Reflections on the Economics of Climate Change

William D. Nordhaus

Albert Einstein’s reaction to quantum mechanics was “God does not play dice with the universe.” Yet mankind is playing dice with the natural environment through a multitude of interventions—injecting into the atmosphere trace gases like the greenhouse gases or ozone-depleting chemicals, engineering massive land-use changes such as deforestation, depleting multitudes of species in their natural habitats even while creating transgenic ones in the laboratory, and accumulating sufficient nuclear weapons to destroy human civilizations. As natural or social scientists, we need to understand the human sources of these global changes, the potential damage they cause to natural and economic systems, and the most efficient ways of alleviating or removing the dangers. Just as towns in times past decided on the management of their grazing or water resources, so must we today and in the future learn to use wisely and to protect economically our common geophysical and biological resources. This task of understanding and controlling interventions on a global scale can be called managing the global commons.

The issue analyzed in this symposium is the threat of greenhouse warming. Climatologists and other scientists warn that the accumulation of carbon dioxide (CO₂) and other greenhouse gases is likely to lead to global warming and other significant climatic changes over the next century. Many scientific bodies, along with a growing chorus of environmental groups and governments, are calling for severe curbs on the emissions of greenhouse gases. In response, governments have recently approved a framework treaty on climate change to

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monitor trends and natural efforts, and this treaty formed the centerpiece of the Earth Summit held in Rio in June 1992.¹

Natural scientists have pondered the question of greenhouse warming for a century. Only recently have economists begun to tackle the issue, studying the impacts of climate change, the costs of slowing climate change, and alternative approaches for implementing policies. The intellectual challenge here is daunting for those who take policy analysis seriously, raising formidable issues of data, modeling, uncertainty, international coordination, and institutional design. In addition, the economic stakes are enormous, involving investments on the order of hundreds of billions of dollars a year to slow or prevent climate change.

My purpose here is to provide a non-technical introduction to the economics of climate change. I will sketch the scientific background and uncertainties, survey the results of existing studies of the impacts of climate change, present a summary of a study of efficient policies to slow global warming, and end with the uncertainties that haunt the entire field.

The Scientific Background

What is the greenhouse effect? It is the process by which radiatively active gases like CO₂ selectively absorb radiation at different points of the spectrum and thereby warm the surface of the earth. The greenhouse gases are transparent to incoming solar radiation but absorb significant amounts of outgoing radiation. There is no debate about the importance of the greenhouse effect, without which the Earth’s climate would resemble the moon’s.²

Concern about the greenhouse effect arises because human activities are currently raising atmospheric concentrations of greenhouse gases. The major anthropogenic greenhouse gases are carbon dioxide (emitted primarily from the combustion of fossil fuels), methane, and chlorofluorocarbons (CFCs)—but of these CO₂ is likely to be the most significant over the coming decades. Scientific monitoring has firmly established the buildup of the major greenhouse gases over the last century. Using the standard but problematical metric of the “CO₂ equivalent” of greenhouse gases,³ atmospheric concentrations of greenhouse gases have risen by over half of the preindustrial level of CO₂.

While the historical record is well established, there is great uncertainty about the potential for future climate change. On the basis of climate models,

¹Formally known as the United Nations Conference on Environment and Development (UNCED), the Earth Summit was the culmination of an effort to reach international agreements on climate, forest, biodiversity and biotechnology, as well as to develop principles for environmentally sound economic development.


³Because greenhouse gases have differing lifetimes, combining them into a single index of their “CO₂ equivalent” poses complex scientific and economic questions, as Schmalensee (1993) shows.
Figure 1
Projections of Global Temperature Increase:
IPCC Report and DICE Model

Note: IPCC Report is from Intergovernmental Panel on Climate Change (1990), while DICE model is from Nordhaus (1995). The dashed lines are from IPCC Report and represent, from top to bottom, high estimate, best estimate, and low estimate. The solid lines are from the DICE model and represent, from top to bottom, the 90th, 50th, and 10th percentiles of calculated temperature increases from 500 Monte Carlo runs. In both cases, the changes represent temperature increases from 1900.

