Needed: A Realistic Strategy for Global Warming

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As the United States, along with other nations, struggles to develop a response to climate change, a swirl of overheated rhetoric and short-term political maneuvering is obscuring the basic features of this issue. One day we hear that all responsible scientists agree that global warming is a dagger at the heart of human civilization and that emissions of carbon dioxide (CO_2) and other greenhouse gases must be slashed immediately to save our planet. The next day we're told that global warming is the illegitimate offspring of sloppy science and green fanaticism and that laying a finger on U.S. CO_2 emissions would wreck our economy and enrich our foreign competitors.

This debate is motivated by intense, ongoing international negotiations on possible near-term CO_2 emission limits. The agenda for these negotiations, the so-called Berlin Mandate, was adopted at the first conference of Parties to the Framework Convention on Climate Change, held in Berlin in 1995. Diplomats were told to devise a set of national ceilings for greenhouse gas emissions for the early years of the next century. To make agreement more likely, developing countries were not to be asked to control emissions, although they account for roughly half the greenhouse emissions now and will emit a larger share in coming decades. These complex negotiations were to be completed in just two years, in time for the third Conference of Parties this December in Kyoto, Japan. Negotiations have become focused on a single question: how much will each of the developed nations promise to cut CO_2 emissions by 2010?

Our aim here is not to settle this near-term question, though the answer (if any) agreed to in Kyoto may be of great environmental and economic importance. Instead, we will show, through a brief look at the science and economics of climate, that if climate change turns out to be a serious threat, an effective response will require a substantial and very long-term global effort. Today's focus on near-term emissions reductions will be counter-productive if it delays development of the institutions and policy architectures that would be necessary to mount and sustain such an effort over much of the next century.

What Do We Know About Global Warming?

Global warming or cooling can be driven by an imbalance between the energy the Earth receives from the sun, largely as visible light, and the energy it radiates back to space as invisible infrared light. The "greenhouse effect" is caused by the presence in the air of gases and clouds that absorb some of the infrared light flowing upward and radiate it back downward. This warming effect is opposed by substances at the surface and in the atmosphere that reflect sunlight directly back into space. These include snow and desert sand, as well as clouds and aerosols from smog and volcanic action. (Aerosols are very tiny, submicroscopic solid or liquid particles suspended in the air. Smoke and fog are familiar examples.)

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The most important greenhouse gas is water vapor, which typically remains for a week or so in the atmosphere. Central to the climate change debate, however, are less important but much longer-lived greenhouse gases, most notably CO_2. Concern arises because the atmospheric concentrations of CO_2 and other long-lived greenhouse gases have increased substantially over the past century. When this happens, the flow of infrared energy to space is reduced, so that, *all else equal*, the Earth receives slightly more energy than it radiates to space. This imbalance, which is often called "radiative forcing," tends to raise temperatures at the Earth's surface. These aspects of the greenhouse effect are not controversial. It is also generally accepted that emissions of CO_2 from combustion of fossil fuels (primarily coal, oil, and natural gas) are the most important way humans can affect radiative forcing, and that this emitted CO_2 remains in the atmosphere for a long time, on the order of a century or so. Thus today's radiative forcing reflects, in small part, the CO_2 emitted when coal was burned to keep President William McKinley warm in the White House.

What is much more uncertain, and the cause of serious scientific debate, is the response to radiative forcing of the complex system that determines our climate. "Climate" is usefully defined as the average of the weather we experience over a ten- or twenty-year time period. In this context, it is important to emphasize that year-to-year changes in weather patterns or storm tracks should not be, but often are, confused with climate change. Some poorly understood processes in the climate system tend to amplify the warming effect of radiative forcing, while others, equally poorly understood, tend to counteract or delay that effect.

