The RFF Guide to Climate Change Economics and Policy

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MISSION

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Preface

Raymond J. Kopp
Resources for the Future

In 1996, Resources for the Future (RFF) established a substantial new program of research, policy analysis, and outreach on climate change issues. The goal of the program is to help improve understanding of the issues that must be addressed to assess the extent and types of policy intervention needed and to design reliable and cost-effective domestic and international climate policies. The program was established in response to the general debate about climate change risks and policies, as well as the specific debates surrounding the international negotiations being carried out under the United Nations Framework Convention on Climate Change (UNFCCC).

The publication of the Second Assessment Report of the Intergovernmental Panel on Climate Change signaled the beginning of a broader agenda of research and debate on global climate change. While there is still scientific uncertainty about the magnitude of climate change risks, the world's policymakers have shifted more of their attention to a debate of policy responses.

As public discussion moves in the direction of how governments should appropriately respond to climate change, RFF's economic research and policy analysis on climate policies are increasingly valuable to policymakers. RFF comprises one of the largest groups of environmental and natural resource economists and policy analysts working under one roof anywhere in the world. For more than 50 years, we have devoted our expertise to the study of environmental and natural resource problems and to the formulation and analysis of environmental policy. RFF brings a well-recognized and respected reputation for objective research to the policy debate and can be relied upon as a source of unbiased information.

This guide is designed as an introduction to the topic of climate policy and addresses issues of both international and domestic importance. The difficulty of combating climate change, due in large part to the link between energy consumption and greenhouse gas emissions, is discussed in the first chapter. A brief history of the Kyoto Protocol—the first major attempt to set binding targets for greenhouse gas reductions under the UNFCCC—is provided in the second chapter, while the third chapter tackles the important but provocative question, how much climate change is too much? The last three chapters examine the design of public policies to limit greenhouse gas emissions and the roles that might be played by renewable energy resources and energy conservation.

Additional information on the topics discussed in these chapters as well as a vast array of other aspects of climate policy can be found on the RFF website, www.rff.org.

Note: Much of the material in this guide is drawn from *Climate Change Economics and Policy*, edited by Michael A. Toman and published by RFF Press.

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The Energy–CO_2 Connection

A Review of Trends and Challenges

Joel Darmstadter

A major—and undisputed—challenge that faces every country is access to energy on terms that facilitate economic growth while respecting environmental integrity. This challenge affects different countries to different degrees; even countries with highly developed economies such as the United States cannot avoid making energy choices that involve trade-offs between these sometimes conflicting goals.

The United States and other advanced industrialized countries have in varying degrees met this challenge under circumstances where the environmental problems were *localized* (for example, automotive pollution) or posed a *regional* threat (for example, acidification). Not surprisingly, ways of dealing with *global* problems have proven to be far less tractable.

In this chapter, I do not address the conundrum of designing and implementing workable multinational policies to restrain global greenhouse gas (GHG) emissions. Rather, my more limited purpose is to spotlight the intimate connection between carbon dioxide (CO_2)—the GHG of primary focus in the climate change debate—and energy consumption. The crux of the message is that any attempts to curb CO_2 emissions that fail to consider the need for changes in energy production and consumption (rates of growth, mix of fuels, and composition of demand) are likely to be futile. I emphasize the United States in my discussion; however, given the global nature of the GHG issue, I also direct some attention to growth trends and prospects of less industrialized and developing economies.

GHG Emissions, CO_2, and Energy: Basic Relationships

Serious discussion about climate change invariably involves serious discussion about energy consumption. The coupling is well grounded: Even though some precursors believed to be responsible for global warming are unrelated to energy use (for example, the application of nitrogen fertilizer, which releases nitrous oxide) and certain energy activities have no direct impact on greenhouse warming (such as nu-

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

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

Note: See Box 1 for additional information about how emissions are measured.

Source: U.S. EPA (see Sources for Data and Projections).

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

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

Notes: The electric power sector is treated as a consumer of energy sources and an emitter of CO_2. An alternative treatment would bypass the power sector and ascribe its energy use to ultimate consumers of electricity. 1 quad = 1 quadrillion (10^{15}) Btu; NA = not applicable.

[a] Includes small unallocable amounts emitted in U.S. territories, not shown separately. Excludes small amounts attributable to nonfossil (biogenic) resources.

[b] Figures for totals may not exactly correspond to the sum of the constituent parts because of rounding.

Source: U.S. DOE/EIA *Annual Energy Review 1997* (see Sources for Data and Projections).

clear power), a major focus of the global warming debate is the role of fossil energy. Tables 1 and 2 show why. The energy sector accounts for some 86% of total U.S. GHG emissions (measured in carbon equivalents—see Box 1), and energy-related CO_2 alone accounts for 81%. Within the energy sector, coal and petroleum (and the sectors in which the two fuels predominate, electric power generation and transport) give rise to a major portion of the country's CO_2 emissions. Roughly the same broad pattern prevails in all industrialized countries.

However, the policy emphasis on energy's contribution to GHG emissions reflects not only the quantitative importance of energy but also the possibilities for abatement through incentives and regulations that reshape the energy system. The electricity sector in particular can avail itself of different generation technologies, siting options (centralized or distributed), and energy sources for producing power. Especially telling is the fact that coal, which in recent years has fueled close to 60% of U.S. electricity production, contains about 80% more carbon per unit of heat energy than natural gas and 30% more than oil. Of course, technical and cost factors are critical in defining the comparative options, as are other considerations, such as the nature of public policies for local environmental improvement.

Box 1: Measuring Greenhouse Gases

Radiative Forcing, Residence Time, and Global Warming Potential

In Table 1, methane (CH_4) and other greenhouse gas (GHG) emissions—principally nitrous oxide (NO_2) and certain fluorocarbon compounds—are expressed in carbon equivalents. Using this metric as a common denominator unit makes it possible to aggregate the different kinds of emissions and thereby get a sense of the relative importance of each contributor to greenhouse warming.

The aggregation procedure is based on the fact that each of the principal GHGs has two important attributes. The first is radiative forcing—that is, the extent to which the gas magnifies the greenhouse effect. The second is residence time in the atmosphere—that is, how long the gas exercises its climatic influence.

An example will help clarify how these attributes relate to climate change. The radiative forcing of CH_4 is 30 times that of CO_2. However, the estimated residence time of CO_2 is around 250 years, whereas CH_4 (and the climatic effects it causes) will dissipate in only 10–15 years. To capture the combined effect of both factors, climate analysts have developed the notion of global warming potential (GWP). Its purpose is to "provide a simple measure of the relative radiative effects of the emissions of various greenhouse gases." The IPCC has chosen 100 years as its basic yardstick for calculating GWP; however, shorter or longer periods can be assumed as well. Under the 100-year assumption, methane's GWP is valued at 21 relative to 1 for CO_2. Other gases have a still much higher GWP—for example, NO_2 has a value of 310. Although GWP is an important tool for quantifying the relative effects of GHGs, the volume of emissions for each particular gas must also be taken into account. The volume of CO_2 emissions is so high that non-CO_2 emissions are far less consequential.

GWPs also do not—and are not meant to—reflect the different economic impacts of different gases over time. Economists argue that transforming the GWP into some index of economic damage would provide a more discriminating basis for decisions regarding the priority attention to controlling one or another greenhouse gas.

To clarify this point, consider a scenario in which future damages were expected to closely coincide with a peak in global temperature. Normally, the incremental emissions of CO_4 (or another gas with a short atmospheric residency time) would have a negligible effect compared with that of a long-lived greenhouse gas such as CO_2; however, their relative importance would invert as the peak temperature approached. In such a situation, the effects of CH_4 emissions would be more damaging than those of CO_2.

Developing an economic damage index that reflects both the peak-temperature phenomenon and the application of an appropriate discount rate is important for refining assessments of the benefits and costs of different greenhouse gas control initiatives. Whereas knowing the damages associated with, say, CO_2 versus CH_4 would provide a useful clue in assessing the benefits of damage reduction, it would obviously also be important to compare the costs of those control initiatives. Thus, even if CH_4 was likely to cause serious damages, it still might prove more economically efficient to concentrate on controlling CO_2 emissions if they were judged more tractable than, say, altering rice cultivation practices to limit CH_4 release.

Throughout this paper, quantitative measures of CO_2 emissions are expressed in terms of the carbon content of the fuel being burned. The mass of CO_2 gas equals 3.667 the mass of elemental carbon.

Very small amounts of CO_2 are released from nonenergy production. The principal example is cement manufacturing, which accounts for around 2% of global emissions. Notwithstanding that fact, for the purposes of this paper, statistical convenience dictated relating energy use to total CO_2 emissions, irrespective of origin. The broad findings I present are negligibly affected by this inconsistency.

Table 3. Average Annual Rates of Change in the United States and Major World Regions, 1973–90 and 1990–97.

		Average annual rate of change (%)					
Determinant of CO_2 emissions	*Years*	*United States*	*Other OECD countries*	*Total OECD countries*	*Former Soviet Union*	*Other*	*World*
Population	1973–90	0.98	0.81	0.85	0.86	2.07	1.74
	1990–97	1.00	0.69	0.76	0.12	1.73	1.46
GDP/population	1973–90	1.68	2.40	2.16	2.57	0.60	1.17
	1990–97	1.44	1.79	1.70	–7.81	2.44	0.93
Energy consumption/GDP	1973–90	–1.89	–2.13	–2.06	–0.76	2.13	–0.90
	1990–97	–0.80	–0.93	–0.88	1.64	0.04	–1.14
CO_2 emissions/energy consumption	1973–90	–0.27	–0.02	–0.13	–0.55	–1.10	–0.33
	1990–97	–0.24	–0.63	–0.46	–0.12	–1.36	–0.69
CO_2 emissions	1973–90	0.46	1.01	0.77	2.10	3.72	1.67
	1990–97	1.39	0.90	1.11	–6.30	2.83	0.54

Notes: To the extent possible, the gross domestic product (GDP) figures used in these calculations represent U.S. dollar estimates of other countries' GDPs based on so-called purchasing power parity (PPP), rather than market exchange rate means of conversion. Although the PPP estimates are often very approximate, they track more faithfully what people's income actually commands in terms of goods and services consumed. For example, China's PPP-based GDP is estimated at three or more times the level calculated using market exchange rates. OECD = Organisation for Economic Co-operation and Development.

Sources: The data in this table were constructed using several sources as the primary building blocks. In some cases, separate and not totally consistent data sets over different time intervals had to be spliced together. Additionally, in several instances, proxy indicators served as the basis for calculating the item of interest. For example, estimated CO_2 emissions in 1973 for certain world regions required using consumption data for different energy resources multiplied by their unit carbon content. (See British Petroleum Company, ORNL, U.S. DOE/EIA *Annual Energy Review 1997,* U.S EPA, World Bank, and World Resources Institute in Sources for Data and Projections.)

Determinants of CO_2 Emission Trends

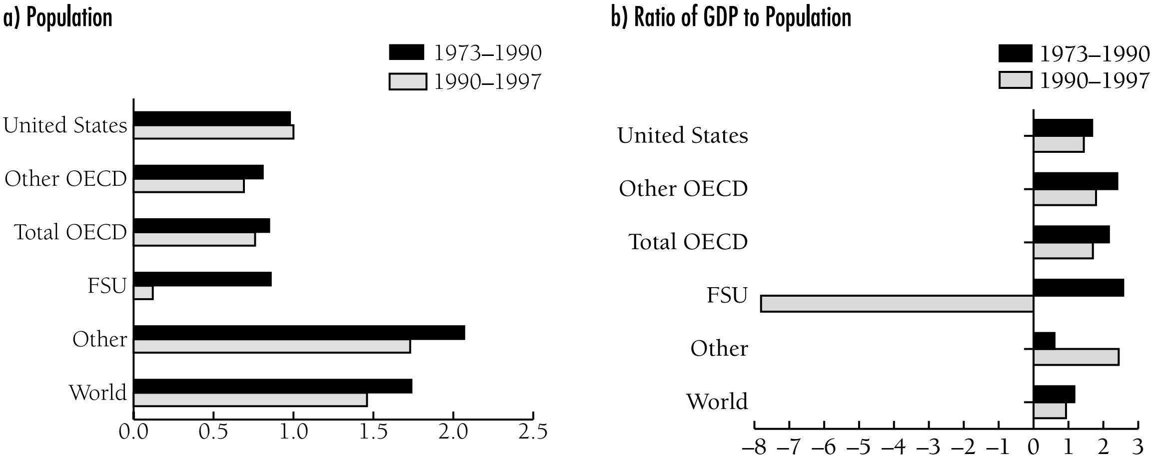
Demographic, economic, and technological factors underlie trends in CO_2 emissions. Table 3 and Figure 1 point out the role of these key elements. They indicate that reduced levels or growth rates for CO_2 emissions from the energy sector can come about in various ways, which can be consolidated into four key elements: population, GDP/person, energy/GDP, and CO_2/energy (where GDP is gross domestic product).

From this framework, a straightforward arithmetic identity can be constructed:

$$CO_2 \text{ emissions} = \text{Population} \times \frac{\text{GDP}}{\text{person}} \times \frac{\text{Energy consumption}}{\text{Unit GDP}} \times \frac{CO_2 \text{ emissions}}{\text{Unit energy consumption}}$$

Thus, other things being equal, slower population growth means less growth in CO_2 release, whereas higher GDP per capita signifies a greater volume of CO_2 emitted. The energy-to-GDP ratio (also referred to as energy intensity) is a measure of an economy's aggregate energy intensity that reflects the structural, technological, and energy use characteristics of the society. All else unchanged, a falling energy intensity means less CO_2 emitted. The forces that can contribute to a decline in energy intensity—such as efficiency improvements through use of combined-cycle technology in generating electricity—are critical elements in the analysis of CO_2 abatement strategies. Finally, the CO_2-to-energy consumption ratio (sometimes called carbon intensity) spotlights the effect of a changing mix of energy types consumed in terms of carbon characteristics. Clearly, an important is-

Figure 1. Average Annual Rates of Change in the United States and Major World Regions, 1973–90 and 1990–97.


a) Population

b) Ratio of GDP to Population

Continued on next page

sue in the determination of CO_2 mitigation possibilities and costs is the ease or difficulty of altering that mix away from carbon-intensive components such as coal toward low-carbon or carbon-free resources such as natural gas, solar, or nuclear power. In one way or another, the four determinants of CO_2 emissions listed in Table 3 and shown in Figure 1 must enter into any analyst's attempt to determine the feasibility of CO_2 mitigation.

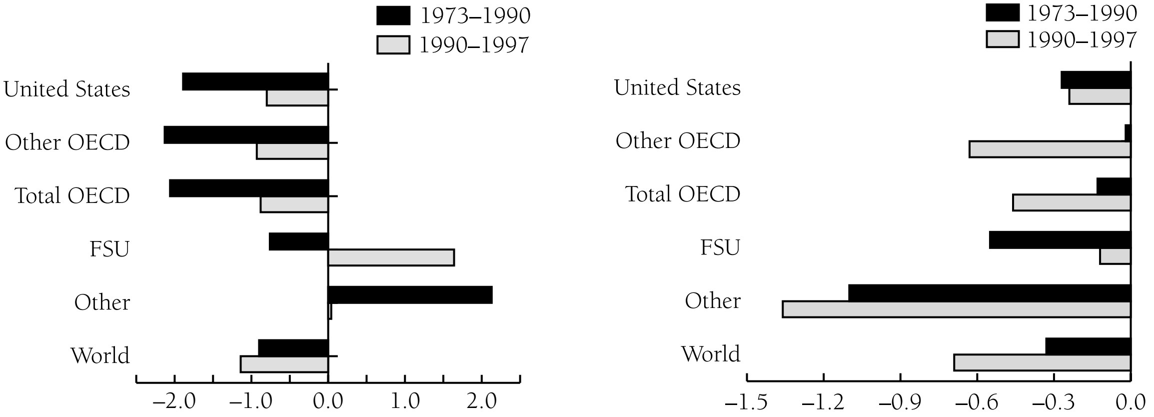
CO_2 Emission Trends and Implications

In looking at the weight exerted by these four factors in the growth of U.S. and global CO_2 emissions during the past quarter of a century, we see that the United States recorded "desirable" trends in terms of a declining energy intensity and a diminishing degree of carbon intensity in the use of energy resources (Table 3). However, neither improved energy efficiency nor the increased degree of "decarbonization" was sufficient to counter the combined effect of economic and demographic growth. Consequently, overall CO_2 emissions have continued to rise steadily in the United States.

It is worth recalling that the earlier of the two periods shown in Table 3 (1973–90) was marked by significant energy price increases that, reinforced by several conservation policy measures, helped curb the growth of fuel consumption, most notably in automotive transportation, but also in residential and business activities. For example, the fuel efficiency of passenger cars improved by more than 50% between 1973 and 1990. More conscious conservation practices contributed to reduced use of energy in the average household by more than 25% between 1978 and 1987; and energy consumption per square foot of commercial building space declined by 30% between 1979 and 1992. The industrial sector, no doubt sensitive to the effect of rising costs on its competitive standing, reduced its ratio of energy use to gross output by one-third during the first 15 years after the 1973–74 oil price shock.

In contrast to these earlier trends, the situation worsened for most of the 1990s, during which the annual rate of increase in U.S. CO_2 emissions more than doubled—largely because of a striking decline in both aggregate and sectoral energy efficiency advances (Table 4). In numerous sectors, efficiency

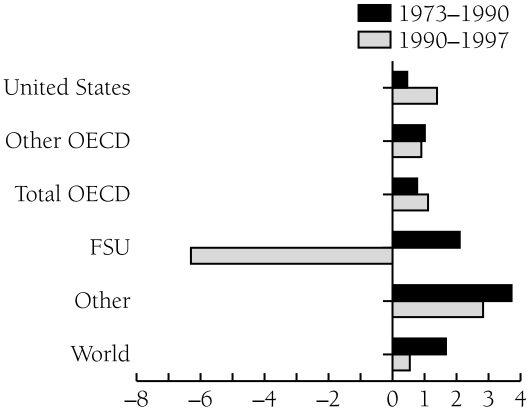
Figure 1. (continued)



c) Ratio of Energy to GDP

d) Ratio of CO_2 to Energy

e) CO_2 Emissions



Notes: OECD is Organisation for Economic Co-operation and Development; FSU is former Soviet Union.

Source of all graphs: Same as Table 3.

gains ceased entirely, as buoyant income growth reinforced attractive energy prices to spur energy-related expenditures. (Although Tables 3 and 4 are divided at 1990, I recognize that the mid-1980s, marking a sharp break in real energy prices, would have provided a somewhat more meaningful benchmark from which to map the subsequent disincentive in energy conservation. But many of the non-U.S. data needed to construct the table were benchmarked at 1990.)

The dramatically increased popularity of sport utility vehicles and minivans (which weigh in at the low end of the energy efficiency scale) is a telling example of the forces at work. Rising incomes made the capital outlay for the vehicles affordable, and the cheap gasoline prices prevailing in the mid- to late 1990s—as low in real terms as before the oil market upheavals in the early 1970s—minimized their operating costs. In the absence of policies that

Table 4. Selected Sectoral Trends in U.S. Energy Consumption and CO_2 Emissions, 1980–96.

	Average annual rate of change (%)	
Sector and indicator	*1980–90*	*1990–96*
Passenger cars		
Energy consumption	0.1	0.3
Miles/gallon	2.4	0.8
CO_2 emissions	0.1	0.3
Motor vehicles[a]		
Energy consumption	0.9	1.5
Miles/gallon	2.1	0.5
CO_2 emissions	0.9	1.5
Industry		
Energy consumption	0.5	1.7
Energy/gross output	–1.7	–1.5
CO_2 emissions	–0.7	0.8
Residential sector		
Energy consumption	–0.1	1.7
Energy/household	–1.5	2.1
CO_2 emissions	0.2	2.1
Commercial buildings[b]		
Energy consumption	1.5	1.4
Energy/square footage	–2.2	–0.2
CO_2 emissions	1.5	2.1
Electric utilities		
Fossil energy consumption	0.9	0.9
Kilowatt-hours generated (fossil)	1.0	1.1
Kilowatt-hours generated (total)	2.1	1.5
Fossil energy/fossil kilowatt-hours	–0.1	–0.2
Fossil energy/total kilowatt-hours	–1.2	–0.6
CO_2 emissions	1.3	1.3

[a] Includes passenger cars as well as vans, sport utility vehicles, and light trucks.

[b] Values are for 1979–89 and 1989–95.

Sources: Council of Economic Advisers, U.S. DOE/EIA *Annual Energy Review 1997* (see Sources for Data and Projections).

constrain travel and/or tighten fuel economy, rising gasoline use is inevitable.

These energy efficiency trends were mirrored in other parts of the economy, as Table 4 shows. Still, even before the oil-price spikes of 1999–2000 added a new factor—and one of uncertain duration—to the picture, there was some evidence that, low energy prices notwithstanding, the U.S. industrial sector was in the process of generating some significant energy savings. My conjecture about future U.S. energy and CO_2 emission trends touches on this development.

As these energy intensity trends proceeded, modest reductions in overall carbon intensity continued (Table 3). One important factor driving this trend has been the rising share of electricity generation fired by natural gas, which was 12.5% in 1990 and had reached 14.1% by 1997. This shift contributed to making the electric power sector the only example of those shown in Table 4 whose CO_2 emissions did not worsen in recent years. But such changes could moderate to only a limited extent the accelerated rate of increase in CO_2 emissions.