Scientists project that a doubling of the atmospheric concentrations of CO₂ will in equilibrium lead to a warming of the earth’s surface of 1 to 5 degree Celsius; other projected and equally uncertain effects include an increase in precipitation and evaporation, a small rise in sea level over the next century, and the potential for hotter and drier weather in mid-continental regions such as the U.S. midwest. Atmospheric scientists have engaged in a spirited debate about the climatic impact of increasing greenhouse-gas concentrations, but it is unlikely that the uncertainties will be resolved until this vast geophysical experiment has run its course.

To translate these equilibrium results into a projection of future climate change requires a scenario for emissions and concentrations. Using rudimentary economic modeling, the Intergovernmental Panel on Climate Change (or IPCC), an international panel of distinguished scientists, projected that “business as usual” would produce a 3 to 6 degree C warming in 2100 (relative to 1900) with the best guess being 4 degrees C. The dashed lines in Figure 1 show the high, best, and low estimates from the IPCC.

I have recently used a dynamic optimization model (the DICE model, described more fully later in this paper) to develop a distribution of future
temperature increases. Figure 1 shows as solid lines the 10th, 50th, and 90th percentiles of the temperature-increase distribution from the DICE model. In general, economic models project rising relative energy prices and slowing economic growth in the coming decades; as a result, they tend to show lower emissions and temperature trends than the extrapolative approaches often used in the scientific community and exemplified by the IPCC projections. However, virtually all projections are worrisome because climate appears to be heading out of the historical range of temperatures witnessed during the span of human civilizations.

Climate models resemble large macroeconomic models in their ability to answer virtually any question that modelers care to ask. However, the reliability of climate models for global climate changes is unproven, and climate modelers do not expect to be able to forecast regional climates accurately in the foreseeable future. Some believe that there may be “regime changes” in which the climate flips from one locally stable equilibrium to another, say because of changes in ocean circulation. Elaborating bigger and better models will provide fruitful full employment for climatologists well into the next century.

Impacts of Climate Change

What are the likely impacts of projected climate changes over the next century? To begin, we should recognize that in the long march of economic development, technology has increasingly insulated humans and economic activity from the vagaries of climate. Two centuries ago, work and recreation were dictated by the cycles of daylight, the seasons, and the agricultural growing season.

Today, thanks to modern technology, humans live and thrive in virtually every climate on earth. For the bulk of economic activity, variables like wages, unionization, labor-force skills, and political factors swamp climatic considerations. When a manufacturing firm decides between investing in Hong Kong and Moscow, climate will probably not even be on the list of factors considered. Moreover, the process of economic development and technological change tend progressively to reduce climate sensitivity as the share of agriculture in output and employment declines and as capital-intensive space heating and cooling, enclosed shopping malls, artificial snow, and accurate weather or hurricane forecasting reduces the vulnerability of economic activity to weather.

In thinking about the impact of climate change, one must recognize that the variable focused on in most analyses—globally averaged surface temperature—has little salience for impacts. Rather, variables that accompany or are the result of temperature changes—precipitation, water levels, extremes of droughts or freezes, and thresholds like the freezing point or the level of dikes and levees—will drive the socioeconomic impacts. Mean temperature is chosen because it is a useful index of climate change that is highly correlated with or
determines the more important variables. Moreover, it must be emphasized that impact studies are in their infancy and that studies of low-income regions are virtually non-existent.

Existing research uses a wide variety of approaches including time-series analysis, engineering studies, and historical analogs. Climate change is likely to have different effects on different sectors and in different countries. In general, those sectors of the economy that depend heavily on unmanaged ecosystems—that is, are heavily dependent upon naturally occurring rainfall, runoff, or temperatures—will be most sensitive to climate change. Agriculture, forestry, outdoor recreation, and coastal activities fall in this category. Countries like Japan or the United States are relatively insulated from climate change while developing countries like India are more vulnerable.

This survey of impacts will concentrate primarily upon the United States, because that is where the evidence is most abundant. In reality, most of the U.S. economy has little direct interaction with climate. For example, cardiovascular surgery and parallel supercomputing are undertaken in carefully controlled environments and are unlikely to be directly affected by climate change. More generally, underground mining, most services, communications, and manufacturing are sectors likely to be largely unaffected by climate change—sectors that comprise around 85 percent of GDP.