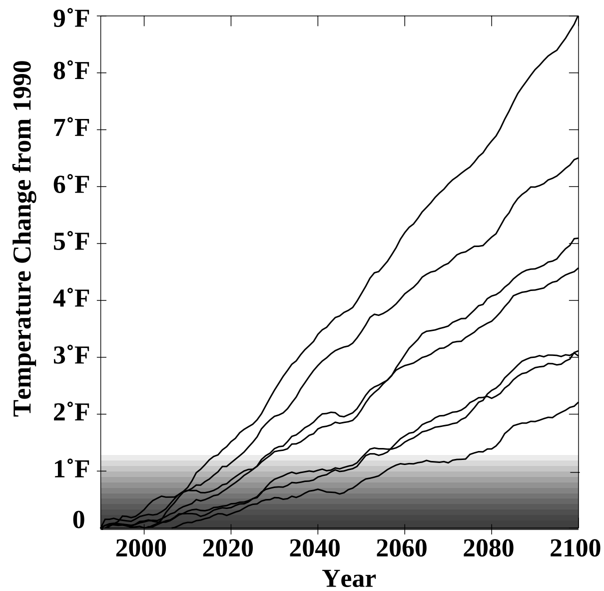
To take a familiar example, clouds in the daytime provide a cooling mechanism by reflecting sunlight back to space. But abundant clouds and high humidity at night help keep temperatures high because they contribute to the greenhouse effect. This is why on clear, cloud-free nights we can get rapid lowering of temperatures by tens of degrees Fahrenheit. Unfortunately, the processes that drive long-term changes in daytime and nighttime humidity and cloud cover are not well understood. Similarly, we know that any global warming will tend to be delayed because it takes a lot of heat to warm the oceans, but we're quite uncertain exactly how rapidly heat is carried into the deeper parts of the ocean.

Computer models used to predict climate attempt to simulate these and many other important processes on regional and global scales. These models are remarkable in their complexity and are invaluable tools for scientific research. However, their complexity taxes the capabilities of the world's largest computers. Moreover, they are based on incomplete knowledge about the key processes that control clouds, the ocean circulation, the natural cycles of greenhouse gases, and natural (volcanic) and manmade (smog) aerosols. Current climate models cannot reproduce the succession of ice ages and warm periods over the last 250,000 years, let alone the smaller climatic changes observed over the last century. In addition, climate models are driven by forecasts of emissions of greenhouse gases, and these rest on highly uncertain long-term forecasts of population and economic growth and of technological advance.

To help quantify the uncertainty in climate forecasts, a group of scientists and economists at MIT (including the authors) have recently developed a coupled model of global economic development, climate processes, and ecosystems. This model is unique in its combination of detailed treatments of the relevant natural and economic processes. Within this model, the researchers have explored the consequences of a range of plausible assumptions about future economic development (assuming no regulations are enacted to restrict future greenhouse gas emissions) and about fundamental climate processes, to produce a family of seven forecasts of climate change over the next century. Each forecast in the family can be defended as reasonable given current knowledge.

To illustrate the range of uncertainty involved in climate forecasts, the first figure shows the predictions for the change in global average surface temperature from its 1990 value. Temperature increases by the year 2100 as small as two degrees Fahrenheit or as large as nine degrees Fahrenheit can be defended as plausible. About two thirds of the overall difference here is due to uncertainty about climate processes; the other third reflects uncertainty about emissions. Despite a great deal of research, we simply do not know which of these paths (or indeed other plausible paths) we are now on. Indeed, there may be rapid climate changes driven by purely natural processes that are not well handled by any current climate models and are not reflected in any of the forecasts shown here.

Sample Forecasts of Future Temperature Change



Unfortunately, we know less about the likely impacts of plausible changes in climate than about either future emissions or the natural processes determining climate. Warming may increase storm damage, for instance, but it may also decrease it. Almost nothing is known about likely (as opposed to possible) impacts on human health or about the ability of unmanaged ecosystems to adapt to climate change. Civilization has adapted to climate change in the past and can, to at least some degree, adapt to future changes. What we do know suggests that the changes summarized by the lowest path in the figure would do little harm over the next century and might even be beneficial on balance for some countries. Most analysts would agree, however, that the highest path would correspond to significant risks to a variety of important natural processes (including ocean circulation, polar glaciers, and unmanaged ecosystems) as well as to agriculture and other human activity.

In some respects the most important finding of climate research is that the range of possible outcomes is enormous. We believe it is impossible to make sound policy decisions in this field without taking explicit account of this profound uncertainty. In addition, it is plainly vital to continue research aimed at improving emissions forecasts, climate models, and impact estimates in order to narrow the range of plausible forecasts. An important component of this work is the search for a so-called “fingerprint” that would reveal human influence on the climate system.

Has Human-Induced Warming Begun?

Last year, the Intergovernmental Panel on Climate Change (IPCC) declared in its *Summary for Policymakers* that “the balance of evidence suggests a discernible human influence on climate.” There were some qualifications and hedging in the *Summary* and much more in the detailed

Working Group Report upon which it was based. Nevertheless this statement, largely in isolation, was widely reported and has since shaped policy discussions around the world. But was this isolated, unqualified summary statement, written by governments' representatives, a scientifically defensible conclusion?

