Expert Opinion on Climatic Change

Interviews with social and natural scientists reveal vast disparities in estimates of the economic impact of potential greenhouse warming

William D. Nordhaus

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Concerns about the prospect of global warming offer a signal example of the tension between two different views of the relation between economic growth and resources.

At one extreme lies a cheerful frontier mentality that looks forward to limitless economic expansion for the human race. The earth, in this view, has endless rangeland to graze, oceans of offshore oil and gas for drilling, deserts on which to build airports and parking lots, and substitutes readily available wherever scarcities arise. The frontier view sees human societies adapting readily to the modest projected rise in global temperatures that might accompany greenhouse warming. "Frontierniks" might anticipate a new frontier in Russia and other polar regions, trusting that warming will open vast new terrain for mineral exploitation and human expansion, and perhaps even imagine surfing in Alaska or sunbathing in Siberia.

At the other extreme is a dour conviction that finds constraints on every front for people and especially for the natural systems on which they depend. Economic development will inevitably be limited by the depletion of resources, overpopulation and lethal pollution. In this view, unintended consequences threaten to overwhelm human ingenuity, and we must be ever vigilant lest the dikes that hold back catastrophe break and we find ourselves inundated by the threatening seas. "Limitniks" see clouds behind every silver lining, believe that global warming poses dire risks to natural ecosystems, and hold that these risks will spill over to threaten human civilizations as well. They warn of losses in systems that cannot adapt quickly, such as coral reefs and forests; they worry about invasions of pests and viruses that will be bred in enlarged tropical regions; and they fret about a breakdown in vital human-support systems as we undertake this vast geophysical experiment.

At this point, no one can say with any assurance which of these views of the impact of global warming is the right one or in what measure either is closer to the truth. Neither natural nor social science is capable today of predicting with high confidence how climate may change, nor are the geophysical, ecological or social reactions to such changes easily foreseen.

We have only "best guess" scenarios for climatic change and the social reactions it might cause. And even there, the range of possible alternative outcomes overwhelms even the most fertile imagination. For example, many who analyze the perils of future climatic change argue that the greatest impact would not come from the smooth and linear projection that comes out of climatic and economic models. Rather, the major danger to the human prospect may lie in the low-probability, high-consequence events—possibly including catastrophic changes that are difficult or impossible to foresee.

Because of the difficulties of using conventional techniques to gather information, the present study takes another approach—that of surveying expert opinion. The original purpose of the survey reported here was to establish estimates of impacts of climatic change that could be used in quantitative modeling of global change. Once under way, however, the survey took on a life of its own. It became a means of exploring the diversity of views held by those who have thought deeply about global warming and its impacts and about the extent of uncertainties.

The survey revealed that the range of estimated impacts was indeed enormous, and the stakes in both better understanding and wise policies are clearly equally large. Aside from the not-surprising finding of great dissension, the opinions of experts revealed major differences among disciplines, particularly between mainstream economists and natural scientists. One might even say that over the two centuries since Malthus, economists have cast off the mantle of the dismal science while Malthus's intellectual progeny in ecology and the evolutionary sciences have donned that cloak. But I get ahead of the results, so let us turn next to the survey itself.

How the Survey Developed

I developed the survey in an interactive process with respondents. It started with a letter circulated to three people (two experts in climatic change and one economist who had extensive experience in surveys), outlining the idea. Our discussions led to a letter to several potential respondents inviting them to participate.

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Expertise in the area of global warming was the key criterion used for selecting people to participate in the survey. Within this broad category, those who were conversant with issues of the economic impacts of global warming and those who had working knowledge of economic statistics were preferred. This first round of choices was drawn primarily from greenhouse-warming panels of the National Academy of Sciences and from those who had written on the economics of climatic change. I then prepared an interview protocol based on comments from this group.

Next, the respondents were asked to nominate for the survey persons who represented a cross section of knowledgeable expert opinion. This process tended to fission rapidly, and the growing list was trimmed by giving preference to those who were mentioned more than once and to those who had written on the issue of the economics of climatic change. In the end, 22 persons (including the author) were invited to participate, but three did not. Although this selection procedure was arbitrary, it was designed to yield both diversity and informed opinion. The respondents consisted of 10 economists, four other social scientists and five natural scientists and engineers. The names of the respondents, along with their backgrounds, are provided at the end of the article. The respondent numbers are shuffled to ensure anonymity.

