inches (10 to 20 centimeters) over the past century.

Scientists generally agree that the observed warming is roughly consistent with the expected effects of changing concentrations of greenhouse gases and other emissions. However, other phenomena also appear to be influencing the Earth's climate—for example, variations in the Sun's brightness and magnetic field, and poorly understood fluctuations in the circulation of the oceans. As a result, although scientists have dramatically improved their understanding of the atmosphere, oceans, and climate in recent years, they are uncertain about how much of the observed warming is due to greenhouse gas emissions. They are even more uncertain about whether the warming that has occurred has caused more-extreme weather, such as more and bigger hurricanes, floods, and droughts. However, some evidence suggests that unusually warm conditions may have contributed to persistent droughts in North America, Europe, and Asia between 1998 and 2002 (Hoerling and Kumar, 2003).

Some researchers believe that if people immediately halted emissions of greenhouse gases, gradual warming of the oceans would ultimately contribute to an additional warming of the atmosphere of between 0.9ºF and 2.7ºF, or 0.5ºC and 1.5ºC (Mahlman, 2001, p. 8). Over the following centuries, the climate would return nearly to its pre-industrial state, as the oceans gradually absorbed most of the extra carbon dioxide from the atmosphere and other greenhouse gases broke down.

However, as the world's population grows and the global economy continues to industrialize, the pace of emissions—particularly of carbon dioxide—is accelerating. The period since World War II has seen 80 percent of all carbon dioxide ever emitted from the burning of fossil fuels—and two-thirds of the entire increase in atmospheric concentrations (Marland, Boden, and Andres, 2002). During the 1990s, annual global emissions of greenhouse gases ran at about 10 billion metric tons of carbon equivalent (mtce; see footnote 2), and carbon dioxide concentrations grew by more than 4 percent. Fossil fuels accounted for about 6 billion mtc per year; of that total, oil claimed a share of 45 percent, natural gas, 20 percent; and coal, 35 percent.[7] Net deforestation contributed roughly 1 billion to 2 billion mtc annually (Watson and others, 2000, p. 32). About 2½ billion to 3 billion mtce per year of other greenhouse gases, mostly methane, came from a wide variety of sources, mainly agricultural activities but also

5. Atmospheric concentrations of carbon dioxide are usually measured in parts per million (ppm). In those terms, atmospheric carbon dioxide has increased from about 280 ppm to about 370 ppm.

6. Estimates of emissions and reabsorption of carbon from land use are based on data for 1850 to 1990 from R.A. Houghton of the Woods Hole Research Center and an extrapolation based on data from Houghton and Skole (1990). Estimates of emissions from fossil fuels are from Marland, Boden, and Andres (2002). Much of the available data on greenhouse gas emissions, changes in atmospheric concentrations, and changes in temperature is available from the Carbon Dioxide Information Analysis Center at http://cdiac.esd.ornl.gov/pns/pns_main.html. For a discussion of recent research, see Schimel and others (2001).

7. Coal contains about 80 percent more carbon per unit of energy than gas does, and oil contains about 40 percent more. For the typical U.S. household, a metric ton of carbon equals about 10,000 miles of driving at 25 miles per gallon of gasoline or about one year of home heating using a natural gas-fired furnace or about four months of electricity from coal-fired generation.

fossil fuel production, diverse industrial processes, and landfills.

The international distribution of emissions from fossil fuels largely reflects the global pattern of economic development because fossil fuels have powered the dramatic increase in industrial output and material well-being that has taken place in many nations over the past two centuries. In the United States, for instance, fossil fuels provided nearly 90 percent of all energy used in the 20th century, and they account for about 85 percent of the energy used today. Developed, industrialized countries—the members of the Organisation for Economic Co-operation and Development (OECD) and of the former Soviet bloc—are responsible for nearly 80 percent of historical carbon emissions, even though they have only about 20 percent of the world's population. Historically speaking, people in developed countries have emitted roughly 10 times more carbon per person than people in developing countries. Indeed, it is the technological access to energy from fossil fuels that has helped make them roughly 10 times wealthier.

Yet the relationship between the use of fossil energy and economic prosperity is not a strict one. Countries that have significant reserves of nonfossil energy, that rely on imports for much of their fuel supply, or that tax the consumption of fuel tend to have lower emissions levels. Some high-income countries have emissions levels per person that are quite low: for instance, Sweden maintains roughly the same standard of living as the United States does but emits only 30 percent as much carbon per person, largely by relying extensively on hydroelectric and nuclear power. In contrast, countries that have large reserves of fossil fuels or that subsidize their population's consumption of fuel tend to have higher per capita emissions levels. Such nations include oil-exporting countries and members of the former Soviet bloc.

Nor is the relationship between economic growth and emissions a smooth one. Developing countries in the initial stages of industrialization tend to have fairly high levels of emissions per dollar of output, because a large share of their economic activity involves the energy-intensive manufacturing of metals, cement, and other basic commodities. In contrast, developed countries devote an increasing share of their resources to the production of less energy intensive outputs, including services. Economic development therefore tends to involve rising energy intensity in its initial stages and falling energy intensity as the efficiency of energy use and the service sector's share of economic activity grow (Holtz-Eakin and Selden, 1995). In the United States, for example, per capita emissions of carbon dioxide from fossil fuels grew nearly sevenfold between 1870 and 1920 but have grown by less than one-third since then and are roughly the same now as they were 30 years ago.

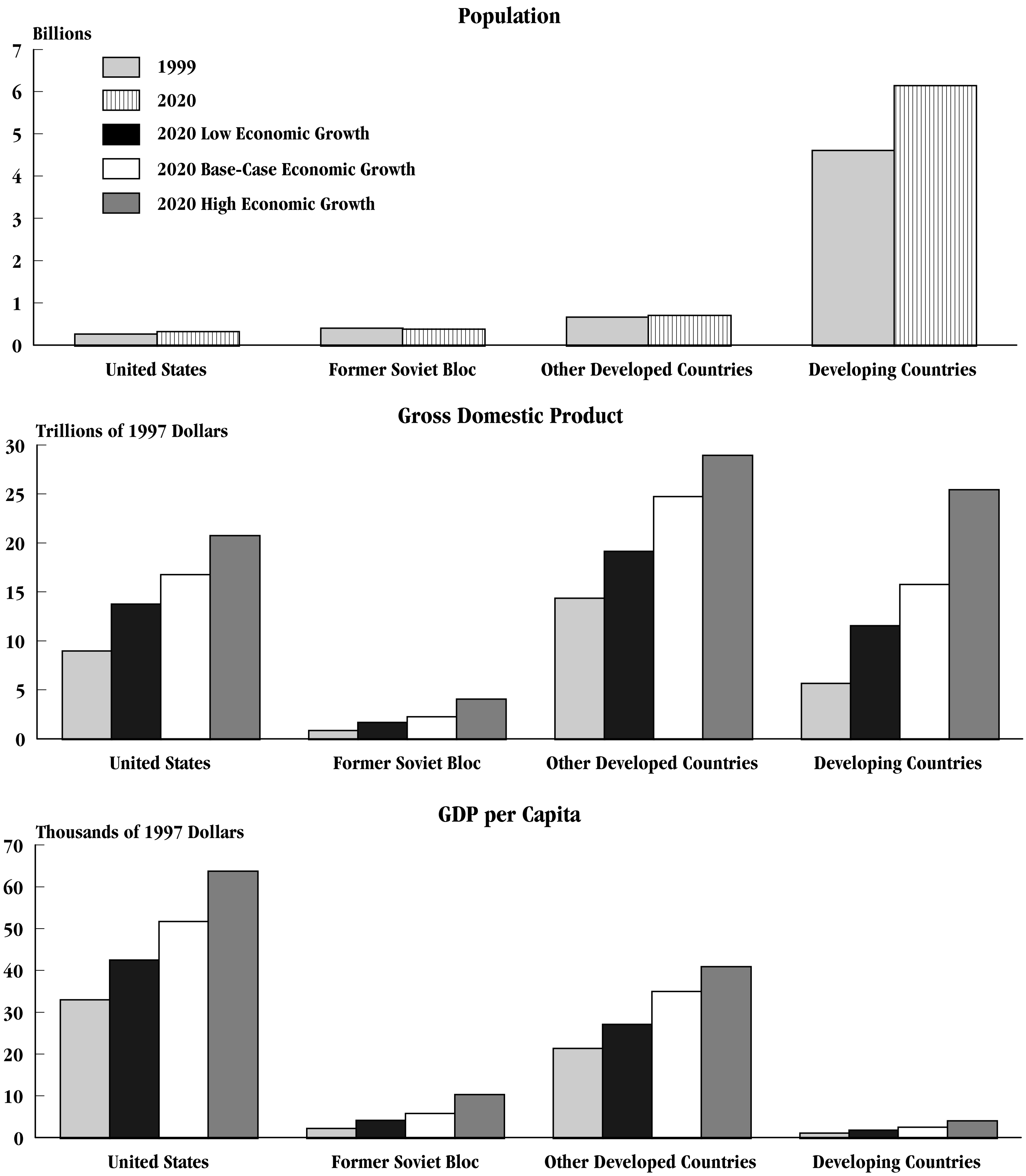
On a per-person basis, OECD countries currently burn about 3 mtc of fossil fuels per year—three times the world average—with national figures ranging from over 5½ mtc per person for the United States to less than 1 mtc for Mexico and Turkey.[8] The former Soviet bloc countries had very high per capita emissions levels before their economic collapse but now average about 2 mtc per person—the figures range from nearly 3 mtc for Russia to less than a third of a ton for Armenia. Developing countries average only ½ mtc per capita annually—or one-sixth the OECD average and only one-tenth that of the United States. The poorest 2 billion people—one-third of the world's population—average less than a fifth of a ton annually, or the equivalent of about 80 gallons of gasoline. (*Figures 4 and 5* compare different regions' populations, per capita economic activity, and per capita emissions, as well as ranges of uncertainty about those factors' future growth.)

Because of their greater reliance on subsistence farming and forestry, developing countries currently account for most of the world's carbon dioxide and methane emissions from land use. Even so, on a per capita basis, people in developing countries are responsible for far fewer greenhouse gas emissions than are their counterparts in the industrialized countries, and their total emissions levels are lower as well.

8. The United States accounts for nearly as many emissions as the former Soviet bloc, the Middle East, Central and South America, and Africa combined. Use of fossil fuel in the United States is split roughly into three categories: commercial and residential buildings and appliances, industry, and transportation. More than a third of that fuel is used to generate electricity, two-thirds of which goes to buildings and one-third to industry (see Department of Energy, 2002a). Other developed countries have somewhat different consumption patterns for fossil fuel, depending on their income levels, climates, and other factors.

Figure 4.

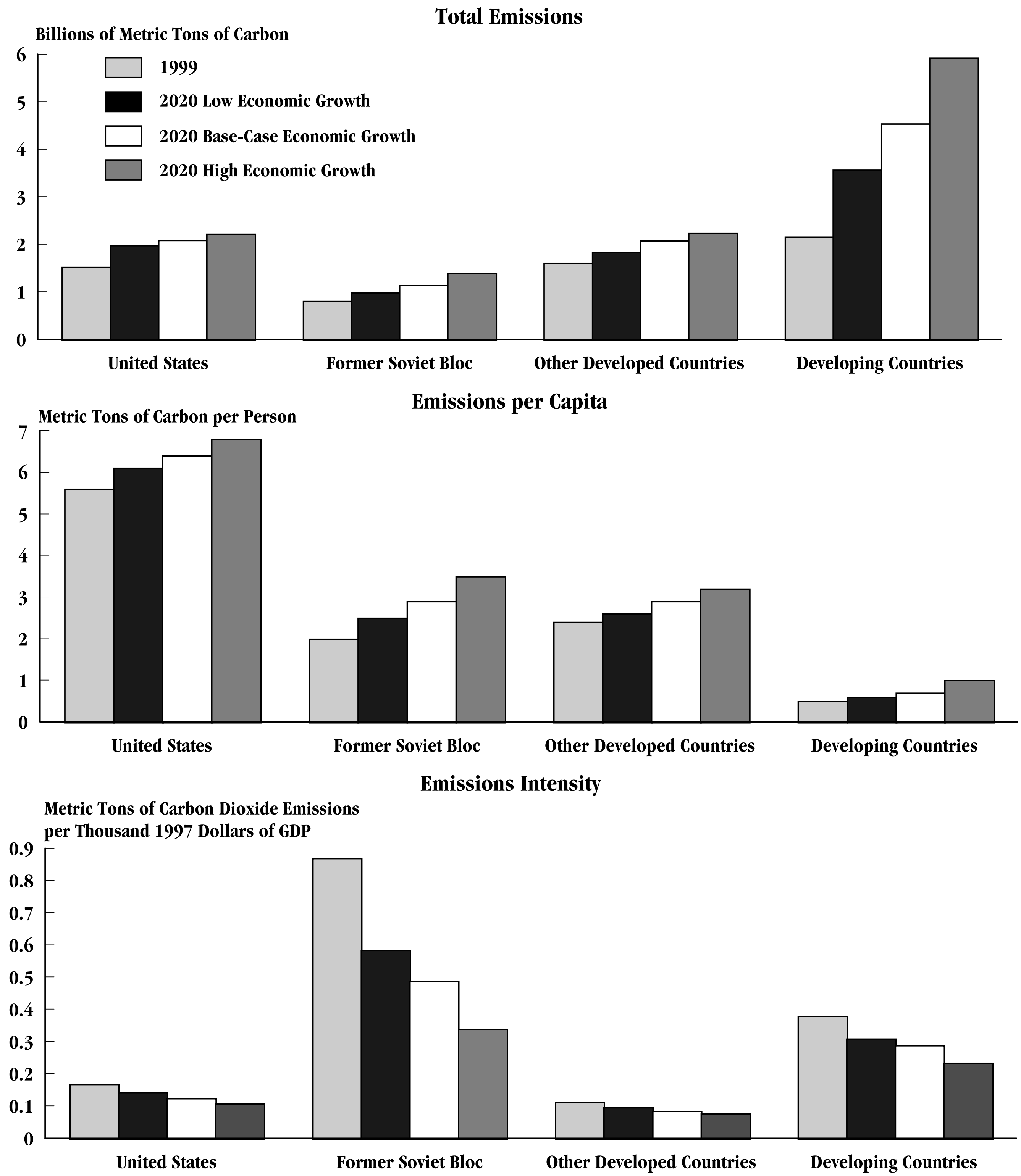
Uncertainty in Projections of Regional Population and Economic Growth



Source: Congressional Budget Office based on Department of Energy, Energy Information Administration, *International Energy Outlook 2002,* DOE/EIA-0484 (2002).

Figure 5.

Uncertainty in Projections of Regional Carbon Dioxide Emissions and Emissions Intensity



Source: Congressional Budget Office based on Department of Energy, Energy Information Administration, *International Energy Outlook 2002,* DOE/EIA-0484 (2002).

Note: All emissions are from fossil fuels.

What the Future May Hold

Recent studies have estimated that the average global temperature is likely to rise by between 0.5°F and 2.3°F (0.3°C and 1.3°C) during the next 30 years (Zwiers, 2002). Most of the warming during that period will be due to emissions that have already occurred. Over the longer term, the degree and pace of warming will depend mainly on future emissions. Given current trends in population, economic growth, and energy use, global emissions are likely to increase substantially. The populations and economies of developing countries are growing rapidly, and their total greenhouse gas emissions could surpass those of developed countries over the next generation or so—although on a per-person basis, emissions from developing countries will continue at much lower levels than emissions from developed countries for a long time to come.

Even with substantial research, development, and adoption of alternative energy technologies, fossil fuels are likely to remain among the cheapest abundant energy resources for many years. There are roughly 1,500 billion to 1,700 billion mtc in proven coal, oil, and natural gas reserves that can be extracted using current technology, along with an estimated 7,000 billion to 16,000 billion mtc in resources that might ultimately be recovered using advanced technology—not including reservoirs of methane hydrate under the ocean.[9] Without some sort of intervention, increasing levels of emissions—mainly of carbon dioxide from the use of fossil fuels—will continue to raise atmospheric concentrations of greenhouse gases for the foreseeable future.

To illustrate how concentrations might change over the next century, a study for the Intergovernmental Panel on Climate Change presented a series of scenarios of greenhouse gas emissions, with cumulative carbon dioxide emissions from both developed and developing countries ranging from under 700 billion mtc to nearly 2,500 billion mtc (Nakićenović and Swart, 2000; *see Figure 6*). By 2100, under the scenario with the lowest levels of emissions, atmospheric concentrations of carbon dioxide would be about one-third more than today's levels; under the high-emissions scenario, concentrations would be nearly triple today's. Under the more likely scenarios in the middle of the range, carbon dioxide concentrations could roughly double during the next century, to levels not seen in over 20 million years (Pearson and Palmer, 2000). Concentrations of other greenhouse gases are also likely to grow by a considerable amount. Under the above range of emissions projections—to which the authors do not assign any probabilities—the average global temperature could rise over the next century by about 2°F (1°C) or by more than 9°F (5°C).[10]

Other researchers have explicitly addressed a variety of uncertainties in economic and climate forecasting; one recent study projected an increase in the average global temperature of 4.3°F (2.4°C) between 1990 and 2100, with a 95 percent chance that the change will be between 1.8°F (1.0°C) and 8.8°F (4.9°C) (Webster and others, 2002; *see Figure 7*). The economic and physical factors included in the study accounted for roughly similar shares of the uncertainty surrounding the human contribution to warming by 2100. Other factors, including variations in solar radiation and volcanic activity, could also influence the future climate in ways that are harder to quantify, but those factors were not included in the study.