Table 3 shows that what happened in the United States (and to a considerable extent in other OECD countries) occurred much more pointedly elsewhere in the world. This non-OECD group comprises countries of the former Soviet Union and some 100 “Other” countries, the majority of which are more or less in a state of underdevelopment—a situation borne out by the well-known disparities in per capita income (about 18% of the average OECD level), energy use (13%), and CO_2 emissions (13%). (The reason for separating the former Soviet Union from other non-OECD countries is that exceedingly poor former Soviet Union performance during the past decade distorts any totals in which they are included.) The combination of developing countries’ energy-to-GDP and CO_2-to-energy ratios would have produced an annual growth rate in CO_2 emissions of just 1% during 1973–90 and a decline of 1.3% during 1990–97. Actual growth rates in carbon emissions of 3.7 and 2.8% during the two respective periods attest to the weight that demographic and economic forces can exert on trends in emissions.

As evidence that we are dealing with phenomena and trends that are not straightforward or predictable, Table 3 also reveals a striking, almost anomalous statistic. In contrast to its increase during 1973–90, energy intensity in the Other countries remained almost unchanged during the 1990s, even though a continuing momentum toward industrialization (not to mention more affordable energy prices) would have suggested intensification.

The reason for that striking statistic, it turns out, is that in China (which exerts a strong weight in the Other group), energy consumption grew at substantially below half the more than 11% GDP growth rate. (By contrast, India's energy consumption grew 21% faster than its GDP.) If true—and there is some doubt about the reliability of Chinese energy statistics—the country has evidently been able to increase energy efficiency significantly in its manufacturing and other sectors to achieve that overall outcome. Without such energy efficiency improvement in China, Table 3 would have shown a marked increase in the energy-to-GDP ratio (rather than 0.04%) and a faster rise in CO_2 emissions, with proportionately less of that rise attributable to demographic and economic forces. Even if population growth in the developing world does slow, the imperative pursuit of increases in per capita income in these countries will likely make the search for a serious dent in global CO_2 emissions a major challenge for the pattern of energy supply and use in richer and poorer countries—both in energy's relationship to growth in the overall economy and in the carbon content of the energy consumed.

Conjectures about Future Developments

The historical record I have sketched thus far provides an appropriate backdrop for speculation about future developments in the interplay among population, GDP, energy consumption, and CO_2 emissions. One could spin out a diverse set of outcomes predicated on a diverse set of assumptions. However, my purpose here is more limited. Reverting to the framework of Table 3, I consider the circumstances under which one could envisage a significant slowdown in the growth of CO_2 emissions in the United States and elsewhere. Somewhat arbitrarily, I conduct this exercise within a 20-year time frame, looking out to 2020. A much shorter period would have exposed the unrealistic nature of contemplating significant short-term changes in factors characterized by a substantial degree of inertia in both their physical and policy dimensions; for example, coal-fueled power plants and numerous other kinds of energy infrastructure may require a 30-year amortization period. To contemplate a much longer time frame would require assumptions about such things as technological change and behavioral dynamics, with uncertainties that are simply too great to account for in the present broad-brush discussion.

The U.S. Scene

Consider specifically the circumstances surrounding a U.S. resolve to stabilize its CO_2 emissions at 1997 levels over the next two decades. To explore this possibility, suppose first that the U.S. population continues to grow at about 0.8% annually, a rate projected by the U.S. Census Bureau (see U.S. Department of Commerce in Sources for Data and Projections). Suppose also that per capita income grows at the modest pace of 1.5% yearly. (GDP or income cannot actually be treated as independent of what is assumed about energy, because unusually costly energy use disincentives can penalize overall economic performance. I sidestep this "feedback loop" problem here; doing so does not affect the thrust of the discussion.) According to the earlier equation describing the components of emissions, it follows that the combined result of these two assumptions would be a 2.3% annual growth in emissions, *if,* in combination, the energy intensity of GDP and the carbon intensity of energy use remained unchanged. Conversely, to hold emissions constant with these population and GDP growth figures would require decreases in either energy intensity of GDP or carbon intensity of energy use averaging 2.3% per year. However, achieving such results without noticeable increases in energy prices seems questionable.

Energy Intensity Outlook. An important part of the energy intensity issue involves recognizing the potential contribution of "autonomous" technological advances—improvements in the energy-to-GDP ratio that occur over time and in a profit-seeking environment, even with a flat energy price trajectory and without any particular encouragement via public policy initiatives. Such technological progress allows manufacturers and other energy users to make do with less energy, even without the prospect of having to pay more for energy or being forced to economize by government dictate. The size of this autonomous component is subject to dispute; some analysts assert that all change is induced by specific and identifiable factors, not a reflection of an inherent technological phenomenon. Most mainstream economists would place the figure for autonomous technical change between 0.5% and 1.0% per year.

One intriguing prospect, which could augment energy-saving technological advances, revolves around the role of the Internet in both commerce and industry. Growing anecdotal evidence indicates that the Internet can enhance both economic and energy efficiency. Telecommuting is one obvious and commonly cited example of reduced motor fuel consumption. Another example relates to online purchase of goods, which can improve the economic and energy efficiency of inventory management and distribution processes relative to a more decentralized distribution network. (Whether a society bereft of bookstores in which to browse improves one's quality of life is a more subjective issue.) Space-saving electronic media could significantly cut down on square-footage requirements of new commercial structures, attenuating the input of construction-related energy. Manufacturers' supply chains— already benefiting from just-in-time inventory controls introduced in recent decades—could be further streamlined, with transactions coupled to electronic channels of communication. On the other hand, some Internet-based transactions can stimulate energy use. Internet surfing to pinpoint lower airline fares or electricity costs will give rise to increased, rather than decreased, energy demand.

Romm suggests that electronic commerce explains a significant part of the country's energy intensity drop during 1997–98, despite low energy prices (see Suggested Reading). However, the extent to which this is the case, and the extent to which it will be a sustained influence on energy conservation in the years ahead, remain open questions.

Carbon Intensity Outlook. Numerous options for lowering carbon intensity may also be possible. For example, the hydrogen fuel cell releases far less carbon than the gasoline-powered internal combustion engine but still faces a substantial period of development before it will qualify as a technologically reliable, safe, and economically competitive contender in the automotive market. Although unrealistic from today's vantage point, the prospects of a revived nuclear industry based on vastly improved safety characteristics should not be ruled out. Also, several renewable energy systems have succeeded in lowering their electricity generation costs to a remarkable degree. Indeed, by the 1990s, these technologies—wind power in particular—had managed to reduce their generation costs to levels even lower than had been projected by "green" advocates (credited, at the time, more for enthusiasm than realism) 25 years earlier. The fact that, in contrast to falling costs, *market share* continued to elude renewable technologies was largely due to the falling real price of fossil energy resources, making them the fuels of choice in electricity production.

Role for Energy Prices. Let us now suppose that improvement in energy efficiency were to occur at 1% per year, the top end of the range generally embraced by economists. To stabilize CO_2 emissions given our assumptions for population and income growth then would require a "decarbonization" rate—a decline in the carbon intensity of energy use—of 1.3% per year. This is well above the historical experience over the past quarter century of less than 0.3% (Table 3). Conversely, emissions stabilization with a decline in carbon intensity of 0.3% would require a decline in energy intensity of GDP of 2.0%, more than twice what seems plausible for autonomous efficiency improvement.

Thus, unless some "new economy" phenomenon were to drastically alter energy–economy relationships relative to the past, it seems highly unlikely that autonomous trends could lead to emissions stabilization. One must turn instead to the possibility of energy price increases or regulations that stimulate energy efficiency and decarbonization, both directly and through the development and diffusion of new technologies. In particular, technologies such as the hydrogen fuel cell or wind turbines probably would mature faster if fossil fuel prices were higher. But a narrowing of the wedge between fossil and renewable energy costs seems less likely to happen because of rising real costs of conventional energy—increasing scarcity is a prospect that seems continually to recede with the horizon—than as the result of policy-driven economic disincentives to emit CO_2.

Past experience illustrates the powerful effect of energy prices on energy use. For example, as the annual rate of decline in electricity prices during 1960–73 (3.4%) gave way to a rise of 2.4% during 1973–85, electricity sales growth dropped from 7.2% to 2.4% per year. In the case of gasoline, a real price decline of 1.4% per year during 1960–73 was followed by a rise of 2.4% per year during 1973–85, and a turnaround in sales from an increase of nearly 4% annually during 1960–73 to almost flat consumption over the subsequent 12 years. (Although 1973–85 was a period of significant macroeconomic dislocation, GHG policies implemented gradually, with foresight and complementary macroeconomic buffering, need not produce comparable dislocation.)

Apart from the effect of structural factors in the economy that signify lower energy intensity (for example, growth of the service sector, or as noted earlier, the increase in Internet transactions), debate continues over the potential for cost-effective energy conservation even without the spur of higher prices. Undoubtedly, such opportunities exist in various sectors of the economy. The reasons for their lagging application are variously given as imperfect information, distorted credit and capital market arrangements, unnecessarily high transaction costs, and a failure of public R&D support where the target of such support can be justified as serving the public good rather than simply displacing or duplicating private R&D activity. However, the magnitude of the missed—and attainable—energy savings remains contentious, with most economists taking a fairly conservative view of the potential.

The Global Scene

Although the burden of adjustment for the United States (and the rest of the OECD member countries) in stabilizing emissions is challenging but (with some fortuitous mix of policy and technological prospects) arguably manageable, other parts of the world face a more formidable task. Some perspective on this point is provided in Table 5, which presents the "business as usual" (or reference case) set of pertinent indicators to 2020 from the U.S. Department of Energy's Energy Information Administration.

As already pointed out in connection with the U.S. scenario discussion, demographic and economic forces are major determinants of the outlook

Table 5. Projected Average Annual Rates of Change for "Business-As-Usual" Scenario in Non-OECD Countries, 1997–2020.

	Annual rate of change (%)	
Indicator	*Including eastern Europe*	*Excluding eastern Europe*
Population	1.2	1.2
GDP/population	3.6	3.5
Energy/GDP	–1.3	–1.1
CO_2/energy	–0.7	–0.1
CO_2	2.7	3.5

Notes: Countries of the former Soviet Union are excluded. Because many eastern European countries are frequently excluded from statistics on developing countries of the world, the table shows data with and without eastern Europe. See text for a detailed discussion.

Source: U.S. DOE/EIA *Annual Energy Review 1997* (see Sources for Data and Projections).

for CO_2 emissions. Notwithstanding an expected slowing of population growth, the assumption of a sharply accelerated rise in per capita income puts significant pressure on CO_2 emissions. The projections in Table 5 also show a reduction in energy intensity of somewhat more than 1% annually, a respectable rate by historic norms. The carbon content of total energy also continues to diminish, though more slowly than in the past. For example, the projections presume that coal will remain the energy source of choice in the developing regions of Asia.

Taking all the various factors into account, the projections in Table 5 show CO_2 growing at 3.5% per year for the developing world, somewhat under 3% per year if eastern European countries are included. Suppose that a 1% reduction in the rate of growth in emissions were deemed a desirable target to pursue. Given assumed population and income growth, achieving this target would put a substantial burden of adjustment on the already declining energy-to-GDP ratio and the CO_2 intensity of energy use. Moreover, the "High Economic Growth" scenario in the Energy Information Administration's projections raises the rate of growth in CO_2 emissions by about 1% above the values shown in Table 5. These figures indicate the limits to what can be expected from autonomous energy sector adjustments in terms of slower emissions growth.

Nonetheless, economically exploitable energy-saving opportunities beyond those indicated in Table 5 should not be casually dismissed. Market-determined rather than subsidized prices for fuels and power promote greater energy conservation and confer real overall economic benefits to society. Taxing the worst forms of pollution could contribute to more rational energy use. Sound rules and institutions encouraging private foreign investment could enhance the international diffusion of energy-saving technology. Some developing and transitional countries already are making progress along these lines, and there is room for additional "win–win" improvements.

But after all is said and done, a serious commitment to CO_2 mitigation in the United States and abroad requires a willingness to consider some major changes in the use and mix of energy resources. These far-reaching changes—which will extend beyond the next couple of decades considered here—will not be easy and probably won't be cheap. They will require considerable political will as well as technological acumen.

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2

How the Kyoto Protocol Developed

A Brief History

J.W. Anderson

With the Kyoto Protocol, the world's governments proposed to adopt legally binding commitments to slow global warming. Although this treaty is still hardly more than a draft and not yet in force, it constitutes an unprecedented attempt to organize international cooperation to protect the global environment. It would require fundamental changes in the ways in which the world produces and uses energy. But the protocol has become the center of great political controversy, for reasons that in some part arose from the way it developed.

In this chapter, I present the issues that rapidly evolving scientific knowledge first began to press on politicians and diplomats nearly half a century ago. I consider the Montreal Protocol to protect the stratospheric ozone layer—a tremendous success for international environmental cooperation, but an unsatisfactory model for the climate change agreement with its different circumstances. I then discuss the negotiation of the Kyoto text and conclude with a review of the current efforts by some of the signatory governments to put the treaty into effect.

Beginnings

Like most environmental issues, questions about Earth's changing climate began with scientists. Scientists had known for many years that the concentration of carbon dioxide (CO_2) in the atmosphere could affect worldwide temperatures. They also knew that industrial growth and rising oil and coal consumption were increasing the amounts of CO_2 being emitted into the air enormously. But through the first half of this century, they had generally assumed that most of that CO_2 was being absorbed harmlessly by the oceans. It was only in 1958 that researchers began to test that assumption by taking measurements from the top of Mauna Loa, a Hawaiian volcano far from any smokestacks. The Mauna Loa data series soon showed that the amount of CO_2 in the atmosphere was steadily increasing.

For the next decade, the concern about the effects of human activity on the climate remained largely theoretical, because temperatures seemed stable. From the early 1900s

Table 1. Summary of Key Milestones in Climate Policy, 1979–2002.

1979	First World Climate Conference
1985	A conference on greenhouse gases in Villach, Austria, demonstrates a growing scientific consensus that human activity is affecting the climate. Here, for the first time, the need for policies to respond to climate issues is discussed.
1988	The Toronto Conference, an unofficial gathering of scientists and politicians from 48 countries, ends with a call for a 20% reduction of carbon dioxide emissions from 1988 levels by 2005.
1990	First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is published; initial evidence that human activities might be affecting climate, but significant uncertainty exists.
1990	Second World Climate Conference; agreement to negotiate a “framework treaty.”
1992	The U.N. Framework Convention on Climate Change (UNFCCC) is established at the U.N. Conference on Environment and Development (also known as the Earth Summit) in Rio de Janeiro, Brazil. This treaty sets a nonbinding goal for the developed countries of reducing emissions of greenhouse gases. Annex I developed countries pledge to return emissions to 1990 levels by 2000. United States ratifies UNFCCC later in the year.
1993	Clinton administration publishes its Climate Change Action Plan, a collection of largely voluntary emission-reduction programs.
1995	IPCC Second Assessment Report completed (published in 1996); strong conviction expressed that human activities could be adversely affecting climate.
1995	Berlin Mandate developed at the first Conference of the Parties (COP-1) to the UNFCCC. Agreement to negotiate *legally binding* targets and timetables to limit emissions in Annex I countries.
1997	U.S. Senate passes Byrd–Hagel resolution, 95 to 0, stating that the United States should accept no climate agreement that did not demand comparable sacrifices of all participants and calling for the administration to justify any proposed ratification of the Kyoto Protocol with analysis of benefits and costs.
1997	COP-3 is held in Kyoto, Japan, leading to the Kyoto Protocol. The agreement would require the developed countries to reduce their emissions of greenhouse gases by an average of about 5% of 1990 levels by the 5-year period 2008-12.
	Annex I/Annex B countries agree to binding emission reductions averaging 5% below 1990 levels by 2008–12, with “flexibility mechanisms” (including emissions trading) for compliance; no commitments for emission limitation by developing countries.
1998	COP-4 is held in Buenos Aires, Argentina; emphasis on operationalizing the “flexibility mechanisms” of the Kyoto Protocol.
	IPCC Third Assessment begins.
1999	COP-5 is held in Bonn, Germany; continued emphasis on operationalizing the flexibility mechanisms.
2000	COP-6 is held in The Hague, Netherlands.
2001	The United States withdraws from Kyoto protocol.
	COP-7 Marrakesh, Morocco; work to complete the “rules package” that would set the stage for Parties to the UNFCCC to ratify the protocol.
2002	COP-8 New Dehli, India; work on international actions to limit greenhouse gases beyond 2012.

Source: UNFCCC (see Suggested Reading).

until about 1940, the global average temperature rose. From then until 1970, for reasons that are still not entirely clear, it leveled off and even fell a little. But around 1970, it started to increase again, strongly and consistently.

When that happened, the possibility that human activity was changing the global climate began to attract serious attention among scientists and government officials with environmental responsibilities. Table 1 summarizes some of the key milestones in the international evolution of climate policy over the past 20 years. In the United States, the National Academy of Sciences addressed the possibility of greenhouse warming several times; its 1979 report concluded that CO_2 emissions would lead to warming in the next century. Also in 1979, the World Meteorological Organization (WMO) and other U.N. agencies held the First World Climate Conference, where CO_2 was a major topic. Later that year, the WMO established the World Climate Program to coordinate research. That in turn led to a 1985 conference in Villach, Austria, that demonstrated a growing consensus among scientists on the probability of a warmer climate caused by greenhouse gases (GHGs)—CO_2 and several other gases generated by industry and agriculture.

This prospect was deeply troubling to anyone with an interest in the environmental ethic. From its beginnings, the science of ecology has been based on the concept of an intricate system of balances. Research increasingly showed a high risk that industrial development and rising standards of living were tipping, perhaps irrevocably, one crucial balance in a way that could affect all life on the planet.

But until the mid-1980s, the initiative remained almost entirely with the professionals—scientists, public officials, and international bureaucrats running agencies devoted to weather and climate. The advocacy organizations that had transformed environmental policy over the previous two decades, carrying it to the highest levels of politics in North America and Europe, were largely absent from the issues of climate change.

One reason was that few of the advocacy organizations considered themselves equipped for international politics. They had grown strong in the struggles over domestic issues, and their techniques were adapted to the political and legal processes of their own countries. But climate change would have to be addressed internationally, and re-equipping the environmental movement to deal with the very different institutions of international cooperation seemed a daunting challenge.

In 1987, the scene changed suddenly with a great triumph for environmental protection in a closely related matter, the worldwide campaign to preserve the stratospheric ozone layer. The ozone treaty suggested enormous new possibilities for worldwide environmental action. Because it established a model strategy that advocacy groups and governments followed closely in their approach to climate change, it is useful to recall how and why that was accomplished.

Stratospheric Ozone Accord

In the early 1970s, scientific evidence had begun to suggest that a family of synthetic chemical compounds, chlorofluorocarbons (CFCs), was eroding a layer of ozone that lay in the upper atmosphere. The ozone layer provided a vital protection against harmful ultraviolet radiation from the sun. Unscreened, this radiation could cause skin cancers and other damage in people exposed to it.

The CFCs had many uses, but were most commonly used as propellants of aerosols in products such as hair sprays. The suggestion of a connection to cancer immediately set off boycotts by consumers and a race for substitutes among manufacturers. The U.N. Environment Program called for worldwide action. In 1978, the United States and several other countries banned most aerosol sprays. A succession of meetings and scientific reports followed.

These meetings and reports culminated in 1985 at the Vienna Convention for the Protection of the Ozone Layer, an agreement that was deliberately written loosely to attract the widest possible support with the fewest possible arguments over details. It committed governments to take only unspecified actions and to do so only if the chemicals involved should be found to have adverse effects. The idea was not to bind governments to a precise program, but to start a process of research and consultation that could be adapted as further findings and necessities became clear. That strategy was brilliantly successful.

Two months after the convention was signed, a British research team reported the first actual observations of thinning of the ozone layer from the Antarctic. These findings revived public anxiety about the health effects, which was fueled by the discovery that the scale of damage was considerably greater than the models had predicted. This development, incidentally, was a warning that environmental change is not always gradual or predictable, even in a process that is under careful study.

By late 1986, the United States was calling for international controls. It began pushing for a freeze and an eventual phase-out of production of the gases that erode the ozone layer. The American chemical industry gave powerful support to the idea of a world agreement. For the American producers, CFCs were not a major product, and they were unwilling to jeopardize their public reputations to defend them. As a practical matter, they understood that the choice was between a ban worldwide or one only in the United States, and they very much preferred rules that would also apply to their European competitors. As for competition, the American companies believed that they were ahead of the Europeans in the search for substitutes for the CFCs, and world limits on CFCs would increase the competitive value of their lead. This difference between the American and European industries' positions is the chief explanation for the difference between the governments' positions. Throughout this period, the United States forcefully pushed for action while most of the European countries dragged their feet.

Despite its backing from business, the movement toward a binding agreement generated fierce infighting in the conservative Republican administration in Washington. Some officials saw it as a precedent for international regulation. In the spring of 1987, the dispute went public when Secretary of the Interior Donald Hodel suggested that the dangers of ultraviolet radiation were greatly exaggerated and that people could easily protect themselves by wearing hats and sunglasses. His comment brought a deluge of ridicule down on the administration. The question was finally put to President Ronald Reagan at a White House meeting in June. To the great surprise of the antiregulators, the President sided with Secretary of State George Shultz and U.S. Environmental Protection Agency (EPA) Administrator Lee Thomas in supporting binding limits on CFCs. Perhaps Hodel had forgotten that two years earlier, the President had undergone surgery to remove skin cancer from his nose.

Three months after that White House meeting, negotiators in Montreal, Quebec, Canada, completed a second treaty on CFCs—technically, a protocol to the first one—and most of the industrial countries quickly signed it. Unlike the Vienna Convention, the Montreal Protocol contained firm and legally binding limits on CFC consumption. There was to be an immediate freeze, followed by a 20% decrease (from the 1986 level) in 1993, then a 50% decrease in 1998. The Montreal Protocol was a powerful signal that effective international action to protect the environment was possible.