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Figure 1. Will greenhouse warming lead to fruitless plains or fruited paradise? Experts on global change are deeply divided on this question. At one extreme, the author's survey shows, are mainstream economists who view the prospect of greenhouse warming with little concern, confident that human societies will adapt handily to such changes. At the other extreme, natural sci-

Surveying Opinion

A preliminary word on the interpretation of probabilities: Clearly, there is no handbook of climatology, economics or statistics that provides objective probability distributions for the impacts of global warming. Instead, this survey examines "subjective probabilities"—what Howard Raiffa has called the "subjective degree of belief interpreted as operationally meaningful in terms of willingness to act or of overt betting behavior."

Put differently, I asked people to quote the odds of different events taking place, much as they would if they were to bet on electoral candidates or horses. In operational terms, when quoting odds it is useful to ask, "Would I be equally willing to undertake a small wager on either side of the bet at the odds I quote?" Only when one is indifferent to wagering on A or B at the stated odds are the subjective probabilities at the right level. In this survey, respondents were asked to provide estimates of the global economic impact in three categories: the best guess, which would have even odds (technically, the 50th percentile of outcomes), along with high and low outcomes, representing the 90th and the 10th percentile of outcomes.

Two important methodological issues may contaminate the results. The first is the interviewer effect. I am known to the respondents as one who has developed estimates of the impact of climatic change that are modest compared with some of the scientific concerns and popular rhetoric, and this knowledge might have influenced the respondents. Second, a measure of impact based on the change in global output may underestimate the impact on human welfare—especially in low-income regions. To some extent, this flaw is addressed through a question about the difference in impacts in high- and low-income countries, but it does point to the broader issue of the importance of improving our understanding of the impact of climatic change on low-income regions.

The Means Are Not the Ends

The survey examined several aspects of the issue of what economic impacts would be expected with major changes in the world's climate. (The full results of the survey are available from the author.) One set of questions concerned the impact on global output of three different scenarios for warming: a doubling in the atmospheric concentration of carbon dioxide by the mid-21st century, resulting in a 3-degree-Celsius rise by 2090 (scenario A); a continuation of that trend to reach a six-degree warming by 2175 (scenario B); and a more rapid warming in which global average temperature increases by 6 degrees by 2090 (scenario C).

Most respondents gave their response as a percent of gross world product, GWP; estimated GWP in 1991 was $21.6 trillion (excluding Russia and a number of small countries, and converting outputs with 1991 U.S. dollars at market exchange rates).

All respondents stated that the economic impacts would be lowest with

entists worry about major and irreversible impacts on natural systems. They warn of unpredictable extreme events, such as shifting ocean currents or migrating monsoons. Which picture more closely depicts the future reality cannot now be predicted. (Right photograph courtesy of North Carolina State University Visual Communications.)

scenario A and highest with rapid-warming scenario C. The best-guess estimate of the impact of scenario A, which is in the middle range of the projections made by the IPCC (the Intergovernmental Panel on Climate Change), is a median loss of 1.9 percent of GWP. Because the estimates are highly skewed, however, the mean is greatly affected by extreme observations. The range of best guesses is from 0 to 21 percent, and the mean is 3.6 percent loss of GWP.

This distribution of responses is also seen in scenarios B and C. For scenario B, which requires estimating further into the future than most respondents were comfortable with, the best-guess outcome had a median loss of 4.7 percent of GWP, with a mean of 6.1 percent loss in GWP and a range from 0 to 35 percent.

Scenario C is at the outer edge of outcomes examined by the IPCC and climatic models. Although it seems quite improbable based on recent climatic trends, it is not outside the range of historical shifts according to recent ice-core data. Again, the mean of the respondents' best-guess estimates for the impact of this scenario—10.4 percent loss in GWP— was driven up by the extensive range, from 0.8 to 62 percent. The median comes in at 5.5 percent of GWP.

The next set of questions addressed uncertainties about these three scenarios. After being asked for their best-guess (50th-percentile) evaluation, the respondents were asked about extreme events in two different ways.

They were first asked to designate both the 10th percentile (smaller impact) and 90th percentile (higher impact) of outcomes for each scenario. Here again, the respondents showed a tremendous diversity of estimates. For scenario A, the 10th-percentile estimates ranged from a 2.0-percent *gain* in GWP to a 10.0-percent loss. Both mean and median were below 1.0. At the 90th percentile, the mean and median were closer—8.0 and 6.0—with a range from 0.5 to 31.3 percent loss.

At the low end (the 10th percentile) for scenario B, the respondents foresee a modest impact, ranging from a gain of 1 percent in GWP to a loss of 10 percent. At the 90th-percentile outcome, however, there was a great dispersion of estimates, ranging from a 1.5-percent to a 50-percent loss in GWP.