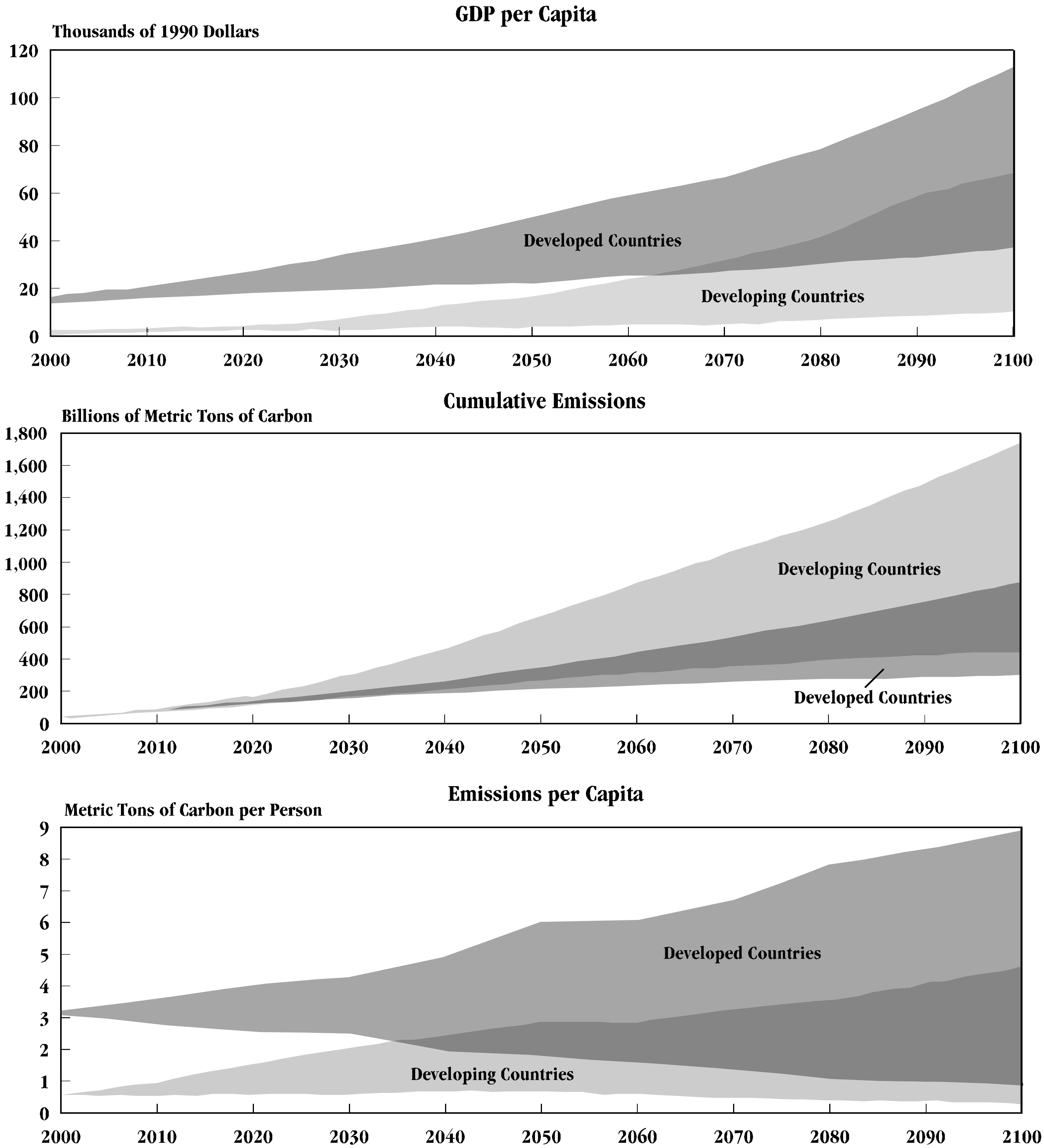
At the low end of the projected range, the effects of climate change would probably be relatively mild—although even modest warming might trigger an abrupt, larger-than-expected shift in weather patterns. At the high end of the range—an unlikely but possible prospect—the world could face an abrupt change in climate that would be roughly as large as the one at the end of the last ice age but much more rapid. In the more plausible middle of the range, the effects of climate change might still be quite significant. Moreover, even if emissions were eliminated before the end of the century, the oceans would continue to warm—and thus further warm the climate—for centuries thereafter. And, of course, continued emissions be-

9. Those estimates are derived from Babiker and others (2001), Department of Energy (2001), Metz and others (2001), Porter (1995), and World Energy Council (2001).

10. The economic projections for developing countries that underly those scenarios were criticized in an article appearing in the February 15, 2003, issue of *The Economist*. The criticism appears to be valid but does not undermine the study's main conclusions about the range of possible climate change.

Figure 6.

Range of Uncertainty in Economic and Carbon Dioxide Emissions Projections



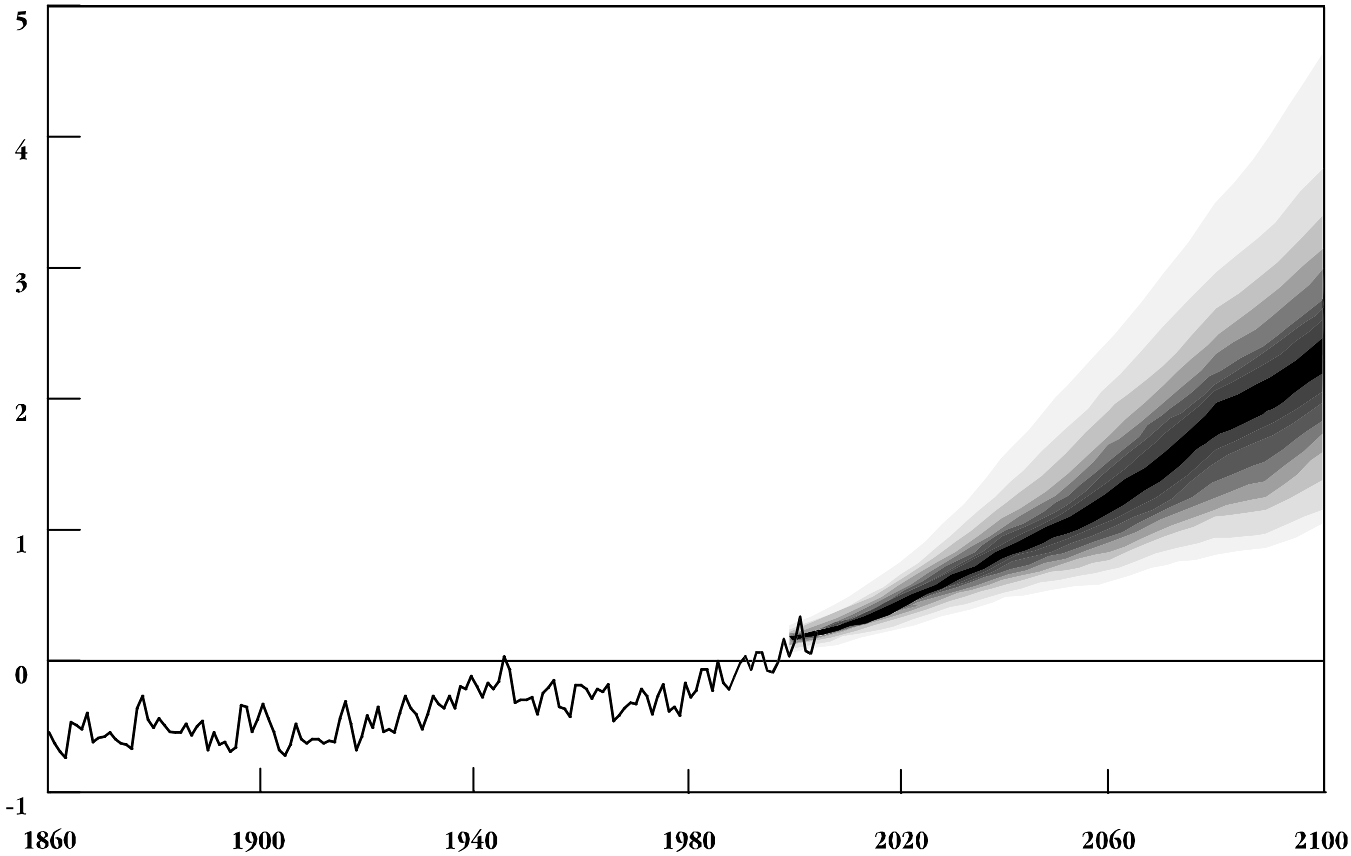
Source: Congressional Budget Office based on Nebojša Nakićenović and Rob Swart, eds., *Emission Scenarios* (Cambridge, U.K.: Cambridge University Press, 2000).

Note: All emissions are from fossil fuels.

Figure 7.

Historical and Projected Climate Change

(Average Global Temperature (°C) Relative to 1986-1995 Average)



Source: Congressional Budget Office. Historical data are from the Hadley Centre for Climate Prediction and Research, available at www.met-office.gov.uk/research/hadleycentre/CR_data/Annual/land+sst_web.txt and described primarily in C.K. Folland and others, "Global Temperature Change and Its Uncertainties Since 1861," *Geophysical Research Letters*, vol. 28 (July 1, 2001), pp. 2621-2624. The projection is based on data provided by Mort Webster, University of North Carolina at Chapel Hill, in a personal communication, December 11, 2002; the results are discussed in Mort Webster and others, *Uncertainty Analysis of Climate Change and Policy Response*, Report no. 95 (Cambridge, Mass.: Massachusetts Institute of Technology Joint Program on the Science and Policy of Global Change, December 2002).

Note: The projection, which is interpolated from decadal averages beginning in 1995, shows the possible distribution of changes in average global temperature as a result of human influence, relative to the 1986-1995 average and given current understanding of the climate. Under the Webster study's assumptions, the probability is 10 percent that the actual global temperature will fall in the darkest area and 90 percent that it will fall within the whole shaded area. However, actual temperatures could be affected by factors that were not addressed in the study (such as volcanic activity and the variability of solar radiation) and whose effects are not included in the figure.

yond the next hundred years would contribute to additional warming.

The potential effects of any particular amount or rate of climate change over the next few centuries are very uncertain. Research on the connection between the climate and economic well-being yields particularly ambiguous conclusions. Humans generally appear to have prospered during warmer (or warming) periods and suffered during colder (or cooling) ones. People did not—perhaps could not—begin farming until after the last ice age ended. Agriculture spread rapidly 6,000 to 8,000 years ago, when the Sahara was largely grassland instead of desert and average global temperatures were warmer than they are today by perhaps a degree Celsius. Conversely, numerous episodes of cooling seem to have disrupted cultures throughout history. Europe prospered during a warm period that occurred in the Middle Ages, but it suffered during the colder Little Ice Age of between 300 and 800 years ago.

Yet the past effects of climate change on preindustrial societies may not provide much information about its future effects on technologically advanced societies—especially the effects of significantly greater warming.[11] Researchers who study the sources of economic growth consistently find that at least during the past half-century, regions in temperate climates tended to prosper more than regions in tropical ones, even after differences in levels of income and education, rates of saving and investment, and other factors were taken into account. (For example, Masters and McMillan, 2000, and Sala-i-Martin, 1997, discuss the positive correlation between temperate climate and economic development.)

When considered as a whole, the historical and statistical evidence suggests that a warmer global climate—as well as the period during which warming occurred—could have both beneficial and harmful effects. One global effect would be generally harmful: sea levels would rise as glaciers melted and the oceans warmed and expanded. The gradual inundation of seashores would create problems for countries (particularly low-lying island nations), regions, and cities that were mostly near sea level. In the middle of the range of climate change described earlier, sea level would rise by up to 1½ feet (50 centimeters) over the next century. And even if emissions were eliminated after 2100, thermal expansion of the oceans could ultimately raise sea level by roughly 6 feet (2 meters) over a few centuries.

Because climate is generally a regional phenomenon, however, the effects of climate change would vary by region—and be even more uncertain than the effects globally. If warming followed recent patterns, it would tend to be concentrated in colder areas and periods—near the poles, in the winter, and at night—but daylight temperatures in the tropics during the summer would also rise.[12] A somewhat warmer Earth would probably have more rainfall, and the resulting moderately warmer, wetter climate —combined with more carbon dioxide in the atmosphere —would probably improve global agricultural productivity overall. Nevertheless, dramatic warming could reduce the yields of important food crops in most of the world. Shifts in weather patterns would probably cause more heat waves and droughts in some regions, which would substantially reduce their crop yields and supplies of drinking water as well as exacerbate the effects of urban air pollution. Other areas would experience more flooding. Moreover, as Alley and others (2003) discuss, the climate's response to rising concentrations of greenhouse gases could involve unexpectedly large and abrupt shifts, which would be much more disruptive and costly to adapt to than would gradual changes.

People in developing countries are probably more vulnerable to the damaging effects of climate change than are people in developed countries, in large part because they have fewer resources for coping with the impacts. In addition, a number of developing countries have large populations that are either concentrated in low-lying regions vulnerable to a rise in sea level or flooding or that subsist on marginal agricultural lands vulnerable to drought.

In contrast, industrial economies can draw on many more resources to ease the adaptation to changes in climate. Moreover, recent comprehensive study of the potential impacts of climate change suggests that for a 4.5˚F (2.5˚C) increase in average global temperature, some developed countries could actually experience economic benefits because warming would improve climates for agriculture (Nordhaus and Boyer, 2000). The United States could experience a loss of about half a percent of total income; the poorest developing countries could experience losses of more than 2.5 percent—and from much lower levels of income per person than those of developed countries.

11. Moore (1998) describes the potentially beneficial effects of warm climates. Richerson and others (2001) discuss the relationship between warming and the development of farming. Lamb (1995) addresses the broader effects of climate over human history.

12. Until recently, evidence from fossils indicated that tropical weather was relatively insensitive to global climate change. However, research by Kump (2001) suggests that tropical regions are, indeed, affected.

But point estimates like those conceal a great deal of uncertainty. As an example, estimates of the effects on the United States of a rise of 4.5°F (2.5°C) in average global temperature range from a loss of 1.5 percent of gross domestic product to a gain of 1.0 percent.[13] For particular temperate regions of the United States, the likely changes in temperature and rainfall and the possible intensity of extreme weather conditions are very poorly understood. For example, recent reviews of the potential regional effects of climate change in the United States (National Assessment Synthesis Team, 2000, and Department of State, 2002) found that rainfall and summer soil moisture might rise significantly in much of the Midwest, or it might fall significantly.

In addition, some researchers fear that climate change might occur so rapidly that some types of plants—most notably, in marginal ecosystems such as alpine meadows and barrier islands and in immobile ecosystems such as coral reefs—would not be able to adapt to the altered climate and would disappear. Migratory animals, birds, and insects could be similarly affected.[14] Moreover, warming would probably increase the natural range of insect-borne diseases that are now found mainly in warmer regions.

Finally, among the most worrisome possible consequences of rising greenhouse gas concentrations is the potential disruption of deep ocean currents that strongly influence the global climate. Those currents are directed partly by thermohaline circulation; that is, the evaporation or freezing of seawater in various regions leaves the remaining water increasingly salty, and therefore dense, and it sinks into the deep. Warmer weather could slow or even stop the current pattern of thermohaline circulation by increasing rainfall and reducing the formation of sea ice in the North Atlantic.

13. Nordhaus (1994, 1998a,b), Nordhaus and Boyer (2000), Mendelsohn and Neumann (1999), and Moore (1998) discuss those cost estimates.

14. That problem could be aggravated by the environmental stresses of population growth and industrialization. As Field (2001) discusses, under an intermediate definition of appropriation, human beings already appropriate an estimated 10 percent to 55 percent of the energy transferred from plants to other life on Earth, and that fraction is expected to grow in the future.

Northern Europe appears to be particularly vulnerable to such a change because its relatively warm, rainy weather depends on the northerly flow of warm water from the Gulf Stream, which in turn is linked to thermohaline circulation in the North Atlantic. An abrupt halt of that circulation—such as the halt that occurred after the last ice age, as the climate warmed up—could seriously disrupt the flow of warm water into the North Atlantic, leading to much colder weather in parts of North America and Europe for decades or centuries coupled with greater warming elsewhere in the world. (Clark and others, 2001, discuss that scenario.) Most climate models project that the North Atlantic thermohaline circulation will weaken during the next century because of higher levels of rainfall in a warmer climate. However, they do not predict a complete shutdown over that period.

Potential Responses

To control the long-run growth of greenhouse gas concentrations in the atmosphere, countries could either limit emissions or develop means of drawing greenhouse gases back out of the atmosphere after they were emitted. One significant remedy would be to control the long-run growth of fossil fuel use. There are many alternatives to current patterns of energy use, including technologies that could make that use more efficient and others that could exploit alternative energy sources—for example, solar energy, wind, biomass, and hydroelectric and nuclear power. However, expanding the reliance on any of those alternatives is relatively expensive compared with the market cost of using fossil fuels. Restrictions on such use would therefore impose economic costs—costs that would rise with the stringency of the restrictions and would climb particularly quickly if extensive controls were imposed in the short run. Over the longer term, control of fossil fuel use will depend on the development of relatively inexpensive alternative energy technologies (Edmonds, 2002).