To establish a human influence on the global climate, we would ideally want to show that the observed global patterns of climate change over the past 100 years, say, are consistent with those predicted by climate models which include human activities such as production of CO_2 and aerosols from fossil fuels, but are not consistent with the patterns predicted when those activities are omitted. The latter predictions would reflect the natural variability of climate—the "noise" out of which the human "signal" (or "fingerprint") must arise for a definitive detection. Unfortunately, current climate models are both uncertain predictors of the climate response to human influences and inadequate tools for assessing natural variability. In addition, data on the global climate and human influences in past decades, and our understanding of the cooling effects of manmade aerosols, are far from ideal.

For these and other reasons, some scientists have been skeptical about the IPCC's "balance of evidence" statement from the beginning. This group has grown substantially over time. Even some scientists who were significantly involved in producing the IPCC statement are now publicly expressing doubts. In an important news report on this subject in the journal *Science* in May 1997, Richard A. Kerr describes the growing skepticism about the original IPCC *Summary* conclusion, and the growing realization that it may be a decade or more before the human effects can be discerned above the noise of natural climate variability.

This does not mean that we should wait to take action until and unless human effects on climate are definitively detected. As the discussion above indicates, we know enough to know that significant global warming, with significant adverse impacts, may occur in the future. It would be irresponsible to ignore such a risk, just as it would be irresponsible to do nothing when you smell smoke at home until and unless you see flames. It would also be irresponsible, of course, to call the fire department and hose down all your belongings at the slightest whiff of what might be smoke.

Nevertheless, the search for a definitive detection of human-induced climate change can provide valuable information for the policy process. The figure above provides a simplified illustration of the point involved. The shaded region at the bottom represents a plausible estimate of the range of natural variability or noise in global mean temperature over the course of a century. As the figure shows, the greater the eventual warming, the sooner observed temperatures will rise above this range, and the signal of a human influence will emerge from this noise. (This conclusion holds whatever the noise level; higher noise levels simply imply later detection, all else equal.) The larger the human effects on climate, the sooner it should be possible to find definitive evidence of those effects, and the stronger will likely be the case for substantial emissions reductions.

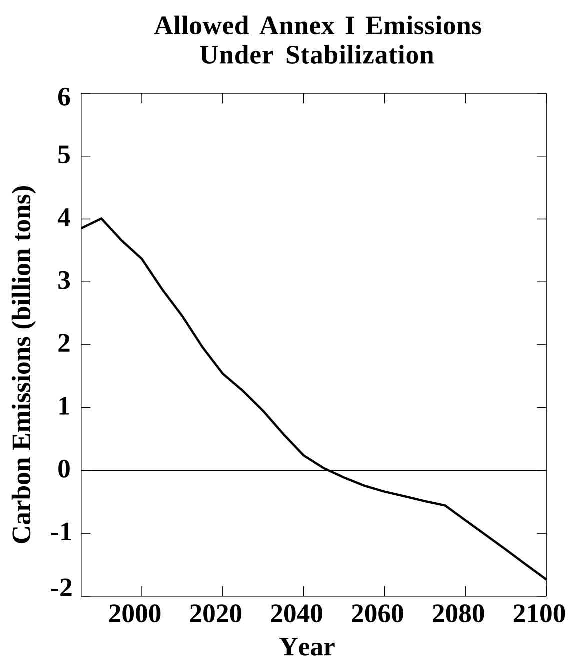
Should Global Warming Be Stopped?

If climate change turns out to be a serious problem, the sorts of emissions reductions being fiercely debated in the run-up to the Kyoto meeting will not *by themselves* do much to solve it. Under the Berlin Mandate, emission reductions are to be sought only from countries listed in Annex I to the original climate treaty: the members of the Organization for Economic Cooperation and Development (OECD) as of 1990 (Western Europe, the United States, Canada, Australia, New Zealand, and Japan) and the "economies in transition" (Eastern Europe and most of the Former Soviet Union). To illustrate the effects of restrictions limited to these nations, let us consider one of the toughest proposals now on the table: the call by the European Union (EU) to cut Annex I CO_2 emissions to 15% below 1990 levels by 2010.