Toward a Climate Treaty

In 1988, climate change and global warming became a widespread public concern and a political issue, no longer confined to meetings of scientists and specialists. In the background was the rising average global temperature. By the late 1980s, it was clear that the decade would be the warmest in the century or so for which reliable measurements were available. Several events brought this fact and its implications to public attention.

In the United States, Senator Tim Wirth of Colorado, who had been interested in climate change for some time, had grown increasingly exasperated by the country's refusal to notice it. In late June of 1988, amidst growing concern about a severe and widespread drought in the South and the Midwest, he called a hearing on a day forecast to be spectacularly hot. As the temperature reached 98 °F that afternoon, Wirth called a series of experts to testify. One of them, James E. Hansen, director of the National Aeronautics and Space Administration's Institute for Space Studies, told the committee that NASA was 99% certain that the cause of the warming trend was synthetic gases, not natural variation. “It is time to stop waffling so much and say the evidence is pretty strong that the greenhouse effect is here,” Hansen said to a reporter for the *New York Times*, which put the story on its front page (“Global Warming Has Begun, Expert Tells Senate,” June 24, 1988). Hansen’s testimony had an immediate impact because he was the first scientist of his stature to declare that the rising temperatures were very probably related to burning fossil fuel.

Four days later, a conference called by the Canadian government opened in Toronto, attended by not only scientists but also politicians from dozens of countries. Although it grew out of the succession of meetings and reports sponsored by the U.N. agencies, it marked the stage in this international process where the meetings expanded beyond the U.N. agencies and the usual specialists. It also was at this point that the discussion turned to specific preventive action. In its final statement, the Toronto conference called for a 20% reduction in global emissions of CO_2 by 2005.

This statement turned out to be highly influential, setting its key goal in terms of a reduction of the volume of emissions in the near term. That target was not based on any economic analysis, because at that time, economists were only beginning to study the subject. The conference knew that a 20% reduction would not be sufficient to stabilize the concentration of CO_2 in the atmosphere, but it did not want to set a figure so high that governments would dismiss it as implausible. On the other hand, it wanted to choose a figure that would show a serious intent to make fundamental changes.

It is never a simple matter to trace the origins of people’s ideas about what shows serious intent. But 20% was also the figure that the Montreal Protocol—negotiated a year earlier, to great applause, in the same country—set as the first cut in world CFC consumption.

In mid-1988, at their annual summit meeting, the heads of the seven big industrial democracies called for a framework treaty to limit the world’s production of CO_2, and negotiations were soon under way. In December 1988, the U.N. General Assembly approved the establishment of an expert Intergovernmental Panel on Climate Change (IPCC) to provide an authoritative review of the science of global warming to inform the talks.

But this time, reversing their positions in the ozone negotiations, Europe pushed for rapid action and the United States resisted. One reason was that, as a matter of principle, hostility to regulation and interference with markets remained strong in the Bush administration. Another reason was that, this time, the United States was being forcefully pressed by its industries to delay. In Europe, most of the indigenous energy industries are relatively small and are often tied closely to their governments. In the United States, the coal, oil, gas, and power producers are huge, and their interests are defended by not only corporations but also influential labor unions.

The first IPCC reports appeared in late 1990, showing broad agreement among scientists in the field that the possibility of global warming at least had to be taken seriously. The Europeans, urging action, cited the reports’ warnings of the possible consequences of higher temperatures, whereas the Bush administration replied by pointing to their emphasis on the scientific uncertainties. In the negotiations over the U.N. Framework Convention on Climate Change (UNFCCC), the United States flatly opposed any firm targets for reductions of CO_2 emissions. The Europeans were able to gain an acknowledgement that, at least in principle, reductions were desirable. The final language set a voluntary goal of cutting emissions back to the 1990 level by 2000, but like the Vienna Convention on ozone, the UNFCCC contained no enforceable commitments. Even that purely aspirational goal represented substantial movement from the United States’ original inclination to do no more than study the climate. The text of the UNFCCC was completed in time to be signed with great ceremony by nearly every country on Earth in June 1992 at the United Nations’ huge and colorful Conference on Environment and Development in Rio de Janeiro, Brazil.

Development of an Action Plan

At this point, if the politics of global warming had followed the ozone model, increasingly ominous scientific reports would have pushed the diplomats and politicians rapidly from the voluntary commitments of the UNFCCC to tight and obligatory cuts in emissions of CO_2 and the other GHGs. But that didn't happen, for several reasons.

First, the campaign to protect the ozone layer was driven by a fear of cancer. No similarly compelling motive pushed a climate agreement forward. Vice President Al Gore and many others spoke of the possibilities of terrible storms and epidemics, but scientists said that the evidence was not conclusive. Rather than becoming more precise and urgent, as the ozone findings had done, the science of global warming remained unclear on many important points. Most scientists concluded that it would not be possible for years, perhaps decades, to predict with any assurance how fast the world would warm, or what consequences might come of it. The scientific uncertainties deflated the impulse toward action.

It also was true that in the ozone case, action had meant reducing the consumption of certain products for which technology was rapidly providing satisfactory substitutes. But most of the world's energy comes from burning fossil fuels, and at present, there is no way to burn fossil fuels without releasing CO_2 to the atmosphere. Treating exhaust gases to remove CO_2 and storing or recycling it are not yet economically practical or even technically feasible on a large scale. How rapidly the world could turn to other sources of energy, and at what cost, were subjects for intense controversy throughout the 1990s. The answers remained sufficiently unclear that many political leaders hesitated to impose policies that attempted to change people's long-established habits in the use of energy (such as driving) and that seemed likely to cause great disruption in economic life.

President Bill Clinton, who took office in early 1993, had sharply criticized President George Bush's reluctance to take action on greenhouse emissions. In February, he proposed a broad tax on all energy consumption, and in April, to celebrate Earth Day, he announced that his administration would adopt measures to stabilize emissions at 1990 levels as the Rio treaty had urged. But the President was soon distracted by the great struggle over his budget. Congress, hostile to the idea of an energy tax from the beginning, pared it down to a mere increase of 4.3 cents a gallon in the gasoline tax—too little to have any significant effect on consumption. When the specific details of the President's Climate Change Action Plan were presented in fall 1993, they turned out to be entirely voluntary. The Clinton administration did not intend to take on the massive and politically costly campaign that would have been necessary to change Americans' accustomed practices in using energy.

But neither were the European governments willing at that time to undertake difficult and drastic energy programs. The European Union tentatively proposed a tax on carbon emissions, but it got no farther than President Clinton's energy tax. By the mid-1990s, it was clear that of the world's major industrial powers, only three would meet the Rio goal of getting their emissions back to 1990 levels by 2000. Russia would meet it because the old Soviet economy, profligate in its use of energy, was collapsing. Germany would meet it because it had shut down most of the grossly inefficient power plants in its formerly Communist eastern region. And Britain, to save money, was cutting down its subsidies to coal and swinging its power production toward less carbon-intensive natural gas. Nowhere in any of the large economies was there any sign of a serious and purposeful effort to reduce CO_2 emissions for environmental reasons.

In early 1995, under these unpromising circumstances, the United Nations held the first Conference of Parties to the Rio treaty (COP-1) in Berlin, Germany. The purpose was to assess progress toward the grand promises made at Rio. Noting that progress was exceedingly modest, the 120 countries represented at COP-1 agreed to begin work on a further agreement to strengthen their commitments by setting specific targets for emissions limits and reductions by certain years such as 2005, 2010, and 2020. These targets and timetables were to apply to the industrial countries, but not the developing countries.

A few months later, the IPCC brought out its second survey of the science of global warming; the tone was much more conclusive than five years earlier. In a widely quoted line, it declared, "The balance of evidence suggests that there is a discernible human influence on global climate." However, this sentence was preceded by a warning about the present state of knowledge: "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors" (see Suggested Reading). The reference to "a discernible human influence" was enough to encourage the politicians and diplomats who were working for a stronger treaty. But it wasn't enough to change many minds among the opposition.

At the next negotiating session, the second Conference of Parties (COP-2), in the summer of 1996, the United States announced a clear and important change of policy. Tim Wirth, the former senator, was now an assistant secretary of state and head of the American delegation. The United States would support legally binding limits on emissions, he said, if other countries did.

In Berlin, the Conference of Parties had set a deadline for the negotiations, agreeing to draft a treaty at the third Conference of Parties (COP-3), which would be held in 1997 in Kyoto, Japan. The Europeans kept pressing for substantial action. In Britain, where an election campaign was under way, the Labour Party pledged in its manifesto to take the lead in the world environmental movement by supporting a 20% reduction by 2010. Labour's huge victory in May gave additional force to its demands.

Meanwhile, a rapidly growing economic literature, especially in the United States, was making the discussion of alternative control strategies very much more complicated and was multiplying the trade-offs with which policymakers were confronted. A comparison with the ozone case is, once again, instructive. In late 1987, shortly after the Montreal Protocol on the ozone layer was signed, EPA published a cost–benefit analysis of an 80% reduction in CFC use. The costs would amount to $31 billion, the EPA found, but the benefits would be $6.4 trillion—nearly all of it representing the value of cancer deaths averted, at $3 million/death (see Hammitt in Suggested Reading). These figures only added momentum to the drive for further sweeping reductions in CFCs. But similar attempts at cost–benefit analysis of CO_2 reductions were ambiguous and much less compelling. They depended on assumptions that were open to challenge, and the long-term nature of climate change exposed the calculations to further doubts.

One widely cited paper argued persuasively that the cost of controlling CO_2 levels could be much lower without compromising long-term environmental protection if emissions reductions were delayed and commenced gradually before accelerating (see Wigley and others in Suggested Readings). Another paper suggested that society would be better served by policies that began by fixing the cost of making reductions, rather than fixing the volume to be reduced and leaving the cost unknown. By 1997, a substantial economic literature had emerged in the United States that challenged the emerging Kyoto strategy and its emphasis on relatively near-term goals expressed as reductions in volumes of emissions.

For politicians, environmental advocacy groups, and a growing public audience, the basic idea of goals and timetables had been laid down at the 1988 Toronto conference and seemed self-evident: The goals were to be expressed in reductions of GHG by volume, and the timetables were to be in the near term, with deadlines only a decade or so away, because anything farther in the future sounded like mere procrastination.

Other papers emphasized that flexibility of location could cut costs enormously. Flexibility meant, for example, allowing trading in emission rights. The sulfur dioxide trading program in the United States had been a great success in holding down the cost of combating acid raid, and the same principle would apply to CO_2. It made good sense to the White House, but traditionally, Europeans are suspicious of the market as an instrument of public policy. Even among Americans, debate continued between economists seeking efficiency and regulators who suspected that flexibility was simply a synonym for a loophole. Most of the environmental movement agreed with the regulators, creating an uncomfortable disagreement between the administration and one of its most conspicuous constituencies.

By the spring of 1997, President Clinton was aware that although his administration was committed to legally binding limits on CO_2 emissions, he was going to have difficulty getting legislation through Congress. In 1993, when he was at the height of his authority, a Congress controlled by Democrats had refused to enact his proposed energy tax; in 1997, Congress was in the hands of conservative Republicans who were not only hostile to taxes but also skeptical about climate change in general. The President knew that relatively few Americans were even aware of the issue of global warming and that they were sharply divided over whether to do anything about it. But his administration had promised to impose legally enforceable limits on itself and the rest of the industrial world at the coming Kyoto conference. The President's dilemma tightened over the spring, as the conference approached. A wide range of lobbies were engaged with the environmentalists on one side and industrial organizations and conservative political groups on the other. By this time, the news media gave regular coverage to climate change.

European criticism of the United States' energy policy—or lack of it—was no longer confined to small meetings of professional negotiators. President Clinton was the host of the 1997 meeting of the heads of the seven big industrial democracies. Control of GHGs was a prominent topic there, and French President Jacques Chirac publicly pushed Clinton for a specific American commitment. A week earlier, the European Union had agreed on a reduction of 15% from 1990 levels by 2010. At a news conference, Chirac pointedly observed that, per capita, the United States' GHG emissions were three times as high as France's.

From that meeting, the seven leaders took themselves to New York, where the U.N. General Assembly was assessing the meager progress toward the goals set by the Rio conference five years earlier. There, led by the new prime minister of Britain, Tony Blair, the Europeans—including Chirac and Chancellor Helmut Kohl of Germany—again demanded, publicly, more aggressive action by the United States.

President Clinton's speech that week to the General Assembly was the next step in his campaign to educate the American public and create a constituency for action. He offered a dire view of the future and called for a new era in technology (Presidential Document 973, June 26, 1997):

> The science is clear and compelling. We humans are changing the global climate. . . . Climate changes will disrupt agriculture, cause severe droughts and floods and the spread of infectious diseases, which will be a big enough problem for us under the best of circumstances in the twenty-first century. There could be 50 million or more cases of malaria a year. . . .
>
> We must create new technologies and develop new strategies like emissions trading that will both curtail pollution and support continued economic growth. . . . We will work with our people, and we will bring to the Kyoto conference a strong American commitment to realistic and binding limits that will significantly reduce our emissions of greenhouse gases.

But the President still gave no hint of the level at which he wanted to place those limits. While some environmental organizations chided him for delay, public reaction to the speech was otherwise modest. The previous day, the President had acted to tighten the standards on smog and soot in the air that Americans breathe, a decision for which he received strong public support. In contrast to smog, the threat of global warming still seemed remote and abstract to most people.

The next step in the President's education campaign was a White House conference that he and Vice President Gore held in late July, a month after the U.N. speech. "We see the train coming," the President told the conference, "but most Americans in their daily lives can't hear the whistle blowing" (Presidential Document 1116, July 24, 1997).

In response, the next day, the Senate passed a resolution (95 to 0) admonishing the President not to sign any treaty limiting American emissions unless the treaty also committed the developing countries to similar restrictions. The resolution reflected widespread fears that tightening environmental restrictions in this country would send manufacturing plants and jobs overseas to countries with less rigorous emissions restrictions or none at all. The two chief sponsors of this resolution were Robert C. Byrd of West Virginia, a very senior Democrat vigilant in his protection of his state's coal mining industry, and Chuck Hagel of Nebraska, a newly elected Republican.

With the Byrd–Hagel resolution, the role of the developing countries became central to the politics of a treaty. Although the industrial countries, including the former Soviet bloc, produced three-fifths of the world's CO_2 emissions, emissions were rising much faster in the developing countries. Some Americans cited projections suggesting that China would overtake the United States as the largest emitter around 2020 and argued that any agreement omitting China would be useless. The developing countries replied that the threat of global warming had been created over two centuries by the countries that were now rich, and it was up to them to address it without adding burdens to the poor. Furthermore, they added, by any reasonable definition of equity, it was not emissions per country that counted but rather emissions per capita. Even under the most expansive scenarios for Chinese growth, it would be a very long time indeed before the Chinese produced as much CO_2 per capita as Americans did.

In the fall, the President held another White House conference. Vice President Gore was there again, along with much of the Cabinet. President Clinton declared that he was convinced that the science was accurate. Once again, he said that the United States must be prepared to commit itself to binding targets. However, he added, all the world's nations must participate. The United States wanted fair but significant contributions by all countries. This caveat was new, a concession to the Senate. But it raised severe difficulties for the negotiators working on the text of the Kyoto Protocol. Most of the developing countries were adamantly opposed to any restrictions on their emissions, at the very least until they had seen a serious and substantial effort by the rich economies. The Europeans complained that President Clinton was changing the terms agreed in the Berlin Mandate two years earlier. This new requirement was being introduced by the United States in the final weeks of a long and cumbersome process that involved more than 140 governments.

Whereas President Clinton's speeches and conferences had succeeded in broadening public interest in the subject of climate change, they had also attracted powerful and articulate opponents. According to one study of public opinion, large majorities of Americans believed that global warming was occurring and that government had a responsibility to take action. However, at the same time, the intense debate of the subject by the White House and its adversaries had sharpened the differences between the two parties. Most Republicans continued to feel that the science was too uncertain to justify a large, expensive program to change the national economy. The industries and labor unions that would be touched by emissions restrictions initiated their own counter-campaign against any world agreement.

Finally, in late October 1997, less than six weeks before the Kyoto conference was to open, President Clinton laid out the American position. The United States would support a legally binding target of returning its emissions of GHGs to the 1990 level by the five-year period 2008–12. He also spoke of additional reductions in the years beyond 2012 but did not offer specific numbers. President Clinton again made it clear that he did not propose to challenge a unanimous Senate on the inclusion of the developing countries. The negotiators were left to write around a major disagreement among the governments.

The Kyoto Protocol

The Kyoto conference was a huge affair, bringing together more than 10,000 people—officials who represented nearly 170 countries, press, and lobbyists of every political persuasion from the greenest of green to coal black. The main focus was on targets and timetables, that is, how much the annual emissions of GHGs were to be reduced by industrialized countries and by when. The conference appeared to be deadlocked between the Americans, who were ready to return only to 1990 emissions levels, and the Europeans, who wanted deeper cuts. At the last moment, when the conference seemed about to collapse, President Clinton sent Vice President Gore on a rescue mission to make a one-day appearance and tell the American delegation that it could give a little more. By stopping the clock and working through the last night of the scheduled conference into the following day, the negotiators were able to draft a text that everyone could accept. The United States agreed to a target, for average emissions over the period

2008–12, that was 7% below its 1990 emissions. The European Union was to reduce emissions 8%. Emissions from all of the industrial countries together would go down 5.2%.

The conference proceeded by consensus, not by decisions taken on formal votes, and it achieved consensus only by leaving many issues out. One conspicuous example was the limitation of developing countries' emissions. On another point of intense interest to the Clinton administration, the provisions for trading emissions permits among the industrialized countries that agreed to cap their total emissions—known as the Annex I countries—were incomplete. (The reference is to Annex I of the 1992 Framework Convention. To be legally precise, the relevant list for emissions trading is actually the similar but slightly different Annex B of the Kyoto text.) The protocol also provided for a Clean Development Mechanism (CDM) through which industrial countries could earn emissions credits by financing projects that reduced emissions in developing countries, but again, details were scarce. The United States was counting on permit trading to hold down the costs of compliance. President Clinton told Congress that he would not send the Kyoto Protocol to the Senate for the necessary vote on ratification until American concerns about both developing countries' participation and trading were satisfactorily addressed in subsequent negotiations.

Other omissions in the draft represented additional issues too difficult to be dealt with in the conference. For example, there was no mention of who was to measure and verify countries' emissions, nor was there any suggestion of what might happen if a country failed to meet its commitments or of sanctions to enforce those commitments. These lapses showed the distance between the bold pioneering concept that the Kyoto Protocol represented and a tight legal agreement that could withstand the criticism of its enemies.

The text also contained vague references to financial aid to poor countries, without any of the specifics on which the finance ministers of the donor countries would insist before it went into effect. Although the developing countries were not required to cut their emissions, they were committed to keeping emissions inventories and setting up programs to mitigate their emissions. The Kyoto text obligated the industrial countries to provide funds to cover the costs of that work, as well as to finance the transfer of environmentally sound technology to the countries that lacked it. Regarding the CDM, the text promised that a share—unspecified—of the costs of these projects was to be taken to cover administrative expenses, as well as to help the most vulnerable developing countries meet the costs of adapting to climate change. All of the hard questions regarding amounts of money and control of the spending were left unanswered in the rush to get a quick agreement and end the conference on a note of harmony.

Beyond these omissions in the text lay a broader issue. The Kyoto Protocol called for substantially lower emissions of GHGs by most of the industrial countries, and few of them had any clear strategy to get there. The most conspicuous example was the United States. With no change in policy and with expected economic growth, according to the administration's own projection, the country's emissions would be more than 30% higher in 2010 than in 1990. But the treaty would require the emissions to be 7% lower than in 1990, a reduction of nearly one-third the business-as-usual volume in less than 15 years—a massive change in a very short time.

In Washington, the debate was largely over the costs and burdens of compliance. Janet Yellen, the chair of the President's Council of Economic Advisers, testified before a succession of congressional committees in March 1998 that the costs would be low. The administration's figures were about $14–23/ton of carbon or its equivalent in the other GHGs, assuming all the potential flexibilities in the Kyoto Protocol were fully and frictionlessly implemented. By the years 2008–12, it would amount to an increase of 3–5% in retail energy prices or, for the average household, $70–110 a year. In fact, Yellen noted, these increases might not be noticeable at all because they would be offset by the drop in electric power rates that the administration expected to result from the deregulation of the electric utilities.

Although her basic estimates were low, they lay within the range of plausibility. But they depended on certain assumptions which, while not spelled out, could be inferred from the mathematical models that the administration was using. The most important of these assumptions, it appeared, was that the United States would in fact make few reductions in its own emissions but would depend on an international trading system to buy about 85% of the emissions permits it needed to meet its Kyoto target.

The administration's low estimates assumed not only that there would be worldwide trading of emissions permits but also that the trading would be as efficient as, say, trading on the New York Stock Exchange. In the absence of international trading, the cost of meeting the Kyoto target in the United States would be four times as high, other economists soon showed with calculations from the same model that the administration was using (see Edmonds and others in Suggested Reading). Trading, as well as the limits and conditions that might be imposed on it, would make a huge difference in the costs of compliance. But, as already noted, the protocol contained only brief and general language about trading, even among Annex I countries. Regarding the rest of the world, it envisioned only project-based emission reduction credits through the CDM.