Because plants absorb carbon dioxide from the atmosphere, countries could sequester carbon by planting and growing trees and partly offset emissions from the burning of fossil fuels. (Scholes and Noble, 2001, and McCarl and Schneider, 2001, discuss the role of sequestration in limiting carbon dioxide emissions.) In theory, the potential for sequestration in forests is very large: if people could replant all of the forest land around the world that has been cleared in the past two centuries and then leave the forests alone, the trees and soils could eventually trap much of the carbon that has accumulated in the atmosphere since the beginning of the industrial revolution. In practice, though, reforestation on that scale is infeasible: people need much of the land to grow crops and to live on. Furthermore, people would continue to use fossil fuels, and all of the carbon sequestered in trees over several decades would be replaced in the atmosphere by the continued emissions. So carbon sequestration in forests and agricultural soils can only partially offset past and future carbon emissions from fossil fuels.

But forests can offer a partial alternative to fossil fuels as a source of energy. Although burning wood releases carbon into the atmosphere (and is relatively dirty and expensive as well), the carbon is removed again as another tree grows in place of the one cut down, a cycle that could be repeated over and over. Thus, a wood lot capable of producing 1 mtc of renewable biomass fuel every 20 years or so could, over a century, replace 5 mtc from fossil fuels that would otherwise be emitted into the atmosphere.

Engineers have developed technologies to remove carbon dioxide from the exhaust of a combustion process and to store it underground or in the ocean. Those carbon-capture technologies appear to be relatively straightforward for large emissions sources such as electric power generating plants, but they also significantly increase the cost of generating power (Department of Energy, 1997).[15] Geoengineering solutions, such as adding iron to oceans to fertilize the absorption of carbon by plankton, have also been advanced. Some research suggests that iron fertilization may help reduce atmospheric concentrations of carbon dioxide, although its effectiveness and cost are very uncertain, as are its potential side effects (Boyd and others, 2000). Other geoengineering technologies, such as removing greenhouse gases directly from the atmosphere, are extremely expensive.

15. An extensive discussion of technological options and the costs of capturing and sequestering carbon dioxide from power plants can be found at the Web site of the International Energy Agency's Greenhouse Gas Research and Development Programme at www.ieagreen.org.uk/index.htm.

Some relatively simple and inexpensive options are available for controlling some emissions of greenhouse gases other than carbon dioxide. However, controlling those gases in a cost-effective manner is considerably complicated by the fact that they come from so many different and widespread agricultural, industrial, and other activities (Reilly, Jacoby, and Prinn, 2003).

Types of Uncertainty

As the preceding discussion emphasized, scientists and economists are very uncertain about the potential economic threat posed by a changing climate. Some of the uncertainty is scientific. For a given amount of greenhouse gas emissions, what portion will accumulate in the atmosphere? How much will a given change in those concentrations affect the global climate? How will that global change be distributed throughout the world, and how rapidly will it occur? How much will regional climate change affect sea level, agriculture, forestry, fishing, water resources, disease risks, and natural ecosystems? Will rising greenhouse gas concentrations increase the probability of threshold effects, which could suddenly shift the climate into a significantly different global pattern?

Other sources of uncertainty are essentially economic. How rapidly will the world's population and economies grow? How energy- and land-intensive will human activities be, and how much of the energy used for those activities will come from fossil fuels? How will policies to control emissions of greenhouse gases or to encourage technological developments affect the accumulation of gases in the atmosphere? And how much will those policies cost? At a deeper level, how will future generations value the effects of averting climate change? Future generations are likely to be wealthier, on average, than people are today and thus better able to adjust to changes in climate. But they might also have been willing to forgo some of their affluence to have their natural surroundings and climate preserved.

Researchers' increased understanding of climate change has often uncovered areas of inquiry whose importance had previously gone unrecognized. In that respect, greater knowledge has sometimes served to expand the range of scientific and economic unknowns, even as it has resolved specific issues (see Kerr, 2001, pp. 192-194). Because of that tendency, policymakers for the foreseeable future will continue to face great uncertainty in determining the potential costs and effects of different policies to address the problem of climate change. Furthermore, policies that explicitly take into account that range of uncertainty are likely to be more effective than policies that do not.[16]

16. See Heal and Kriström (2002) for a more extensive discussion of uncertainty and climate change.

CHAPTER

3

The Economics of Climate Change

The Earth's atmosphere and climate are part of the stock of natural resources that are available to people to satisfy their needs and wants over time. From an economic point of view, climate policy involves measuring and comparing people's valuations of climate resources, across alternative uses and at different points in time, and applying the results to choose a best course of action. Effective climate policy would balance the benefits and costs of using the atmosphere and climate and would distribute them among people in an acceptable way.

Common Resources and Property Rights

Prosperity depends not only on technological advances but also on developing legal, political, and economic institutions—such as private property, markets, contracts, and courts—that encourage people to use resources to create wealth without fighting over or, in the case of renewable resources, significantly degrading them. The effectiveness of those institutions depends in part on characteristics of the resources. Market institutions do not work well when resources have the characteristics of public goods—that is, when it is difficult to prevent people from using the resources without paying for them (consumption is "nonexcludable") and when the incremental cost of allowing more users is near zero (consumption is "nonrival"). Market failures also arise when the many people using a resource affect each others' use—for instance, when rush-hour drivers create congestion and air pollution. (In that case, consumption is nonexcludable but rival.) Those characteristics make property rights for public goods difficult to create and enforce. Private industry finds it relatively unprofitable to produce such goods, and consumers have relatively little incentive to maintain them.

The Earth's oceans and air are particularly hard to carve up into private property, and in the ongoing process of attempting to develop effective institutions to manage them, access to those resources has largely remained open —for the most part, no one owns them, anyone can use them, and no one has to pay. For most of human history, open access to the oceans and air was appropriate because the world's population was too small and its technologies too limited to deplete stocks of fish, degrade air quality, or affect the climate.

But population growth and advances in technology have changed the way people use natural resources and made them vulnerable to overuse, depletion, and degradation. If resources are free for the taking, people will tend to overuse them; if nobody owns them, nobody will take care of them. That phenomenon is referred to as the tragedy of the commons: everyone wants to use free resources but will degrade them if they do, to the detriment of all.

In the case of climate, people want to use the atmosphere to absorb greenhouse gases so that they may benefit from cheap food and timber and from plentiful fossil energy. In the long run, however, that use may significantly degrade the climate.

An Example: Common Fishing Resources

To keep from overusing a common resource, people must negotiate and agree on rules about who may use it and how much of which types of uses are acceptable. Fisheries provide a common, straightforward example of the problem: a fishing community may have to determine the sustainable level of fishing for each kind of fish and then limit catches to those levels. Limits on fishing will reduce the market supply of fish and raise their market value. People who are allowed to keep fishing will reap a windfall profit on the fish they can legally catch. (Cheaters, or "free riders," who catch more than their allowance will also get windfall profits.) In the meantime, anyone whose fishing is restricted is likely to sustain a loss.[1] The community's challenge is to reach a consensus about who gets to fish and how much; about whether, how, and how much to compensate the losers to win their support; and about how to prevent free riders from catching extra fish and breaking down the agreement. In short, the challenge is to negotiate and enforce a new set of property rights.

The task of developing and enforcing property rights generally falls to governments—and it may be further complicated if several countries are involved and international negotiations are needed to resolve conflicts. Governments use a variety of approaches to regulate fisheries, many of which explicitly involve the technology of fishing. For instance, the government may restrict the size of fish that can be taken, prohibit the use of large dragnets, or require the use of handheld lines. Other regulatory strategies apply more directly to the market for fish. One alternative is to create and distribute a fixed number of fishing permits that limit recipients' catches (see, for example, Newell, Sanchirico, and Kerr, 2002). Under that approach, fishermen may lose part of their previously unrestricted catch, but their losses are at least partly offset because greater scarcity drives up the price of fish. Consumers lose by paying more per fish for fewer fish. If the government auctions off the limited fishing rights to the highest bidders, fishermen will have to pay to fish; they will thus lose the profits they could have reaped from higher, scarcity-driven fish prices. However, the government will take in revenue that it can use for various purposes, including partially compensating consumers and fishermen.

Whether it distributes or sells them, a government can create private fishing rights (which recipients can buy and sell on open markets) or common property rights (in which a restricted group of people own the fishery together and can exclude everyone else from fishing). A government can also keep or appropriate the common resource as a public property under public management and create a use right—such as a fishing license or a catch limit—that gives recipients temporary or limited access to the resource.

Another alternative for the government is to sell use rights by levying a tax on fishing activity or a "landing fee" on fish catches. Because the tax becomes a cost of catching fish, fishermen will raise the market price of their fish, consumers will buy fewer fish as the price rises, and the government will receive tax revenues. As the demand for fish falls, fishermen will make less money, and some of them will be pushed out of the market. As in the case of auctioned rights, the government will receive revenues that it can use to partially offset consumers' and fishermen's losses, and fishing will be maintained at a sustainable level.

A Second Example: Common Air Resources

As a resource problem, air pollution is typically more complicated than overfishing. Unlike markets for fish, in which a product actually changes hands, people generally do not buy and sell air, so there is no market price that reflects the value of air. In addition, modest air pollution may hurt only some especially sensitive people, or it may contribute to health problems in ways that are hard to trace back to it. Pollution levels may have to be very high before many people notice a problem and demand a remedy. Moreover, there may be many different types of emissions from a variety of sources, so it can be difficult or even impossible to trace particular problems to particular origins.

For example, regional air pollution may come from power plants, factories, buildings, trucks, and cars. Emissions from cars alone can involve millions of drivers, each having a minor effect on the health of millions of people, including each other. No practical way exists for each inhabitant to bargain with each driver over the minor effect that that driver has on him or her.

Nor is it simple to measure the economic trade-offs involved. The benefits from less pollution—improved health, better visibility, and so on—are certainly real but notoriously difficult to evaluate because they are generally not bought and sold in markets. The relative costs of reducing emissions from different sources can also be hard to determine. And the people who enjoy the benefits of

1. Under certain circumstances, limits on fishing may drive up the market price for fish to such an extent that it raises the total value of the catch. In that case, it may be easier to get fishers to agree to restrictions—although limits will raise costs for consumers.

lower pollution levels may not be the ones who incur the costs.

Those complexities make it very difficult to determine the costs and benefits of reducing air pollution and to balance or distribute them in a politically acceptable way. Nor is it easy to develop standard property rights for air resources. As a result, people find it extremely challenging to use private markets to resolve conflicts over the use of air resources. The fundamental problem is transaction costs—the costs of motivating and coordinating exchanges; too many parties are involved in too many interactions to negotiate agreement in private markets. High transaction costs force governments to come up with other approaches to managing air pollution.

The Atmosphere and Climate

The problem of climate change involves very large transaction costs. Emissions come from the land- and energy-using activities of practically everyone in the world, and the potential burden of their effects will be borne throughout the world by generations of people who are not even born. Moreover, many of the potential impacts of climate change—the disruption of ecosystems and extinction of species, for instance—are themselves public in nature.

Those factors make it very hard—if not impossible—to clearly define individual rights and responsibilities for many of the activities that may contribute to climate change and the effects that may come from it. Certain types of rights, such as rights to emit greenhouse gases by burning fossil fuels, could be delineated without great difficulty. Other rights, such as credits for carbon stored in the soil and trees of a forest stand or in the ocean, would be more complicated to define. Still others—such as the right to enjoy a particular type of climate in a particular part of the world at a particular time—would be impossible. Without clearly delineated, enforceable rights, individuals cannot easily bargain with one another in markets to resolve their conflicting claims. And as Chapter 2 discussed, the scientific and economic uncertainty involved makes climate trade-offs extremely difficult to evaluate.

In sum, policymakers may be faced with the extraordinarily complicated task of managing a resource that no one owns, that everyone depends on, and that provides a wide range of very different—and often public—benefits to different people in different regions over very long periods, benefits for which property rights would be very difficult to define, agree on, and enforce. The causes and consequences of climate change are international, and that fact has several ramifications: governments will probably have to cooperate for any management approach to be effective; for some time to come, they will have only very imperfect information on which to base decisions; and their decisions may affect the world for centuries. If governments decided that the risks associated with climate change called for action, they might have to persuade people to make sacrifices today to benefit future generations.

Reaching collective agreement on a policy involving use of the atmosphere and climate change is an immense challenge because everyone has an incentive to "free ride." A successful agreement need not require equal action by all parties, but an agreement of any kind will break down if some parties sacrifice to meet an overall goal and other parties cheat, increasing their emissions in violation of the goal. Moreover, without a clear sense of whether, when, and by how much emissions should be constrained, nations will find it very hard to agree on the appropriate level of action. Equally important, nations have very different historical and economic circumstances; they vary widely in their ability and willingness to bear the cost of reducing emissions—or the possible costs of climate change. These factors help explain the great difficulty nations are experiencing in trying to reach agreement on a distribution of rights and responsibilities.

Further complicating any collective agreement is the fact that governments generally are not subject to the market forces that drive competitive firms to efficiently provide the goods and services that consumers most want to buy. Instead, governments tend to represent coalitions of private and bureaucratic interests that often engage in rent-seeking behavior—attempting to redirect the economy's resources to their own advantage. As a result, governments do not necessarily provide the public services most desired by consumers; nor do they provide them at the lowest cost. There is consequently no guarantee that governments will be better than markets at managing common resources.

Economic Trade-Offs

Economic valuation is inherently about measuring trade-offs—among people and resources and across time. Resources are limited, and people are forced to choose among alternative uses, trading some things that they might like to have for things of higher priority. The economic value of a resource reflects those choices rather than something intrinsic to it. Value is measured by people's willingness to pay for the benefits that a resource provides—or, nearly equivalent, their willingness to accept compensation for lost benefits.[2]

When markets work well, market prices communicate people's preferences—their choices among alternative uses of resources and between using resources today (and perhaps damaging or depleting them) and maintaining them in their current state to be used later. For nonrenewable resources such as oil, the trade-off involves balancing the benefits of using them up now against the benefits of preserving them so that they can be used later. For renewable resources such as fisheries, the trade-off involves balancing the benefits of fish consumption today against the benefits of maintaining a breeding stock for tomorrow. In an efficient market, resources are used to provide people with the goods and services that they most want to have, when they most want to have them.

When markets do not work well, prices may not adequately reflect people's willingness to pay for the benefits that the use of a resource provides. That situation can arise when property rights are poorly delineated or inherently difficult to define, as in the case of public goods. It also can arise when limited information makes it difficult or impossible for individuals to decide what value they place on a resource. For instance, even experts are uncertain about the likelihood of abrupt changes in climate, or how changes in climate might disrupt species and ecosystems, or how those disruptions might affect society. Those factors converge in the case of climate change, which involves great uncertainty about a public good.

In attempting to manage such resources, policymakers may simulate markets by estimating individuals' willingness to pay, using proxy measures that economists have developed for resources that are not directly bought and sold. Even with those measures, however, policymakers face the challenge of limited information, as well as the impossibility of learning what values future generations might assign to those resources.

Balancing Competing Uses of the Atmosphere

Effective management of the atmosphere involves balancing the incremental benefits of using it as a sink for greenhouse gas emissions—that is, the additional benefits provided by the last ton of emissions—against the incremental costs (or benefits) of the climate change that may gradually result from that ton of emissions.[3] Similarly, effective management involves balancing the incremental costs of investing in research on climate change against the incremental benefits of the advancements in knowledge that result. That balancing of current costs and future benefits also includes weighing the cost of reducing emissions to avert climate-related problems in the future against the cost of adapting to the climate change that occurs—that is, balancing mitigation and adaptation. If the incremental costs of reducing emissions today are higher than those of adapting to the consequences of emissions in the future—say, by spending more on insect control to prevent the spread of tropical diseases—then it would be more cost-effective to reduce emissions less and to adapt more.

Put another way, effective climate policy involves making investments today to yield future returns in the form of a beneficial climate—with due regard for the scientific and economic uncertainty involved. Those investments could take several forms, such as restrictions on emissions levels and research to improve understanding of the phy-

2. People may express their beliefs about intrinsic values in their willingness to pay for environmental benefits. For instance, they may be willing to pay to ensure that a forest they may never see is not cut down or that a species of animal does not become extinct. They are expressing their willingness to sacrifice some other benefits —cheap timber, for example—for the benefit of knowing that the forest or species will be preserved.

3. The atmosphere is a partly renewable resource because the oceans can indefinitely absorb only limited amounts of greenhouse gases. Beyond those limits, the gases begin to build up in the atmosphere and gradually affect the climate. (For carbon dioxide, the limit appears to be roughly a billion metric tons of carbon per year.) In that sense, the atmosphere is a depletable resource.

sical processes of climate change and to develop alternatives to fossil fuels.[4]

Climate policy thus involves balancing investments that may yield future climate-related benefits against other, non-climate-related investments—such as education, the development of new technologies, and increases in the stock of physical capital—that are also beneficial. If climate change turned out to be relatively benign, a policy that restricted emissions at very high expense might divert funds from other investments that could have yielded higher returns. Conversely, if climate change proved to be a very serious problem, the same policy could yield a much higher return.