When measured not in relation to 1990 but against emissions today or those expected in another 13 years, this proposal would require much more than a than a 15% reduction in most countries. There is little doubt that such sharp cuts in CO_2 emissions over little more than a decade would be very expensive, even if economic growth were to slow from its pace in recent decades. It would be even harder for Annex I nations to maintain the proposed 2010 level of emissions for the rest of the next century. Yet, largely because of projected emissions growth in the developing world, the MIT climate model shows that such a costly effort by the Annex I countries would reduce projected warming in 2100 by only about 20 percent in the mid-range of the forecasts illustrated in the first figure. If climate change turns out to be a serious threat, this response, by itself, would be inadequate; if it turns out not to be a threat, this response would be a large-scale waste of resources.

A policy aimed at reducing near-term emissions may, if properly designed, be a valuable first step toward a more serious (and even more expensive) response strategy that could be used if we learn that human-induced warming is a serious threat. The Framework Convention on Climate Change calls for stabilizing atmospheric concentrations of greenhouse gases at levels that will avoid "danger" to economies and ecosystems. The European Union, among others, has recommended stabilizing the concentration of CO_2 in the atmosphere at 550 parts per million, which is roughly twice pre-industrial levels. Doing this would substantially slow (but not stop) climate change. Following the particular path to stabilization at this level that was estimated by the IPCC would lower the projected warming in 2100 in the mid-range forecast in the earlier figure by only about 30%, though it would have larger relative effects in the following century.

Following this EU recommendation would require sharp cuts in global CO_2 emissions, however, and the Annex I nations almost certainly could not do the job by themselves. We can illustrate the magnitude of the task using a mid-range forecast from the set shown in the first figure, along with the IPCC's estimate of a global emissions path that would lead to the 550 parts per million target. The second figure shows the maximum Annex I emissions consistent with this path, assuming that non-Annex I nations accept no restrictions. (To calculate the emissions allowed to Annex I countries, we simply subtracted the forecasted non-Annex I emissions from the global total.) Without participation by the developing world, emissions by Annex I nations would somehow



have to become negative around the middle of the next century! Even a total ban on all use of fossil fuels in all developed nations within a few decades would not do the job.

Of course, if the richer nations continue to reduce emissions over time some voluntary abatement by non-Annex I nations would probably occur. Over the coming decades, some non-Annex I nations will no doubt become wealthy enough to join the Annex I emissions reduction club voluntarily. But the countries most likely to do this account for only a small fraction of projected non-Annex I emissions. In China, India, Indonesia, Brazil, and other high-population, high-emissions countries, income growth seems unlikely to stimulate voluntary abatement much before the end of the next century. Until then, these nations will be more concerned with feeding themselves and their children than with protecting their grandchildren from potential global warming. Thus, if the rich countries want to stabilize greenhouse gas concentrations, they will have to pay poor countries to reduce their emissions. Rough estimates of the costs that would be involved, even assuming fully efficient abatement policies and neglecting costs of monitoring and enforcement, imply massive international transfers of wealth on a scale well beyond anything in recorded history.

What Should We Do Now?

There is little or no political support today for a long-term commitment to such a Herculean effort. Moreover, since climate change could turn out to be relatively harmless, making such a commitment now would make little economic sense. On the other hand, since climate change may also be a significant threat, it would make no more sense to do nothing. Unfortunately, there are no simple rules that can be relied upon to tell us what to do. We must consider costs and risks and take actions in the face of profound uncertainty about their consequences.

In such a setting, it is important not to lose the long-term perspective. Today's actions should aim to reduce the costs of massive global emissions reductions, in case advances in climate science show such reductions to be desirable. Investments in new technology and in the development of policy architectures and institutions are particularly attractive in this regard. While it is almost certainly too late to agree on investments of this sort before December's Kyoto meeting, that meeting is but one step in what will very likely be a long political and diplomatic process. Whatever else happens there, the participants will produce some sort of "Kyoto Mandate" to guide the next round of international negotiations. That Mandate should focus the process on investments with long-term benefits.

The potential value of investments in new technology is clear. It may well prove impossible to slow warming appreciably without condemning much of the world to poverty unless carbon-free energy sources become roughly competitive with conventional fossil sources. Further, a serious attempt to produce important new technological options would be cheap relative to the cost of controlling emissions resulting from the use of current technologies. The range of possible options is wide, stretching from solar electricity to the continued use of fossil fuels with capture and sequestration of the CO_2 their combustion produces.