Relying heavily on undefined mechanisms was both open to criticism on economic grounds and inflammatory as foreign policy. American industry was more efficient in using fuel than most of the developing countries. It was obviously cheaper to make emissions reductions in the developing world. But with so much uncertainty about the practical operation of the Kyoto Protocol's flexibility mechanisms, the administration figures could hardly be regarded as firm estimates. Meanwhile, officials in both Europe and the developing countries reacted with hostility to the implication that the United States intended to use its financial power to enable itself to stay close to a business-as-usual track of steadily rising emissions. In May 1999, the European Union adopted the position that no more than one-half of any country's permits should come from abroad.

This strategy of buying permits abroad also proved to be controversial in the United States. Environmentalists immediately observed that, because of the severe economic decline in the former Soviet states, Russia and the other countries would have enormous numbers of emissions permits that they could sell without reducing their actual emissions. They derided the concept as "hot air." Meanwhile, economists noted that buying permits on the scale envisioned by the Clinton plan would not be inexpensive. The previous year, two analysts—using figures less optimistic than Dr. Yellen's but still well within the range of the possible—had pointed out that this outflow of dollars would be sufficient to affect currencies' exchange rates and to distort international trade (see McKibbin and Wilcoxen in Suggested Reading). Congressional representatives soon began to express concern that the trading provisions of the Kyoto Protocol would result in large payments to foreign countries.

Trading was not the only point of contention. In making its cost estimates, the Clinton administration had also used highly favorable assumptions regarding the speed and ease with which the economy would adjust to emissions limits. Industrial lobbies quickly commissioned studies that, using different assumptions on both trading and economic adjustment, showed that the costs of compliance might well be ten times as high as the administration's figures. Nor was the attack solely from Republicans. Rep. John Dingell (D-Michigan), ranking minority member of the Commerce Committee and a power in the House of Representatives, called for a sweeping renegotiation of the Kyoto Protocol, declaring that in its present form, it would do less to protect the environment than to promote commercial advantages for other countries at American expense.

Since the Kyoto Conference

While this debate roared along in Washington, the negotiators who had written the Kyoto text were thinking about the omissions in it. Soon it became conventional to defend the treaty by describing it as "a work in progress," suggesting that it could not be fairly judged until it had been completed. The fourth Conference of Parties (COP-4) was held in Buenos Aires, Argentina, in November 1998 to consider the process of bringing the outstanding issues to resolution.

It ended without much progress on the political differences among the major countries, but it set a plan of action for addressing them over the next two years. Two developing countries created a flurry by announcing that they intended to place themselves under enforceable emissions limits. One was Argentina, the host of the meeting, which was anxious to show movement on the most difficult of these disputes. The other was Kazakhstan, which—like the rest of the former Soviet Union—had suffered a sharp industrial depression and would have permits to sell. Both were denounced by the other developing countries for breaking ranks, and no others followed suit.

By this time, the United Nations had provided the negotiating process with a substantial professional staff and headquarters in a handsome house on the bank of the Rhine River in Bonn, Germany. This staff oversaw a heavy schedule of meetings on the Kyoto issues. Two or three times a year, the Conference of Parties' subsidiary bodies met, and they in turn commissioned specialized workshops, all leading up to the annual conference. This procedure generated a series of sophisticated and useful discussions of the technical points, even while the major political questions remained unresolved.

At the fifth Conference of Parties (COP-5), held in Bonn in November 1999, the negotiators agreed that the following year, they would try to prepare the Kyoto Protocol to go into force. The rules necessary to implement the protocol were under vigorous negotiation at the sixth Conference of Parties (COP-6), held in November 2000 in The Hague, the Netherlands. Many governments, especially among the Europeans, hoped for a final agreement that would lead to the protocol's entry into force by 2002. But these talks ended in continued disagreement.

To put the Kyoto Protocol into force would require ratification by 55 countries, which together represent 55% of the 1990 emissions of the industrial countries. Most countries have signed the treaty, including the United States, but a signature in this case is a mere gesture with no legal significance. By the end of 2003, 119 countries had ratified the protocol but they accounted for only 45% of 1990 emissions. Ratification procedures vary from one country to another. In the United States, two-thirds of the Senate must vote approval. Because the United States contributed slightly less than 40% of the industrial countries' 1990 emissions, it is possible that the protocol could take effect without American participation.

A Final Comment

The Kyoto Protocol is by far the most complex environmental treaty that governments have ever attempted. It does not affect merely one restricted class of products, like the Montreal Protocol on stratospheric ozone. It does not affect merely one industry, like a fishing treaty. In a world that runs on fossil fuel, the Kyoto Protocol reaches nearly every industry, nearly all forms of transportation, and most households. The lack of progress in the negotiations since the Kyoto conference reflects chiefly a need among governments and citizens, not only in the United States, to reread and reconsider a document that would deeply affect every industrial economy. This reconsideration proceeds while emissions continue to grow and the technical debate goes on regarding the risks of climate change, the costs of different response options, and the prospects for sustained international cooperation in the face of divergent national interests.

Although President Clinton's 1997 campaign to generate support for an agreement on climate change was perhaps less successful than he had hoped, he certainly succeeded in making Americans more conscious of the prospect of global warming. Although governments around the world have promised more than they know how to achieve, a broader public has now joined the discussion. Governments of rich countries are spending very large amounts of money on climate research. The leader in this enterprise, the United States, has for several years been putting nearly $2 billion a year into the science of the climate. The flow of new findings is impressive.

A rising worldwide temperature over the past century is a reality. More and faster warming over the next century is a high probability. The world has not yet decided how to deal with this phenomenon. But it has begun—slowly, uncertainly, and contentiously—to think about it.

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3

How Much Climate Change is Too Much? An Economics Perspective

Jason F. Shogren and Michael A. Toman

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

Lurking behind these policy activities is a deceptively simple question: How much climate change is acceptable, and how much is "too much"? (The other key question is: Who is going to pay for mitigating the risks?) The lack of consensus on this issue reflects the uncertainties that surround it and differences in value judgments regarding the risks and costs.

In this chapter, we review the economic approach to the question of how much climate change is too much. The economic perspective emphasizes the evaluation of benefits and costs broadly defined while addressing uncertainties and important considerations such as equity. We also consider some important criticisms of the benefit–cost approach. Then, we discuss the key factors that influence the benefits and costs of mitigating climate change risks. This discussion leads to a review of findings from the many quantitative "integrated assessment" models of climate change risks and response costs. This review does not lead to a simple answer to our overarching question about how much climate change is too much. But we do identify several

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good reasons for taking a deliberate but gradual approach to the mitigation of climate change risks.

The issues we cover are both diverse—ranging from the economics and philosophy of long-term cost-benefit analysis, to modeling strategies for representing climate change risks and greenhouse gas abatement costs—and, at times, somewhat complex. We have tried to be fairly comprehensive while seeking to make the discussion as accessible as possible.

Overview of the Risks and Response Costs

Life on Earth is possible partly because some gases such as carbon dioxide (CO_2) and water vapor, which naturally occur in Earth's atmosphere, trap heat—like a greenhouse. CO_2 released from use of fossil fuels (coal, oil, and natural gas) is the most plentiful human-created greenhouse gas (GHG). Other gases—which include methane (CH_4), chlorofluorocarbons (CFCs; now banned) and their substitutes currently in use, and nitrous oxides associated with fertilizer use—are emitted in lower volumes than CO_2 but trap more heat. Human-made GHGs work against us when they trap too much sunlight and block outward radiation. Scientists worry that the accumulation of these gases in the atmosphere has changed and will continue to change the climate.

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

- Reduced productivity of natural resources that humans use or extract from the natural environment (for example, lower agricultural yields, smaller timber harvests, and scarcer water resources).

- Damage to human-built environments (for example, coastal flooding from rising sea levels, incursion of saltwater into drinking water systems, and damage from increased storms and floods).

- Risks to life and limb (for example, more deaths from heat waves, storms, and contaminated water, and increased incidence of tropical diseases).

- Damage to less managed resources such as the natural conditions conducive to different landscapes, wilderness areas, natural habitats for scarce species, and biodiversity (for example, rising sea levels could inundate coastal wetlands, and increased inland aridity could destroy prairie wetlands).

All of these kinds of damage are posited to result from changes in long-term GHG concentrations in the atmosphere. Very rapid rates of climate change could exacerbate the damage. The adverse effects of climate change most likely will take decades or longer to materialize, however. Moreover, the odds that these events will come to pass are uncertain and not well understood. Numerical estimates of physical impacts are few, and confidence intervals are even harder to come by. The rise in sea level as a result of polar ice melting, for instance, is perhaps the best understood, and the current predicted range of change is still broad. For example, scenarios presented by the Intergovernmental Panel on Climate Change (IPCC) in *Climate Change 1995: The Science of Climate Change* (see Suggested Reading) indicate possible increases in sea level of less than 20 cm to almost 100 cm by 2100 as a result of a doubling of Earth's atmospheric GHG concentrations. The uncertainty in these estimates stems from not knowing how temperature will respond to increased GHG concentrations and how oceans and ice caps will respond to temperature change. The risks of catastrophic effects such as shifts in the Gulf Stream and the sudden collapse of polar ice caps are even harder to gauge.

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

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

In weighing the consequences of climate change, it is important to remember that humans adapt to risk to lower their losses. In general, the ability to adapt contributes to lowering the net risk of climate change more in situations where the human control over relevant natural systems and infrastructure is greater. Humans have more capacity to adapt in agricultural activities than in wilderness preservation, for example. The potential to adapt also depends on a society's wealth and the presence of various kinds of social infrastructure, such as educational and public health systems. As a result, richer countries probably will face less of a threat to human health from climate change than poorer societies that have less infrastructure. Beyond this general point, the potential for adaptation to reduce climate change risks continues to be debated.

GHGs remain in the atmosphere for tens or hundreds of years. GHG concentrations reflect long-term emissions; changes in any one year's emissions have a trivial effect on current overall concentrations. Even significant reductions in emissions made today will not be evident in atmospheric concentrations for decades or more. This point is important to keep in mind in deciding when to act—we do not have the luxury of waiting to see the full implications of climate change before taking ameliorative action. Many observers characterize responding to the risks of climate change as taking out insurance; nations try to reduce the odds of adverse events occurring through mitigation, and to reduce the severity of negative consequences by increasing the capacity for adaptation once climate change occurs. The insurance analogy underscores both the uncertainty that permeates how society and policymakers evaluate the issue and the need to respond to the risks in a timely way.

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

Why Consider the Costs and Benefits of Climate Policy?

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

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

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

- The damages due to climate change, and thus the benefits of climate policies to mitigate these damages, are uncertain and thus inherently difficult to quantify given the current state of knowledge. Climate change also could cause large-scale irreversible effects that are hard to address in a simple benefit–cost framework. Therefore, the estimated benefits of action are biased downward.

- Climate mitigation costs are uncertain and could escalate rapidly from too-aggressive emission control policies. Proponents of this view are indicating a concern about the risk of underestimating mitigation costs.

- Climate change involves substantial equity issues—among current societies and between current and future generations—that are questions of morality, not economic efficiency. Policymakers should be concerned with more than benefit–cost analysis in judging the merits of climate policies.

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

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

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

The benefit–cost approach can address both uncertainty and irreversibility. We do not mean to imply that estimates in practice are always the best or that how one evaluates and acts on highly uncertain assessments will not be open to philosophical debate. For example, as people become more informed about climate change, it is safe to presume that the importance they attach to the issue will change. Critics of the economic methodology argue that this process reflects in part a change in preferences through various social processes, not only a change in information. Moreover, under conditions of great uncertainty, the legitimacy of a policy decision may depend even more than usual on whether the processes used to determine it are deemed inclusive and fair, as well as on the substantive evidence for the decision.

But it is fundamentally inaccurate to see analysis of economic benefits and costs from climate change policies as inherently biased because of uncertainty and irreversibility. Nor should benefit–cost analysis be seen as concerned only with market values accruing to developed countries. One of the great achievements in environmental economics over the past 40 years has been a clear demonstration of the importance of nonmarket benefits, which include benefits related to the development aspirations of poorer countries. These values can be given importance equal to that of market values in policy debates.

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

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

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

Equity and Fairness Issues

The fairness of climate change policies to today’s societies and to future generations continues to be at the core of policy debates. These issues go beyond what economic benefit–cost analysis can resolve, though such analysis can help illustrate the possible distributional impacts of different climate policies. In this section, we focus first on intergenerational equity issues. Then, we address contemporaneous equity issues.

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

Supporters of the conventional approach to discounting on grounds of economic efficiency argue just as vehemently that any evaluation of costs and benefits over time that understates the opportunity cost of forgone investment is a bad bargain for future generations because it distorts the distribution of investment resources over time. These supporters of standard discounting also argue that future generations are likely to be better off than the present generation, casting doubt on the basic premise of the critics’ concerns.

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

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

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

We turn next to a brief discussion of international equity issues associated with climate change. The most immediate aspect of this debate involves the international distribution of responsibility for reducing GHGs and the associated costs. Developing nations have many pressing needs, such as potable water and stable food supplies, and less financial and technical capacity than rich countries have for mitigating GHGs. These nations have less incentive to agree to a policy that they see as imposing unacceptable costs.

Beyond this question are even more vexing issues surrounding the distribution of climate change risks. As already noted, it is likely that developing countries are both relatively more vulnerable to climate change than advanced industrialized countries and have less adaptive capacity; however, these disadvantages likely will be reduced in the future with further economic development. These differences are only beginning to be accounted for in climate change risk assessments. Analyses that consider only aggregate benefits and costs of climate change mitigation, without addressing the distribution of these benefits and costs, miss an important dimension of the policy problem. For example, the absolute magnitude of avoided costs from slowing climate change may be smaller in developing countries simply because per capita incomes are lower. But the implication that climate change mitigation should be given short shrift just because it mainly affects poorer people is ethically troubling.

Differences in perceptions about what constitutes equitable distributions of effort complicate any agreement. No standard exists for establishing the equity of any particular allocation of GHG control responsibility. Simple rules of thumb, such as allocating responsibility based on equal per capita rights to emit GHGs (advantageous to developing countries) and allocations that are positively correlated to past and current emissions (advantageous to developed countries) are unlikely to command broad political support internationally.

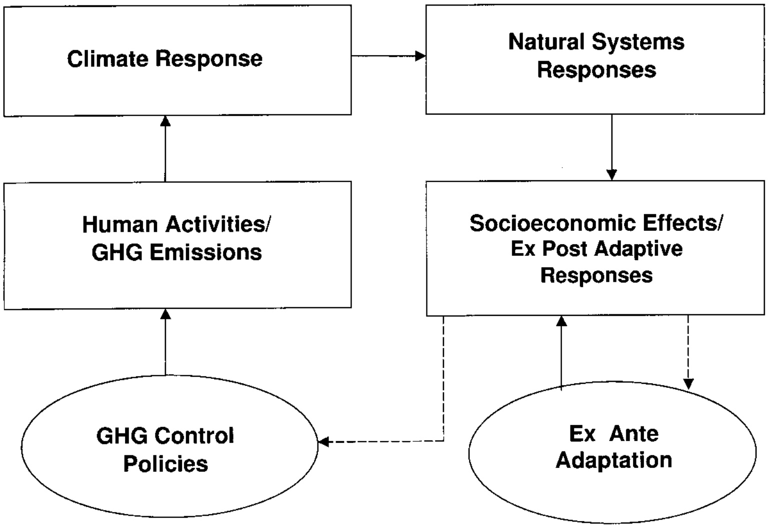
What Do Existing Economic Analyses Say?

Analyzing the benefits and costs of climate change mitigation requires understanding biophysical and economic systems as well as the interactions between them. Integrated assessment (IA) modeling combines the key elements of biophysical and economic systems into one integrated system (Figure 1). IA models strip down the laws of nature and human behavior to their essentials to depict how more GHGs in the atmosphere raise temperature and how temperature increase induces economic losses. The models also contain enough detail about the drivers of energy use and interactions between energy and economy that the economic costs of different constraints on CO_2 emissions can be determined.

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

A striking finding of many IA models is the apparent desirability of imposing only limited GHG

Figure 1. Climate Change and Its Interaction with Natural, Economic, and Social Processes.



Note: The key components of an integrated assessment model are illustrated. Solid lines represent physical changes; dotted lines represent policy changes.

Source: Darmstadter and Toman (see Suggested Reading).

controls over the next 20 or 30 years. According to the estimates in most IA models, the costs of sharply reducing GHG concentrations today are too high relative to the modest benefits the reductions are projected to bring.

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

Even more striking is the finding of many IA models that emissions should rise well into this century. In comparison, the models indicate that policies pushing for substantial near-term control, such as the Kyoto Protocol, involve too much cost, too soon, relative to their projected benefits. Critics argue that IA models inadequately address several important elements of climate change risks: uncertainty, irreversibility, and risk of catastrophe. Assessing the weight of these criticisms requires us to explore the influences on the economic benefits and costs of climate protection.

Influences on the Benefits

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

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

Assumptions about adaptation also affect estimates of potential benefits. Some critics of the earlier IPCC estimates argue that damages likely will be lower than predicted because expected temperature increases from a doubling of atmospheric GHG concentrations probably will be less than projected, ecosystems seem to be more resilient over the long term than the estimates suggest, human beings can adapt more than was supposed, and damages are not likely to increase proportionally with GDP. The implication is that the optimal path for GHG control (in a present value sense) should be even less aggressive than the IA results indicate. These new assessments remain controversial. One ongoing question concerns the cost of adjusting to a changing climate versus the long-term cost of a changed climate. Another is whether the effects of climate change (for example, in encouraging the spread of human illness through a greater incidence of tropical diseases, reducing river flows that concentrate pollutants, and increasing the incidence of heat stress) are being underestimated.

A third factor affects benefits: Damage costs not only are uncertain but also involve a chance of a catastrophe. However, a general finding from IA models is that GHG reductions should be gradual, even if damages are larger than conventionally assumed. A risk of catastrophe provides a rationale for more aggressive early actions to reduce GHG concentrations, but the risk has to be very large to rationalize near-term actions as aggressive as those envisioned in the Kyoto Protocol in a present-value IA framework. Part of the reason for this finding is that the outcome with the lowest cost also is the most likely to occur. IA models also do not incorporate risk-averse attitudes, which would provide a stronger rationale for avoiding large costs. Moreover, discounting in the models reduces the effective impact of all but the most catastrophic costs after a few decades.

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

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

Influences on the Costs

Estimates of the cost of mitigating GHG emissions vary widely. Some studies suggest that the United States could meet its Kyoto Protocol target at negligible cost; other studies claim that the United States would lose at least 1–2% of its GDP each year. A study by the Energy Modeling Forum helped explain the range of results in assessing the costs to meet the Kyoto Protocol policy targets (see Weyant and Hill in Suggested Reading). For example, the carbon price (carbon tax or emissions permit price) needed to achieve the Kyoto Protocol

Table 1. Implications of a Carbon Tax for U.S. Gasoline and Coal Prices.

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

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

Sources: U.S. DOE (see Suggested Reading).

emissions target in the United States with domestic policies alone ranges from about $70 per metric ton of carbon to more than $400 per ton (in 1990 dollars) across the models. The corresponding GDP losses in 2010 range from less than 0.2% to 2.0% relative to baseline. (The percentages of GDP are not reported in Weyant and Hill but implied from graphs presented there.) Carbon prices are put in perspective by relating them to prices for common forms of energy, as listed in Table 1.

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

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

Another important factor in assessing the costs of CO_2 control is the capacity and willingness of consumers and firms to substitute alternatives for existing high-carbon technologies. Substitution undertaken depends partly on the technological ease of substituting capital and technological inputs for energy inputs and partly on the cost of lower-carbon alternatives. Some engineering studies suggest that 20–25% of existing carbon emissions could be eliminated at low or negligible cost if people switched to new technologies such as compact fluorescent light bulbs, improved thermal insulation, efficient heating and cooling systems, and energy-efficient appliances. Economists counter that the choice of energy technology offers no free lunch (for further discussion, see Chapter 17, Energy-Efficient Technologies and Climate Change Policies). Even if new technologies are available, many people are unwilling to experiment with new devices at current prices. Factors other than energy efficiency also matter to consumers, such as quality, features, and the time and effort required to learn about a new technology and how it works. People behave as if their time horizons are short, perhaps reflecting their uncertainty about future energy prices and the reliability of the technology.

In addition, the unit cost of GHG control in the future may be lower than in the present, as a consequence of presumed continuation in trends toward greater energy efficiency in developed and developing countries (as well as some increased scarcity of fossil fuels). These trends will be enhanced by policies that provide economic incentives for GHG-reducing innovation. It is possible that the cost associated with premature commitment to irreversible long-lived investments in low-emissions technologies is more important in practice than climatic irreversibility, at least over the medium term. The reason is that sunk investments cannot be undone if climate change turns out to be less serious than might be expected, whereas society can accelerate GHG control if it learns that the danger is greater than estimated. The strength of this point depends in part on how irreversible low-GHG investment is and on the costs of irreversible climate change. In addition, critics of this view argue that without early action to reduce GHG emissions, markets for low-emissions technologies would not develop and societies would lock in to continued use of fossil fuel–intensive energy systems.