Since resources devoted to climate policy would be diverted from other uses, the total benefit from all types of investment would be greatest if the rates of return were the same "at the margin"—that is, for the last dollar of each type of investment. However, efforts to ensure equal rates of return become extremely complicated in the case of long-term issues such as climate change. Few other investments compare with climate policy in yielding an enormous variety of returns on a global scale and over such long periods, or in having returns that are as uncertain. Furthermore, very long time horizons render the results of cost-benefit analyses extremely sensitive to the rate of return that is assumed for the analysis.

The appropriate course of action—and the appropriate level of climate-related investment—depends on how one balances the competing interests of present and future generations and how one accounts for the existing scientific and economic uncertainty. Those choices, in turn, are expressed in the desired rate of return on that investment—that is, the chosen discount rate (*see Box 1*). While analysts have reached no consensus on what discount rate should be applied, several of them have argued that it should be lower than the rates assumed in typical cost-benefit analyses, for several reasons:

- Society's investment opportunities over the long term are uncertain;

- There are no centuries-long financial markets in which to invest risk free or from which to determine very long-term rates of return; and

- People's attitudes toward the distant future may not be correctly reflected in the assumption of a constant discount rate based on historical market returns.[5]

The challenge is to come up with valuations that reflect what people, taken together, may plausibly be said to consider appropriate and that are also consistent with how people may actually be able to transfer resources across time (by making investments today that yield income in the future).

If lower discount rates are deemed appropriate for evaluating very long-term costs and benefits, they justify taking measures to increase society's rate of investment not only in preserving a benign climate but in expanding the stock of all types of long-lasting capital. By increasing investment to the point at which the last investments all earn rates of return that are consistent with the lower discount rate, such measures would tend to reduce current generations' consumption in order to provide more wealth for generations in the future.

Integrated Assessments of Costs and Benefits

Over the past 15 years, a large number of studies have analyzed the potential costs and benefits of averting climate change. Some researchers have attempted to incorporate the studies' results in global and regional models of economic growth and climate effects and have used the models to conduct so-called integrated assessments of policy proposals related to climate change. They have also estimated the costs of emissions control policies that would yield the greatest net benefits in terms of economic growth, reduced emissions, and the resulting climate effects.

4. To the extent that they encouraged research or reduced emissions, such investments might also yield benefits in the form of technological side effects, or "spillovers," or a decline in conventional air pollution. And to the extent that greenhouse gas emissions also contribute to conventional pollution, the costs and benefits of abating such pollution need to be factored in as well.

5. Weitzman (1999, 2001) and Newell and Pizer (2001) discuss that issue further; Cropper, Aydede, and Portney (1994) describe efforts to determine people's attitudes toward intergenerational equity by measuring long-term discount rates.

Box 1.

Discounting and the Distant Future

For a variety of reasons, people place less value on the future than they do on the present; a dollar today is worth more to them than a dollar tomorrow. The practice of valuing future income less highly than current income is called discounting. A person who greatly devalues, or discounts, future consumption and hence does not save and invest much is said to have a high discount rate. A person who places great value on the future is said to have a low discount rate.

Such valuations are expressed in the market as interest rates. Market interest rates balance everyone's current supply of and demand for savings—they represent the market's summing up of society's competing preferences for present and future income. Some people save part of their income, thus accumulating wealth; others spend more than their income, making up the difference by borrowing or by running down their savings. Overall, savers outpace dissavers; thus, society as a whole saves a fraction of current income and invests it in activities—such as conducting research, building physical capital, and developing human skills—that will help provide goods and services in the future.[1] Adjusted for taxes and risk, interest rates also represent the marginal rate of return on investment (the rate on the last dollar of investment), or the rate—given the existing stock of resources, capital, technology, and labor—at which savings can be converted into future income.

If people had less of a preference for current consumption (a lower time preference)—and thus lower discount rates—they would save and invest more of their current income. Because highly profitable investment opportunities are not unlimited, people's pursuit of increasingly less profitable ones would drive down the marginal rate of return. Ultimately, their lower time preference would be reflected in a larger stock of capital, greater output and income, and lower interest rates. Conversely, greater preference for current income would be reflected in lower future income and higher interest rates.

Economists who analyze public policy reason that if a public investment is going to improve public welfare, it should produce rates of return similar to those of the private investments that it displaces. So in analyzing the costs and benefits of policies intended to avert climate

1. Physical capital is land and the stock of products set aside to support future production and consumption. Human skills—education, training, work experience, and other attributes that enhance the ability of the labor force to produce goods and services—are sometimes referred to as human capital.

Those assessments and their findings are best thought of as general illustrations rather than as exact calculations of the cost of optimal policies. Analysts must make many simplifying assumptions for such evaluations; consequently, every study excludes some potentially important dimension—dealing with different gases, technologies, countries, generations, environments, and so forth. Nonetheless, integrated assessments provide a sense of the relative importance of different factors, highlight those of greatest importance, and help policymakers focus on the trade-offs involved.

Integrated assessments of the potential costs and benefits of averting climate change typically find relatively small net benefits from stringent emissions controls in the near term, even though they conclude that the continued growth of emissions could ultimately cause extensive physical and economic damage. In balancing alternative investments, the assessments conclude, modest restrictions on emissions today would yield net benefits in the future, but extensive restrictions would crowd out other types of investment. The loss of that investment would in turn reduce the rate of economic growth and thus damage future generations' material prosperity even more than the avoided climate change would have.

Integrated assessments generally conclude that the most cost-effective way to respond to the risks of climate change is through a gradual process of adjustment. Several considerations support that conclusion (see Wigley, Richels, and Edmonds, 1996):

Box 1.

Continued

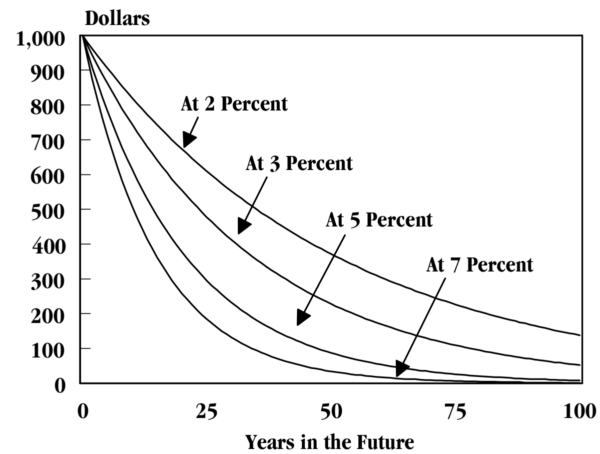
change, economists typically apply discount rates that are similar to market interest rates, after adjusting for taxes, risk, and inflation. Those discount rates reflect the distributional choices that people in the economy, taken together, actually make.

However, conventional discounting arouses a great deal of controversy when it is applied to long-term issues because at discount rates that approximate market rates, even very large long-term costs and benefits are dramatically devalued (*see the figure*).[2] The choice of discount rate therefore makes a huge difference in thinking about long-term problems such as climate change.

2. For instance, imagine a stream of income equal to your current income but beginning in the year 2200 and stretching into the distant future. In one sense, that stream of income is not worth anything to you today because you will not be around to enjoy it. However, you might wish to make an investment today to ensure that your descendants will have that income. If you evaluated that extended stream of income at a discount rate of 2 percent, it would be worth one year of your present income to you today. At 3 percent, it would be worth one month of your current income. At 5 percent, it would be worth half a day's income, and at 7 percent, it would be worth 10 minutes of income.

Long-term discounting has such a strong effect precisely because private investments yield relatively high rates of return. As long as society continues to have extensive opportunities for investment, it will be able to set aside modest resources today, continuously reinvest the earnings, and have enormous wealth in the distant future. If income continues to grow at 20th-century rates, future generations will have much greater resources than current generations have to offset a climate-related loss of well-being.

The Present Discounted Value of $1,000



Source: Congressional Budget Office.

- Much of the energy-using capital stock is in the form of very long lived power plants, buildings, and machinery. Gradual adjustment would give people time to use up the existing stock and replace it with more-efficient equipment.

- When viewed from the present, the cost of reducing emissions in the future is cheaper because of discounting.

- Technological change will probably lower the cost of controlling emissions. (In addition, it might take a long time to develop alternative technologies, and there would be more incentive to engage in research and development over the long term if it was fairly certain that the policies in place were gradually going to create a large market for nonfossil energy.)

- People are likely to be wealthier in the future and therefore may find it easier to pay to reduce emissions. If income and wealth grow and technology improves as expected, future generations may find it relatively easy to cope with the impacts of climate change and to gradually impose increasingly strict restraints on emissions to avert further change.

- At least for carbon dioxide, emissions that occur sooner rather than later will have more time to be absorbed from the atmosphere by the oceans. As a result, any given future target for concentrations could be met with

Box 2.

An Example of Integrated Assessment

A recent study by William Nordhaus, reported in 2000, illustrates how integrated assessment can be used to analyze the trade-offs involved in climate policy.[1] Drawing on an extensive review of the literature, the study concluded that modest warming of up to 2.3° Fahrenheit (1.3° Celsius) would have essentially no net impact on the world economy and might even yield some net benefits. But the study also concluded that in the absence of efforts to reduce emissions, the average global temperature would rise by about 3.6°F (2.0°C) over the next century and by 6.1°F (3.4°C) over the next two centuries. Those changes would inflict damages—measured as a reduction in world economic output—of roughly 1.0 percent (about $1 trillion in 2000 dollars) in 2100 and about 3.4 percent (nearly $7 trillion) in 2200. Such damages would include losses of agricultural land, forests, fisheries, and freshwater resources; gradual inundation of coastal areas as sea level rose; adverse effects on people's health; and, to some extent, possibly catastrophic surprises.

Yet the study concluded as well that those significant damages would have only a relatively minor economic impact because the world economy was likely to grow very rapidly over the period. Under the study's "best guess" assumptions, costs and benefits would be best balanced by imposing a charge today on greenhouse gas emissions throughout the world of roughly $10 per metric ton of carbon (mtc) and gradually raising that charge at a pace related to the rate of global economic growth.[2] (More-rapid economic growth would lead to higher levels of emissions and therefore require an emissions charge that also grew more rapidly.) By 2100, the study's recommended policy would have reduced global emissions by only about 10 percent. The cumulative reduction in emissions over the century would have little effect on average global warming, reducing it from about 4.4°F to 4.2°F (2.5°C to 2.4°C).

The study found little net advantage in averting climate change because the assessment balanced current prosperity against future prosperity and the future benefits of economic growth against the future benefits of a stable climate. To avert climate change over the long run, society would have to reduce emissions both today and later. That policy would reduce current generations' prosperity and slow the rate of economic growth, thus leaving future generations less affluent, too. Given the contribution of fossil fuel use to both economic growth and climate change, the study found little benefit in slowing warming.

Sensitivity to Assumptions

The study's results were strongly influenced by its estimates of how much warming would occur in the future and of the impacts from such warming. Another important factor was its assumptions about how future generations would value those effects. More-rapid warming from a given quantity of emissions would justify higher charges on emissions, as would a higher level of damages from a given amount of warming. But if those greater damages occurred sufficiently far in the future, they would not justify higher charges on emissions today. For instance, if warming of more than 4.5°F (2.5°C) would cause an economic catastrophe, it would be cost-effective to impose very high emissions charges as warming approached 4.5°F toward the end of the century to force the economy to move away from its reliance on fossil energy sources. Even in that case, however, the most cost-effective approach would still be to impose relatively small charges on emissions today and then raise them rapidly in the future.[3]

Like the results of all such assessments, the Nordhaus study's findings were also strongly tied to its assumptions about the sources of future growth and its weighing of the welfare of current generations against that of future generations.[4] Apply-

1. The estimates provided here, which are in 2000 dollars, come from Nordhaus's DICE99 model, available as an Excel spreadsheet file at www.econ.yale.edu/~nordhaus/homepage/homepage.htm. The model is a recent update of the original DICE model (described in Nordhaus, 1994), which was one of the seminal integrated assessments of climate change. Both models address emissions only of carbon dioxide rather than of all greenhouse gases, but the results roughly generalize to policies that include all gases.

2. An emissions charge of $10 per mtc would add about $5 to the price of a short ton of coal, about 2.5 cents to the price of a gallon of gasoline, and about 15 cents to the price of a thousand cubic feet of natural gas.

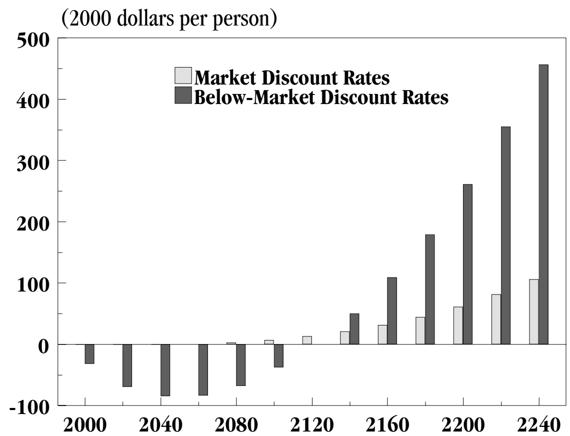
3. Keller and others (2000) come to a similar conclusion in a study that explicitly considers the possibility of a shutdown of thermohaline circulation.

4. The study imposed a discount rate that gradually declined from over 4 percent today to under 3 percent in 100 years. Those rates led the model to assign a present value of about $25 billion—one-fortieth the future value—to a trillion dollars of damages a century from now. The rates had two components. The first and

Box 2.

Continued

Projected Benefits of Climate Mitigation Under Different Discount Rates



Source: Congressional Budget Office, using the DICE99 model.

ing a lower discount rate gives more weight to the well-being of future generations, shifting the balance of costs and benefits in favor of investing more to reduce emissions today (and investing more in other kinds of capital formation as well). An extreme case would be to apply a discount rate that took into account only the expected gradual increase in future generations' well-being that sprang from economic growth. Such a rate would still discount events a century from now by about two-thirds, but it would justify much higher current charges on emissions—on the order of $160 per mtc—to balance current and future costs and benefits. That stringent a policy would slightly reduce the consumption of people alive over the coming century but greatly increase the consumption of succeeding generations (*see the figure*).[5] Conversely, a higher discount rate would give more weight to the present and shift the balance of costs and benefits in favor of less investment and more consumption today.

The study's recommended policy is much less sensitive to estimates of costs for abating emissions than to the choice of discount rate.[6] If abatement turned out to be considerably cheaper (or considerably more expensive) than the study's "best guess," the recommended charge would still be roughly $10 per mtc, but it would induce greater (or fewer) reductions in emissions.[7]

Evaluating the Integrated Assessment Method

The Nordhaus study illustrates both the usefulness and the limitations of integrated assessment. On the plus side, the study assesses different aspects of the climate problem in a consistent, relatively simple framework. It also provides a point estimate based on best guesses about global economic growth, energy use, and emissions; the climate's response to rising greenhouse gas concentrations; the economic value of the resulting impacts; and the discount rate. The model's simplicity helps analysts understand how changes in those assumptions affect estimates of costs and benefits.

On the minus side, the assessment includes only energy-related carbon dioxide emissions. Moreover, it ignores distributional issues within generations, in part because it combines all impacts into a single estimate—which offers little insight into the extent to which positive and negative effects might offset each other or might be experienced by different groups of people. (Nordhaus, 2000, addresses some international distributional issues in an extension of the model discussed here.) The model is also based on crude guesses about the value of changes in unmanaged ecosystems, for which there are no market measures. Perhaps most important, it does not explicitly consider the wide range of uncertainty that exists on many dimensions—which, if incorporated into an assessment, can strongly influence its conclusions.

dominant one simply reflected current generations' preference for income today over income for future generations. The second, relatively minor, component took into account that future generations would be wealthier than current generations, so an additional dollar of income would be worth less to them than to people alive now.

5. Lower discount rates would also justify much higher rates of investment than society currently undertakes, so they would not be consistent with the market's balancing of the welfare of current and future generations.

6. Compared with the range of cost estimates in the literature, the Nordhaus study assumed that it would be relatively inexpensive to reduce emissions and that technological improvements would make such reductions even easier over time.

7. In the Excel version of DICE99, raising marginal abatement costs tenfold reduces the abatement rate by a factor of eight but raises the currently cost-effective charge on carbon by only 3 percent. Reducing marginal abatement costs by a factor of 10 raises the abatement rate by a factor of six; however, it reduces the cost-effective charge by only about 20 percent.

somewhat greater total emissions over the next century if the bulk of the emissions occurred early on.

Box 2 on pages 30 and 31 summarizes findings from a particularly well-known integrated assessment model developed by William Nordhaus. The study illustrates how integrated assessment can be used to provide a "best guess" of the climate policy that would yield the greatest net benefits and how sensitive that sort of estimate is to the assumptions built into the assessment. However, the study does not explicitly consider the wide range of uncertainty about scientific and economic aspects of climate change—the topic of the next section.

Coping with Uncertainty

The extensive scientific and economic uncertainty discussed in Chapter 2 greatly complicates assessment of the costs and benefits of averting climate change. No one wishes to undertake extensive, expensive actions to solve a problem that turns out to be relatively mild—or to take no action to solve a problem that later proves catastrophic. Policymakers are thus forced to hedge their bets and prepare for more than one possible outcome, with the additional complication that whatever outcome occurs is likely to be largely irreversible.[6]

In general, uncertainty about a problem may indicate the need for more, or less, action to address it, depending on the nature of the unknowns (Webster, 2002). The amount of appropriate action also depends on how risk-averse people are—that is, how much they are willing to pay to avoid an uncertain but costly outcome. The greater their degree of risk aversion, the more people will be willing to sacrifice today to reduce the likelihood of adverse changes in climate.