For the rapid-change scenario C, the difference of opinion among respondents is most dramatic. At the 90th percentile, the range was a 3-to-100-percent loss of GWP. Even at the low end, the estimates of GWP losses ranged from –1 to 20 percent.

For a second measure of uncertainty, I asked about the probability of a "high-consequence outcome"—one defined as a lowering of global incomes by 25 percent or more (the economic equivalent of the Great Depression). Here the respondents showed considerably greater relative concern about scenarios showing large and rapid temperature increases. The median probability of extremely unfavorable impacts was 0.5 percent for scenario A, 3.0 percent for scenario B and 5.0 percent for scenario C. These responses were again highly skewed because of the views of a few respondents who had extremely pessimistic outlooks. For example, three respondents held that scenario C had a likelihood of catastrophic outcome of at least one-half, whereas four thought that even the most rapid warming would have less than a 1-in-100 chance of provoking the severely reduced economic outcome. Because of the skewness, the means were, respectively, a probability of the high-consequence outcome of 4.8, 12.1, and 17.5 percent for scenarios A, B and C.

Studies of the economic impact of climatic change have concentrated on the impacts on those sectors where outputs, such as food or manufacturing, were bought and sold in markets, these sectors being covered by the standard national accounts (SNA). Sectors outside the SNA, such as amenities, ecosystem effects or human health, have resisted careful economic measures. I therefore asked how the economic impacts were likely to be divided between these two areas. The surprising result was that virtually all respondents agree that more than half of the impacts are expected to be within the SNA for all three scenarios in the best-guess and 90th-percentile cases.

Another area that has received scant empirical analysis is the impact of climatic change outside the high-income countries. Because many analysts think that the response to changing climate will differ between developed and developing countries, one question in-

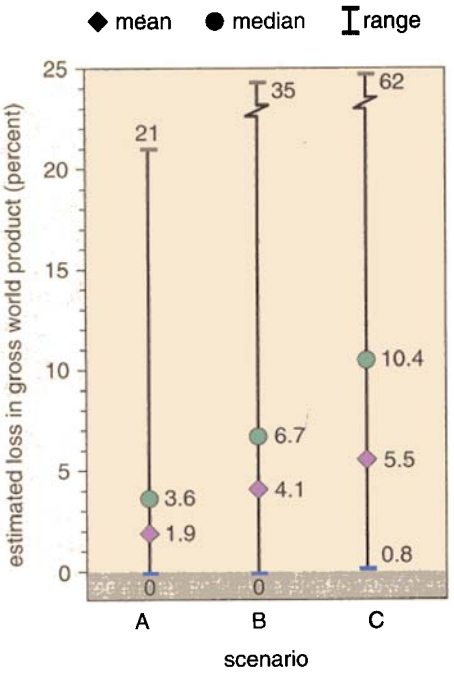

Figure 2. Estimates of the impact on global output in the event of global warming varied greatly among the 19 respondents to the survey. In scenario A, a 3-degree-Celsius rise in global average temperature by 2090, experts predicted a loss ranging from 0 to 21 percent of gross world product (GWP). Ranges for scenario B, a continuation of scenario A to a 6-degree warming by 2175, and scenario C, a more rapid warming of 6 degrees by 2090, were even greater, at 0 to 35 percent and 0.8 to 62 percent of GWP.

volved estimating the impact of climatic change on countries or regions with different levels of income and development. More precisely, respondents were asked to estimate the ratio of the impact on the top quintile to the impact on the bottom quintile of the world income distribution. All but one of the respondents were of the opinion that the developing countries (that is, the lowest quintile) would be more seriously affected than the high-income countries.

The Influence of Point of View

I shall turn next to a qualitative review of the results. The major impression that emerges from this survey is that experts hold vastly different views about the potential economic impact of climatic change. At one extreme are the natural scientists, all three of whom have profound concerns about the economic impacts of greenhouse warming. For example, the mean of these three respondents' answers has a 12-percent probability of severe economic consequences under scenario A. At the other extreme are the "other subdisciplines" of economics (those whose principal concerns lie outside environmental economics); these eight respondents see much less potential for the calamitous outcome—0.4 percent, or about one-30th of the magnitude estimated by the natural scientists. For the more rapid warming in scenario C, the estimated range of probabilities of economic calamity was 20 to 95 percent for the natural scientists and 0.3 to 9 percent for the mainstream economists. The same gap—although it was sometimes less pronounced—ran through the responses to most of the rest of the questions.