A few studies have estimated the impact of an equilibrium CO₂ doubling (2.5 to 3 degrees C) on the United States, and the results of three such surveys are shown in Table 1. The first column of Table 1 shows the results of Nordhaus (1991) updated to 1988 prices. The other two comprehensive studies by Cline (1992) and Fankhauser (1993) use largely the same data base but extend the Nordhaus analysis to other sectors. The convention used in most damage studies is to calculate impacts in terms of today's level and composition of output. Hence, the $53 billion estimate of damage from CO₂ doubling estimated by Cline and shown in Table 1 superimposes the estimated impacts that would occur roughly a century from now upon today's economy.

Cline has performed the most detailed economic analysis of the potential impact of climate change on a number of market and non-market sectors, and the overall results are shown in the second column of Table 1. While Cline examined a wide variety of possible impacts, many of the estimates are extremely tenuous and may lean toward overestimating the impacts. For example, Cline’s estimates of the impact of losses from storms assume that storms become more severe, whereas both the IPCC and the National Academy studies concluded that the effect of warming on storm intensity is ambiguous. Another example is leisure activities, where he includes only losses to skiing but excludes any gains from the much larger warm-weather industries such as camping.

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1 An early review, emphasizing the potential costs of climate change, is contained in EPA (1989). A more balanced approach, emphasizing the potential for adaptation, is contained in National Academy of Sciences (1992).
Table 1
(in billions of 1988 U.S. dollars per year)

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<thead>
<tr>
<th></th>
<th>Nordhaus</th>
<th>Cline</th>
<th>Fankhauser</th>
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<tr>
<td>Heavily affected sectors</td>
<td></td>
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<td>Agriculture</td>
<td>1</td>
<td>15.2</td>
<td>7.4</td>
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<td>10.7</td>
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<td>0.5</td>
<td>9</td>
<td>0</td>
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<tr>
<td>Other sectors</td>
<td></td>
<td></td>
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<tr>
<td>Wetland and species loss</td>
<td>b</td>
<td>7.1</td>
<td>14.8</td>
</tr>
<tr>
<td>Health and amenity</td>
<td>b</td>
<td>8.4</td>
<td>30.3</td>
</tr>
<tr>
<td>Other</td>
<td>b</td>
<td>11.2</td>
<td>12.1</td>
</tr>
<tr>
<td>Total: billions of $</td>
<td>50.3</td>
<td>53.4</td>
<td>66.9</td>
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<tr>
<td>(Percent of output)</td>
<td>1.0</td>
<td>1.1</td>
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bThese are included in the total for “other sectors.”

boating, and swimming. In agriculture, Cline relies on estimates that involve little or no adaptation. For health effects, Cline bases his estimates on a study that virtually ignores adaptation. For species loss, Cline takes a very costly decision (that of the Northern spotted owl) and uses that as the basis for valuation. Even with this tendency to see the pessimistic side of global warming, Cline’s estimates of impacts are only marginally above those found in other studies (1.1 percent of GNP for a 2.5 degree C warming in Cline, as opposed to 1 percent of GNP for a 3 degree warming in Nordhaus).

A third approach is a compilation by Fankhauser (1993). This study employs much the same methodology as Nordhaus and Cline but uses additional studies and extends the analysis to the OECD countries and to the world. Fankhauser’s results are very close to those in earlier studies, finding a 1.5 percent impact of a 3 degree warming for the United States.

A full assessment of the impact of greenhouse warming must, of course, include regions outside the United States. To date, studies for other countries are fragmentary, and it is not possible to make any general conclusions at this time. A preliminary reading is that other advanced industrial countries will experience modest impacts similar to those of the United States, and some may even have net economic benefits; for example, Fankhauser (1993) extends his analysis and estimates losses from CO₂ doubling of 1.4 percent to OECD countries and 1.5 for the world. Another estimate, more qualitative in nature, is an intensive survey of experts on the economic impacts of climate change.
(Nordhaus, 1993b). For a 3 degree C warming in 2090, the median response was an economic loss of 1.8 percent of world output. However, there is great uncertainty: the median estimate of the 10th percentile of outcomes is for no impact, while the median estimate of the 90th percentile of outcomes is for a 5.5 percent loss of world output.