Studies that explicitly account for uncertainty generally recommend greater effort to avert climate change than do analyses that do not account for it—mainly because the studies include the long-term discount rate as an uncertain variable.[7] However, the way those studies treat uncertainty about the discount rate in effect simply applies greater weight to future generations and therefore recommends more action. Because the issue of discounting is mainly a distributional one, many analysts question whether it should be treated as a matter of uncertainty in the same sense that, say, the sensitivity of the climate to carbon dioxide concentrations is uncertain.

Another area of uncertainty—often ignored in economic analyses—involves the actions of governments in the future. Integrated assessments that conclude that only modest actions are called for today assume that policymakers will in fact take more-stringent action in the future, should it prove prudent. However, governments may not be able to commit themselves to increasingly stringent future policies. That problem is part of a broader difficulty in addressing long-term challenges: current generations have few means to constrain the behavior of succeeding generations.

Because of uncertainty and the long time frame involved, climate policy will inevitably involve a sequence of decisions. At each stage, policymakers would determine a near-term plan, based on the information accumulated to that date and composed of both research to further improve knowledge and action to reduce risk. The information uncovered during the succeeding period would set the stage for the following round of decisionmaking.

Because better information can help policymakers make better choices, there are likely to be benefits to conducting climate-related research and developing technological options to reduce the cost of controlling emissions. One

6. Climate policy involves a degree of irreversibility in both mitigation and impacts. On the one hand, expensive investments to reduce emissions will be impossible to recoup if warming proves modest or largely beneficial. On the other hand, emitted greenhouse gases are likely to be difficult to withdraw from the atmosphere if warming proves to be very damaging.

7. An analysis of climate-related uncertainty can be found in Nordhaus (1994); two analyses that expand on that work are Pizer (1997) and Newell and Pizer (2001). Because small changes in the discount rate can significantly shift the balance of current and future values, uncertainty about the discount rate dominates those analyses. Under the studies' assumptions, costs and benefits would be balanced by imposing an international charge on greenhouse gas emissions of roughly $15 to $20 per metric ton of carbon equivalent (in today's dollars) and raising the charge gradually over time. That estimate is nearly double the estimated charge when uncertainty is not taken into account. Evidence from a wide variety of estimates of mitigation costs suggests that such a charge would reduce global emissions by roughly 4 percent (Lasky, forthcoming).

recent analysis estimated that the potential benefits of research to reduce uncertainty about the risks of climate change could total roughly $1 billion to $2 billion per year in 1990 dollars ($1.3 billion to $2.6 billion in 2002 dollars).[8] About half of those benefits of research would come from better information about the value of damages from different amounts of climate change. Another quarter would come from better information about how much it would actually cost to reduce emissions. Relatively little of the total benefit would come from better information about future growth of the global population or particular nations' economies, or about the functioning of the climate system.

Other studies suggest that research to accelerate the development and deployment of low-emissions technologies might yield net benefits, given the current range of uncertainty about future technological advances (see, for example, Papathanasiou and Anderson, 2001). The benefits would flow from lowering the cost of such technologies and thus making the transition to nonfossil energy less expensive than it would otherwise have been if potential damages from climate change had turned out to be large.

Distributional Issues

Crafting climate policy involves not only balancing costs and benefits but also distributing them—within and among countries, regions, and generations. Policies that balance overall costs and benefits do not necessarily balance them for every person, and policies that maximize the net benefits to society do not necessarily provide benefits to each individual. A policy may yield positive net benefits by causing both very large aggregate losses and only slightly larger aggregate gains.[9]

Distributional concerns are at the heart of much of the controversy about climate policy. For example, imposing controls on emissions today would cut coal mining companies' profits but would benefit manufacturers of solar energy equipment. Preventing climate change in the future might greatly benefit countries at very high risk of damage but might actually hurt countries that stood to gain from a warmer climate. Similarly, emissions control policies would impose costs on people today and yield benefits to people in the future.[10]

Issues Among Generations

Acting to prevent climate change today would place a burden on people now alive and would probably leave coming generations with a climate more similar to today's—but with somewhat less wealth—than they would have had otherwise. In contrast, not acting would benefit people today and probably yield somewhat more wealth in the future—but it might also leave the world with a different and possibly worse climate for many generations to come.

Choosing among policies is not purely a matter of balancing costs and benefits but also a question of how to distribute the benefits of energy consumption, land use, and climate among generations. Policy recommendations from the integrated assessments described earlier are very sensitive to such intergenerational choices. (Howarth, 2001, provides an example of an integrated assessment that explicitly considers intergenerational equity.)

Instead of restricting emissions, current generations could address these distributional concerns by making additional capital investments to benefit future generations, with the intention of offsetting potential future damages from climate change or of compensating future generations for

8. Nordhaus's and Popp's analysis (1997, pp. 1-47) measures only the expected benefits of research and not what the required studies would cost.

9. In studying economic problems, economists seek policies that will improve economic efficiency—that will make at least one person better off without making anyone worse off. Such policies are termed *Pareto improvements*. However, many policy proposals whose net benefits exceed their net costs also have substantial distributional effects. That is, the improvements are worth more than the losses, all told, but some people are made worse off even while others are made better off. Economists refer to such policies as *potential Pareto improvements*: in principle, the winners could compensate the losers for their losses and still be better off. Such a policy passes a standard cost-benefit test but could still make many people worse off unless it also provided for their compensation.

10. Gradually rising emissions taxes or permit prices would also effectively imply a particular distribution of emissions rights across generations.

those damages. However, because of uncertainty about the kind of damages climate change would cause, it is unclear whether (or how much) more capital would be necessary—or useful—to offset them. Also uncertain is whether intervening generations would pass the additional resources on to subsequent generations or consume the resources themselves.

Concerns Within and Among Countries

Dealing with the issue of climate change is likely to involve difficult decisions about distributing costs and burdens within countries. Some workers and industries—coal producers, electric utilities, and others—would probably bear a disproportionate share of the burden of restrictions on domestic emissions, as would the regions of a country that produced fossil energy. (The Congressional Budget Office discusses issues of equity in domestic climate policy in its 2000 report on carbon-allowance trading.)

Distributional concerns also dominate discussions of international climate policy and are likely to play at least as important a role in its development as the balancing of costs and benefits will. Policymakers in many developing countries emphasize that developed countries are responsible for the bulk of historical emissions and that many developing countries are apparently more vulnerable to—and less able to cope with—the more damaging effects of climate change. Such leaders tend to argue that developed countries should not only shoulder any near-term burden of reducing emissions but also compensate developing countries for climate-related damages. They also tend to be skeptical of arguments that favor balancing net economic costs and benefits, recognizing that such reasoning may be used to gloss over both distributional issues and disparities in impacts.

In contrast, other policymakers in both developed and developing countries tend to be less concerned about climate-related issues because they believe that their nations are not particularly vulnerable to potential changes in climate or will be able to adapt to whatever changes may occur.

CHAPTER

4

Trade-Offs Among Policy Options

Governments may respond to the challenge that climate change poses by adopting a "wait-and-see" approach or by pursuing research programs to improve scientific knowledge and develop technological options, regulating emissions, or engaging in a combination of research and regulation. Should policymakers decide to act, they can choose from among a wide variety of approaches to regulate emissions and encourage the development of low-emissions and emissions-removal technologies.

Several characteristics of greenhouse gases make it possible to lower the costs of regulation by allowing for a great deal of flexibility in controlling emissions. Different greenhouse gases, measured in metric tons of carbon equivalent, have essentially the same effect on climate; they mix uniformly throughout the atmosphere and will only gradually affect the climate as they accumulate over time. Consequently, which gas is controlled and where—and, to some extent, whether a given reduction in emissions occurs this year or next—are immaterial. That principle is often referred to as "what, where, and when" flexibility in discussions of climate policy.

Governments could control greenhouse gas emissions in a variety of ways. Under direct *command-and-control regulation*, the government could specify the types of equipment and technology that may be used, or it could specify energy-efficiency or emissions standards for buildings, vehicles, and equipment. Alternatively, the government could impose *emissions taxes or fees*, which would discourage emissions by increasing their cost. It could also directly control emissions through a system of *emissions permits*, or allowances, that would strictly limit the total quantity of emissions.

Another option combining elements of taxes and permits would be a hybrid permit system under which the government allocated a fixed quantity of permits but sold an unlimited number of additional permits at a set "trigger" price. In such a system, if the cost of reducing emissions rose above the trigger price, emitters would simply buy additional permits rather than reduce emissions further. The system would thus cap the incremental cost of emissions at the trigger price—acting, in effect, like a tax.

Although U.S. environmental regulations are largely of the command-and-control type, most economists agree that as a general rule, taxes or permits—loosely termed "market-based" systems—can control emissions while offering greater flexibility and lower costs. In contrast to direct controls, market-based systems give firms and households stronger incentives to find low-cost ways to reduce emissions through behavioral changes and innovative technologies.

In the case of carbon dioxide emissions from the burning of fossil fuels, the most direct approaches would involve taxes or permits based on the carbon content of fossil fuels.[1] Under either system, fossil fuel suppliers—pro-

1. The quantity of carbon dioxide emitted is directly proportionate to the carbon content of fuels and is therefore easy to measure. Carbon taxes fall most heavily on coal, which is composed almost entirely of carbon; they fall somewhat less heavily on petroleum products and least heavily on natural gas because those fuels also contain hydrogen. An emissions tax of $100 per metric ton of carbon equivalent translates to roughly $50 per short ton of coal, 25 cents per gallon of gasoline, and $1.50 per thousand cubic feet of natural gas. Other taxes on fuels—for instance, *ad valorem* (or value-added) taxes in proportion to sales prices or energy taxes in proportion to the energy content of fuels—would not be targeted

ducers and importers of coal, oil, and natural gas—would have to pay taxes or acquire permits in proportion to the carbon content of the fuel they sold. Such systems would be relatively simple to administer, monitor, and enforce if they were applied at the point of import or first sale because relatively few companies actually import or produce fossil fuels. The system would impose price increases or restrictions on output that would filter down the distribution chain, but it would avoid the administrative difficulties of a system that directly taxed "downstream" retailers and consumers.[2]

The relative ease of regulating energy-related emissions contrasts with the difficulties of regulating emissions from most other sources, particularly the substantial fraction that originates from forestry and farming. Because those other emissions come from many different kinds of mainly small sources under highly variable conditions, they tend to be much more difficult to track and measure. Although some such emissions could be regulated in a cost-effective manner (Reilly, Jacoby, and Prinn, 2003), controlling those sources would generally require different and varying approaches. That could complicate the regulatory process and might easily swamp the relatively low engineering costs of controlling some non-energy-related emissions.

For instance, carbon emissions from fossil fuels could be partly offset by paying landowners to plant trees to absorb and sequester carbon, thus reducing net emissions. Some tree planting is already supported for other purposes, such as soil conservation, and expanding those policies would be relatively straightforward. However, for the purposes of carbon sequestration, such policies are complicated by issues that do not arise in regulating fossil fuels. They include the costs of monitoring tree growth to determine how much carbon is absorbed and the difficulty of determining whether landowners would have grown the trees anyway. Another complicating factor is how sequestration activities might ripple through markets and affect carbon flows on agricultural and forest land not dedicated to sequestration. For instance, a decision to set aside a certain amount of forest for sequestration might lead to another area of forest being cleared that otherwise would have remained untouched. In that case, the carbon sequestered in the set-aside area would simply be offset by clearing elsewhere.

Taxes and Permits: Similarities and Differences

Taxes and permits affect a regulated activity in similar ways as long as people can buy and sell the permits on open markets. A tax on the carbon content of fuels directly raises the price of those fuels for the end user; a strict permit system indirectly raises the price by reducing the quantity of fuel that suppliers can sell. (As noted earlier, a fixed-price permit system works like a tax.) Either way, higher prices lead people to reduce their fuel consumption and thus their emissions. So for any level of emissions restrictions in a permit system, there is a corresponding tax level that will achieve the same purpose. In principle, both approaches should lead to identical levels and prices of emissions.

In practice, however, uncertainty about the costs and benefits of restricting emissions can greatly influence the relative cost-effectiveness of the two approaches. The government could impose a tax, expecting some level of reduced emissions; but emissions could end up higher or lower than it expected. Likewise, the government could impose a permit system with a cap on emissions and expect a given cost for meeting the cap; but that cost could end up being much higher or lower. And in either case, the price might not be consistent with the uncertain benefits of mitigating climate change. Which system is preferable depends on which type of uncertainty is the greatest and how rapidly costs rise—and benefits fall—as the government tightens restrictions on emissions.

Some research indicates that climate-related uncertainty gives an emissions tax (or fixed-price permit system) significant economic advantages over a system of strictly fixed permits, or allowances. Those advantages stem from two factors: both the costs and benefits of reducing carbon

specifically toward the carbon content and would therefore be somewhat less cost-effective in discouraging carbon emissions.

2. The characteristics of such emissions permit systems are discussed in greater detail in two studies published in 2000 and 2001 by the Congressional Budget Office. Another CBO study, published in 2002, discusses the relative merits of different approaches to regulating gasoline consumption, including a carbon tax.

emissions are uncertain, and the incremental costs can be expected to rise much faster than the incremental benefits fall as regulation becomes more restrictive. Because climate change will result only from the long-term buildup of gases over many years, incremental benefits are essentially flat in any given year; that is, the incremental benefits of the millionth ton of carbon reduced are essentially the same as those of the billionth. In contrast, the incremental costs of reducing emissions are likely to rise sharply the more emissions are constrained.[3] Thus, choosing to strictly limit the quantity of emissions could prove very expensive compared with the potential benefits, but choosing to impose a tax whose level reflected the expected benefits probably would not. A pricing system—of either taxes or fixed-price permits—is therefore likely to constrain emissions more cost-effectively than will a system with fixed limits on emissions.[4]

The Distributional Effects of Regulation

Regulatory systems generally create winners and losers, even when the benefits of less pollution are ignored. Balancing the distributional effects of such systems can be more complicated and controversial than balancing their costs and benefits. Economic analysis provides several useful insights about the distributional issues involved in regulating greenhouse gas emissions.[5]

Regulations Impose Costs

Regulations come with a price: one way or another, someone ends up paying for the environmental benefits they may generate. Households and firms, for instance, may have to make do with less energy, paying higher prices either directly or indirectly (in the form of lower wages, salaries, and profits)—or both.

Some analysts have argued that the regulation of energy markets might not be costly because energy conservation pays for itself. According to that point of view, people fail to use energy efficiently, either because they do not make sensible decisions about energy use or because they are poorly informed, or because they face a variety of market failures or barriers that deter them from making more-sensible decisions or becoming better informed. Proponents of that view believe that the government may be able to regulate energy use and emissions at a net savings to the economy by providing information, overcoming market barriers, and correcting market failures—for example, by including energy-efficiency requirements in standards governing buildings and appliances—and that the resulting energy savings may more than pay for the additional costs of more-efficient equipment.[6]

Although energy markets do not necessarily function with textbook perfection—for instance, energy use produces pollution, the electricity distribution system is largely composed of regulated monopolies, and the electricity industry remains heavily regulated—neither are governments always able to correct energy market failures without imposing other costs that offset or even exceed the savings that the corrections might achieve. For example, inefficient electricity consumption is sometimes the result of regulations that are intended to prevent monopoly behavior by utilities. Nevertheless, governments may be able to intervene in some circumstances—for instance, by setting standards in markets in which reliable product information is hard to obtain or in situations in which specific regulatory failures may constrain businesses and households from making the most cost-effective capital

3. In technical terms, price controls dominate when the marginal cost curve is steep or very uncertain and the marginal benefit curve is flat; quantity controls dominate when the marginal cost curve is flat or well understood and the marginal benefit curve is steep. A permit system would be more appropriate than a tax system if the unit cost of reducing emissions was relatively constant while the incremental damages from emissions increased very quickly with rising emissions levels. Weitzman (1974) and Pizer (1997, 1998, 1999) discuss these issues in more detail.

4. The balance could shift in favor of a strict permit system if technological advances made large reductions in emissions possible at a low unit cost that was more or less fixed.

5. Congressional Budget Office (2000) discusses the distributional impacts of different control policies for greenhouse gases.

6. Sutherland (2000, pp. 89-112) examines the differences between this "energy conservation" view and that of mainstream economics. A recent report from the energy conservation standpoint, prepared by five U.S. Department of Energy national laboratories, can be found in Interlaboratory Working Group (2000). The Energy Modeling Forum, in a 1996 report, offers a comprehensive discussion of the difficulties of identifying and measuring market failures and barriers in the energy sector.

investments. Economists find it difficult, however, to determine the circumstances in which standards clearly induce people to reduce their use of energy at no cost or with net savings.[7]

Consumers Bear Most of the Direct Costs in the Long Run

Producers who are required to pay a tax will not necessarily bear the burden of the tax if they can pass it on to others. Characteristics of the markets for fossil fuels would enable producers to pass on most of the costs of emissions taxes—or the burden of higher prices under a permit system—to consumers.[8]

Nevertheless, producers would still bear some of those costs in the short run. And many firms and workers in the energy sector—coal mine operators and miners, oil companies, and electricity producers that rely on fossil fuels for generation—would bear a disproportionate burden in lost profits and wages. (In the oil sector, however, foreign oil producers would probably bear a significant portion of those losses.) So would companies and workers in energy-intensive industries such as petroleum refining, primary metals, chemicals, and paper.[9] In contrast, alternative energy suppliers would tend to benefit from higher demand for their products, as would natural gas producers (since natural gas contains much less carbon per unit of energy than coal does).