What might lead to such a difference in outlook? One respondent suggested whimsically that it was hardly surprising, given that the economists know little about the intricate web of natural ecosystems, whereas scientists know equally little about the incredible adaptability of human economies. One respondent (4) explained the difference of views as follows:

> I have not heard a compelling scenario about the crisis scenario. People tend to have an apocalyptic streak—for example, many scientists held that the probability of nuclear war was a few percent per year in the 1950s and 1960s whereas a more realistic number would have been an order of magnitude smaller. On the basis of that tendency and the ability to adapt, even if climate change were very rapid, it wouldn't be all that terrible....

Another respondent (9) spoke of the views of different participants in the policy debates:

> What is my impression of the view of people involved in the policy process? On the whole, their views are very sketchy and ill-thought-out. People have fears about the future that are not grounded in reality. Scientists tend to be more conservative and don't see such adverse outcomes whereas politicians tend to see weird possible outcomes. There are big differences among people because of the impact of affluence. Policies tend to get discussed in Colorado in August above 7,000 feet, and above 7,000 feet people lose the concept of discount rates.

Apocalypse or Small Potatoes?

The second impression that arises from this survey is that for most respondents the best guess of the impact of a 3-degree-warming by 2090, in the words of respondent 17, would be "small potatoes." Only three respondents expect the impact of scenario A to be more than 3 percent of

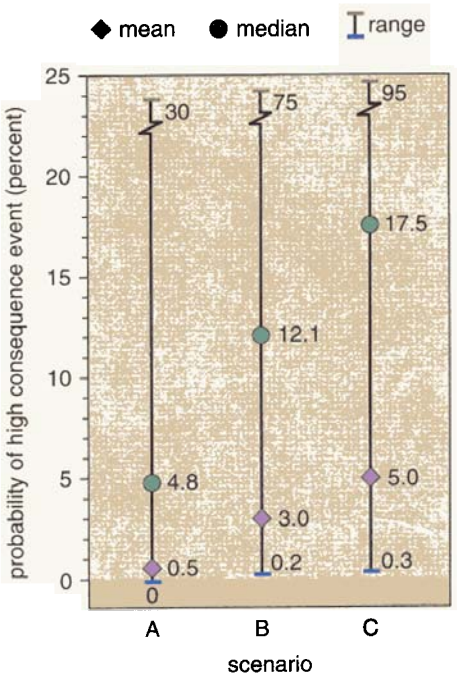

Figure 3. Estimates of the likelihood of a high-consequence event (a loss of at least 25 percent in global output, equivalent to the Great Depression) from global warming give an indication of the potential for catastrophic impacts. Note that averages were greatly affected by a few extreme responses. Estimates went as high as 30, 75 and 95 percent for scenarios A (3-degree warming by 2090), B (continuation of A to 6-degree warming by 2175) and C (6-degree warming by 2075).

GWP. In terms of economic growth, the median estimated impact for scenario A over the next century would reduce the growth of per capita incomes from, say, 1.50 percent per year to 1.485 percent per year. One respondent summarized the relaxed view: "I am impressed with the view that it takes a very sharp pencil to see the difference between the world with and without climate change or with and without mitigation."

Among the problems that face humanity (as opposed to natural systems), global warming does not rank very high for many respondents. Respondent 16 stated that "global warming is way down the list of people's concerns, especially compared to the conventional economic concerns."

Concerns about Ecosystems

Many of the non-economists voiced deep concern about the ability of natural ecosystems to adapt to climatic change, particularly for the large temperature increases. A scientist (respondent 19) stated:

> In [scenario B], I continue to assume that there will be larger temperature

changes in the polar regions of the order of 20 degrees Fahrenheit. In this case, there would be a major change in that we would be moving to a nearly ice-free world with all that would imply. It is hard to imagine what the world would be like with an ice-free Arctic, with a weakening of the circumpolar vortex and a movement of storms to the north, mild temperature in the Arctic regions, agricultural possibilities in high northern latitudes, as well as substantial mid-latitude desiccation....

If we move to the rapid-change case [scenario C], this would add a rapidity of change so that ecosystems could not adjust. The biosphere would be radically changed, and I suspect that there would be severe economic effects.

Secondary Effects

Some respondents foresee the potential for society to respond in highly nonproductive ways as global warming turns from prediction to reality. Respondent 18 stated that as the reality of greenhouse warming becomes clearer, even a modest climatic change "will create a sense of crisis that could lead to short-term irrational policies." A scientist (respondent 10) stated his concerns as follows:

> My concern about future climatic change is a complicated *Gestalt*. I believe that the climatic stresses will make it more difficult to accomplish a number of important objectives, particularly the appreciation or utility of the diversity of nature. Particularly at high rates and numbers, the tropics will be a mess, it will trigger numerous feedbacks, and nature and many human activities cannot adapt at those rates. This could lead to pest invasions, waves of refugees, and wars. All these concerns lead to the idea that 6 degrees [Celsius] in a century could be catastrophic at a first decimal-place probability.