Still another important factor is the flexibility and cost-effectiveness of the policy instruments imposed, both domestically and internationally. For example, Weyant and Hill's review showed that the flexibility to pursue CO_2 reductions anywhere in the Annex I countries (the industrialized countries that would cap their total emissions under the Kyoto Protocol) through some form of international emissions trading system could lower U.S. costs to meet the Kyoto Protocol target by roughly 30–50%. Less quantitative analysis has been done of alternative domestic policies. Nevertheless, it can be presumed from studies of the costs of abating other pollutants that cost-effective policies will lower the cost of GHG abatement, perhaps significantly. In contrast, constraints on the use of cost-effective policies—for example, the imposition of rigid technology mandates in lieu of more flexible performance standards—will raise costs, perhaps considerably. This factor often is neglected in analyses of domestic abatement activity that consider only the use of cost-effective policies such as emissions permit trading, although use of such policies is hardly foreordained. Ignoring this factor means that the costs reported in the economic models probably understate the costs societies will actually incur in GHG control. By the same token, studies of international policies that assume ideal conditions of implementation and compliance are overly optimistic.

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

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

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

Uncertainty, Learning, and the Value of New Information

Another key factor in choosing the timing and intensity of climate change mitigation is the opportunity to learn more about both the risks of climate change and the costs of mitigation. Several studies show that the value of more and better information about climate risks is substantial. This value arises because one would like to avoid putting lots of resources into mitigation in the short term, only to find out later that the problems related to climate change are not serious. However, one also would like to minimize the risk of doing too little mitigation in the short term, only to find out later that very serious consequences of climate change will cost much more to avert because of the delay.

Manne and Richels, as well as Kolstad, showed that it generally pays to do a little bit of abatement in the short run under these conditions—to hedge against the downside without making too rapid a commitment. One virtue of some delay in emissions control is that it allows us to learn more about the severity of the risk of climate change and the options for responding to it. If the risk turns out to be worse than expected, mitigation can be accelerated to make up for lost time. To be sure, the strength of this argument depends on how costly it is to accelerate mitigation and on the degree of irreversibility of climate change. Analysts will continue to debate these points for some time to come.

Concluding Remarks

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

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

Economic analysis also could be used to justify not only a slower approach to GHG mitigation but also a less stringent long-term target. Here is where the potential conflict can arise between individuals' narrower economic self-interests and their concern for the well-being of future generations. Determining the right long-term policy goals ultimately requires us to address our attitudes toward intergenerational equity as well as to better understand the scale of environmental and economic risks that different climate policies imply for future generations.

A more gradual GHG policy over the next 10–20 years does not preclude any but the most environmentally stringent targets, while potentially increasing the political acceptability of increasingly demanding mitigation measures. These considerations warrant renewed attention as the international community continues to grapple with the problem of finding a climate policy it can really live with.

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4

Choosing Price or Quantity Controls for Greenhouse Gases

William A. Pizer

Much of the debate surrounding climate change has centered on verifying the threat of climate change and deciding the magnitude of an appropriate response. After years of negotiation, this effort led to the 1997 signing of the Kyoto Protocol, a commitment by industrialized countries to reduce their emissions of carbon dioxide (CO_2) to slightly below 1990 recorded levels. Without approving or disapproving of the response effort embodied in the Kyoto Protocol, I believe that an important element has been ignored. Namely, should we specify our response to climate change in terms of a quantitative target?

The appeal of a quantitative target is obvious. A commitment to a particular emissions level provides a straightforward measure of environmental progress as well as compliance. Commitment to an emissions tax, for example, offers neither a guarantee that emissions will be limited to a certain level nor an obvious way to measure a country's compliance (when other taxes and subsidies already exist). Yet, this concern points to an important observation.

Quantity targets guarantee a fixed level of emissions. Emission taxes guarantee a fixed financial incentive to reduce emissions. Both can be set at aggressive or modest levels. Aside from the appeal of the known and verifiable emissions levels that quantity targets can ensure, might there be other important differences between price and quantity controls? Economists would say "Yes." With uncertain outcomes and policies that are fixed for many years, it is important to carefully consider both the costs and benefits of alternate price and quantity controls to judge which is best. My own analysis of the two approaches indicates that price-based greenhouse gas (GHG) controls are much more desirable than quantity targets, taking into account both the potential long-term damages of climate change and the costs of GHG control. This can be argued on the basis of both theory and numerical simulations. On the basis of the latter, I find that price mechanisms produce expected net gains five times as high as even the most favorably designed quantity target.

To explain this conclusion, I first characterize the differences between price and quantity controls for GHGs. I then present both theoretical and empirical evidence that price-based controls are preferable to quantity targets on the basis of these differences. Finally, I discuss how price controls can be implemented without a general carbon tax. This point is particularly salient for the United States, where taxes are generally unpopular. The "safety valve," as it is often called, involves a cap-and-trade GHG system accompanied by a specified fee or penalty for emissions beyond the initial cap.

How Do Quantity- and Price-Based Mechanisms Work?

A quantity mechanism—usually referred to as a permit or cap-and-trade system—works by first requiring individuals to obtain a permit for each ton of CO_2 they emit, and then limiting the number of permits to a fixed level. (CO_2 emissions from fossil fuel sources constitute the bulk of GHG emissions and are the general focus of most policy discussions. However, the arguments made in this context apply equally well to the regulation of GHG emissions more broadly defined.) This kind of system has been used with considerable success in the United States to regulate sulfur dioxide and lead. The permit requirement could be imposed on the individuals who release CO_2 into the atmosphere by burning coal, petroleum products, or natural gas. However, unlike the emissions of conventional pollutants, which depend on various other factors, CO_2 emissions can be determined very accurately by the volume of fuel being used. Rather than requiring *users* of fossil fuels to obtain permits, we could therefore require *producers* to obtain the same permits. This method has the advantage of involving far fewer individuals in the regulatory process, thereby reducing both monitoring and enforcement costs.

One key element in a permit system is that individuals are free to buy and sell existing permits in an effort to obtain the lowest cost of compliance for themselves, which in turn leads to the lowest cost of compliance for society. In particular, when individuals observe a market price for permits, those who can reduce emissions more cheaply will do so to sell excess permits or to avoid having to buy additional ones. Similarly, those who face higher reduction costs will avoid reductions by buying permits or by keeping those they already possess. In this way, total emissions will exactly equal the number of permits, and only the cheapest reductions will be undertaken.

A price mechanism—usually referred to as a carbon tax or emissions fee—requires the payment of a fixed fee for every ton of CO_2 emitted. Like the permit system, this fee could be levied upstream on fossil fuel producers or downstream on fossil fuel consumers. Either way, we associate a positive cost with CO_2 emissions and create a fixed monetary incentive to reduce emissions. Such price-based systems have been used in Europe to regulate a wide range of pollutants (although the focus is usually revenue generation rather than substantial emissions reductions).

Like a tradable permit system, price mechanisms are cost-effective. Only those emitters who can reduce emissions at a cost below the fixed fee or tax will choose to do so. Because only the cheapest reductions are undertaken, we are guaranteed that the resulting emission level is obtained at the lowest possible cost.

The important distinction between these two systems is how they adjust when costs change unexpectedly. A quantity or permit system adjusts by allowing the permit price to rise or fall while holding the emissions level constant. A price or tax system adjusts by allowing the level of total emissions to rise or fall while holding the price associated with emissions constant. Ignoring uncertainty and assuming that we know the costs of controlling CO_2, both policies can be used with the same results. Consider the following example:

Suppose we know that with a comprehensive domestic CO_2 trading system in place in the United States by 2010, a permit volume of 1.2 gigatons (billion tons) of carbon equivalent emissions (GtC) will lead to a $100 permit price per ton of carbon. (U.S. emissions of carbon from fossil fuels were estimated at 1.5 GtC for 1998.) In other words, faced with a price incentive of $100 per ton to reduce emissions, regulated firms in the United States will find ways to reduce emissions to 1.2 GtC. Then, the same outcome can be obtained by imposing a $100 per ton carbon tax.

Uncertainty about Costs

In reality, we have only a vague idea about the permit price that would occur with emissions of 1.2 GtC or any other emission target. These costs are hard to pin down for three reasons. First, little evidence exists concerning reduction costs. There are no recent examples of carbon reductions on a substantial scale from which to base estimates. In the 1970s, energy prices doubled and encouraged increased energy efficiency, but these events occurred in a context of considerable uncertainty about the future and alongside many other confounding factors (such as increased environmental regulation). Alternatively, engineering studies provide a bottom-up approach to estimating costs. However, comparisons of past engineering forecasts with actual implementation costs suggest that forecasts are inaccurate at best.

A second source of uncertainty arises because we need to forecast compliance costs in the future. This task involves difficult predictions about the evolution of new technologies. Proponents of aggressive policy argue that reductions will be cheap as new low-carbon or carbon-free energy technologies become available. Proponents of more modest policies argue that these are unproven, pie-in-the-sky technologies that may never be practical.

Finally, it is impossible to know how uncontrolled emission levels will change in the future. That is, to achieve 1990 emission levels in 2010, it is unclear whether reductions of 5%, 25%, or even 50% will be necessary. The Intergovernmental Panel on Climate Change (IPCC), the international agency charged with studying climate change, gives a range of six possible global emission scenarios in 2010 that include a low of 9 GtC and a high of 13 GtC. My own simulations suggest a broader possible range, 7–18 GtC.

The low end of both ranges reflects the possibility that population and economic growth may slow in the future and the energy intensity of production may fall. The high end reflects the opposite possibility, that growth remains high and energy intensity rises. Figure 1 shows the distribution of uncontrolled emissions arising from my simulations of 1,000 possible outcomes in 2010 alongside the six IPCC scenarios. (For details about the model, see Pizer in Suggested Reading.)

In summary, we have only vague ideas about the cost of alternative emission targets for two important reasons. First, there is little historic evidence about costs. Second, as we examine policies 10 or more years in the future, it is unclear how baseline emissions and available technologies will change between now and then. Figure 1 indicates that global emissions could be anywhere from 7 to 18 GtC in 2010. The cost associated with a target of 8.5 GtC (1990 level) will be uncertain because the necessary reduction is uncertain—somewhere between 0 and 10 GtC—and because costs are difficult to estimate, even knowing the reduction level.

Effects of Price and Quantity Controls with Cost Uncertainty

When the cost of a particular emission target is uncertain, price and quantity controls will have distinctly different consequences for the actual level of emissions as well as the overall cost of a climate policy. Even if both policies are designed to deliver the same results under a best-guess scenario, they

Figure 1. Distribution of Emissions in 2010.

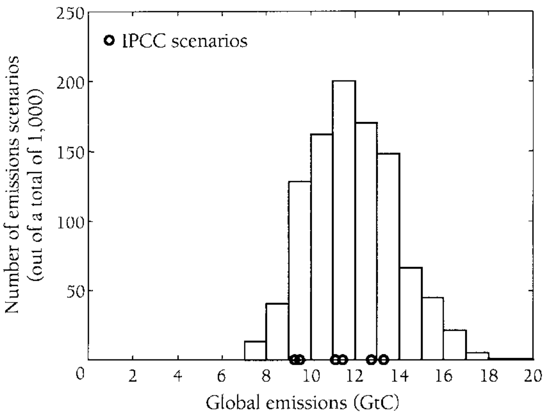
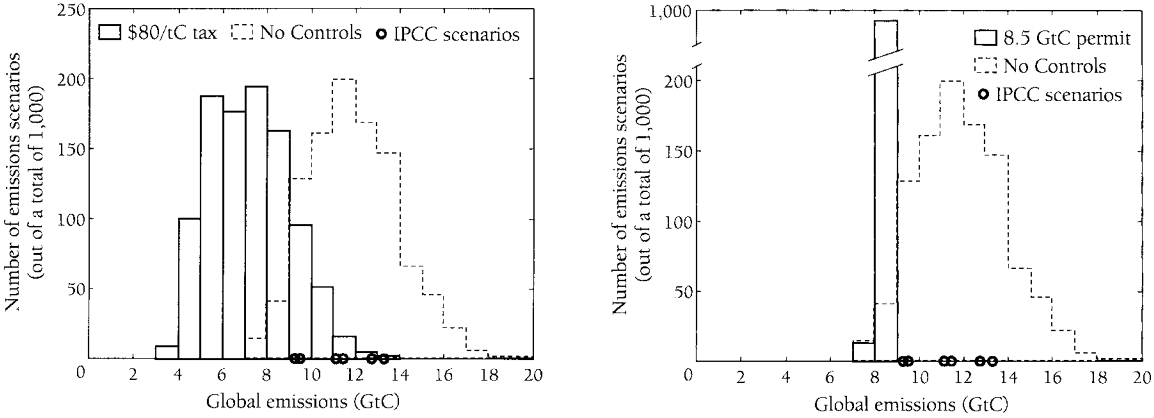


Figure 2. Effect of Price and Quantity Controls on Emissions in 2010.



Two policies are roughly equivalent under a best-guess scenario: a carbon tax of $80/ton (left) and a quantity target of 8.5 GtC (right).

will necessarily behave differently when control costs deviate from this best guess. These differences arise because a price policy provides a fixed incentive (dollars per ton of CO_2 emissions), regardless of the emission level, and a quantity policy generates whatever incentive is necessary to strictly limit emissions to a specified level.

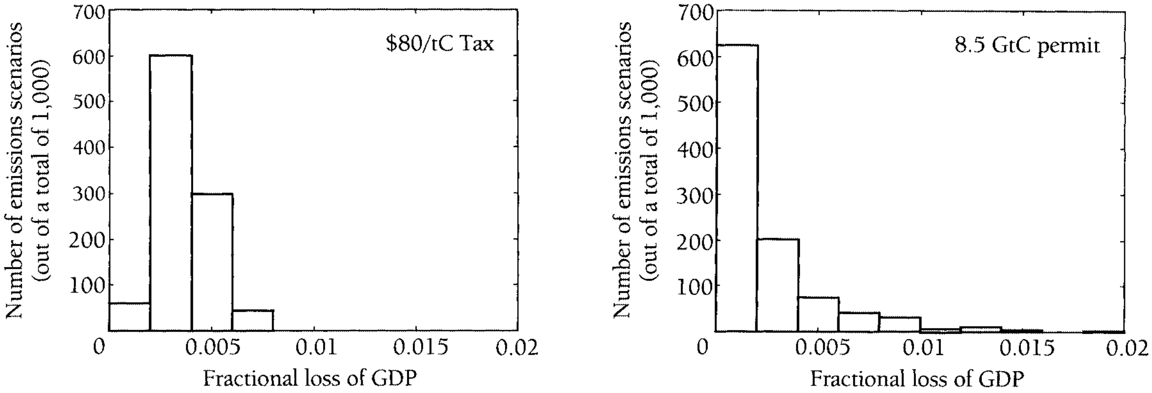
Figure 2 illustrates these differences by showing the emission consequences in 2010 associated with two policies that are roughly equivalent under a best-guess scenario: a quantity target of 8.5 GtC and a carbon tax of $80/ton. Using the same 1,000 emission scenarios shown in Figure 1, simulations are used to calculate the effect of these two policies for each outcome. With a carbon tax, emissions are below 8.5 GtC in more than 75% of the outcomes. In other words, on average the carbon tax achieves more reductions than a quantity target of 8.5 GtC. Sometimes, the reductions are much more; emissions may be as low as 3 GtC. Yet, the carbon tax fails to guarantee that emissions will always be below any particular threshold.

The quantity target, in contrast, never results in emission levels above 8.5 GtC. Because some emission outcomes in the absence of controls were rather high, on the order of 18 GtC, we would expect that the cost of this policy could be quite high. At the other extreme, the quantity policy would be costless if uncontrolled emissions were unexpectedly low.

These data suggest that the cost associated with quantity controls will be high or low depending on future reduction costs as well as the future level of uncontrolled emissions. In contrast, price controls create a fixed incentive to reduce each ton of CO_2 regardless of the uncontrolled emission level. Therefore, costs under a carbon tax should fluctuate much less than costs under a quantity control.

Figure 3 shows the estimated cost consequences of both policies. The range of costs associated with the quantity target is quite wide, as we suspected. The estimates extend from 0 to 2.2% of global gross domestic product (GDP), almost four times the highest cost outcome under the carbon tax. In fact, the cost associated with emission reductions under a carbon tax are concentrated entirely in the range 0.2–0.6% of GDP. Because the carbon tax always applies the same per ton incentive to reduce emissions, the cost outcomes are more narrowly distributed than those occurring under a quantity target.

Figure 3. Distribution of 2010 Costs Associated with Price and Quantity Controls.



Choosing between Price and Quantity Controls

So far, the discussion has been limited to the different emission and cost consequences of alternative price and quantity controls. Choosing between them, as well as choosing the appropriate stringency of either policy, requires making judgments about climate change consequences as well as control costs. To understand when one policy instrument probably will be preferred over the other, it is useful to consider two extreme cases.

First, imagine that there is a known climate change threshold. When CO_2 emissions are below this threshold, the consequences are negligible. Above this threshold, however, damages are potentially catastrophic. For example, research suggests that the process by which CO_2 is absorbed at the surface of the oceans and circulated downward could change dramatically under certain circumstances. If we also believe that these changes will have severe consequences and that we can identify a safe emission threshold for avoiding them, then quantity controls seem preferable. Quantity controls can be used to avoid crossing the threshold, and in this case, large expenditures to meet the target are justified by the dire consequences of missing it.

Now, imagine instead that every ton of CO_2 emitted causes the same incremental amount of damage. These damages might be very high or low, but the key is that each ton of emissions is just as bad as the next. Such a scenario is also plausible, as indicated by a survey of experts including both natural and social scientists who do research on global warming. Their beliefs suggest that the damage caused by each ton of emitted CO_2 may be quite high but that there is no threshold: Damages are essentially proportional to emissions. Each additional ton is equally damaging, whether it is the first ton emitted or the last.

In this case, it makes sense to use a price instrument. Specifically, a carbon tax equal to the damage per ton of CO_2 will lead to exactly the right balance between the cost of reducing emissions and the resulting benefits of less global warming. Every time a firm decides to emit CO_2, it will be confronted with an added financial burden equal to the resulting damage. It will lead to reduction efforts as well as investments in new technology that are commensurate with the alternative of climate change damage. In this scenario, little emphasis is placed on reaching a particular emission target because there is no obvious quantity target to choose. This argument applies even if we are uncertain about the magnitude of climate damage per unit of CO_2.

Arguments for Price Policies

Given this characterization of circumstances under which alternative price and quantity mechanisms are preferred, we can make the argument for price controls. This argument hinges on two basic points. The first point is that climate change consequences generally depend on the stock of GHGs in the atmosphere, rather than annual emissions. GHGs emitted today may remain in the atmosphere for hundreds of years. It is not the level of annual emissions that matters for climate change but the total amount of CO_2 and other GHGs that have accumulated in the atmosphere. The second point is that although scientists continue to argue over a wide range of climate change consequences, few advocate an immediate halt to emissions. For example, the most aggressive stabilization target discussed by the IPCC is a 450-ppm concentration in the atmosphere (roughly 1,035 GtC), a level that we will not reach before 2030, even in the absence of emission controls (see the Technical Summary of the IPCC report in Suggested Reading).

If only the stock of atmospheric GHGs matters for climate change, and if experts agree that the stock will grow at least in the immediate future, then there is almost no rationale for quantity controls. The fact that only the stock matters should first draw our attention away from short-term quantity controls for emissions and toward long-term quantity controls for the stock. It cannot matter whether a ton of CO_2 is emitted this year, next year, or in 10 years if all we care about is the total amount in the atmosphere. Taking the next step and presuming that the stock will grow over the next few decades, this approach suggests that there is some room to rearrange emissions over time and that a short-term quantity control on emissions is unnecessary.

Quantity controls derive their desirability from situations where strict limits are important, when dire consequences occur beyond a certain threshold. Such policies trade off low expected costs in favor of strict control of emissions in all possible outcomes. However, under the assumption that it is acceptable to allow the stock of GHGs to grow in the interim, there is no advantage to such strict control. We give up the flexible response of price controls without the benefit of an avoided catastrophe.

Even for those who believe the consequences of global warming will be dire and that current emission targets are not aggressive enough, price policies are still better. An aggressive policy designed to stabilize the stock eventually does not demand a strict limit on emissions before stabilization becomes necessary. Additional emissions this year are no worse than emissions next year. Why not abate more when costs are low, less when costs are high—exactly the outcome under a price mechanism? When we eventually move closer to a point where the stock must be stabilized, a switch to quantity controls will be appropriate.

In addition to these theoretical arguments, integrated assessment models can provide support. To this end, I have constructed an integrated model of the world economy and climate based on the dynamic integrated climate-economy (DICE) model developed by William Nordhaus (see Suggested Reading). In contrast to the DICE model, I simultaneously incorporate uncertainty about everything from growth in population and energy efficiency to the cost of emission reductions, the sensitivity of the environment to atmospheric CO_2, and the damages arising from global warming.

The results of these simulations indicate the price-based mechanisms can generate overall economic gains (expected benefits minus expected costs) that are *five times that of* even the most prudent quantity-based mechanism. These results are robust. Even allowing for catastrophic damages beyond 3 °C of warming, price mechanisms continue to perform better. This robustness can be explained in two ways. First, the catastrophe—if it exists—is in the future. Before we reach that point, it is desirable to have some flexibility in emission reductions. Specifically, we will want to delay those reductions if the costs are unexpectedly high in the short run, provided those reductions can be obtained more cheaply in the future but before the catastrophe.

Second, unlike the stylized description in which climate consequences depended directly on CO_2

concentrations presented earlier, in this model, damages depend on temperature change. In reality, damages probably depend on an even more complex climatic response. Either way, the links between CO_2 emissions, concentrations, temperature change, and other climatic effects are not precisely known. Therefore, a quantity control on *emissions* is not equivalent to a quantity control on *climate change*. Both price and quantity controls will lead to uncertain climate consequences. Therefore, the advantage of the quantity control—namely, its ability to avoid with certainty the threat of climate catastrophe—is substantially weakened.