All these studies indicate the great uncertainty about the impact of climate change. More recent analysis suggests that the studies reported in Table 1 may well overestimate the impact of climate change because they ignore many ways in which economies can adapt to changing climate. One kind of adaptation ignored in most studies is the buffering of shocks by trade. A study by Reilly and Hohmann (1993) begins with the results of agricultural production-function studies such as those used in Table 1; these studies estimate the impact of climate change on crop yields in individual regions. These yield estimates are then imbedded in a model of international trade. Reilly and Hohmann find that trade tends to reduce the economic impacts by a factor of from five to ten as reactions of supply and demand buffer production shocks. For example, the estimated impact of a substantial (30 percent) yield shock in temperate regions, buffered by the adaptive response in markets, produces a negligible impact on incomes: 0.06 percent of income for the U.S. and 0.08 percent loss for the world over a period of nearly a century. This careful study is a good lesson on how impact estimates often tend to exaggerate losses while ignoring gains and adaptations.5

Another approach to measuring impacts is a “Ricardian” analysis that estimates the rents to climate in particular climate zones and then uses these to estimate the impact of climate change on income. The Ricardian approach is useful because it allows all forms of adaptation, whereas the production-function approaches omit all but a few forms of adaptation to changing climate. A study by Mendelsohn, Nordhaus, and Shaw (1993a, b) developed such an approach by examining the impact of climate on U.S. agriculture. This study uses cross-sectional data on climate, farm-land prices, and other economic and geophysical data for almost 3000 counties in the United States.

Applying the model to a global-warming scenario found a range of impacts. The traditional analysis of global warming analyzes the impact upon the

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5One might suspect that there is often an unconscious impulse to find costs and ignore benefits of climate change. A comparison of two sets of studies is instructive in this respect. Almost two decades ago, a series of studies was undertaken to investigate the impact of flights in the stratosphere on global cooling. Studies by d'Arge and others (summarized in National Research Council, 1979) found that global cooling of 1°C would impose costs in a number of areas. Of the nine areas of costs identified in the global cooling studies (agriculture, forest products, marine resources, health, locational preferences, fuel demand, housing, public expenditures, and aesthetics), only two were examined in the 1989 EPA study of global warming and none were calculated by the EPA to produce benefits. The largest estimated cost in the global cooling studies was the amenity effect of cooling, determined through regional wage differentials. This topic was completely ignored in the EPA studies. One is tempted to say that environmental impact studies can find the cloud behind every silver lining.
grains. Under this approach, the Ricardian model finds annual losses ranging from $6 to $8 billion annually (without CO$_2$ fertilization in 1988 prices at 1988 levels of farm income). This can be related to gross farm income in 1982 of $175 billion. Strikingly different results emerge if we use a broader approach which includes all agricultural crops. For these, the net impact of warming is slightly positive, ranging from a loss of $0.7 billion to a gain of $2 billion per year. The differing results arise because the broader approach weights relatively more heavily the irrigated lands of the American West and South that thrive in a Mediterranean and subtropical climate, a climate that will become relatively more abundant with a warmer climate.

The one area where our information is particularly sparse is for developing countries. Small and poor countries, particularly ones with low population mobility in narrowly restricted climatic zone, may be severely affected. Much more work on the potential impact of climate change on developing countries needs to be done.

The Balancing Act in Climate Change Policies

The greenhouse effect is the granddaddy of public goods problems—emissions affect climate globally for centuries to come. Because of the climate externality, individuals will not produce the efficient quantity of greenhouse gases. An important goal of economic research is to examine policies that will find the right balance, on the margin, of costs of action to slow climate change and the benefits of reducing future damages from climate change.

The benefits of emissions reductions come when lower emissions reduce future climate-induced damages. To translate these into a marginal benefit function, it is necessary to follow the emissions through greenhouse-gas concentrations to economic impacts, and then take the present value of the impact of an emission of an additional unit. Graphically, we can depict the marginal damages averted per unit of emissions reduction as the downward-sloping marginal benefit (MB) curve in Figure 2.