Our Ability to Adapt

There is a clear difference in outlook among the respondents, depending on their assumptions about the ability of society to adapt to climatic changes. One was concerned that society's response to the approaching millennium would be akin to that prevalent during the Dark Ages, whereas another respondent held that the degree of adaptability of human economies is so high that for most of the scenarios the impact of global warming would be "essentially zero." An economist (14) explains that in his view energy and brain power are the only limits to growth in the long run, and with sufficient quantities of these it is possible to adapt or develop new technologies so as to prevent any significant economic costs. This respondent also points out that the time frame over which the climatic changes are expected to take place is sufficient to allow developments of new technologies and other adaptations.

Another respondent (16) elaborated on the role of technology:

> What is missing most is an understanding of the role of technology, of how society will change as technology advances. If we had been concerned with global warming in the 1890s, it would have concerned transportation by horses rather than automobiles. It is impossible to contemplate what society will be like a century from now as technology changes.

Respondent 19 expressed a similar viewpoint:

> Technology will develop to adjust to and accommodate many of the climatic changes and even provide approaches to countering warming effects. However, projecting technological changes a century or two into the future is hazardous at best. All we can really say is that there will be technological changes and that as in the past they will probably offset adverse effects to some degree.

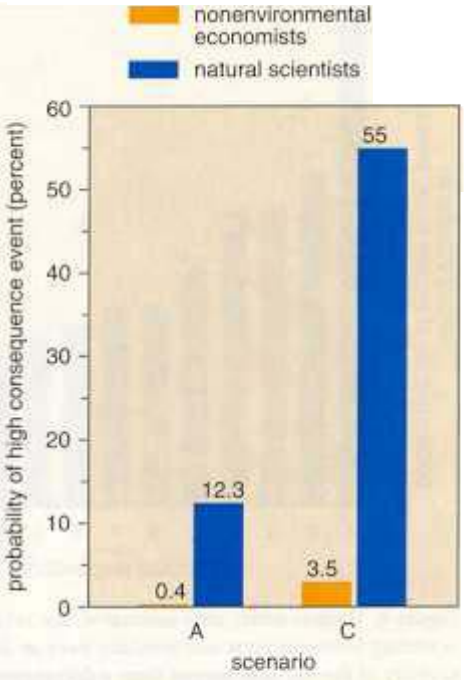

Figure 4. Difference in academic discipline separated those making high estimates of the economic impacts from global warming from those who were comparatively unconcerned. Natural scientists' estimates were 20 to 30 times higher than mainstream economists'.