Unfortunately, we know too little about what produces fundamental technical change. The available evidence points to the importance of marketplace incentives for private sector research and development and (with somewhat more controversy) to public expenditure on basic research and fundamental technologies. Politicians love to call for more research instead of more regulation, but we see only a tiny and diminishing commitment to the development of greenhouse-friendly technology by those countries most capable of performing it.

It is at least as important to begin the development of an institutional structure for managing global emissions agreements that can evolve easily over time. Such a structure must be able to adjust the stringency of abatement effort to the evolving science, giving incentives for national participation but accommodating failures along the way, and to provide compensation to induce participation by the developing world.

This is a tall order, and we do not pretend to know the best design. Some useful insight and perspective can be gained from the international trade regime developed under the General Agreement on Tariffs and Trade (GATT), now the World Trade Organization. This regime has grown and evolved over time, adding countries and goods along the way, peacefully resolving substantial conflicts in national economic interests, contributing importantly to global economic growth, and producing a stunning success by the standards of international affairs. But it has taken 50 years of hard work to do this!

In this connection, experimenting with national emission ceilings of the type that are the near-total focus of the Berlin Mandate process may be of long-term value. Naturally, one objective of such an effort is to make actual reductions in the quantities of greenhouse gases we would otherwise put into the atmosphere over the next decade or two. We do not belittle this motivation. But it should not be allowed to completely dominate the design of international agreements in this area. Such experiments will be of long-term value only to the extent that they facilitate development of sets of possible policy measures, a policy architecture if you will, that can, if necessary, contribute to effective and cost-efficient stabilization of greenhouse gas concentrations. This architecture would need to address all important sources and sinks of significant greenhouse gases, not just CO_2 produced from fossil fuels. Such a system would need to provide for reliable emissions monitoring and for some system of sanctions for those who violate their obligations. A host of other important issues must also be confronted.

For example, since global participation will be necessary if global emissions are to be reduced, it is important to structure any Annex I targets and timetables to facilitate the inclusion of non-Annex I countries. This involves, at a minimum, development of a regime to govern climate-related international wealth transfers. In this regard, the Berlin Mandate's exclusive focus on Annex I countries is a double-edged sword. On the one hand, unless the rich nations control their emissions first and support abatement by poor nations, the latter are unlikely even to slow their emissions growth. On the other hand, CO_2 emissions controls will raise the cost of producing energy-intensive goods in Annex I countries, tending to encourage the development of energy-intensive industries in non-Annex I nations. (This is sometimes referred to as "emissions leakage.") Once this has happened, non-Annex I nations will be more reluctant to take actions to curb the CO_2 emissions that have become a more important source of wealth. Attempts by the rich Annex I countries to use trade policies to slow the migration of energy-intensive industries to poorer nations may create major international tensions.

In order to minimize the global cost of CO_2 emissions reductions, the cheapest abatement opportunities should be exploited first. In principle, a regime involving emissions trading, like that used to control sulfur dioxide pollution in the U.S., could contribute substantial savings. But this approach, which has been advanced by the U.S. in the ongoing negotiations, runs into a problem if participation is restricted to Annex I countries. Trading can only work effectively among countries that have agreed to emissions caps. Without the participation of the developing countries, where most observers agree that many of the cheaper emissions reductions are to be found, the advantages of trading are drastically reduced.

Finally, agreeing to lower future emissions may increase incentives to develop energy-saving consumer devices, along with low-carbon energy sources. But commitments to modest, short-term emissions reductions may focus R&D efforts on small advances over current technologies. Credible commitments to substantial, long-term reductions may be necessary to stimulate the fundamental research necessary to produce needed breakthroughs in energy technology. Lack of adequate political support seems to rule out making such commitments now, however, and the inability of any government to bind its successors would limit the credibility of any long-term commitments that were made.

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Unless climate scientists discover soon that greenhouse warming is definitely not a threat, the struggle to devise a global response will occupy our children, along with their children and grandchildren. We have discussed three legacies that our generation could leave that would make this struggle easier: (1) an international climate agreement that could, if necessary, reduce greenhouse gas emissions substantially, at least cost, while being responsive both to changes in our scientific understanding and to evolving political and economic conditions, (2) enhanced technical options that could, if necessary, ease the task of maintaining economic growth while controlling greenhouse gas emissions, and (3) an international system that could, if necessary, transfer substantial sums to developing countries to assist their participation in an emissions control effort. Building these legacies is a huge challenge, but this task merits at least the same sense of urgency that has motivated pre-Kyoto negotiations about short-term CO_2 emissions reductions.