The second relationship is the marginal cost of emissions reduction, which portrays the costs that the economy undertakes to reduce a unit of greenhouse-gas emissions (or the equivalent in other policies that would slow greenhouse warming). A wide variety of approaches are available to slow climate change. Most policy discussion has focused on reducing CO$_2$ emissions by reducing the consumption of fossil fuels through energy conservation, alternative energy sources (some would even contemplate nuclear power), and other measures. Such policies could be implemented through carbon taxes of the kind James Poterba analyzes in this symposium, while some prefer regulations such as tradable emissions permits. Other approaches include reforestation to remove CO$_2$ from the atmosphere and putting even more stringent controls on CFCs.
Figure 2
Marginal Costs and Benefits of Greenhouse-Gas Emissions Controls

Note: Efficient policy comes at point $E$, where marginal cost of further emissions reduction (MC) equals marginal benefit of emissions reductions in slowing climate change (MB). $T^*$ is the efficient carbon tax while $r^*$ is the efficient reduction rate.

Another option, definitely not in the environmentally correct package, would be to offset greenhouse warming through climatic engineering, primarily through measures to change the albedo (reflectivity) of the earth. Such options include injecting particles that would increase the backscattering or reflecting of incoming sunlight or stimulate absorption of carbon. Two particularly interesting proposals include shooting smart mirrors into space with 16-inch naval rifles or seeding the oceans with iron to accelerate carbon sequestration.\(^6\) Whatever the approach, economists emphasize the importance of cost-effectiveness—structuring policies to get the maximal reduction in harmful climatic change for a given level of expenditure. Figure 2 shows schematically the marginal cost of cost-effective emissions reductions as MC.

The shape of the cost function for reducing $CO_2$ emissions has been thoroughly studied, and the effort discussed by John Weyant in this symposium represents the most careful comparative examination of the results of different models. In addition, policies should include other cost-effective measures, and a recent National Academy of Sciences Panel (1992) has compared the costs of a wide variety of measures, including rough estimates of the costs of climate engineering.

From an economic point of view, efficient policies are ones in which the marginal costs are balanced with the marginal benefits of emissions reductions. Figure 2 shows schematically how the efficient rate of emissions reduction and

\(^6\) The issues of geoengineering are discussed in National Academy of Sciences (1992, Chapter 28).
the optimal carbon tax are determined. The pure market solution comes with emissions reductions at 0, where MB is far above the zero MC. Point E represents the efficient point at which marginal abatement costs equal marginal benefits from slowing climate change. The policy can be represented by the efficient fractional reduction in emissions, \( r^* \) on the horizontal axis, or by the optimal carbon tax, \( T^* \) on the vertical axis.

**Empirical Modeling of Optimal Policies**

Sketching the optimal policy in Figure 2 demands little more than pencil, paper, and a rudimentary understanding of economics. To move from theory to useful empirical models requires understanding a wide variety of empirical economic and geophysical relationships. Work has progressed to the point where the economics and natural science can be integrated to estimate optimal control strategies. In one study, I developed a simple cost-benefit analysis for determining the optimal steady-state control of \( \text{CO}_2 \) and other greenhouse gases based on the comparative statics framework shown in Figure 2 (Nordhaus, 1991). This earlier study came to a middle-of-the-road conclusion that the threat of greenhouse warming was sufficient to justify low-cost steps to slow the pace of climate change.

A more complete elaboration has been made using an approach I call the “DICE model,” shorthand for a Dynamic Integrated Model of Climate and the Economy.\(^7\) The DICE model is a global dynamic optimization model for estimating the optimal path of reductions of greenhouse-gas emissions. The basic approach is to calculate the optimal path for both capital accumulation and reductions of greenhouse-gas emissions in the framework of the Ramsey (1928) model of intertemporal choice. The resulting trajectory can be interpreted as the most efficient path for slowing climate change given inputs and technologies; an alternative interpretation is as a competitive market equilibrium in which externalities or spillover effects are corrected using the appropriate social prices for greenhouse-gas emissions.