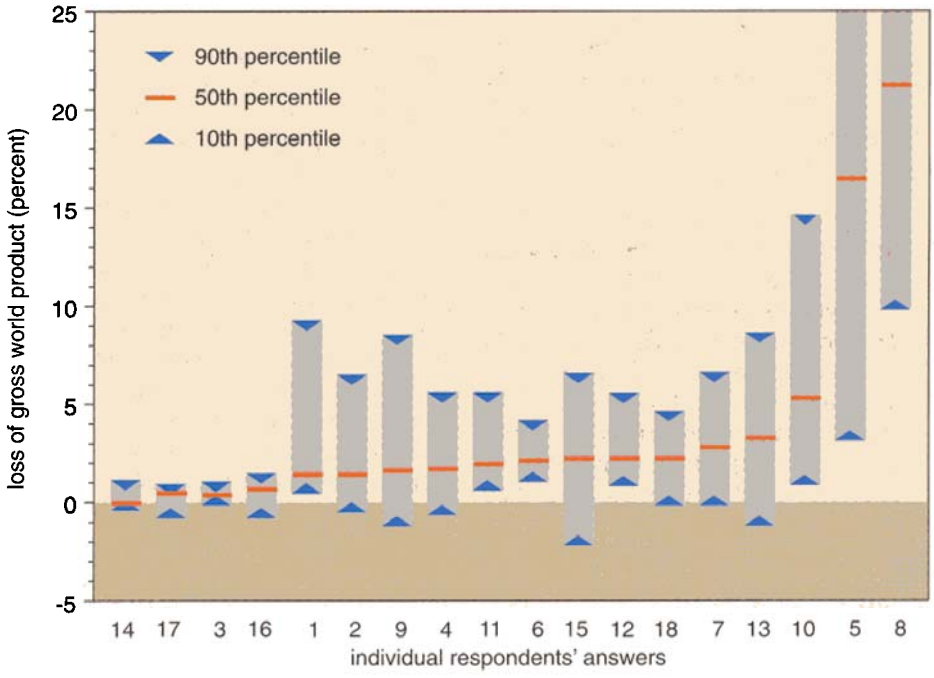

Figure 5. Respondents were queried on the distribution of impacts for scenario A. The 90th percentile is the level of impacts for which a respondent believes that the odds are 9 to 1 that the actual outcome will better. Each respondent's best guess of impacts is shown as the 50th percentile. From the ranges of these estimates can be inferred some measure of each respondent's degree of uncertainty about the economic impact of a 3-degree warming by 2090.

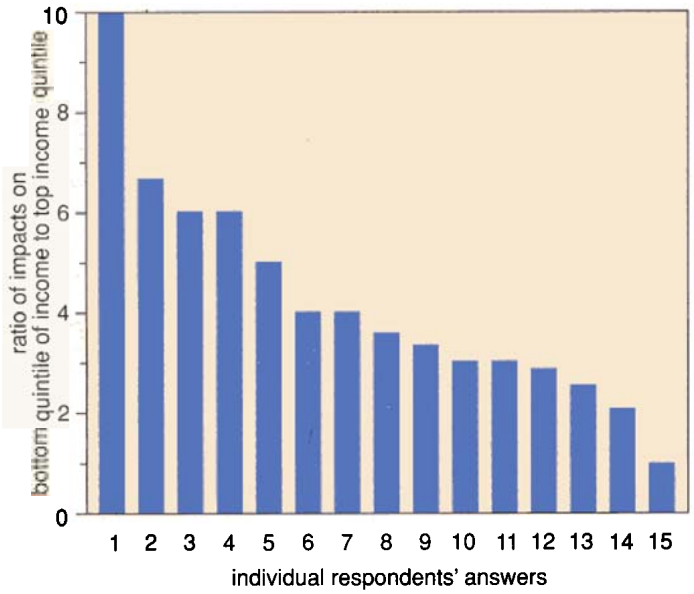

Figure 6. Respondents also estimated the relative impacts of global warming between poor and wealthy people. Estimates of the relative severity of the impacts ranged from a disproportionate burden (by a ratio of 10 to 1) on the lowest quintile of incomes to an even split of impacts between the top and bottom quintiles of incomes.

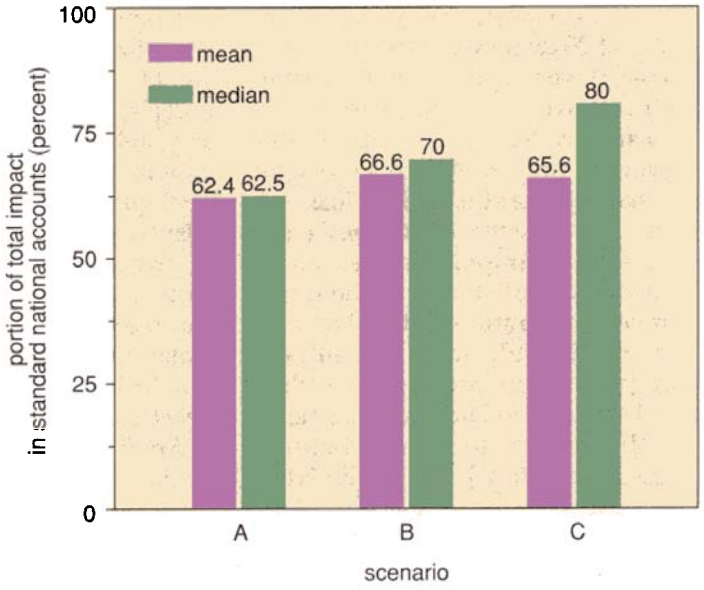

Figure 7. Majority of respondents estimated that the impacts of global warming would register mainly in the standard national accounts (SNA), such as food production or construction, rather than in nonmarket areas such as human health or biodiversity. Respondents thought the proportion of impacts in the SNA would be greater in the more extreme scenarios.