Regulations and Taxes Have Substantial Distributional Effects

A third important insight is that the distributional consequences of pricing and permit systems can be very large compared with their costs and benefits. Whenever the government restricts something of value, people will bid up the market price in trying to obtain it. The difference between the supply, or production, price and the higher market price is known as a *scarcity rent*.

If the government restricts emissions by imposing a tax, it will receive the scarcity rent as tax revenues. By contrast, if it imposes a permit system and gives the permits away, the permits' recipients will receive the scarcity rents as higher profits—because they can either charge higher prices for the fuel they sell or sell the permit. The income received as tax revenue or scarcity rents can be many times larger than the net efficiency loss.[10] One important consequence of that fact is that efforts to restrict emissions may encourage the affected parties to seek regulatory provisions

7. In recent years, the U.S. government has tried to restrain the growth of emissions through a system of voluntary programs that attempt to identify opportunities for low-cost or costless emissions reductions and to promote them in the private sector. However, the programs have not been very successful in controlling emissions. For example, the Climate Change Action Plan developed in 1993 by the Executive Office of the President projected that voluntary programs would nearly stabilize U.S. greenhouse gas emissions at 1990 levels in 2000. (The plan is available at www.gcrio.org/USCCAP/toc.html.) In fact, emissions were roughly 12 percent higher in 2000 than they had been at the beginning of the decade. The plan's failure was due in part to unexpectedly high levels of economic growth and low energy prices. Nevertheless, the voluntary programs' successes are very difficult to evaluate because it is nearly impossible to determine what businesses and households would have done in the absence of the program. Welch, Mazur, and Bretschneider (2000) present a rigorous study that concludes that one such program had relatively little effect on emissions.

8. The supply of fossil energy is fairly elastic: for example, coal suppliers can easily raise or lower their production in response to small changes in coal prices. Moreover, demand for fossil energy is fairly inelastic because currently there are few cheap, plentiful substitutes for it. Inelastic demand and elastic supply together imply that energy producers can pass on taxes to consumers.

9. The Department of Energy (1997) notes that those four industries accounted for about 22 percent of manufacturing gross product originating in 1994 but 78 percent of manufacturing energy use. Yuskavage (1996) also treats this issue; updated data can be found at www.bea.doc.gov/bea/dn2/gpo.htm.

10. Tax revenues equal total emissions under the tax times the tax, whereas the net economic costs from the tax (called the *efficiency loss*, or the *deadweight loss*) are roughly one-half the tax times the reduction in emissions. A higher tax raises more revenues, but it reduces emissions even more; so the income loss rises faster than the tax revenues, and the ratio of revenues to income loss declines. For example, based on the analysis of the potential costs of the Kyoto Protocol by Lasky (forthcoming), a reduction of 5 percent in U.S. carbon dioxide emissions in 2010 would involve direct costs of just over $1 billion but would raise almost $50 billion in revenues. However, a reduction of 15 percent would cost $12 billion (10 times as much) and raise over $150 billion in revenues (less than four times as much); a reduction of 30 percent would cost almost $60 billion and raise $330 billion in revenues. In those examples, tax revenues (or permit values) are between six and 40 times the direct costs.

that provide them with tax exemptions or access to permits—that is, they may engage in rent-seeking behavior. For example, fossil fuel suppliers might advocate a system in which they were given emissions permits free of charge —so that they would receive the entire scarcity rent resulting from the emissions limits.

Distributional Effects Depend on How the Government Regulates Emissions

Under a system of taxes or auctioned permits, the government would receive revenues, and it could redistribute some of them in various ways—by cutting other taxes, reducing government debt, or funding new programs.[11] Each method of "recycling," or returning revenues to the economy, would benefit different groups of consumers and suppliers in different ways. Some of those approaches could offset some of the costs of regulation but probably not all of them.

The case of permits is more complicated than that of taxes because permits can be distributed in different ways: the government could auction them and receive revenues, it could give the permits away, or it could use a combination of the two approaches.[12] Auctioned permits are similar to emissions taxes in their distributional effects.[13] In contrast, freely allocated emissions permits would greatly benefit their recipients, who could reap profits from the now-scarce right to sell fossil fuels (while passing on most of the costs to fuel-consuming businesses and households) or from the sale of permits to a fuel supplier. One possible approach to a permit system, known as grandfathering, would be to give all the permits to fossil fuel suppliers in proportion to their historical sales. Another method would be to distribute permits free to households and require that fuel suppliers buy them. Suppliers would then include the cost of the permits in the price of fuel. That approach would spread regulatory costs more evenly across the population but would also involve high transaction costs.

Alternative Uses of Revenues

Most government revenues are collected from income, payroll, and sales taxes, which tend to distort taxpayers' behavior by discouraging people from working or saving. The government also uses tax incentives to encourage certain types of activities—for example, home ownership, through the home mortgage interest deduction. Such subsidies distort households' and businesses' behavior by encouraging greater spending on tax-favored goods and services, relative to spending on other items. In economic terms, taxes and tax incentives impose significant losses of economic efficiency.[14]

In contrast, emissions restrictions are intended to correct existing market failures—and thus improve economic efficiency—by discouraging harmful emissions. (When those restrictions take the form of taxes, they are referred to as Pigouvian taxes.) Of course, the restrictions also discourage productive activity to some degree and so impose a direct cost on the economy. However, if the restrictions

11. Not all of the revenues from an emissions tax would be available for redistribution. The tax would curb economic activity, reducing other tax revenues and raising government spending for income-related programs. The tax would also raise the government's costs for purchasing fossil energy and energy-intensive goods. As a consequence, some emissions tax revenues would be needed to cover higher spending and lost revenues from other taxes. However, emissions tax revenues would generally be greater than policy-induced increases in government expenditures and revenue losses from other taxes, so net government revenues available for redistribution would rise.

12. Regarding auctions of permits for greenhouse gas emissions, Crampton and Kerr (1998) show that a standard ascending-clock auction is the most effective system to ensure that all bidders pay a uniform price that reflects the market value of the standard emissions permit. Under that kind of system, the auction would begin at a low asking price, and in each succeeding round, the price would rise and bidders would reveal the number of permits they wanted to buy at that price. The process would continue until the number of permits demanded was exactly equal to the number being auctioned.

13. Even if the government gave permits away, it would collect some revenues because permit recipients would pay taxes on their higher income. However, the government would also lose revenues from other taxes and would spend more on transfers, fossil energy, and energy-intensive goods.

14. Congressional Budget Office (1996) and Gravelle (1994) examine the distorting effects of taxes on labor supply and on saving and investment, respectively.

were set at an appropriate level, their cost would be balanced by the benefits of lower levels of emissions.

But there is a catch: emissions controls—be they taxes, permits, or old-fashioned command-and-control regulations—also interact with the existing tax system and tend to aggravate its distortions. For instance, emissions restrictions would raise the prices of energy-intensive products, thus lowering real (inflation-adjusted) wages and further discouraging people from working. Through that sort of tax interaction effect, any regulation that raised the prices of products and lowered income would also impose additional, hidden costs by enhancing the distortions caused by the existing tax system. The more distortionary the existing system, the larger the interaction effect—and the higher the hidden costs—tend to be.[15]

However, policymakers could offset at least part of the interaction effect by using the revenues from the emissions tax (or auctioned permits) to reduce the marginal rates—the rate on an additional dollar of taxed activity—of some existing distortionary taxes.[16] Some analysts (for example, Jorgenson and Goettle, 2000, and Shackleton and others, 1993) argue that emissions taxes could even yield a "double dividend" of fewer emissions and more output if the revenues were used to eliminate particularly distortionary taxes in the current code—especially taxes that discourage saving and investment.[17] The existing research on the question is not definitive, however.

Emissions restrictions that raised revenues, coupled with reductions in distortionary marginal tax rates, would impose significantly lower economic costs than emissions controls would in two circumstances: if the controls did not raise revenues (as in the cases of command-and-control regulations or freely allocated permits) or if they returned revenues to the economy in ways that did not reduce distortionary marginal rates. Policymakers would face a tradeoff between using such revenues to offset some of the distributional effects of emissions controls (by making payments to affected producers and consumers) and using the revenues to offset some of the controls' effects on economic efficiency (by reducing marginal tax rates). As a general rule, policymakers cannot fully achieve both goals.

These points are true for any sort of regulation, but they are particularly applicable to climate change policy because greenhouse gas regulations could involve so much money. The United States alone emits roughly 1.5 billion metric tons of carbon annually, so every dollar of tax per mtc would raise up to $1.5 billion per year. A carbon tax of $100 per mtc would raise about 15 percent as much revenue as the individual income tax and nearly 80 percent as much as the corporate income tax. Those large amounts suggest that some of the revenues from a carbon tax could be used to finance cuts in marginal income tax rates.

Emissions could also be reduced by eliminating subsidies and tax incentives that encouraged the production and consumption of fossil fuels or that encouraged deforestation. In the United States, such subsidies and incentives are fairly modest, and removing them would have relatively little impact on emissions (Congressional Budget Office, 1990).[18] But many developing countries heavily

15. For discussions of the tax interaction effect, see Congressional Budget Office (2001), Parry (1997, 2002), Parry and Bento (1999), Parry and Oates (1998), and Parry, Williams, and Goulder (1996).

16. That "revenue recycling" effect could be particularly strong in the presence of tax incentives such as the home mortgage interest deduction (see Parry, 2002). However, as discussed in Babiker, Metcalf, and Reilly (2002), if the existing tax system was sufficiently distortionary, some forms of revenue recycling might actually enhance the interaction effect, so that the negative economic effects of the emissions tax would actually outweigh the positive environmental benefits.

17. Proponents of the "strong" version of the hypothesis argue that substituting appropriately set environmental fees for existing taxes would more than offset the tax interaction effect and thus improve both the environment and the economy. Proponents of the "weak" version argue that such a substitution would offset at least part of the tax interaction effect. The potential for a double dividend depends mainly on the distortions of the existing tax system and is thus more a statement about the existing system than about the benefits of emissions taxes. In principle, policymakers could also reduce the existing system's distortions by replacing it with other, less distortionary taxes. That alternative would tend to lower the potential for a double dividend from an emissions tax.

18. Using a conservative definition, the Department of Energy's Energy Information Administration (1992, 2000) estimates that federal subsidies and tax incentives to the energy sector amounted to about

subsidize energy use and land development. In those economies, the elimination of subsidies might lead to both reduced emissions and higher output.

Proposals for emissions taxes sometimes include a provision that the revenues be used for environmental purposes, such as an investment tax credit for energy-efficient equipment. Some studies suggest that such tax credits are considerably more effective than equivalent energy price changes in encouraging users to purchase such equipment, perhaps because purchasers focus more on up-front capital costs than on longer-term operating costs or because they are more uncertain about longer-term costs (see Jaffe, Newell, and Stavins, 2000, pp. 51-52 and 63).

However, such tax credits also have disadvantages. An emissions tax is intended to signal polluters to cut emissions; in effect, a tax credit for abatement distorts that message. Tax credits can cost the government a great deal per unit of reduced emissions, since purchasers who would have bought the equipment even without the credit receive it, too. Taken together, the literature on environmental taxation and revenue recycling suggests that using revenues from emissions taxes to finance a general reduction in taxes on all sorts of investment would be more cost-effective than using them to target investments for environmental purposes (Oates, 1992; and Baumol and Oates, 1988).[19]

Regulation and Innovation

To a great extent, the cost of controlling greenhouse gas emissions and stabilizing atmospheric concentrations will ultimately depend on technological developments over the next century. Innovation that dramatically reduces the cost of producing energy from nonfossil sources or of sequestering carbon dioxide emissions will ease the process of controlling emissions; innovation that tends to reduce the cost of finding, extracting, and using fossil fuels will complicate it.

Although technological innovations over the long run are impossible to predict with any reliability, relative energy prices have influenced the direction and pace of research and development (R&D). For instance, when energy prices rose in the 1970s, not only did people use less energy and install more energy-efficient capital goods but businesses shifted resources into the development of energy-efficient equipment, more-efficient ways of finding and extracting fossil fuels, and alternative energy sources (Newell, Jaffe, and Stavins, 1998; Jaffe, Newell, and Stavins, 2000; and Popp, 2001).[20]

Emissions controls that raised the prices of fossil fuels would be likely to have somewhat similar effects, tending to redirect R&D efforts from finding more fossil fuels to improving energy efficiency, developing alternative sources of energy, and removing greenhouse gases from the atmosphere. Over time, those efforts would tend to lower the incremental cost of controlling emissions, reducing the tax (or permit price) needed to achieve a given emissions target and inducing more reductions at a given tax rate. Moreover, emissions controls are likely to induce more innovation if they exact a payment from emitters, as emissions taxes and auctioned permits do. In contrast, companies would have less incentive to innovate under a system of freely allocated permits—and even less under a command-and-control regulatory system.[21]

Although the inducement effect would tend to lessen the incremental costs of controlling emissions, analysis suggests that such benefits would be offset to some extent by the costs of research and development (Goulder and Schneider, 1996). Some of the resources used to finance R&D projects would simply be redirected from the fossil

$7.3 billion in 1992 and $6.2 billion in 1999 (both in 1999 dollars)—or roughly 1 percent of total energy expenditures. Applying a much broader definition, a study funded by the Alliance to Save Energy and reported by Koplow (1993) estimates that subsidies in 1989 totaled from $21 billion to $36 billion in 1989 dollars—or from 5 percent to 8 percent of total energy expenditures.

19. Gravelle (1994, Chapter 5) provides a broader discussion of the cost-effectiveness of investment tax credits.

20. Some research—for example, Nordhaus's 1997 study—suggests that the innovation inducement effect of higher energy prices will not be very large, compared with the more basic inducement to substitute capital and labor for energy.

21. Under certain circumstances, which are discussed at length in Fischer, Parry, and Pizer (1998), freely allocated permits may induce more innovation than taxes or auctioned permits. However, the case of climate change does not involve such circumstances.

fuel sector, but some would probably be redirected from other economic activities.

Basic research is often considered to be a public good. Private firms have relatively little incentive to undertake basic scientific research on the functioning of the climate or on the costs and benefits of averting climate change because they cannot easily reap profits from the widespread, long-term public benefits of learning about or averting such change. Nor does industry have sufficient incentive to develop low-emissions and emissions-free energy technologies as long as the prices of fossil fuels do not reflect the potential costs of the damages to the climate that fossil fuel use may cause. Because of the disparity between private incentives and public benefits, the government may be able to play a useful role by investing in—or encouraging private industry to invest in—basic and applied R&D projects that will yield widespread public benefits. However, constraints on emissions would tend to enhance private incentives to undertake such projects and weaken that rationale for government-sponsored research.

Ancillary Benefits of Greenhouse Gas Restrictions

By reducing the use of fossil fuels, restrictions on greenhouse gas emissions would also reduce emissions of other pollutants such as sulfur dioxide from coal burning and nitrous oxide from automobiles. Those reductions, in turn, could yield a variety of benefits such as improvements in health, visibility, and water quality. Thus, the costs of mitigating emissions of greenhouse gases would be partially offset by the ancillary benefits of reducing the problems caused by conventional pollutants.

In the United States, some economic studies (for example, Burtraw and others, 1999; and Burtraw and Toman, 1997) have found that ancillary benefits from modest restrictions on carbon dioxide emissions in the electric utility sector could offset a significant part of the restrictions' cost. Those side benefits would include lower costs for complying with current and impending regulations that restrict conventional air pollution, and health-related benefits from reduced emissions of conventional pollutants that are not already strictly controlled. More-restrictive limits on greenhouse gases could also lead to reductions of conventional emissions beyond those already mandated, yielding further ancillary benefits. However, the more emissions were reduced, the smaller the share of total costs that the ancillary benefits would offset—mainly because the additional benefits from reducing conventional air pollutants would decline while the additional cost of reducing carbon emissions would continue to rise.

In developed countries that already control pollution, ancillary benefits from restricting greenhouse gas emissions are likely to be similar to those found in the United States. But in developing countries with extensive conventional pollution problems that remain unaddressed, ancillary benefits—such as improvements in people's health—could be significant.

CHAPTER

5

International Coordination of Climate Policy

Because the causes of climate change are global, the stabilization of greenhouse gas concentrations in the atmosphere will ultimately require international cooperation. However, the nature of the climate problem will make agreement difficult to reach. Near-term, concentrated costs of regulation combined with diffuse, long-term future benefits make it easy for countries to postpone action. The scientific and economic uncertainty discussed in earlier chapters also makes it difficult to reach a consensus about the appropriate response. Although nations have found it relatively easy to agree to expand, coordinate, and report climate-related scientific and technological research, they have found it very hard to agree about whether and how much to restrict the growth of greenhouse gas emissions.