Combined Price and Quantity Mechanisms

Even if a carbon tax is preferable to a cap-and-trade approach in terms of social costs and benefits, this policy obviously faces steep political opposition in the United States. Businesses oppose carbon taxes because of the transfer of revenue to the government. Under a permit system, there is a hope that some, if not all, permits would be given away for free. Environmental groups oppose carbon taxes for an entirely different reason: They are dissatisfied with the prospect that a carbon tax, unlike a permit system, fails to guarantee a particular level of emissions. Such antagonism from both sides of the debate makes it unlikely that a carbon tax will become part of the U.S. response to the Kyoto Protocol.

However, the advantages of a carbon tax can be achieved without the baggage accompanying an actual tax. In particular, a combined mechanism (often referred to as a hybrid, or a safety valve) can obtain the economic advantages of a tax while preserving at least some of the political advantages of a permit system.

In such a scheme, the government first distributes a fixed number of tradable permits—freely, by auction, or both. The government then provides additional permits to anyone willing to pay a fixed ceiling or "trigger" price. The initial distribution of permits allows the government the flexibility to give away a portion of the right to emit CO_2, thereby satisfying concerns of businesses about government revenue increases. The sale of additional permits at a fixed price then gives the permit system the same compliance flexibility associated with a carbon tax.

With a combined price/quantity mechanism, it will be necessary to consider how both the trigger price and the quantity target should evolve over time. One possibility is to raise the trigger price over time to guarantee that the quantity target is eventually reached. A second possibility is to carefully choose future trigger prices as a measure of how much we are willing to pay to limit climate change. As we learn more about the costs of future emission reductions, however, this distinction between price and quantity controls will diminish. That is, after uncertainty about future compliance costs is reduced through experience, then price and quantity controls can be used to obtain similar cost and emission outcomes.

Operationally, when this safety valve is used in conjunction with international emissions trading, as the Kyoto Protocol allows, problems potentially arise. In general, there would be a need for either harmonization of the trigger price across countries or restrictions on the sale of permits from those countries with low trigger prices. Otherwise, there would be an incentive for countries with a low trigger price to simply print and export permits to countries with higher permit prices. This action would not only effectively create low trigger prices everywhere; it also would create large international capital flows to the governments of countries with the low trigger prices.

Instead of harmonizing trigger prices, the trigger price could be set low enough to avoid the need for international GHG trades. This may be a desirable end in light of concerns about the indirect economic consequences of large volumes of international GHG trade flows.

Finally, if we find it desirable to raise the trigger price rapidly, it will be necessary to limit the possibility that permits can be purchased now and held for long periods of time. Otherwise, there will be a strong incentive to buy large volumes of cheap permits now to sell them at high prices in the future. This problem is easily addressed by assigning an expiration date for permits as they are issued, for perhaps one or two years in the future.

Building Domestic and International Support for a Price-Based Approach

Although the safety valve approach is potentially appealing to businesses concerned about the uncertainty surrounding future permit prices, environmental groups will be wary of giving up the commitment to a fixed emission target. Such a commitment is already an integral part of the Kyoto Protocol. However, a strict target policy ultimately may lack political credibility and viability. Although a low trigger price would clearly rankle environmentalists as an undesirable loosening of the commitment to reduce emissions, a higher trigger price could allay those fears while still providing insurance against high costs.

Perhaps more controversial than the concept of a safety valve is the fact that a hybrid policy requires setting a trigger price. It extends the debate over targets and timetables to include perceived benefits on the basis of the trigger price. Business interests undoubtedly will seek a low trigger price and environmental groups a high trigger price. I believe this conflict is desirable. The debate will focus on the source of disagreement between different groups—namely, the value placed on reduced emissions. Rather than leaning on rhetoric that casts reduction commitments as either the source of the next global recession (according to businesses) or the costless ushering in of a new age of cheaper and more energy-efficient living (according to environmentalists), it will be necessary to decide how much we are realistically willing to spend to deal with the problem.

Although seemingly provocative in its challenge of the core concept of targets and timetables embedded in the Kyoto Protocol, some concept of the safety valve is already part of many countries' notion of their commitments to the protocol. European countries that are likely to implement carbon taxes must have some idea how they will handle target violations if their tax proposals fail to sufficiently reduce emissions before the end of the first commitment period. Likewise, other countries that are considering either a quantity or command-and-control approach must envision a way out if their actual costs begin to surpass their political will to reduce emissions.

Among the many implicit safety valve possibilities, one could imagine a more flexible interpretation of existing provisions, such as the clean development mechanism or the use of carbon sinks. Alternatively, Article 27 specifies that parties can withdraw from the protocol by giving notice one year in advance. A country that foresaw difficulty in meeting its target in the first commitment period could serve notice that it wished to withdraw before the commitment period ended.

Therefore, flexibility in meeting current commitments already exists implicitly. Countries can choose to massage their commitments using existing provisions, violate their targets and risk penalties (which have yet to be defined), or simply withdraw. In these cases, however, the outcome and consequence are unclear. The advantage of a price mechanism is that it makes the safety valve concept explicit and transparent. Establishing a price trigger for additional emissions allows countries, and private economic decisionmakers in turn, to approach their reduction commitments with greater certainty about the future. This method not only improves the credibility of the protocol but also its prospects for future success in reducing GHG emissions.

Conclusions

The considerable uncertainty surrounding the cost of international GHG emission targets means that price- and quantity-based policy instruments cannot be viewed as alternative mechanisms for obtaining the same outcome. Price mechanisms will lead to uncertain emission consequences, and quantity mechanisms will lead to uncertain cost consequences. Economic theory as well as numerical simulations indicate that the price approach is preferable for GHG control, generating five times the net expected benefit associated with even the most prudent quantity control. The essence of this result is that a rigid quantity target over the next decade is indefensible at high costs when the stock of GHGs is allowed to increase over the same horizon.

Importantly, a price mechanism need not take the form of carbon tax. The key feature of the price policy is its ability to relax the stringency of the target if control costs turn out to be higher than expected. Such a feature can be implemented in conjunction with a quantity-based mechanism as a safety valve. A quantity target is still set, but with the understanding that additional emissions (beyond the target) will be permitted only if the regulated entities are willing to pay an agreed-upon trigger price.

This approach can improve the credibility of the protocol and its prospects for successful GHG emission reductions. The last point is particularly relevant for ongoing climate negotiations. Should the emission incentives and consequences remain ambiguous and uncertain, or should they be made explicit and transparent? Specifying a price at which additional, above-target emissions rights can be purchased provides a transparent incentive; the current approach does not. Although ambiguity may prove to be the easier negotiating route, it also may be a disincentive for true action.

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5

The Role of Renewable Resources in U.S. Electricity Generation

Experience and Prospects

Joel Darmstadter

The use of fossil energy is by far the largest source of human-induced CO_2 emissions in the United States and worldwide. This fact has stimulated interest in the development and deployment of lower-emitting renewable energy resources, or “renewables” (see Box 1). The United States has been developing and advancing renewable energy technologies for more than 20 years to ease problems—actual and anticipated—that arise from the use of fossil fuels. Nevertheless, the penetration of renewables remains minuscule, and many technological, economic, and regulatory uncertainties still persist in U.S. renewable energy markets.

In this chapter, I focus on nonhydro renewable energy resources for generating electric power. Unless otherwise indicated, by renewables I refer to wind, photovoltaic and thermal solar, biomass, and geothermal sources. A broader definition would also include agricultural residues, municipal and industrial wastes, and other combustible materials. As customarily used, the term “renewables”—which implies the possibility of replenishment of what is taken from the relevant resource stock—is more convenient than precise. Thus, geothermal resources are, strictly speaking, exhaustible because a given site may lose useful heat after a number of years of extraction.

I consider three aspects of renewables. First, I concentrate on the use of renewables in electricity generation, where an expanded role for renewables probably has greatest promise for CO_2 displacement over the medium term. Second, I largely consider developments in the United States, whose experience with and potential for renewables use in the electric power sector parallel the situation in numerous other industrial economies. Finally, and perhaps most importantly, my discussion is conditioned by the view that the role and prospects of renewable energy can be sensibly assessed only within an economic setting that considers a range of competing energy technologies and sources, both renewable and conventional. An electron is an electron, whether produced by a wind turbine or coal-based steam generator. What matter most are three issues: actual and expected market realities (that is, cost and price), the extent to which the market captures or masks imperfections brought

Box 1: CO_2 Emissions from Renewable Energy Sources

Subject to three provisos, one can intuitively, and for the most part legitimately, view CO_2 emissions from the use of renewable energy as inconsequential. First, it takes energy to produce energy-using capital stock—a coal-burning power plant or a photoelectric array. This aspect is unlikely to alter the balance of advantage of renewables over conventional energy from a CO_2 standpoint, but it needs to be recognized.

Second, the production of renewable energy inputs itself may involve fossil fuel emissions. For example, carbon emissions associated with a possible "hydrogen economy"—such as the use of hydrogen as the basis of automotive fuel cells—would be negligible only to the extent that fossil fuels play little role in the production of hydrogen. It would not be the case if fossil-based electricity were used in the electrolytic extraction of hydrogen from seawater.

The third and probably most important proviso has to do with the use of biomass as an energy source. Combustion of biomass, largely in the form of wood and wood wastes, has accounted for a bit more than 3% of total U.S. energy consumption in recent years. Such combustion releases CO_2 at a rate (carbon release relative to the heat content of the fuel) that is even greater—by around 15%—than that of coal. To the extent that such release is matched by new and equal biomass growth, then biomass fuel use is an effective CO_2-mitigating option.

As long as statistical treatment is internally consistent, it might not make much difference whether CO_2 emissions from biomass combustion are shown as nil on the assumption of being netted out by equal photosynthetic uptake or whether the estimated releases are part of (gross) nationwide emissions, with the assumed or estimated uptake separately shown as a component of total sequestered CO_2. The least satisfactory—and unnecessarily confusing—way of handling the matter is that provided by the IPCC's Working Group II (see Data Sources). In one table, the use of biomass in a power plant is illustrated by indicating zero emissions (Table 19-2); elsewhere, an emission factor for wood is given as approximately 28 metric tons of carbon/1 billion Btu (Box B-2).

I prefer the second of the two measurement options, particularly given increasing interest in present and prospective interrelationships among deforestation, afforestation, reforestation, and productive use of biomass combustion worldwide. These interrelationships are especially important to consider in a context of potential competition between biomass products (crops and forest products) and fuels markets. But for now, on the assumption of reabsorption and no net change in the overall carbon budget, the statistical practice by the Energy Information Administration is to treat U.S. CO_2 emissions biomass fuels as zero (rather than, for example, adding their 75 million tons to total U.S. CO_2 emissions of approximately 1,500 million tons in 1996 to reflect gross emissions from combustion of all fuels).

on by environmental externalities and other distortions, and the role of public policy in promoting socially beneficial outcomes.

A Word on Renewable Energy Worldwide

Although my principal focus is on the United States, it may be helpful to put things into a global perspective. (Quantitative observations are based on references listed under Data Sources at the end of the chapter.) In terms of energy consumption in the aggregate (not only resources going into electric power generation), the 7% of the worldwide total accounted for by renewables in 1995 was of some significance; it was almost identical to the nuclear energy share. In poorer regions of the world, the percentage was markedly higher. In Africa, for example, renewables (dominated by wood and other biomass) contributed 37% of total energy. But far from reflecting a productive and sustainable role for renewables in the contemporary and prospective energy scene, such numbers in fact signify something quite different in desperately poor parts of the world: the need to gather energy, through foraging and other means (contributing to a loss of soil fertility in the process), to meet the most basic survival requirements of cooking and heating. The statistics constitute an artifice in a related respect, one which gives an altogether distorted picture of renewable energy use in the African example. As a metric, the British thermal units (Btus) contained in a lump of coal may be comparable to the Btus contained in a cubic meter of firewood. But because the latter is typically burned with incomparably worse efficiency, its effective importance recedes greatly.

In the electric power sector, the focus of my discussion, statistics are probably somewhat more meaningful, because the mere fact of renewables serving as an input into power generation implies a more sophisticated technological application than, say, their use in open fireplaces in rural households. In any case, it turns out that only about 1% of worldwide electric generation is based on nonhydro renewable resources. Around 80% of such generation occurs in North America and Western Europe. In developing economies, whose share is essentially nil, the use of renewables for electricity production seems to be limited to a few opportune circumstances, such as the exploitation of bagasse (agricultural waste) as a boiler fuel on sugar plantations. Probably for that reason, renewables account for approximately 3% of Brazil's electric generation. For now, therefore, the rational exploitation of renewable energy poses entirely different challenges for developing and developed countries.

The Prevailing Role of Renewables in U.S. Electricity Generation

Table 1 provides a broad perspective on how renewables fit into the present fuel and power picture in the United States. It is immediately apparent that the magnitude of renewable energy is negligible on the national level. Few nonhydro renewables figure in electric power generation. And outside the electric power sector, the balance of renewables use is concentrated in industrial biomass utilization—much of it undoubtedly in the form of wastes in wood processing and in pulp and paper mills. Nor is this picture likely to change appreciably over the next several decades, at least if the analysis of the U.S. Department of Energy's Energy Information Administration is to be believed. Specifically, conventional hydro power generation is projected to decline a bit (at a rate of 0.3%/year), whereas all other renewables in the aggregate are projected to grow by around 2%/year—a very small rate of increase, considering the low absolute values from which growth proceeds.

Table 1. Role of Renewable Resources in U.S. Energy Consumption and Production, 1997.

Electric generation (quads)	4.35
Conventional hydro	3.60
Geothermal	0.43
Municipal solid waste	0.23
Biomass	0.04
Solar (thermal and PV), wind	0.05
Nonelectric consuming sectors (quads)	2.57
Residential wood	0.60
Industrial biomass	1.84[a]
Industrial hydro	0.03
Ethanol in transportation	0.10
Total renewable resources (quads)	6.92[b]
Share of U.S. energy production	9.5%
Share of U.S. energy consumption	7.4%
Nonhydro renewable resources (quads)	3.32
Share of U.S. energy production	4.5%
Share of U.S. energy consumption	3.5%
Share of electricity generation	2.2%

Note: 1 quad = 1 quadrillion (10^{15}) Btu.

[a] About one-fifth of this figure can be attributed to on-site electric generation at wood-processing facilities.

[b] This figure excludes about 0.04 quads in nonmarket residential and commercial applications.

Source: U.S. DOE (Department of Energy). 1998. *Annual Energy Outlook 1999.* December. Washington, DC: U.S. DOE, Energy Information Administration, Tables A1, A18, and 8.14.

U.S. Policies toward Renewables

Over the past quarter of a century, several public policies have been introduced in support of renewable energy. Rather than providing an exhaustive account of these measures, I will mention and illustrate four principal ways in which the federal government has sought, or is seeking, to promote the development and use of renewables: various kinds of research and development (R&D) support, the role of the 1978 Public Utility Regulatory Policies Act, the use of other financial incentives, and the prospective role of a "renewable portfolio standard." Although federal policies have dominated, states have presented some significant initiatives as well. A 1998 report from the Energy Information Administration (see Suggested Reading) provides additional information about renewables programs. In the discussion that follows, I will not try to assess—if, indeed, an approximate quantitative assessment is as yet possible—how these policies have shaped energy markets.

R&D Support

For various reasons—excessive risks, long time horizons, limits to capturing the returns from successful outcomes, nonmarketability of external benefits—industry is commonly believed to underinvest in basic science and technology. Therefore, a federal role to augment private efforts in advancing basic science and technology is widely accepted. In the case of renewable energy, that role largely involves R&D activities conducted at or supported by the U.S. Department of Energy (DOE) and its national laboratories, principally, the National Renewable Energy Laboratory (NREL) in Colorado.

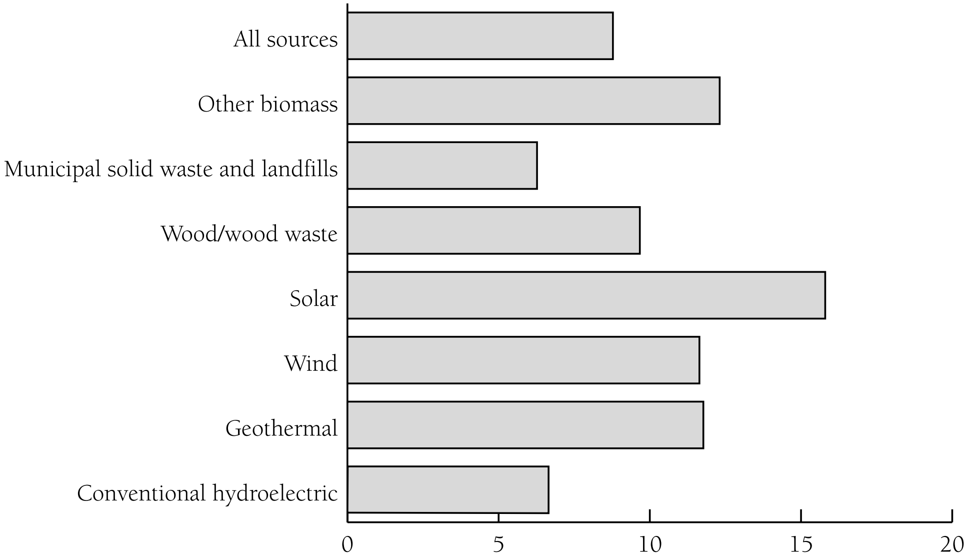
The U.S. General Accounting Office (GAO) reported in 1999 that for the 20-year period 1978–98, $10.3 billion (in current prices) was thus disbursed (see Suggested Reading). Solar photovoltaics were the leading beneficiaries of this program. Over the 20-year period, photovoltaics received about $2 billion and wind power $1 billion. During fiscal year 1999, the respective funding was $72 million and $35 million. In both cases, the GAO sees program objectives having gradually shifted away from fundamental research to enhanced market opportunities, both domestic and international. As just one example of a recent wind power initiative, DOE's Turbine Verification Program has provided for cost-sharing with utilities to facilitate the development and deployment of wind turbines.

In critical comments on the GAO analysis (included in the GAO report), DOE questioned GAO's characterization of a programmatic shift emphasizing market potentials. Whether GAO or DOE is more on the mark in this dispute, a chastening point does perhaps emerge. Programs whose start-up rationale puts major stress on precommercialization challenges—basic science, research, and early developmental barriers—may, subtly or not, slide over into terrain dominated by sales prospects. Perhaps unfortunately, the labels "research" and "development" are broad enough to allow such slippage.

PURPA

The federal Public Utility Regulatory Policies Act (PURPA) of 1978 was one major instrument that encouraged a shift away from conventional energy to renewables. Under this statute, utilities were mandated to purchase power from nonutility producers at prices that were supposed to represent the "avoided cost" that utilities would otherwise have had to pay to produce power using conventional resources such as petroleum. Because numerous beneficiaries of this policy lacked technical expertise in alternative energy production (renewables and certain other innovative categories) and because the calculation of avoided cost was frequently quixotic, PURPA is widely judged to have fallen far short of its objectives. Contracts for utility purchases under PURPA will soon begin to run out, but transactions in 1995 still occurred at prices which, for renewables as a whole, were 150% above the national average electric generation cost of around 3.5 cents/kWh (see Figure 1).

Figure 1. U.S. Electric Utility Average Price of Renewable Electric Power Purchased from Nonutility Facilities, by Energy Source, 1995.



Note: Values are given in cents per kilowatt-hour.

Source: U.S. DOE (Department of Energy). 1999. *Renewable Energy: Issues and Trends 1998.* March. Washington, DC: U.S. DOE, Energy Information Administration, Fig. 11.

Other Financial Assistance

Overlapping with PURPA, and continuing to the present, the federal government has provided significant direct financial benefits to renewable energy producers. Both solar photovoltaics and wind power benefit from investment tax credits, and under the Tax Reform Act of 1986, wind power was accorded a depreciation life of five years—much shorter than the depreciation life of conventional power supply investments. One provision of the Energy Policy Act of 1992 (extended in 1999) provides an inflation-adjusted 1.5 cents/kWh production tax credit for wind power plants. By 1999, this credit had increased to 1.7 cents/kWh.

Renewable Portfolio Standard

In the context of the deregulated electricity market that is presently emerging in the United States, a policy position developed by the Clinton administration during 1999 embodies provisions for a so-called renewable portfolio standard (RPS). Its goal is to ensure that some minimum percentage of generation originate with nonhydro renewable energy sources, regardless of whether or not it is justified by private market forces. An RPS target for 2010 calls for 7.5% of electricity sales to be based on renewable energy resources. (Separately, bills introduced in Congress call for RPS shares ranging from 4% to 20%.) If the RPS is implemented as presently conceived, the means envisaged for meeting the 7.5% target represent a much more economically efficient route to stimulating renewables-based electricity than PURPA does. That is because RPS incorporates a tradable permit system that encourages renewable power production to take place in the most cost-effective location. In addition, it would impose a ceiling on the increment to overall electric power costs that result from the mandate.

By means of various subsidies as well as surcharges on electric bills to consumers who are willing to pay a premium to ensure the presence of "green" power in their electricity mix, several states have introduced renewable minimums of their own. It is too early to judge the success of such efforts. One element of uncertainty is that even if these measures result in *new* investments in renewables generation, it is possible that *existing* facilities may be prematurely retired due to competitive pressures.

Why the Poor Showing for Renewables?

Despite the optimism regarding the emergence of renewables dating from the energy-market upheavals of the 1970s, and notwithstanding considerable policy support over the years, the reality, as noted, is sobering. It is evident from Table 1 that nearly 30 years later, renewable energy systems have not succeeded in emerging as a significant factor in the country's electricity infrastructure. Does this mean that renewable technologies have been such a great disappointment that continuing public policy support is misguided? To answer in the affirmative may be too casual a dismissal of an exceedingly complex matter. Evaluation of the available evidence indicates that renewable technologies have lived up to several significant expectations and public policy goals.