Regional Distribution of Impacts

There is little consensus about the impact of climatic change on different regions of the globe. Most respondents projected modest impacts on high-income regions; virtually all the respondents believe that low-income countries would have larger negative impacts because of the inability of low-income countries to adapt to shocks. One respondent (8) was of the view that tropical regions are likely to be more heavily affected than temperate regions because tropical ecosystems are more fragile than those in higher latitudes, and because of the nature of tropical economies:

> I have worked in the tropics and they tend to be fundamentally dependent on natural resources; they won't compete with us in autos and computers. The only hope for places like Costa Rica istheir resources. Changes even as small as two to three degrees Celsius will have massive effects on their abilities to exploit their natural resources; with their debt burdens, they have mortgaged their natural resources to pay the interest.

But respondent 19 points out that the impact upon tropical regions might be muted:

> Most of the unfavorable impacts would be in temperate and mid-latitude countries; the polar regions will benefit; tropical countries (between 30 degrees north and 30 degrees south latitude) will be largely unaffected except for sea-level rise.

The fate of these regions under climatic change is important because the area between the 30th parallels encompasses much of the developing world. About 52 percent of the world's population lives in these regions, but only 16 percent of the world's output is produced there.

Nonmarket Effects

One of the surprises for me is that most respondents believe that the bulk of the impact of climatic change will lie in areas covered by the standard national accounts, rather than in nonmarket areas such as amenities, human health or biodiversity. There is, however, a major difference of opinion about what the economic impact of global warming might be on ecosystems. One economist (4) stated there would be little impact through ecosystems: "For my answer, the existence value [of species] is irrelevant—I don't care about ants except for drugs." By contrast, another respondent cautioned that the loss of genetic potential might lower the income of the tropical regions substantially. This difference of opinion is on the list of interesting research topics.

Limits to Our Understanding

Many participants expressed deep concern because the global biogeochemical system is so little understood and perhaps even intrinsically unknowable. The point was well expressed by respondent 18:

> [Another] development involved the possibility of destructive, second-order feedbacks, which at present are for the most part largely speculative. Those on climate itself are most often mentioned, but others on biota and oceanic as well as atmospheric circulation cannot presently be excluded. I assume that by the mid-21st century we will have good grounds to dismiss most feedback loops... But suppose that we begin to encounter suggestions of some ominous exceptions?... I have the feeling that this is a source of residual uncertainty in many (all?) of the responses you will have received....

One respondent (9) worried about the spread of tropical diseases:

> In terms of the major impacts, I believe that some of the impacts may involve diseases—for example tropical diseases that are spawned there and transmitted very quickly. Will there be vaccines? Maybe yes, maybe no. But it is a systems change that we have never experienced.

Also, although the willingness of the respondents to hazard estimates of subjective probabilities was encouraging, it should be emphasized that most respondents proffered these estimates

with reservations and a recognition of the inherent difficulty of the task. One respondent (19), however, was a holdout from such guesswork, writing:

> I must tell you that I marvel that economists are willing to make quantitative estimates of economic consequences of climate change where the only measures available are estimates of global surface average increases in temperature. As [one] who has spent his career worrying about the vagaries of the dynamics of the atmosphere, I marvel that they can translate a single global number, an extremely poor surrogate for a description of the climatic conditions, into quantitative estimates of impacts of global economic conditions.

Warming in the Global Perspective

Finally, many of the respondents noted that greenhouse warming is but one of the issues and uncertainties facing civilization in the century to come. Respondent 2 expressed this view as follows:

> "God does not play dice with the universe," was Albert Einstein's reaction to quantum mechanics. Yet mankind *is* playing dice with its natural environment through a multitude of interventions. Depending on one's perspective, it is easy to become either optimistic or pessimistic about our ability to understand and cope with the threat that greenhouse warming poses to our global village. On the one hand, it is true that we are... gambling with our future in more ways than we know. Humans seem just as quarrelsome as they were at the dawn of recorded history, and they have devised new weapons that are awesomely effective at avenging their quarrels. At the same time, our powers of observation and analysis are also orders of magnitude more powerful. The combination of monitoring, measuring, analyzing and computing are growing even faster than our ability to emit greenhouse gases, pollute and cut trees. What will win this race between our tendency to quarrel and pollute and our power to reason and compute? The answer must await the roll of the dice called history.

Survey Participants and Affiliations

Robert M. Adams (anthropology). Secretary of the Smithsonian Institution. Former provost of the University of Chicago. Member of the Synthesis and Science Panels of the U. S. National Academy of Sciences (NAS) Committee on the Policy Implications of Greenhouse Warming (1990–92). Research on the history of irrigation and urban settlements.

Jesse Ausubel (technological and policy sciences). Fellow in Science and Public Policy, Rockefeller University. Staff director of the NAS Carbon Dioxide Assessment Committee (1981–83) and member of the Adaptation Panel of the NAS Committee on the Policy Implications of Greenhouse Warming (1990–92). Research on technology and society.