That lack of agreement may stem in part from uncertainty, but it also reflects nations' differing circumstances and conflicting interests. Policymakers in countries vulnerable to potential changes in climate favor dramatic action to avert warming, while policymakers whose countries appear to be less vulnerable are correspondingly less concerned. Countries with significant fossil-fuel production or high levels of emissions tend to oppose policies that would restrict the use of fossil fuels. Five countries (the United States, China, Russia, Saudi Arabia, and Canada) produce more than half of the world's fossil carbon, and five countries (the United States, China, Russia, Japan, and India) account for about half of all fossil carbon consumption. Thus, a small group of nations can strongly influence the structure and effectiveness of any agreement related to climate change.

But the fundamental differences at the global level are between more and less affluent countries. Developed countries have contributed the majority of historical emissions, but countries that are now in the early stages of development will account for the bulk of emissions over the next century. Even so, on a per capita basis, developing countries will continue to have much lower income and levels of emissions than developed countries will have, and they appear to be more vulnerable to damage from climate change. As a consequence, policymakers in many developing countries favor significant action to reduce global emissions—but only by developed nations. Put another way, they maintain that developed countries have already used up a large portion of their rightful allotment of emissions and that developing countries now have a strong claim to the bulk of emissions to be allowed in the future —those that are unlikely to cause serious damage to the climate.

Because of the global nature of the climate problem and competing national interests, countries have little incentive to act unilaterally to reduce emissions, and every nation has an incentive to free ride and let other countries shoulder most of the burden. As a result, the development of effective coordination of international climate policy is likely to be gradual, as was the 50-year process that brought the World Trade Organization to its current form.

International Policy Considerations

In addition to considering the nature of the climate change problem and the distribution of interests, policymakers who seek to foster effective international coordination may draw from a wide range of past experience in the design and implementation of international environmental and other treaties, and of domestic regulatory systems as well. Some of the factors to be considered are purely international in scope. Other factors, which have been discussed in previous chapters, are common to domestic and international regulatory systems alike.

Cooperation among sovereign, independent nations can involve a variety of formal structures. Governments can agree to formal treaties, which are considered binding instruments under international law; or they can agree to less rigorous, nonbinding instruments—referred to as executive agreements in the United States—that serve as guidelines to action rather than as legal requirements.[1] Cooperation can range from modest commitments to share information and undertake coordinated research, to more extensive agreements to restrict emissions, monitor compliance, and enforce penalties.

Several other institutional considerations can influence the effectiveness of international agreements (Victor and others, 1998). Such agreements tend to be more effective when they:

- Encourage relatively frequent interaction and extensive sharing of information among national delegates;
- Help link the solutions of related problems, such as climate change and energy security or climate change and biodiversity;
- Give countries incentives to continue to participate even if other countries refuse to;
- Allow new countries to enter with relatively little effect on the system; and
- Distribute the cost of the response in a way that is acceptable to participating countries.

1. This distinction is particularly important in the United States, where the terms of treaties, once ratified, take on the force of federal legislation within the U.S. legal system. Under international law, however, both types of agreements are considered binding.

Regulatory Approaches

To regulate the global growth of emissions, international negotiators can draw on essentially the same set of options as domestic policymakers can: command-and-control regulations, emissions taxes or permits, or a hybrid system. Negotiators would need to consider whether and how to coordinate such policies among countries. Alternatively, they might allow each country to choose an independent system but still coordinate action in the form of agreed-upon national targets.

As Victor and others (1998) have noted, agreements are more likely to succeed if they involve commitments that are relatively straightforward to apply and enforce. Nations may find it easier to commit to undertake research programs than to adopt uniform technologies, complex regulatory policies, or specific targets for emissions. Targets may be particularly difficult to decide on or achieve in the face of uncertainty about implementation costs.

Past international agreements have called for varying levels of effort by different countries, but they have not usually called for formally differentiated commitments. Instead, countries tend to interpret their commitments in ways that reflect their different national circumstances and domestic goals. Given the complexities that policymakers face in securing domestic political agreement about implementation, the more ambitious the commitments, the more varied the implementations are likely to be.

Countries with relatively large absolute or per capita emissions, or with large fossil-fuel industries, are likely to insist on some degree of cost-effectiveness before committing themselves to restrictions on emissions—although political and distributional considerations may lead nations to ignore cost-effectiveness. An international command-and-control approach would be much more costly and difficult to monitor and enforce than would other approaches and is therefore unlikely to secure much backing.

Uniform international incentives are likely to be more cost-effective than country-specific regulations because every country has at least some low-cost opportunities to reduce emissions, whereas the incremental cost of controlling emissions in any given country is likely to rise steeply with increasingly tight restrictions. Developing countries have particularly extensive low-cost opportunities, for several reasons: many of the costs of production there tend to be relatively low; energy use is rarely taxed and often subsidized; and energy efficiency is cheaper to build into new infrastructure in developing industries than to retrofit in industries in developed nations. Restricting emissions in only a few countries—particularly developed ones—would therefore significantly raise the cost of achieving almost any global goal for emissions.

Differences between countries' emissions control policies can also lead to "leakage" of energy consumption—and therefore emissions—from one country to another. For instance, if only developed countries controlled emissions, they would consume less oil. International oil prices would fall in response, and developing countries would be able to increase their oil consumption. Similarly, corporations in emissions-intensive industries could simply reduce their investments in countries with stricter controls and increase their investments in countries with less strict or no controls, gradually transferring their production to them. That potential leakage effect would raise the cost and reduce the effectiveness of more-restrictive countries' commitments.

Independent action would allow each country to tailor policies to its national circumstances. But a system of independent approaches would still require international agreement about what constituted an acceptable degree of action and of burden sharing. It would also be unlikely to minimize emissions control costs, could lead to extensive leakage, and might present difficult problems in monitoring and enforcement.

Much of the debate about international climate policy has focused on national quotas, or allowances, for emissions. Under such a system, nations would agree to allocate emissions rights in the form of strict limits, or caps. The limits could apply to one-, five-, or 10-year periods, or indefinitely; nations would be free to meet the caps by using the domestic regulatory system of their choice. Some proposals would allow nations to trade emissions allowances. That feature would tend to equalize permit prices—and thus the incremental costs of mitigation—among participating countries and result in the most cost-effective achievement of the overall emissions cap.

A system of quotas would make the international allocation of rights transparent. If quotas could be enforced, they would ensure that a strict emissions cap was met in participating countries. Given a strict limit, the international trading of emissions allowances could equalize incremental costs, and the system would be relatively straightforward to implement—at least it would be if it was limited to carbon dioxide from fossil fuels—once countries determined how to allocate emissions allowances domestically.

However, an international cap on emissions could entail unnecessarily high costs if the cap was tighter than was warranted for balancing the overall costs and benefits of averting climate change. That pitfall could be avoided by implementing a hybrid permit system with a price cap —but only at the cost of abandoning strict emissions limits and clear emissions rights.

In contrast to quotas, a price mechanism—a system of uniform emissions taxes or fixed-price permits—would guarantee equal incremental costs for emissions controls at a fixed price without requiring any international trading of emissions allowances. Furthermore, as discussed in Chapter 4, price mechanisms are likely to constrain emissions more cost-effectively than strict quotas, given the uncertainty about the net benefits of doing so.

But price mechanisms also present problems. A system of taxes would not, by itself, address issues of international burden sharing. And maintaining strictly uniform taxes on emissions would be difficult in the face of fluctuating exchange rates. Moreover, in negotiating a uniform price mechanism, countries might want to consider the extensive variation in their existing energy taxes: even in the absence of price- or quantity-based controls, the effective price of carbon from fossil fuels differs significantly among countries and across fuels. Gasoline prices in western European countries, for example, are about three times higher, on average, than in the United States, largely because of taxes. In contrast, gasoline prices in many developing countries are lower. Countries that implicitly taxed emissions through their gasoline levies might argue that their existing systems constituted sufficient action and no further efforts were necessary.

Compliance

International agreements are particularly difficult to monitor and enforce because the parties to them are sovereign nations that tend to resist international oversight of domestic policies—and whose participation is ultimately voluntary. Few international environmental agreements have provisions for enforcement, and as a general rule, international organizations lack the jurisdiction or the resources to enforce them (General Accounting Office, 1999). To many observers, binding treaties with penalties seem more likely than nonbinding ones to ensure compliance, and experience shows that nearly all countries do, in fact, fulfill their binding commitments. However, given the uncertainty of politics and markets, governments cannot invariably ensure that they will be able to meet such commitments. They generally do so, not because they would face penalties for noncompliance but because they would not have agreed in the first place to commitments that they were unlikely to fulfill.

Some observers argue that for a problem as complex as climate change, international enforcement would require some form of penalty that involved trade and therefore indirectly the World Trade Organization (WTO). Recent decisions by the WTO have allowed nations to enforce environmental rules by penalizing imports on the basis of the processes used in their production (Victor, 2001, pp. 87-89). But some experts worry that entangling the WTO in complex environmental issues could endanger the international trade system.

Yet experience also shows that countries tend to be more willing to adopt clear, ambitious commitments when those commitments are nonbinding, especially when uncertainty about costs makes nations unwilling to accept binding agreements that they might not be able to fulfill. (Escape clauses in binding commitments can perform the same function.) Moreover, a nonbinding framework allows subsets of countries to undertake deeper cooperation without excluding others from an agreement and promotes learning by doing. The evidence thus suggests that in practice, nonbinding agreements may significantly influence behavior (Victor and others, 1998, p. 685).

Restrictions on greenhouse gases vary in the ease with which emissions can be monitored and the limits on them enforced. Under binding agreements, carbon dioxide emissions from the use of fossil fuels would be relatively easy to monitor, although in countries that had serious problems with law enforcement and tax evasion, compliance with the established limits could be difficult to achieve. For most other types of greenhouse gas emissions, the high costs of monitoring would reduce the likelihood of strict compliance—or even of accurate documentation—in all countries.

International Institutions to Address Climate Change

International cooperation to address the prospect of climate change has been developing since 1988, when the United Nations and the World Meteorological Organization created the Intergovernmental Panel on Climate Change (IPCC) to collect information and report on climate-related issues. Shortly thereafter, negotiations began on the United Nations Framework Convention on Climate Change (FCCC), which was signed in 1992 and subsequently ratified by nearly all the world's nations. The convention provides for a permanent standing bureaucracy dedicated to coordinating international climate policy and for a Conference of the Parties to meet roughly once a year to review and reconsider countries' commitments in light of the most recent findings on climate change.

The FCCC commits its signatories to undertake extensive research (to better understand the climate system) and to stabilize atmospheric concentrations of greenhouse gases at levels that would prevent dangerous climate change. The convention calls for managing the global climate in a manner that is both efficient and equitable, stipulating that climate-related policies should be cost-effective, but it also urges greater effort from a set of 35 developed countries that are listed in the FCCC's Annex I.[2] However, the convention does not specify any targets for greenhouse gas concentrations or a time frame for achieving stabiliza-

2. Specifically, the document states that "policies and measures should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors" (United Nations, 1997, article 3, section 3).

tion. Nor does it commit any country to specific limits on emissions or to specific actions to reduce emissions.

The Kyoto Protocol

After five years of international negotiations following the FCCC's adoption, the third Conference of the Parties adopted the 1997 Kyoto Protocol to the convention. The protocol calls for strict quantitative limits (or allowances) on emissions from 38 developed countries—largely the same ones listed in Annex I of the convention.[3] Those complicated limits, which are specified in Annex B of the protocol, are generally somewhat below the countries' 1990 emissions levels and are scheduled to take effect during the so-called First Budget Period, from 2008 to 2012. Non-Annex B countries remain exempt from overall emissions constraints.

Under the protocol, countries are allowed a significant degree of flexibility in meeting their commitments. Each country may:

- Use any policies or technologies it prefers to meet its targets;
- Achieve its overall target by reducing emissions over a "basket" of six different greenhouse gases rather than just reducing carbon dioxide emissions;
- Average its emissions across the entire five-year period rather than meet a specific target every year;
- Earn a limited quantity of credits (that is, additional allowances) for forestry and agricultural projects that sequester carbon;
- Receive credits by financing emissions-reducing projects in other Annex B countries through a process called Joint Implementation;
- Receive credits by financing projects in non-Annex B countries through another process known as the Clean Development Mechanism;
- Buy, sell, or trade emissions allowances to an undetermined extent; and
- Join with other countries to reduce emissions as a group.[4]

The protocol explicitly mentions that countries should pursue research and development programs but does not require a specific level of expenditures.

To enter into force, the Kyoto Protocol must be accepted, approved, acceded to, or ratified by at least 55 signatories to the convention, including countries that together in 1990 accounted for at least 55 percent of total carbon dioxide emissions from Annex I countries. In effect, the provision means that the protocol must be ratified or approved by either the United States or Russia, which together accounted for over 50 percent of emissions from Annex I countries in that year. It also means that a handful of countries with high levels of emissions could, if they acted together, effectively veto the protocol.

Subsequent Negotiations

The negotiations that followed those in Kyoto brought a substantial shift in direction. Talks collapsed in 2000 over a dispute between U.S. and European delegates about the use of international emissions trading and forestry programs to meet their commitments, with the United States arguing in favor of much greater flexibility than European

3. All of the countries listed in Annex B of the protocol are also listed in Annex I of the FCCC; however, a handful of Annex I countries are not in Annex B. The protocol specifies an annual limit on emissions, measured as metric tons of carbon equivalent for each Annex B country. The limit is figured as a percentage of the country's base-year emissions level. The base year is generally 1990, but countries can choose 1995 as the base year for hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. In addition, former Soviet bloc nations, under some circumstances, can choose an alternate base year for all gases. The specified limits are 93 percent of base-year emissions for the United States, 92 percent for the countries of the old European Community, and 94 percent for Japan. The countries of the former Soviet bloc have limits ranging from 92 percent to 100 percent of their base-year emissions levels. Other Annex B countries have limits ranging from 92 percent to 108 percent of their base-year emissions.

4. The countries of the European Union (EU), for example, intend to meet their individual targets as a group, with some countries reducing emissions by more than the amount required by their targets to allow emissions to increase in other countries while still meeting the overall EU cap.

countries would accept. In early 2001, the Bush Administration indicated that it would not continue to negotiate the terms of the protocol or submit the protocol to the Senate for ratification. Following the effective withdrawal of the United States from the process, the other parties decided to move ahead. In November 2001, they reached agreement on nearly all outstanding implementation issues, largely along the more liberal lines of interpretation that the United States had originally advocated. (Without U.S. participation to potentially drive up the demand for emissions credits, the liberal interpretation allowed the remaining parties to dramatically lower their likely implementation costs; Babiker and others, 2002, provide a detailed discussion.) The European Union ratified the protocol in May 2002, and Japan followed suit in June. As of March 2003, 106 countries had ratified or acceded to the protocol, and the ratifying countries accounted for 44 percent of the carbon dioxide emissions from Annex I countries in 1990 (United Nations, 2003). Ratification by Russia would bring the treaty into force.

Assuming ratification under the current terms of the protocol, participating Annex B countries would probably be able to meet their commitments at very little cost. They would have two sources of low-cost emissions credits: they could earn substantial credit for forestry projects, and they could supplement reductions of domestic emissions with purchases of emissions allowances and credits from other countries. A few nations are expected to have substantial amounts of surplus emissions allowances during the 2008-2012 period—particularly Russia and the Ukraine: their emissions fell dramatically during the economic collapse of the 1990s, and they have experienced substantial forest growth. (The expected surplus is often referred to as "hot air.") Without U.S. participation to boost demand, the remaining Annex B countries will be able to buy the surplus allowances and forestry credits at a low cost and meet their commitments without undertaking extensive domestic emissions reductions.

The upshot of these developments—assuming ratification and implementation by the remaining parties and full use of the treaty's many flexibility provisions—is that the protocol will result in relatively few commitments to undertake research, a complex set of emissions caps for a limited set of developed countries for the 2008-2012 period, financial transfers among the parties amounting to several billion dollars per year for the purchase of emissions allowances, unlimited emissions rights for most countries, and a very limited reduction in the growth of global greenhouse gas emissions.

Implementation Costs

The international negotiations surrounding the protocol inspired a large number of analyses of the cost to the United States of meeting its proposed commitments. Such analyses are complicated by uncertainty about how the details of implementation might have been negotiated in an agreement that included the United States. In a recent review of a number of studies, Lasky (forthcoming) has estimated U.S. mitigation costs under three different sets of implementation rules.

- Under moderately restrictive implementation rules—that is, with some trading of emissions allowances among Annex B countries and modest reductions in emissions by non-Annex B countries—Lasky estimates that the United States could have met its Kyoto commitment in 2010 for an incremental cost ranging from $44 to $245 per metric ton of carbon equivalent (in 2002 dollars) and an overall economic cost of between 0.4 percent and 1.5 percent of gross domestic product.

- Under a loose set of rules that permitted Annex B countries to pay for large emissions reductions in non-Annex B countries and allowed extensive credit for the net absorption of carbon dioxide by forests, the United States would have been able to meet its targets at almost no cost and with little effect on its economy.

- Under a very restrictive set of implementation rules that prohibited international trading of emissions allowances or credits and permitted only limited credit for forestry projects, the United States could have faced incremental costs for emissions reductions ranging from $171 to $297 per mtce. Annual tax revenues (or the annual value of auctioned emissions permits) could have totaled between $261 billion and $452 billion, and the policy might have reduced GDP by nearly 2 percent.