Several RFF colleagues and I recently analyzed what went right and what went wrong in the evolution of renewable energy inputs into U.S. electric power generation over the past quarter century (see the work of Burtraw and of McVeigh and others in Suggested Reading). We evaluated five technologies used to generate electricity: solar photovoltaics, solar thermal, geothermal, wind, and biomass. A principal aim of our study was to see how the actual performance of renewable energy technologies in the 1990s compared with specific goals of cost reduction and market expansion of earlier projections. Many groups (both analytically oriented and unabashedly proactive) that wrote in the 1970s and '80s had judged these goals to be attainable with the help of accommodating public policies.

In general, *market penetration* has been markedly lower than expected. However, the *cost* of renewable technologies has also been lower than projected—in several cases, significantly lower, even when compared with what seemed initially to be the optimistic forecasts of renewable energy advocates. Of course, with time, forecasts for the 1990s began to approach observed trends. Still, whereas 1980s wind power projections of generation costs a decade hence assumed roughly a 64% decline, to reach a level of 5.7 cents/kWh by 1995, costs actually declined by an estimated 67% to a level of approximately 5.2 cents/kWh. (Here and in the paragraphs that follow, costs are expressed in constant 1995 prices.) By contrast, although the volume of wind-generated electricity did show steadily rising absolute numbers in the course of the 1990s (from an almost zero level in the 1980s), it remained an inconsequential part of the nation's electricity system. Only at the end of the 1990s and in 2000 have we seen signs of some meaningful momentum in wind power capacity expansion.

One can argue about which of the two measures (market penetration or cost) has greater relevance in evaluating the performance of renewable energy resource programs. To the extent that public-sector support was particularly driven by the need for and pursuit of cost reductions, the cost outcome seemed to us particularly important. Indeed, the cost outcome seems quite remarkable, because renewable technologies have not attracted large-scale investment and production that can contribute to technological development or economies of scale in production, as many people anticipated when forming their cost projections. Evidently, the characteristics of several renewable energy systems—high capital intensity, uncertainty about interconnections with the electric grid, variability in availability (the intermittency of wind, sunlight, and biomass wastes)—that have frequently been viewed as major barriers to economic viability have not precluded significant reductions in the reported cost of producing power.

The failure of renewables to emerge more prominently in the nation's energy portfolio is intimately linked to the concurrent decline in the cost of conventional generation. Consider that in 1984, the Energy Information Administration projected nationwide electric generation costs to rise from 6.1 cents/kWh in 1983 to 6.4 cents/kWh in 1995; in fact, they declined to 3.6 cents/kWh. That 41% decline, though less percentagewise than what was achieved by wind power, nonetheless preserved a sufficiently large margin of advantage—3.6 cents/kWh vs. 5.2 cents/kWh—for conventional over wind power as to foreclose more than a minute niche for the latter.

Several factors have contributed to keeping the cost of generation from conventional technologies low. They include developments in energy supply markets (notably, the emergence of a more competitive world oil market and productivity improvements in oil exploration and coal production); the successful deregulation of natural gas, oil pipelines, and railroads (the last a major factor in reducing the cost of coal shipping); technological progress in conventional generation itself (such as combined-cycle gas turbine systems); and the ongoing restructuring of the electricity industry. Although changes in the regulation, technology, and market structure of fossil fuels have thus been mostly beneficial for electricity consumers, they have hindered the development of technologies for renewable energy resources that have had to compete in this changing environment. Supporters of renewables have had to fix their sights on what has so far been a steadily receding target. As noted, nationwide electric generating costs of around 3.5 cents/kWh in the mid-1990s constituted a formidable target for even new renewables installations to meet, let alone for electricity based on renewable energy resources surviving from the distortions of the PURPA pricing regime. The inflated costs utilities found themselves having to pay as late as 1995 for such renewables-generated power are shown in Figure 1. All told, renewables have had to overcome something of a loser's image amid the favorable trends in conventional energy and electricity markets and the policy milieu that smoothed the path for those trends.

Is the persistence of the renewables–nonrenewables cost gap perhaps even understated when one considers the subsidies accorded the former? It is a fair question but not easily answered. Nonrenewables, after all, also receive a number of financial benefits. Nevertheless, a deeper probing of the extent to which certain tax and accounting benefits may distort cost comparisons between renewables-based and conventional generation would be a welcome contribution to the economic analysis of renewable energy.

Other countries have hardly fared much better than the United States in the extent of electricity market penetration by renewables (see IEA in Suggested Reading). A few heavily forested places (for example, Austria and the Nordic countries) have had some success exploiting fuelwood resources—aided, in some cases, by extremely favorable tax treatment and other subsidies. Denmark is developing a notable presence in wind energy. (It clearly helps when the wind resource and electricity load centers are close enough to each other to avoid costly transmission costs.) But, as in the United States, competition has not been kind to investment in renewables projects. And not surprisingly, competitive realities and policy dilemmas that face the United States are precisely those that arise when impediments to renewables are considered elsewhere.

Should Renewables Command a Premium Price?

Although the high avoided cost formulas under PURPA and some other financial inducements may have distorted the evolution of a more robust renewables sector, the notion that green power may deserve a price premium over conventional power rates is not thereby repudiated. Energy sources should trade in markets at prices that reflect both their private and social costs. There is as well a fairly common view that energy produced by various renewable systems imposes fewer of these social (external) costs than fossil-fired facilities—keeping in mind, however, that the latter have by now been compelled to internalize to a significant degree the cost of pollution abatement. The question for public policy intended to level the playing field is by how much various fossil sources should be penalized for their remaining externalities. This could be achieved through regulatory surcharges on fossil fuel use or, far less efficiently, through enhanced subsidies for renewables in recognition of their more benign environmental impact.

Quantifying external damages is complicated and controversial; the fact that many environmental impacts vary by location and the distorting nature of tax rates are just two of many complications. Some estimates from a study conducted several years ago by researchers at RFF, along with specialists in the European Community and the U.S. Department of Energy, are instructive. (See the report by Krupnick and Burtraw in Suggested Reading). The purpose was to monetize environmental damage throughout the entire fuel cycle, from resource extraction to final use. Coal was found to impose greater social costs than biomass (the only renewable resource covered in the analysis). The difference was reckoned at about 7 mills/kWh (that is, 0.7 cents/kWh) in the study. However, more than 90% of the differential (about 6.4 mills/kWh) is attributable to imputed values—however crude—of the impact of increased global warming from fossil fuel use. This imputed value is on the order of $18/ton of carbon emitted to the atmosphere, well within the range of plausible values derived from existing assessments of global warming risks. Nonetheless, these kinds of calculations are controversial.

Even if one accepts the estimated externality figures just discussed, the implied superiority of biomass over coal from an environmental costing perspective is far below the cost differential between these two fuels that prevails under current market conditions, as discussed earlier. Even a government subsidy equal to twice that difference, such as the 1.5 cents/kWh tax credit to wind power, does not bring renewables appreciably within the competitive range of conventional energy systems.

Whether a 1.5 cents/kWh tax credit or any other subsidy to renewables is a defensible estimate of externalities brought about by conventional energy systems should not blind us to the inherent defects

Box 2: The Ethanol Charade

Although my primary focus in this chapter is the role of renewable energy resources in electricity production, it is worth noting how a rationale for promotion and financial support of renewables—reminiscent of support for other energy resources in earlier times—can bring about an uneasy blend of policies and politics. A good example in the United States is a federal motor fuels sales tax exemption for producers of grain-based ethanol that works out to approximately $16 per barrel of oil equivalent. (The ethanol is designed to be blended with motor gasoline to produce "gasohol," the use of which is believed warranted seasonally in certain polluted areas.) No one who has observed this ultra-generous support program unfold and endure over the years has any illusions about its nature as anything but a political gift to grain processors and the U.S. agricultural constituency. I mention this as a reminder that noble sentiments on promoting clean energy may mask motives that are neither clean nor economically justified by any stretch of the imagination.

President Bill Clinton's Executive Order of August 12, 1999, created a cabinet-level body charged with supporting a greatly expanded effort to promote biofuels. In official remarks made then, the President stated, "I am setting a goal of tripling America's use of bioenergy and bio-based products by 2010. That would generate as much as $20 billion a year in new income for farmers and rural communities while reducing greenhouse gas emissions by as much as 100 million tons a year—the equivalent of taking more than 70 million cars off the road." The initiative may reflect a genuine determination to pursue a sound and sustained research and development and demonstration program in renewable energy. But it is too early to say whether, once again, it is farm policy—or politics—masquerading as energy policy.

of second-best ways of righting environmental wrongs. A system that held fossil fuel combustion fully accountable for its externalities would be more efficient in avoiding a proliferation of subsidies (hidden and explicit) and thus a waste of resources. It would also stem the political temptation to magnify externalities as a means of supporting one's favorite alternate energy system (see Box 2).

Concluding Comments

All projections are conditional and inherently uncertain. One of the less uncertain ones, however, is that—in support of economic growth, particularly in developing parts of the world—the demand for electricity will increase substantially for many years to come. Several references included under Data Sources at the end of the chapter show a continued worldwide rate of increase ranging between 2% and 3% annually for much of the first half of the new century. (See, for example, the cited studies by the Electric Power Research Institute, International Energy Agency, and U.S. DOE *International Energy Outlook*.) Whatever else it may portend, this increase should be somewhat encouraging news for renewables; a growing electricity market, facilitation of scale economies, and movement up the learning curve are necessary, if insufficient, conditions for greater penetration of renewables. Depending on the extent of policies implemented to limit fossil fuel use out of concern over climate change and the possibility of rising costs of petroleum (a source of anxiety in some quarters), the attractiveness and viability of renewables may be strengthened.

But progress on the part of more traditional energy systems is sure to parallel further development of renewables, and there is no reason to expect that dynamic state of affairs to flag in the future. (On this point, see the views of Bradley under Suggested Reading.) Thus, for example, even as the size and technology of wind turbines improve and their costs decline, other systems aren't standing still. Efficient combined-cycle gas turbines seem to be rapidly becoming the configuration of choice in new utility plants. Fuel cells, other distributed systems of power supply, the emergence of advanced (and publicly acceptable) nuclear technology (even if presently unlikely), and across-the-board realizable improvements in energy efficiency are all possibilities to be reckoned with. Each could be a prospective competitor to power systems based on renewable energy sources.

What emerges from these final thoughts is an argument for retaining a reasonably wide range of options in our electricity and energy portfolio. The role of government is not only to help overcome market failures but also to ensure some degree of efficacy in its programmatic agenda, including injection of the broad public interest in its supportive activities. Policies should be sought that are more economically efficient and less politically influenced than the system of outright renewable subsidies that has prevailed in recent years. The nature of those policies is still being debated. For example, the introduction of an RPS into the nation's electricity mix would be more cost-effective than current and previous policies, but it would still be a forcing measure that may only loosely reflect the externality benefits of avoided fossil energy.

Prudently targeted programs in long-term R&D represent an important complementary strategy. Defending its proposed six-year (constant dollar) doubling of federal R&D support for renewable energy, the 1997 PCAST study (see Suggested Reading) indicated that such an increase:

> . . . makes sense in light of the rapid rate of cost reduction achieved in recent years for a number of renewable energy technologies, the good prospects for further gains, and the substantial positive contributions these technologies could make to improving environmental quality, reducing the risk of climate change, controlling oil-import growth, and promoting sustainable economic development in Africa, Asia, and Latin America.
>
> Opportunities exist for important advances in wind-electric systems, photovoltaics, solar-thermal energy systems, biomass-energy technologies for fuel and electricity, geothermal energy, and a range of hydrogen-producing and hydrogen-using technologies including fuel cells. . . . [T]he increased support for these renewable-energy technologies would focus on areas where the expected short-term returns to industry are insufficient to stimulate as much R&D as the public benefits warrant.

As of mid-2000, congressional deliberations pointed to a level of funding for renewable energy resources in fiscal year 2000–01 of around $440 million, nearly a 20% increase (in current dollars) over a year earlier. Whether consciously or fortuitously, the congressional path seems to embrace, and perhaps even leapfrog, the path recommended by PCAST. R&D funding levels apart, what deserves continued close attention is the extent to which environmental externalities and societal risks associated with energy production and use elude private-market transactions. Where they do, it would be surprising if the needed public sector initiatives seeking economically efficient correctives did not include a consequential role for renewables.

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6

Energy-Efficient Technologies and Climate Change Policies

Issues and Evidence

Adam B. Jaffe, Richard G. Newell, and Robert N. Stavins

Enhanced energy efficiency occupies a central role in evaluating the efficacy and cost of climate change policies. Ultimately, total greenhouse gas (GHG) emissions are the product of population, economic activity per capita, energy use per unit of economic activity, and the carbon intensity of energy used. Although GHG emissions can be limited by reducing economic activity, this option obviously has little appeal even to rich countries, let alone poor ones. As a result, much attention has been placed on the role that technological improvements can play in reducing carbon emissions and lowering the cost of those reductions. In addition, the influence of technological changes on the emission, concentration, and cost of reducing GHGs will tend to overwhelm other factors, especially in the long term. Therefore, understanding the process of technological change is of utmost importance. Nonetheless, the task of measuring, modeling, and ultimately influencing the path of technological development is fraught with complexity and uncertainty—as are the technologies themselves.

The carbon intensity of energy can be reduced by substituting renewable or nuclear sources for fossil fuels (and by substituting lower-carbon natural gas for coal) or by increasing energy efficiency. Recognizing this, recent policy proposals have included tax credits for residential and commercial purchasers of new energy-efficient homes and energy-efficient equipment such as electric and natural gas heat pumps, natural gas water heaters, advanced central air conditioners, and fuel cells as well as an investment tax credit for industrial combined heat and power systems. Extensions have also been proposed for existing tax credits for fuel-efficient vehicles powered by electricity, fuel cells, and hybrid power. In addition to tax incentives, other proposals include direct spending on research, development, and deployment of energy-efficient products.

Public–private partnerships have been created or proposed with the aim of developing and deploying energy-efficient technologies for houses (Partnership for Advancing Technology in Housing); appliances (Energy Star program, Golden Carrot Super Efficient Refrigerator Program); schools (Energy Smart Schools); com-

Table 1. Effective Dates of Appliance Efficiency Standards, 1988–2001.

Technology	*1988*	*1990*	*1992*	*1993*	*1994*	*1995*	*2000*	*2001*
Clothes dryers	X				X			
Clothes washers	X				X			
Dishwashers	X				X			
Refrigerators and freezers		X		X				X
Kitchen ranges and ovens		X						
Room air conditioners		X					X	
Direct heating equipment		X						
Fluorescent lamp ballasts		X						
Water heaters		X						
Pool heaters		X						
Central air conditioning and heat pumps			X					
Furnaces								
Central and small			X					
Mobile home		X						
Boilers			X					
Fluorescent lamps								
8 ft					X			
2 ft, 4 ft						X		

Source: U.S. DOE/EIA (see Suggested Reading).

mercial buildings (Energy Star Buildings, Green Lights); vehicles (Partnership for a New Generation of Vehicles); and industrial processes (Motor Challenge, Climate-Wise). Energy efficiency standards for many products have been established and in some cases revised since 1988 (Table 1). Many of these policies target technologies that embody a mix of improved energy efficiency and decreased carbon intensity (such as credits for natural gas heat pumps).

Although the importance of energy efficiency in limiting GHG emissions incites little debate, intense debate ensues regarding its cost-effectiveness and about the government policies that should be pursued to enhance energy efficiency. At the risk of excessive simplification, we can characterize technologists as believing that there are plentiful opportunities for low-cost or even "negative-cost" improvements in energy efficiency and that realizing these opportunities will require active intervention in markets for energy-using equipment to help overcome barriers to the use of more efficient technologies. These interventions would guide choices that purchasers would presumably welcome after the fact, although they have difficulty identifying these choices on their own. This view implies that with the appropriate technology and market creation policies, significant GHG reduction can be achieved at very low cost.

In contrast, most economists acknowledge the existence of market barriers to the penetration of various technologies that enhance energy efficiency and that only some of these barriers represent real market failures that reduce economic efficiency. This view emphasizes that there are trade-offs between economic efficiency and energy efficiency—it is possible to get more of the latter, but typically only at the cost of less of the former. The economic perspective suggests that GHG reduction is more costly than the technologists argue, and it puts relatively more emphasis on market-based GHG control policies such as carbon taxes or tradable carbon permit systems to encourage the least costly means of carbon efficiency (not necessarily energy efficiency) enhancement available to individual energy users.

In this chapter, we first examine what lies behind this dichotomy in perspectives. Ultimately, the veracity of different perspectives is an empirical question, and reliable empirical evidence on the issues identified above is surprisingly limited. We review the evidence that is available and find that although energy and technology markets certainly are not perfect (no markets are), the balance of evidence supports the view that there is not as much "free lunch" in energy efficiency as advocates would suggest. On the other hand, a case can be made for the existence of certain inefficiencies in energy technology markets, thus raising the possibility of some inexpensive GHG control through energy efficiency enhancement. We conclude with some reflections on the role of appropriate energy efficiency policy in climate change mitigation.

Understanding the Energy Efficiency Gap

Analysts have pointed out for years that there is an "energy efficiency gap" between the most energy-efficient technologies available at some point in time and those that are actually in use. On this basis, debate has raged about the extent to which there are low-cost or no-cost options for reducing fossil energy use through improved energy efficiency. It turns out that technologists and economists have very different views of this gap and of whether and to what degree it is the result of market failures that might be amenable to policy intervention or simply market barriers that would be surmountable only at relatively high cost. This debate is illustrated in the 1995 report from the Intergovernmental Panel on Climate Change (IPCC; see Hourcade and others in Suggested Reading). One part of this report states that energy efficiency improvements on the order of 10–30% might be possible at little cost or even with net benefits (ignoring climate benefits), whereas another part highlights the fact that most economic models indicate a significant cost for stabilizing or cutting OECD emissions below 1990 levels.

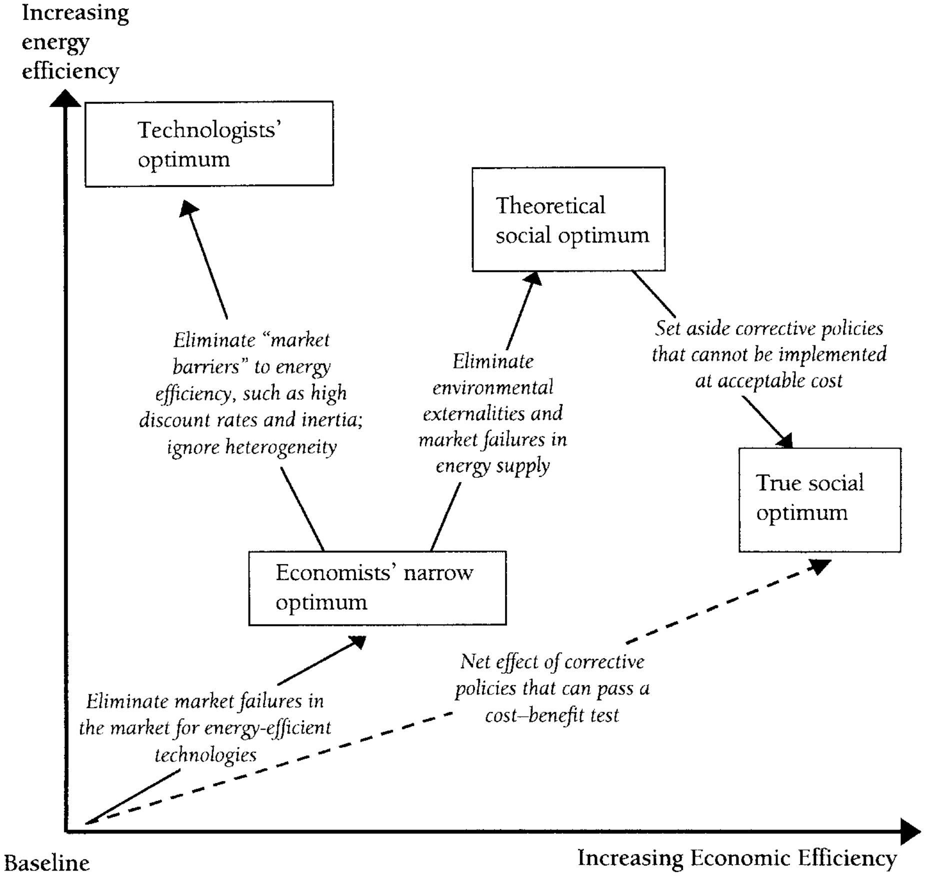
The basic dimensions of this debate are the subject of many studies. To understand the basic elements of the debate, it is helpful to first distinguish between energy efficiency and economic efficiency (Figure 1). The vertical axis measures increased energy efficiency (as decreased energy use per unit of economic activity), and the horizontal axis measures increased economic efficiency (as decreased overall economic cost per unit of economic activity, taking into account energy and other opportunity costs of economic goods and services). Different points in the diagram represent the possible energy-using technologies available to the economy as indicated by their energy and economic efficiency.

Consider two air conditioners that are identical except that one has higher energy efficiency and, as a result, is more costly to manufacture—high-efficiency units require more cooling coils, a larger evaporator, and a larger condenser as well as a research and development effort. Whether it makes sense for an individual consumer to invest in greater energy efficiency depends on balancing the value of energy that will be saved against the increased purchase price, which depends on the value of the additional materials and labor that were spent to manufacture the high-efficiency unit. As we discuss below, the value to society of saving energy should also include the value of reducing any associated environmental externalities, but again, it must be weighed against the costs.