William Cline (economics). Senior researcher, Institute of International Economics. Author of *The Economics of the Greenhouse Effect* (1992). Research on international economics, the debt crisis and the economics of global warming.

Richard N. Cooper (economics). Professor of economics, Harvard University. Former Undersecretary of State for Economic Affairs and former provost, Yale University. Member of the Synthesis and Mitigation Panels of the NAS Committee on the Policy Implications of Greenhouse Warming (1990–92). Research on international economic cooperation.

Rob Coppock (policy studies and risk analysis). Staff of the NAS. Staff director of the NAS Panel on the Policy Implications of Greenhouse Warming (1990–92). Research on risk analysis.

Daniel J. Evans (structural engineering). Business consultant. Former governor of the state of Washington and former U.S. senator. Chairman of the Synthesis Panel of the NAS Panel on the Policy Implications of Greenhouse Warming (1990–92).

Michael Grubb (energy-policy analyst). Senior research fellow at the Energy and Environmental Program of the Royal Institute of International Affairs, London. Main work in this area is the two-volume work *Energy Policy and the Greenhouse Effect*.

Karl-Goran Maler (environmental economics). Professor of economics at Stockholm Institute of Economics. Author of game-theoretical analysis of problems of negotiating climatic change issues. Research on the economics of environment and development, with a chapter on environment and development for *Handbook of Development Economics, Vol. 2*.

Alan Manne (economics). Professor emeritus of operation research, Stanford University. Chairman of the International Energy Workshop (1981–), participant in the U.S. National Academy of Sciences CONAES (Committee on Nuclear and Alternative Energy Systems) study and in several rounds of the Stanford Energy Modeling Forum. Research on mathematical modeling and energy systems.

Richard Morgenstern (environmental economics). Associate director, U. S. Environmental Protection Agency (EPA). Supervised research and reports on the economic impacts and policy implications of global warming. Economic advisor to the administration of the EPA at the Earth Summit, June 1992.

William D. Nordhaus (economics). A. Whitney Griswold Professor of Economics, Yale University, and author of this article.

Gordon Orians (ecology). Professor of zoology and environmental studies at the University of Washington. Past director of environmental studies. Member of the Synthesis and Adaptation Panels of the NAS Committee on the Policy Implications of Greenhouse Warming (1990–92). Coeditor of *Global Biogeochemical Cycles* (Academic Press, 1992).

David Pearce (environmental economics). Professor of economics at University College, London, and director of the Center for Social and Economic Research on the Global Environment. Advisor to Her Majesty's Government on environmental economics (1989–92). Research on environment and development. Professor Pearce was assisted in responding by Samuel Fankhauser, who has undertaken an extensive survey of estimates of the impact of global warming.

Richard Schmalensee (economics). Professor of economics, MIT. Former member of the President's Council of Economic Advisers. Supervised U. S. government report on the economics of climatic change and coordinated the government's economic policies on climatic change. Research on industrial organization and regulation.

Stephen Schneider (climatology). Professor of biological science, Stanford University. Former head of Interdisciplinary Climate Systems at the National Center for Atmospheric Research. Member of the Synthesis and Mitigation Panels of the NAS Panel on the Policy Implications of Greenhouse Warming (1990–92). Research on climate modeling.

Thomas Schelling (economics). Professor of economics, University of Maryland. Chairman or member of several committees on the implications of global warming and author of a chapter on impact and adaptations for the NAS Carbon Dioxide Assessment Committee (1981–83). Research on game theory, national security and microeconomics.

Lawrence Summers (economics). Professor of economics, Harvard University (on leave) and Undersecretary of the Treasury for monetary affairs (1993–). As chief economist at the World Bank, he supervised studies and the writing of *World Development Report 1992*, which surveyed development and the environment, and interacted with authors and the writing of background papers on the economic aspects of global warming.

Paul Waggoner (meteorology and agricultural science). Distinguished scientist at the Connecticut Agricultural Experiment Station. Former director of the Connecticut Agricultural Experiment Station and chairman of the Adaptation Panel and member of the Synthesis Panel of the NAS Committee on the Policy Implications of Greenhouse Warming (1990-92). Research on climate and agriculture, especially water and pests.

Robert White (atmospheric science and engineering). President, National Academy of Engineering. Former chief, U. S. Weather Bureau, and administrator of the National Oceanic and Atmospheric Administration. Research on general circulation of the atmosphere. Oversight and review of reports on global environmental issues.