Actions by the United States

Over the past 15 years, the federal government has made substantial investments in research to understand the global climate system and the potential effects of climate change, and to subsidize the development of carbon-removal and alternative energy technologies. The United States has also continued a variety of longstanding programs that tend to discourage emissions or encourage the removal of greenhouse gases from the atmosphere—but that were originally intended to achieve other goals, such as pollution reduction, energy independence, and the limitation of soil erosion. The programs include corporate average fuel economy (CAFE) standards, taxes on gasoline, air quality improvement programs, and the Conservation Reserve Program. However, the United States has not adopted taxes or quotas that explicitly address the restraint of greenhouse gas emissions.

After negotiating and signing the Kyoto Protocol in 1997, the Clinton Administration did not offer it to the Senate for ratification. It presented a plan for meeting the United States' commitment, but many analysts raised concerns about whether the plan could accomplish its goal. The Bush Administration, having withdrawn the United States from subsequent protocol negotiations, has largely continued the previous administration's level of climate-related expenditures: the President's budget for fiscal year 2003, for instance, proposed $4.5 billion of climate-related spending, with $1.7 billion dedicated to climate science (including potential impacts of climate change) and $1.3 billion to the development of energy and sequestration technologies.[5] The Bush Administration currently defines its goals in terms of a modest acceleration in the rate of decline of emissions per dollar of GDP rather than the achievement of an emissions target at some point in the future.[6] In the meantime, and largely independently of federal action, some states and firms are adopting policies that are intended to reduce their emissions.

Alternative Approaches

The problems associated with the Kyoto Protocol have inspired researchers to propose a variety of alternative policies for coordinating international efforts related to climate change. Each approach represents a distinct interpretation of the available evidence about the likely benefits and costs of climate change, the uncertainty surrounding it, and practical concerns about how climate policy would affect domestic economies and the world economic system. Many of the approaches offer novel ways to address the simultaneous problems of limiting emissions and distributing the burden of regulation.

Some researchers (for example, Michaels, 2001) conclude that the rate of climate change is likely to be at the low end of the current range of estimates and the effects largely benign, and they argue for a laissez-faire approach.[7] Such a policy would take no affirmative steps to avert potential damages from climate change or to develop institutions to help coordinate international action.

Other analysts have proposed systems of emissions taxes or tradable emissions permits with fixed prices to limit the costs of mitigation. One such proposal envisages a system of auctioned emissions permits for the United States

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5. The Clinton Administration's policies are enumerated in Congressional Budget Office (1998), and the Bush Administration's in Executive Office of the President (2002). Relatively little scientific research is dedicated to understanding the potential effects of climate change on society, the area that studies suggest would yield the largest economic benefits. According to the National Science and Technology Council (2001), the U.S. Global Change Research Program allocated over 80 percent of its $1.6 billion budget for fiscal year 2002 to basic climate science and less than 20 percent to research on the human and ecosystem dimensions of climate change.

   The federal government spent approximately $69 billion (in 2001 dollars) between 1978 and 2001 on energy-related research and development, with expenditure levels currently running at roughly one-third of their pre-1980 level. Roughly 41 percent of the cumulative spending was focused on nuclear energy, 27 percent on fossil energy, and 32 percent on conservation and renewable energy. See Department of Energy, Energy Information Administration (2000), Table C1, pp. 114-115, as well as the *Budget of the United States Government* for fiscal year 2003, p. 171.

6. The Administration has released a draft research plan for comments (Climate Change Science Program, 2002) and stated that it will release a revised plan in June 2003.

7. In this view, the Framework Convention on Climate Change and the Kyoto Protocol are "based on a naive interpretation of . . . science" and their benefits are "undetectable."

that would require producers to purchase permits for the right to sell fossil fuels. The permits would be required at the point of import or first sale, and the revenues would be returned to households and states. The charge would start at $25 per metric ton of carbon in 2002 and rise by 7 percent per year (after inflation) through 2007.[8] That approach would be relatively cost-effective, although it would not be as cost-effective as using the revenues to reduce distortionary preexisting taxes. The option would also address distributional concerns but only at the domestic level. A similar system could be envisaged for other countries, and several proposals for an international system call for both setting national targets for emissions and establishing a maximum price (or "safety valve") at which governments provide additional permits for domestic emissions (see Aldy, Orszag, and Stiglitz, 2001, pp. 25-28; McKibbin and Wilcoxen, 2002, pp. 199-221; and Victor, 2001, pp. 101-108).

Another researcher (Nordhaus, 1998) has proposed a system in which countries with per capita income of more than $10,000 (in 1990 dollars) impose emissions taxes on domestic sales of fossil fuels. Under that approach, countries would use a complex voting scheme to decide on a price path for emissions over time, and developing countries would join the system once their per capita annual income rose above the trigger level. Participating nations would enforce the system through duties on imports from nonparticipating countries, which would be levied on each such country in proportion to the carbon content of its total exports. The approach has several advantages: it provides a method for deciding on a uniform emissions price in the face of conflicting views about the appropriate price and allows for gradual implementation and enforcement through international trade institutions. For simplicity's sake, the proposal ignores emissions from non-fossil-energy sources and exempts countries with low per capita income for distributional reasons. The system would yield an estimated two-thirds of the net benefits that could be realized by an ideal system covering only emissions from fossil energy use. Furthermore, nearly all regions would share in the system's beneficial effects on the climate.

An alternative approach (Bradford, 2002) differs from the preceding one by advocating explicit emissions rights, the equivalent of a uniform international emissions tax, and, at the same time, a system of international burden sharing that would be institutionally separate from the allocation of property rights. The approach calls for countries to negotiate and agree on country-specific, long-term, projected "business-as-usual" trends in emissions. For each country, its agreed-upon trend would serve as its emissions quota, which it could allocate domestically as it saw fit. Countries would also contribute financial resources to an international bank that would purchase and retire emissions allowances from their owners at a fixed, negotiated price, which could be renegotiated from time to time in the light of new information. The approach thus involves three elements: allocating emissions, determining a price trajectory, and distributing burdens.[9]

Yet another proposal (McKibbin and Wilcoxen, 2000, 2002) would create and distribute among nations two related types of explicit property rights for emissions. A long-term emissions *endowment*, which would be valid in only one country, would give its owner a permanent right to receive annual emissions *permits*. A limited number of endowments would be allocated to each country on the basis of the Kyoto targets for domestic distribution. Each government could also sell an unlimited number of permits every year at a price that would be fixed each decade by international agreement. There would be no international trading of emissions allowances or credits.

8. Kopp, Morgenstern, and Pizer (1997) describe the original proposal by Resources for the Future (RFF), a nonprofit research group specializing in environmental economics. Another version can be found in Sky Trust (2000). According to RFF researchers' estimates, the program would reduce U.S. emissions by roughly 16 percent in 2007, yielding a substantial fraction of the emissions reductions needed to meet the original U.S. commitment under the Kyoto Protocol. Using Lasky's (forthcoming) estimates of U.S. mitigation costs, that system would reduce emissions by between 5 percent and 8 percent. A number of other proposed domestic programs are described in detail in Congressional Budget Office (2000, 2001).

9. Short of controlling emissions directly, developed countries could slow emissions growth in developing countries by helping finance the installation of energy-efficient and non-fossil-energy technologies during the development process. Such a plan is proposed by Schelling (2002, p. 8).

The system would yield two distinct markets in every country: a market for permits, with the permits' price fixed by international accord and their number determined by market demand; and a market for endowments, with the number of endowments set internationally and their price determined by the market's expectations about future permit prices. If the demand for permits in a country rose above the number of endowments in a given year, the government would sell enough permits to meet demand at the fixed price. If demand did not exceed the number of endowments, the permits' price would be lower.

To address developing countries' distributional concerns, Annex I countries would receive endowment levels that were below their total current emissions; non-Annex I countries would receive endowments above their current levels. That distribution would lead to different prices for permits and endowments in the two groups of countries. But even if developing countries' permit prices were zero in a given year, their endowments would reflect the permits' expected future value—which would send a long-term signal to investors in those countries about the cost of emissions in the future. That signal could help encourage investment in energy-efficient technologies and processes in the long term and discourage emissions "leakage" from Annex I countries.

If the risks of climate change proved to be significant, countries could negotiate an increasingly higher world price for emissions that would gradually reduce each country's to the level of its endowments. After that, the country's government would have to buy back endowments to further constrain emissions and be consistent with the negotiated permit price.

By allowing different permit prices in different regions, possibly for an extended period, the proposed system would trade away some cost-effectiveness to accommodate distributional concerns. Governments could also address domestic distributional concerns through their allocations of emissions endowments. At the same time, the system would build a constituency of endowment owners in both developed and developing countries who would hold property rights for emissions—and who would therefore benefit from a rise in permit prices.

The system would be decentralized but coordinated through the initial international allocation of endowments and the establishment of permit prices. As a result, problems in one country would generally not affect markets for permits and endowments in others. The system would be flexible enough to adapt both to changing political and economic circumstances and to shifts in the rate of climate change. Permit prices could be rapidly adjusted in response to new information, and endowment prices would adjust accordingly. Countries could enter the system simply by agreeing to an internationally negotiated emissions endowment and permit price, allocating their endowments domestically, and enforcing the fixed-price permit system.

APPENDIX

Economic Models and Climate Policy

The economics literature contains hundreds of estimates of the costs or benefits (or both) of slowing, mitigating, or adapting to changes in the global climate resulting from human activities. Those estimates are derived mainly from a variety of computer models of economic activity that have been developed for other purposes and adapted to climate policy analysis. The variety of analytic approaches used makes it difficult even for modelers to interpret the differences among results from different studies. Researchers and policymakers are forced to integrate information from many sources and develop a synthesis based on a range of studies and approaches, each of which provides insight into some aspects of the problem while ignoring others.

Like their climate-related counterparts, modern models of the economy are composed of systems of mathematical equations that represent distinct but interacting processes in the real world and that are solved together to represent the simultaneous interaction of the parts within the whole. Even the most complex models of the physical climate or the economy inevitably lack detail. For example, many studies focus on the costs of mitigating climate change and ignore the potential benefits. Others focus only on costs in one sector or only on certain kinds of costs. Engineering studies evaluate the direct costs associated with adopting specific efficient technologies but tend to ignore larger-scale economic issues such as macroeconomic costs and impacts on international trade. Economic studies attempt to include a wider range of direct and indirect economic costs associated with emissions controls or with the effects of climate change, but they tend to use simple representations of technology. Some integrated assessment studies go further and try to incorporate both the costs of mitigation and the economic impacts of climate change. But to capture those very large-scale aspects of the problem, they rely on simplistic representations of many economic and environmental details.

Types of Models

Economic analyses yield a wide range of cost estimates for a given climate change mitigation policy, but most of the variation in results is due to identifiable differences in the approaches and assumptions that the studies use. Many analyses use one of several “top-down” approaches that represent the entire economy in an internally consistent way: they account for more or less all production and consumption; inputs of capital, labor, and energy; investment, taxes, and government spending; international trade; prices; interest and exchange rates; and so on. Top-down approaches allow researchers to account for many of the indirect economic effects of climate change policies that would primarily affect markets for energy; but they often ignore important details involving the gradual turnover of energy-using equipment, the choice of equipment, energy market barriers, and other factors. Nevertheless, they tend to produce fairly reasonable projections of overall energy use and thus emissions.

In contrast, “bottom-up” models draw on engineering cost studies to represent the details of specific energy-related technologies, but they tend to include much less detail about nonenergy sectors and other aspects of the economy. Unless constrained to do otherwise, bottom-up models always choose the most cost-effective technologies (from an engineering standpoint)—and therefore tend to produce rather unrealistic results.

Top-down modeling approaches, which as a class are sometimes referred to as macroeconomic models, generally fall into one of two groups. The traditional macroeconometric, or "macro," forecasting models that make up the first group are particularly useful in simulating the gradual adjustment of the economy to various kinds of shocks, such as changes in monetary and fiscal policy, higher energy prices, and exchange rate fluctuations. Macro models are particularly helpful in studying short-term (for example, five-year) responses and adjustments to economic shocks, but they do not represent specific markets in detail. Nor do they represent forward-looking expectations and behavior—an important element of economic activity, as discussed in the next section.

In contrast, computable general equilibrium (CGE) models, which form the second group, are useful in analyzing long-term responses to policies, over a decade or more. State-of-the-art CGE models incorporate forward-looking behavior, fairly detailed markets for specific factors and products, some types of gradual adjustment, aspects of long-run growth and technological progress, and detailed representations of the tax system and of international trade and finance. Some CGE models also include different groups and generations of households so that they can analyze the distributional impacts of climate change policies. Their disadvantage is that they do not capture gradual adjustments or elements of the business cycle very well. In particular, they have a hard time representing the gradual process through which industries and households replace equipment that is outmoded by policy shifts (as when consumers replaced cars that used leaded gas) and the gradual process through which a market economy adjusts to the economywide inflation that could result from significant increases in energy prices brought on by restricting emissions.

Many researchers combine several different models within a single modeling framework. For example, the Energy Information Administration's National Energy Modeling System integrates a set of models of particular energy sectors, a national macroeconometric model, and an international econometric model. Other frameworks add models of the agriculture and forestry sectors to simulate flows of carbon dioxide and methane in those areas of the economy. Models that treat in detail the economy's energy- or carbon-intensive subsectors tend to provide greater insight into those sectors' responses to climate policies than do less complex approaches.

Treatment of Expectations

One of the most complicated aspects of economics is that people decide what to do today in part on the basis of their expectations about the future. Modeling people's expectations is crucial to forecasting, but there is no simple formula to describe how people form them. Economists typically model expectations in one of two almost polar ways. One method represents behavior as adaptive: in that representation, people do not have an explicit understanding of how the economy will evolve and simply extrapolate from past experience into the future. The other approach represents people's behavior as forward-looking, which is also termed model-consistent or rational: in that representation, people correctly anticipate the future evolution of the economy unless the modeler engineers an explicit shock.

The assumption of adaptive behavior, which is generally used in macroeconometric models, yields forecasts in which people fail to anticipate known developments—for example, they will fail to prepare for a change in policy that is announced 10 years in advance. In contrast, the assumption of forward-looking behavior, which is used in a number of sectoral and general-equilibrium models, yields forecasts in which people perfectly anticipate all developments. Both assumptions are extreme, and they yield significantly different results.

When models with adaptive expectations are used to estimate the costs of a tax on emissions or a permit system, they tend to produce somewhat higher cost estimates than models with forward-looking expectations, all else being equal. That happens because people in forward-looking models have time to adapt to any policy that is announced in advance. Modelers who use adaptive expectations adjust for that limitation by gradually phasing in the policy, to simulate the anticipation of forward-looking individuals. A more difficult problem for models that use adaptive expectations is how to represent the gradual turnover of the capital stock in response to a policy shift. A few modelers combine adaptive and forward-looking assumptions, yielding results that in many ways are between the two extremes.

Technological Change

To model future economic growth and the effects of emissions restrictions, modelers have to guess what kinds of technologies are going to be available at various points in the future and simulate their effects under scenarios that include and exclude policies to reduce emissions. Forecasting the use of particular technologies for the near to medium term is relatively straightforward, for two reasons: much of the capital stock (especially energy-using capital) lasts a long time, and innovations usually take a fairly long time to make their way into the market. Nevertheless, analysts have often failed in the past to anticipate technological advances that seem fairly obvious in retrospect, such as the relatively rapid development of the Internet in the 1990s, or—an innovation that is closer to the issue of climate change—the adoption of natural-gas-powered combined-cycle electricity generation. As forecasters look forward over two or more decades, their ability to anticipate technological developments becomes increasingly weak.

Most models represent the pace and direction of technological change in a fairly simple way because the underlying forces of change are not well understood. The models typically assume that independent developments will gradually reduce the amount of capital, labor, and, in particular, energy required to produce goods and services. The process of reducing energy inputs per unit of output is often represented by a parameter called the autonomous energy efficiency improvement (AEEI) parameter.[1] For given rates of growth of gross domestic product and energy prices, an assumption of a higher AEEI implies that energy efficiency will improve more quickly and emissions will grow less quickly. A lower AEEI implies the reverse. Such a model can be used to analyze how changes in energy prices might encourage more or less use of energy, relative to the autonomous trend. Somewhat more complex models extend that basic process by projecting a menu of technologies that are expected to be available in the future and then analyzing how changes in energy prices would encourage people to switch to more energy-efficient types of equipment.

However, as discussed in Chapter 4, technological developments also respond to shifts in relative prices. Virtually no model simulates the effect of energy prices on the autonomous trend or on the menu of available technologies. Although the size of that so-called inducement effect is controversial, cost estimates that ignore it probably overestimate the incremental cost of reducing emissions over the longer run—say, 20 years or more.

Integrated Assessment

A consistent analysis of both the costs and benefits of policies related to climate change requires a modeling framework with certain characteristics: it should cover national and international greenhouse gas emissions from many sectors of the economy; it should translate emissions of greenhouse gases into changes in the atmospheric and global climate; and it should evaluate the impacts of climate change on people and ecosystems. A number of so-called integrated assessment models are under development, as are simplified reduced-form models based on more complicated frameworks. To analyze distributional issues, some models separate the world into a number of regions or include several overlapping generations of households. A few of the models also incorporate a range of uncertainty in their choice of parameters or in their solution procedures (see Chapter 3).

1. The simpler models also use the same representation to account for the fact that as people's income rises, they use more and more of it to buy services that do not require as much energy to produce as do manufactured goods.

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