Adoption of more energy-efficient technology is represented in Figure 1 as an upward movement. But not all such movements will also enhance economic efficiency. In some cases, it is possible to simultaneously increase energy efficiency and economic efficiency. This will be the case if market failures impede the most efficient allocation of society's energy, capital, and knowledge resources in ways that also reduce energy efficiency. These are examples of what economists and others refer to as "win-win" or "no regrets" measures.

In Figure 1, the economist's notion of a "narrow" optimum is where failures in the market for energy efficient technologies have been corrected, increasing both economic efficiency and energy ef-

Figure 1. Alternative Notions of the Energy Efficiency Gap.



ficiency. This optimum is narrow in the sense that it focuses solely on energy technology markets and does not consider possible failures in energy supply markets (such as underpriced energy as a result of subsidies or regulated markets) or, more important, environmental externalities associated with energy use (such as global climate change). When analysts speak of no-cost climate policies based on energy efficiency enhancement, they often implicitly or explicitly assume the presence of market failures in energy efficiency.

Market failures in the choice of energy-efficient technologies could arise from various sources. Some of these are relatively uncontroversial, at least in principle, such as inadequate private-sector incentives for research and development and information shortages for purchasers regarding the benefits and costs of adopting technologies. Other potential market failures are more controversial: To what extent is small-scale investment in energy efficiency limited because of financing constraints (a failure of capital markets to efficiently allocate financial resources)? To what extent are there market failures because landlords (rather than tenants) pay utility bills, and landlords are not adequately rewarded in rental markets for providing energy-efficient dwellings (so-called principal agent problems)? To what extent are businesses not pursuing potentially rewarding energy efficiency investments because managers are not adequately rewarded (and capital markets do not adequately punish such inefficiency)? We discuss some evidence on these questions below.

Eliminating broader market failures takes us to what we call the *theoretical social optimum* in Figure 1, which represents both increased economic efficiency and energy efficiency compared with the economists' narrow optimum. But not all market failures can be eliminated at acceptable costs. In cases where implementation costs outweigh the gains from corrective government intervention, it will be more efficient not to attempt to overcome particular market failures; this level is what we refer to as the *true social optimum*. Market failures have been eliminated, but only those whose elimination can pass a reasonable benefit–cost test. The result is the highest possible level of economic efficiency, but a level of energy efficiency that is intermediate compared with what would be technologically possible.

In contrast to the economist's perspective, technologists have focused their interest on another notion of an optimum, which typically is based on a very simple engineering–economic model. The *technologists' optimal energy efficiency* is found by minimizing the total purchase and operating costs of an investment, where energy operating costs are discounted at a rate the analyst (not necessarily the purchaser) feels is appropriate.

The problem with this approach is that it does not accurately describe all the factors affecting investment decisions regarding energy efficiency. First, it typically does not account for changes over time in the savings that purchasers might enjoy from an extra investment in energy efficiency, which depends on trends and uncertainties in the prices of energy and conservation technologies. When making irreversible investments that can be delayed, the presence of this uncertainty can lead to an investment hurdle rate that is larger than the discount rate used by an analyst who ignores this uncertainty. The magnitude of this option-to-wait effect depends on project-specific factors, such as the degree of volatility in energy prices, the degree of uncertainty in the cost of the investment, and the rate of change in the prices of energy and conservation technologies over time. Under the conditions that characterize most energy conservation investments, this effect could raise the hurdle rate by up to 10 percentage points. The effect is magnified when energy and technology price uncertainty is increased, and when energy prices are rising and technology costs are falling more quickly. On the other hand, if there is no opportunity to wait, this effect can be ignored.

Second, the magnitude of important variables used in such engineering–economic analysis can vary considerably among purchasers—variables such as the purchaser's discount rate, the investment lifetime, the price of energy, the purchase price, and other costs. Heterogeneity in these and other factors leads to differences in the expected value that individual purchasers will attach to more energy-efficient or carbon-efficient products. As a result, only purchasers for whom it is especially valuable may purchase a product. For example, it may not make sense for someone who will only rarely use an air conditioner to spend significantly more purchasing an energy-efficient model—they simply may not have adequate opportunity to recoup their investment through energy savings. Analysis based on single estimates for the important factors listed above—unless they are all very conservative—will inevitably lead to an optimal level of energy efficiency that is too high for some portion of purchasers. The size of this group, and the magnitude of the resulting inefficiency should they be constrained to choose products that are not right for them, will of course depend on the extent of heterogeneity in the population and the assumptions made by the analyst.

Finally, evidence suggests that analysts have substantially overestimated the energy savings that higher efficiency levels will bring, partly because projections often are based on highly controlled studies that do not necessarily apply to actual savings realized in a particular situation. For example, studies have found that actual savings from utility-sponsored programs typically achieve 50–80% of predicted savings (see Sebold and Fox, as well as

Hirst, in Suggested Reading). Metcalf and Hassett (see Suggested Reading) draw a similar conclusion based on an analysis of residential energy consumption data, in which they found that the actual internal rate of return to energy conservation investments in insulation was about 10%, which is substantially below typical engineering estimates that the returns were 50% or more.

This is not to say that profitable energy efficiency investments do not exist; rather, attempts to determine optimal or minimum energy efficiency levels for particular investments—as is done, for example, during the process of setting minimum energy efficiency standards—need to account for all costs, not overstate realizable benefits, and use appropriate discount rates.

An important implication of this perspective is that comparisons of an engineering ideal for a particular energy use with average practice for existing technology are inherently misleading, because the former does not incorporate all the real-world factors influencing energy technology decision-making. The overall economic costs of switching to more energy-efficient technology constitute what can be thought of as a market barrier to their use in that individual consumers and producers will not have incentives to use more costly technologies unless policy measures (such as technology standards or carbon taxes) compel or induce behavioral changes. Unlike market failures, however, market barriers cannot be lowered in a win-win fashion.

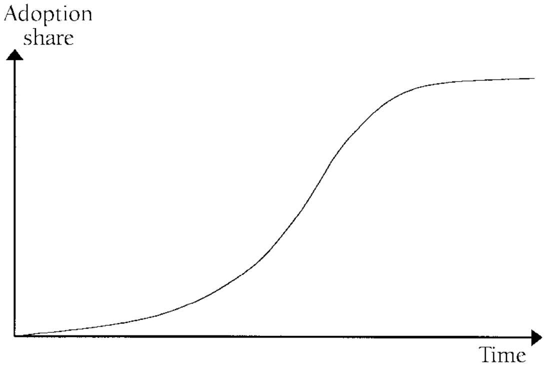
Constraining consumers to purchase appliances with a higher level of efficiency based on simplistic analysis will in effect impose extra costs on consumers. The result is higher energy efficiency but decreased economic efficiency, because consumers are forced to bear costs that they had otherwise avoided. Although it is possible that this effect may be justified by some larger societal goal to address certain environmental externalities associated with energy consumption, the problem should be approached from that broader perspective rather than from the narrow perspective of constraining energy efficiency decisions. Taking this broader perspective leads to a more direct focus on the real problem—climate change associated with CO_2 emissions—rather than constraining available technology options.

Technology Invention, Innovation, and Diffusion

To understand the potential for public policy to affect energy efficiency, we also need to understand the process through which technology evolves: invention, innovation, diffusion, and product use. Policies can affect each stage in specific and different ways. *Invention* involves the development of a new idea, process, or piece of equipment. This activity takes place inside the laboratory. The second stage is commercialization, or technology *innovation*, in which new processes or products are brought to market. The third stage is *diffusion*, the gradual adoption of new processes or products by firms and individuals who then decide how intensively to *use* new products or processes. From this perspective, we can now think of the energy efficiency gap discussed earlier as a debate mainly about the gradual diffusion of energy-saving technologies that appear to be cost-effective.

Tying this all together, we could, for example, think of a fundamentally new kind of automobile engine being invented. It might be an alternative to the internal combustion engine, such as a system that depends on fuel cells. The innovation step would be the work carried out by automobile manufacturers or others to commercialize this new engine, that is, bring it to market and offer it for sale. The diffusion process would be the purchase by firms and individuals of automobiles with this new engine. Finally, the degree of use of these new automobiles will be of great significance to demand for particular types of energy. The reason it is so important to distinguish carefully among these different conceptual steps—invention, innovation, diffusion, and use—is that public policies can be designed to affect various stages and will have very specific and differential effects. Both economic incentives and conventional regulations can be targeted to any of these stages, but with greatly varying likelihood of success.

Figure 2. The Gradual S-Shaped Path of Technology Diffusion.



Diffusion

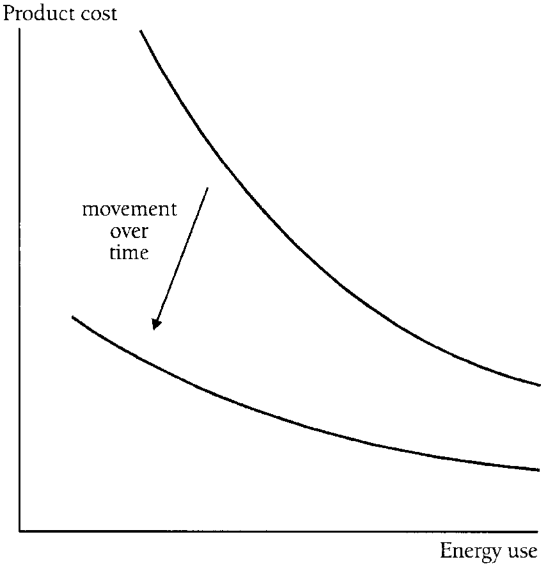
The S-shaped diffusion path has typically been used to describe the progress of new technologies making their way into the marketplace. Figure 2 portrays how a new technology is adopted at first gradually and then with increasing rapidity, until at some point, its saturation in the economy is reached. Some natural questions are what generates this typically observed gradual path of diffusion, how can public policy affect it, and how might public policy accelerate it?

The explanation for this typical path of diffusion that has most relevance for energy-conservation investments is related to differences in the characteristics of adopters and potential adopters. They include differences in the kind and vintage of their existing equipment, other elements of the cost structure (such as access to and cost of labor, material, and energy), and their access to technical information. Such heterogeneity leads to differences in the expected returns to adoption, and as a result, only potential adopters for whom it is especially profitable will adopt at first. Over time, however, more and more will find it profitable as the cost of the technology falls, its quality improves, information about the technology becomes more widely available, and existing equipment stocks depreciate.

Jaffe and Stavins (see Suggested Reading) investigated technology diffusion in the context of energy efficiency by carrying out econometric analyses of the factors affecting the adoption of thermal insulation technologies in new residential construction in the United States between 1979 and 1988. They examined the dynamic effects of energy prices and technology adoption costs on average residential energy efficiency technologies (that is, average R-values) in new home construction. The effects of energy prices can be interpreted as suggesting what the likely effects of taxes on energy use would be, and the effects of changes in adoption costs can be interpreted as indicating what the effects of technology adoption subsidies would be. The researchers found that the response of mean energy efficiency to energy price changes is positive and significant, both statistically and economically.

Interestingly, they also found that equivalent percentage cost subsidies would have been about three times as effective as taxes in encouraging adoption, although standard financial analysis would suggest that they ought to be about equal in percentage terms. However, this finding confirms the conventional wisdom that technology adoption decisions are much more sensitive to up-front cost considerations than to longer-term operating expenses. In a study of residential conservation investment tax credits, Hassett and Metcalf (see Suggested Reading) also found that tax credits or deductions are many times more effective than "equivalent" changes in energy prices—about eight times as effective in their study. They speculate that one reason for this difference is that energy price movements may be perceived as temporary. One downside to efficiency subsidies, however, is that they do not provide incentives to reduce use, as energy price increases do. In addition, technology subsidies and tax credits can require large public expenditures per unit of effect, because consumers who would have purchased the product even in the absence of the subsidy will still receive it. In a time of fiscal constraints on public spending, this speculation raises questions about the feasibility of subsidies that would be sizable enough to have the desired effect.

Figure 3. Innovation in Product Characteristics.



Jaffe and Stavins also examined the effects of more conventional command-and-control regulations on technology diffusion, in the form of state building codes. However, they found no discernable effect. It is possible, of course, that stricter codes (that were more often binding relative to typical practice) might have an effect. However, proponents of conventional regulatory approaches should remember that although energy taxes, for example, will always have some effect, typical command-and-control approaches can have little actual effect if they are set below existing standards of practice.

Innovation and Invention

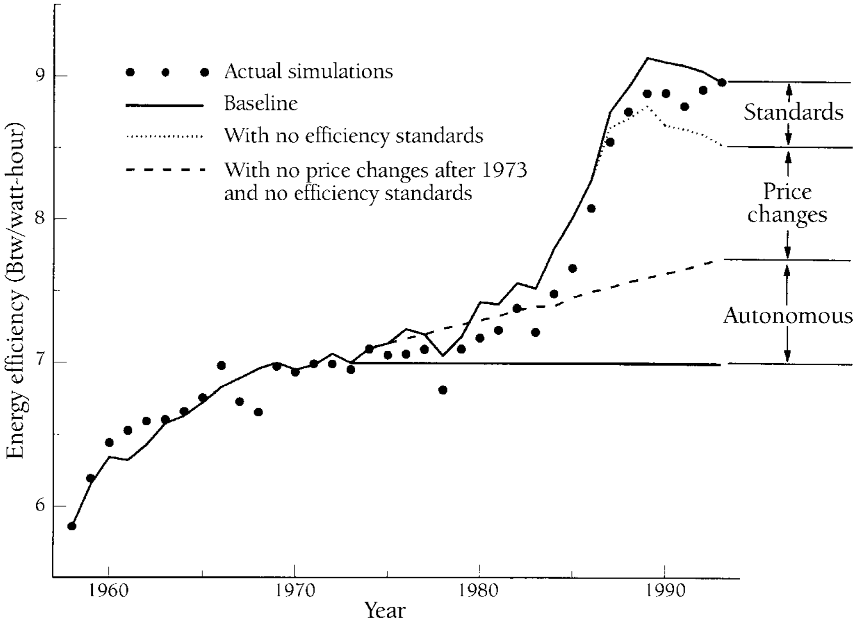
Now we can move back in the process of technological change from diffusion to innovation. In the area of energy efficiency, it is helpful to think of the innovation process as affecting improvements in the characteristics of products. In Figure 3, we represent this process as the shifting inward over time of a curve that represents the trade-offs between different product characteristics for the range of products available on the market. On one axis is the cost of the product, and on the other axis is the energy flow associated with a product—that is, its energy intensity. The downward slope of the curves indicates the trade-off between equipment cost of energy efficiency. Innovation means an inward shift of the curve—greater energy efficiency at the same cost, or lower cost for a given energy efficiency.

Using data from 1960–90, Newell and others (see Suggested Reading) statistically estimated these characteristic transformation curves for a number of energy-consuming durables. By constructing a series of simulations, we can examine the effects of energy price changes and efficiency standards on average efficiency of the menu of products over time. As shown in Figure 4, which illustrates the findings for room air conditioners, a substantial amount of the improvement is what we would describe as autonomous (that is, associated with the passage of time); however, significant amounts are attributable to changes in energy prices and changes in energy efficiency standards. Energy price changes induced both the commercialization of new models and the elimination of old models. Regulation, however, works largely through dropping energy-inefficient models, because that is the intended effect of the energy efficiency standards (in other words, models below a certain energy efficiency simply may not be offered for sale).

Invention is even farther back in the process of technological change. Popp (see Suggested Reading) analyzed U.S. patent application data from 19 energy-related technology groups from 1970 to 1994 and found that the rate of energy-related patent applications was significantly and positively associated with the price of energy.

All of these studies suggest that the response of innovation to energy price changes can be surprisingly swift, typically less than five years for much of the response in terms of patenting activity and introduction of new model offerings. Substantial diffusion can take significantly longer, depending on the rate of retirement of previously installed equipment. The longevity of much energy-using equipment reinforces the importance of taking a long-term view toward energy efficiency improvements—on the order of decades (see Box 1).

Figure 4. Historical Simulations of Energy Efficiency: Room Air Conditioners.



Energy, Technology, and Market Reform Policies

Aside from market influences, public policies also can affect the diffusion of more energy-efficient technologies. Policies that raise the cost of energy will induce the diffusion of extant energy-efficient technology as well as the development of new technology. Are additional nonprice policies needed to promote energy-efficient, climate-friendly technology advances and investment? Here, the debate mirrors that over the energy efficiency gap discussed above. Proponents of such policies argue that economic incentives are not adequate to change behavior. They advocate public education and demonstration programs; subsidies for the development and introduction of new technologies; institutional reforms, such as changes in building codes and utility regulations; and technology mandates, such as fuel economy standards for automobiles and the use of renewable energy sources for power generation.

No one doubts that such approaches might eventually increase energy efficiency and reduce GHG emissions. At issue is the cost-effectiveness of such programs. Advocates of technology mandates often argue that the subsequent costs are negligible because the realized energy cost savings more than offset the initial investment costs. But as we noted earlier, this view ignores several factors that impinge on technology choices. Most economic analyses recognize that energy use suffers from inefficiencies but remain skeptical that large no-regret gains exist. They also acknowledge a role for government when consumers have inadequate access to information and if existing regulatory institutions are poorly designed. This role can include subsidies to basic research and development to compensate for an imperfect patent system, reform of energy sector regulation and reduction of subsidies that encourage uneconomic energy use, and provision of information about new technological opportunities.

Box 1: Technology Diffusion and the Rate of Capital Stock Turnover

Technology diffusion is closely related to the concept of *capital stock turnover*, which describes the rate at which old equipment is replaced and augmented by new. New equipment can be purchased either to replace worn out and obsolete units, or as a first-time purchase. A primary driver of replacement purchases for durable energy-using goods is the product's useful lifetime. The rate of economic growth is also important, especially for first-time purchases of durable goods; the rate of home construction is particularly relevant for residential equipment.

The typical lifetimes for a range of energy-using assets are given here, illustrating that the appropriate time frame for thinking about the diffusion of many energy-intensive goods is on the order of decades.

Type of asset	*Typical service life (years)*
Household appliances	8–12
Automobiles	10–20
Industrial equipment/machinery	10–70
Aircraft	30–40
Electricity generators	50–70
Commercial/industrial buildings	40–80
Residential buildings	60–100

Conclusions and Implications for Climate Policy

We have presented an overview of how to address the question of the appropriate role for government in energy conservation. In doing so, it is essential to decide first on the objective of government policy in this area: economic efficiency or energy efficiency. We find that market signals are effective for advancing the diffusion process, whereas minimum standards may not be unless they mandate certain technologies. We also find that market signals can have effects on the direction of innovation and invention, promoting increased energy efficiency when energy prices are rising. The bottom line is that technological studies that demonstrate the existence on the laboratory shelf of particular energy-efficient technologies are a useful first step. But such studies are not sufficient to address important policy questions. It is necessary to examine whether and how specific policies will affect the processes of invention, innovation, diffusion, and use intensity of products—and how much they will cost.

Although continued research is needed to pin down the precise magnitudes, it seems clear that economic motivations—operating directly through higher energy prices and indirectly through falling costs of technological alternatives due to innovation—are effective in promoting the expanded market penetration and use of more energy-efficient, GHG-reducing technologies. Some policies that support and enhance the effects of market signals, such as information provision and support for basic research and development, can be useful. In contrast, there are many more questions about the efficacy of conventional regulatory approaches, at least in developed market economies, where such policies are more likely to produce limited behavior changes or to incur excessive costs. There are good reasons to doubt the existence of a vast pool of cheap energy-reducing opportunities that offer a free lunch in reducing GHGs.

Although efficiency subsidies and tax credits may provide relatively strong incentives for the marginal purchaser, they also can require large overall public expenditure per unit of effect, because consumers who would have purchased the product even in the absence of the subsidy will still receive it. In a time of fiscal constraints on public spending, the large expenditure required raises questions about the feasibility of subsidies that would be sizable enough to have the desired effect. Energy efficiency improvements can certainly be relevant for climate policy; however, it is also important to remember that primary fuels differ substantially in terms of their GHG emissions per unit of energy consumed. Policies focused on energy use rather than GHG emissions run the risk of orienting incentives and efforts in a direction that is not cost-effective. In particular, policies focused on energy efficiency ignore the other important way in which GHG emissions can be reduced: namely, by reducing the carbon content of energy. Economists generally prefer to focus policy instruments directly at the source of a market failure. Policies focused on carbon emissions — such as tradable carbon permits or carbon fees — will provide incentives for conserving certain fuels in proportion to their GHG content. These policies would raise the price of oil by a higher percentage than the price of natural gas, for instance, thereby targeting incentives for energy efficiency improvements to oil-fired furnaces more than to gas furnaces. In addition, policies focused on GHGs rather than energy per se would also provide incentives for the purchase of gas-fired rather than oil-fired furnaces.

There may be market failures other than the environmental externality of global climate change associated with energy efficiency investments. If the magnitude of these nonenvironmental market failures is large enough and the cost of correcting them small enough to warrant policy intervention, then an argument can be made for attacking these other market failures directly. Any attendant reduction in GHGs can then be viewed as a bonus—a no regrets policy. In fact, this argument is often used by proponents of energy efficiency policy in the context of climate change policy discussions. Therefore, it becomes crucial to investigate the magnitude of these other market failures—in particular cases—and to assess which policies (if any) would be most cost-effective in addressing them. Policies that create clear incentives for changes in energy use and technology must be emphasized by raising the price of GHG emissions and targeting the institutional and other market failures that represent opportunities for cost-effective improvements in market performance.

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