The DICE model asks whether to consume goods and services, invest in productive capital, or slow climate change via reducing greenhouse-gas emissions. The optimal path chosen is one that maximizes an objective function that is the discounted sum of the utilities of per capita consumption. Consumption and investment are constrained by a conventional set of economic relationships (Cobb-Douglas production function, capital-balance equation, and so forth) and by a newly developed set of aggregate geophysical constraints (interrelating economic activity, greenhouse gas emissions and concentrations, climate change, costs of abatement, and impacts from climate change).

\(^7\) The basic model and results are presented in Nordhaus (1992a, b), while complete documentation and analysis are forthcoming in Nordhaus (1993a).
To give the flavor of the results from the DICE model, consider the economic optimum and compare it to two alternative policies that have been proposed by governments or by the environmental community. The three options are (1) economic optimization as described in the previous paragraph; (2) stabilizing greenhouse-gas emissions at 1990 levels, a target that was endorsed at the Rio Earth Summit by the United States and other governments; and (3) stabilizing climate so that the change in global average temperature is limited to no more than 0.2 degrees C per decade with an ultimate limitation of 1.5 degrees C (compare this with the projections in Figure 1).

Solving the DICE model for the three policies just described produces a time sequence of consumption, investment, greenhouse-gas emissions, and carbon taxes. The carbon taxes can be interpreted as the taxes on greenhouse-gas emissions (or the regulatory equivalent, say in auctionable emissions rights) that would lead to the emissions that would attain the policy objectives just described.

Figure 3 shows the resulting carbon taxes. For calibration purposes, in the United States, a carbon tax of $100 per ton would raise coal prices by about $70 per ton, or 300 percent; would increase oil prices by about $8 per barrel; and would raise around $200 billion of revenues (before taking account of emissions reductions). The economic optimum produces relatively modest carbon taxes, rising from around $5 per ton carbon to around $20 per ton by the end of the next century. The stabilization scenarios require much more stringent restraints. For emissions stabilization, the carbon tax would rise from around $40 per ton of carbon currently to around $500 per ton late in the next century;
climate stabilization involves current carbon taxes over $100 per ton carbon
today rising to nearly $1000 per ton by the end of the next century.

The DICE model can also be used to inquire into the estimated net
economic impact of alternative policies. For the global economy, the economic
optimum has a net benefit over no controls for the global economy (in terms of
the discounted present value measured in 1990 consumption units) of $270
billion. On the other hand, stabilizing emissions or climate imposes major net
economic costs. Stabilizing emissions leads to a net present-value loss of around
$7 trillion relative to the optimum, while attempting to stabilize climate would
have a net present-value cost of around $41 trillion. If these present value
figures are converted into consumption annuities using an annuity rate of
4 percent per annum, these strategies represent, respectively, a gain of
0.05 percent and losses of 1.4 and 8.2 percent of today’s annual gross world
output. It would take a major misestimate of either the costs of emissions
reductions or of climate-change damages to make the stabilization options
economically advantageous.

Several other economic studies have also calculated efficient approaches to
slowing global warming. The studies of Manne and Richels (1990, 1992), Peck
and Teisberg (1992), and Kolstad (1993) find conclusions roughly similar to
those reported here. Other studies—those of Kolstad (1993) as well as earlier
studies by the present author (1979, 1991)—also determine the optimal emis-
sions control rates and carbon taxes and show optimal policies in the general
range of those determined here.

Two studies derive quite different results, one more optimistic, one more
pessimistic. The studies by Jorgenson and Wilcoxen (1991, most strikingly)
show a lower set of carbon taxes needed to stabilize greenhouse-gas emissions
than those shown here; the reason for the lower carbon taxes seems to reside
largely in the slow projected economic growth. By contrast, the study by Cline
(1992) proposes much higher control rates. The more stringent controls in the
Cline study are due to a number of features—primarily because the Cline
result is not grounded in explicit intertemporal optimization and assumes a
rate of time preference that is lower than would be consistent with observed
real interest rates. Clearly, if we arbitrarily assume a near-zero discount rate (as
Cline does), society will undertake massive investments in tangible, human, and
environmental capital; who will do all this saving is an unanswered question.

Uncertainties and Anxieties

Most economic studies of the impacts and policies concerning climate
change are based on scenarios like the smooth and gradual warming depicted
in Figure 1. And, as indicated in the last section, the conclusion that emerges
from most economic studies is to impose modest restraints, pack up our tools,
and concentrate on more pressing problems. Given the high costs of controls
and the modest projected impacts of a 1 to 3 degree C warming over the next half century, how high should global warming be on an international agenda that includes exploding population in the South, nuclear proliferation in the Middle East, collapsing economies in eastern Europe, increasing cycles of poverty and drug use along with stagnating incomes in the West, and sporadic outbreaks of violence and civil war just about everywhere? Given the modest estimated impact of climate change along with these other urgent concerns, we might conclude that global warming should be demoted to a second-tier issue.

Yet, even for those who downplay the urgency of the most likely scenarios for climate change, a deeper anxiety remains about future uncertainties and surprises. Scientists raise the specter of shifting currents turning Europe into Alaska, of mid-continental drying transforming grain belts into deserts, of great rivers drying up as snow packs disappear, of severe storms wiping out whole populations of low-lying regions, of surging ice sheets raising ocean levels by 20 to 50 feet, of northward migration of old or new tropical pests and diseases decimating the temperature regions, of environmentally induced migration overrunning borders in search of livable land. Given the potential for catastrophic surprises, perhaps we should conclude that the major concern lies in the uncertainties and imponderable impacts of climate change rather than in the smooth changes foreseen by the global models.

At present, we do not have the scientific basis for making a firm judgment of the likelihood of one of these catastrophic outcomes. In the survey discussed above (Nordhaus, 1993b), experts were asked about the probability of a 25 percent sustained loss in global income from a 3-degree C warming in 2090 (scenario A) and a 6-degree warming in 2175 (scenario B). The median estimated probability of this catastrophic outcome was 0.5 percent for scenario A and 3 percent for scenario B. On the other hand, the assessment of the catastrophic scenarios varied greatly across respondents and particularly across disciplines. For scenario B, according to the most pessimistic quartile of respondents, the mean probability of this catastrophic outcome was 40 percent. The more pessimistic assessments generally came from natural scientists while the more sanguine views were held by mainstream economists.

Once the door is open to consider catastrophic changes, a whole new debate is engaged. If we do not know how human activities will affect the thin layer of life-supporting activities that gave birth to and nurture human civilization, and if we cannot reliably judge how potential geophysical changes will affect civilization or the world around us, can we use the plain vanilla cost-benefit analysis (or even the Häagen-Dazs variety in dynamic optimization models)? Should we be ultraconservative and tilt toward preserving the natural world at the expense of economic growth and development? Do we dare put human betterment before the preservation of natural systems and trust that human ingenuity will bail us out should Nature deal us a nasty hand?

Faced with this dilemma, we might be tempted to say that such questions are beyond the capability of rational analysis and turn the decisions over to
philosophers and politicians. Rather, I believe that natural and social sciences have a central role to play in analyzing potential future outcomes and delineating potential responses. Society often requires that decisions be made in the absence of complete information, whether the decisions be military strategy, oil drilling, or research and development. In each case, a reasoned decision process involves listing the events that may occur, estimating the consequences of the events, judging the probabilities that each of the events will occur, weighing the expected value of the consequences against the expected costs under different courses of action, and choosing the action that maximizes the expected value or utility of the outcome.

Reasoned decision-making under uncertainty is no different for climate-change policy than for other areas, although it may be more complex and require crossing traditional disciplinary boundaries more often. In thinking through the appropriate treatment of future surprises, to the natural scientists falls the crucial task of sorting through the apocalyptic scenarios and obtaining rough judgments as to the likelihood of different geophysical outcomes so as to distinguish between the likely, plausible, possible, and virtually impossible. To the social scientists falls the issue of assessing the probabilities, determining the values of different outcomes, and devising sensible strategies in the face of such massive uncertainties. To our leaders falls the burden of ultimately deciding how to balance future perils against present costs. For all, this is a fruitful use of our collective talents, full of intellectual challenges and practical payoffs.
References


