Global Climate Change: Facts, Projections, Policies
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Facts. Today's atmospheric carbon dioxide concentrations are higher than they were at any time in at least the past 400,000 years (see figure). They are about 30% higher than before the industrial revolution, and this increase is caused by human activities, primarily the burning of fossil fuels.

Carbon dioxide is a greenhouse gas, as are methane, nitrous oxide, a host of other trace gases, and, most importantly, water vapor. Greenhouse gases act like a blanket for infrared radiation, retaining radiative energy near the surface that would otherwise escape directly to space. An increase of atmospheric concentrations of carbon dioxide and of other greenhouse gases augments the natural greenhouse effect (primarily due to water vapor), increasing the radiative energy available to the Earth surface and to the lower atmosphere. Everything else being equal, doubling the atmospheric carbon dioxide concentration increases the radiative energy available to the surface and the lower atmosphere by about 4 Watts per square meter. This difference roughly corresponds to the difference between the radiative energy available today to that available during the coldest period of the last ice age. This we know.

Earth surface temperatures have increased by about 0.6˚C over the past century. The temperature increase has been particularly pronounced in the past 20 years. The scientific consensus about the cause of the recent warming was summarized by the Intergovernmental Panel on Climate Change (IPCC) in 2001: “There is new and stronger evidence that most of the warming of the last 50 years is attributable to human activities. … Changes in natural forcing [e.g., variability in solar luminosity] during most of this period are estimated to be negative and are unlikely to explain the warming.”

Projections. The burning of fossil fuels and other human activities such as tropical deforestation will lead to a continued increase of atmospheric concentrations of carbon dioxide and of other greenhouse gases. The projected consequences of the increased concentrations of greenhouse gases have been widely publicized. Global average surface temperatures are projected to increase by 1.4 to 5.8˚C by the year 2100, with the uncertainty range reflecting scientific uncertainties (primarily about the role of clouds in the radiation budget of a changed Earth climate) as well as socio-economic uncertainties (primarily about the rate of emission of greenhouse gases over the 21st century). Land areas are projected to warm faster than ocean areas. The risk of summer droughts in mid-continental regions is likely to increase. Hurricanes are likely to become more intense. Sea level is projected to rise, both by thermal expansion of the warming oceans and by melting of land ice.

The figure shows that the climate of the past 10,000 years, the Holocene, was very stable, which allowed humans to abandon a nomadic lifestyle, to settle, and to evolve civilizations as we know them. The climatic stability of the Holocene is exceptional in at least the past 400,000 years. The climate of preceding epochs is characterized by frequent abrupt climate changes, during which temperatures at least in some regions changed by several degrees within decades. We do not fully understand the instability of the past climate or the stability of the present climate, which raises the possibility that our current uncontrolled experiment with the climate system could lead to abrupt and unexpected climate changes. Nevertheless, attention-grabbing as

apocalyptic scenarios may be, their probability of occurrence at least in the next century is considered small, albeit not zero.

Less widely publicized but important for policy considerations are projected very long-term climate changes, of which some already now are unavoidable. Even if we were able to keep the atmospheric greenhouse gas concentration fixed at its present level — this would require an immediate and unrealistic reduction in emissions by about 60–80% — the Earth surface would likely warm by another 0.5–1.5°C over the next centuries. The oceans with their large thermal and dynamic inertia provide a buffer that delays the response of the surface climate to changes in greenhouse gas concentrations. The oceans will continue to warm over about 500 years. Their waters will expand as they warm, causing sea level rise. The melting of ice sheets and its contribution to sea level rise is similarly delayed. Studies of climate change abatement policies typically end in the year 2100 and thus do not take into account that most of the sea level rise due to the emission of greenhouse gases in the next 100 years will occur decades and centuries later. Sea level is projected to rise 0.2–0.8 meters by the year 2100, but it may eventually reach values up to several meters higher than today. (A sea level rise of 4 meters would submerge much of southern Florida.)

Policies. Virtually all countries now consider global climate change one of the most important environmental problems and are signatories to the United Nations Framework Convention on Climate Change (1992), which calls for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." However, what level constitutes dangerous interference is unclear, and it is unclear what kind of policies are best suited to achieve a stabilization of greenhouse gas concentrations. Since almost all activities of daily life entail greenhouse gas emissions, which will affect climate for centuries, well beyond the timescales of memory and accountability of political institutions, devising climate change abatement strategies is a formidable challenge.

There is general agreement that policies based on market instruments are more effective than command-and-control policies, which are difficult to enforce because of the weakness of international law. Using market instruments to achieve emission reductions means assigning concrete costs to emissions of greenhouse gases by, for example, creating tradable allowances to emit a certain amount of carbon dioxide. In devising effective market instruments, the point is to strike a balance between the risks of climate change and the risk of excessively costly emission reductions.

Over the past three decades, economists have developed strategies for decision making under uncertainty. In the face of irreversible consequences, such as climate change, it is advantageous to adopt approaches that reduce the risk of the irreversible consequences by adapting sequentially as new information becomes available. For climate change abatement, a sequential decision making approach (or, in the parlance of engineers, a 'dynamic control approach') means to implement policies that lead early to a, perhaps modest, reduction of greenhouse gas emissions and to adapt as we obtain more information about the climate system and as we gain experience about the effectiveness of the policies. Early reductions in emissions would leave future generations with a wider range of achievable stabilized greenhouse gas concentrations and lead to immediate ancillary benefits, such as cleaner air and a reduction of our dependence on foreign oil. Market incentives for reductions of greenhouse gas emissions would spur innovation of low-emission technologies and would also allow the institutions that

are necessary to guarantee a fair global market for tradable emission allowances to grow and evolve gradually.

The Kyoto Protocol (1997) to the Framework Convention on Climate Change is a first step toward achieving modest emission reductions. It specifies binding emission targets according to which, by the period 2008–2012, industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990. The national emission targets for Europe and the U.S. are 8% and 7%. In a limited trading system, countries that do not meet their targets by emission reductions can purchase surplus emission allowances from industrialized countries that reduce their emissions more than they are required. The Protocol also provides additional mechanisms through which industrialized countries can receive credit toward greenhouse gas emissions, for example, by promoting emission reductions in developing countries.

The Kyoto Protocol was immediately criticized for a number of shortcomings that made its ratification by the U.S. Congress unlikely. For example, developing countries are exempt from the binding targets of the Kyoto Protocol, reflecting the international consensus that industrialized countries should take the lead in reducing greenhouse gas emissions because most of the greenhouse gas emissions that have accumulated in the atmosphere so far are from industrialized countries and per capita emissions in the industrialized countries far exceed those in developing countries. In 1997, the U.S. Senate voted 95–0 for a resolution against the U.S. ratifying any treaty that exempts developing countries, arguing that their emissions may exceed those of the industrialized countries by the year 2015. More fundamentally, economists criticized the cap-and-trade mechanism of the Kyoto Protocol because it set ad hoc emission caps. The emission caps entailed a risk that the emission reductions may become excessively costly for countries such as the U.S., which experienced significant economic growth accompanied by increases of greenhouse gas emissions in the 1990s, after the baseline year for the Kyoto emission targets. Many economists prefer more flexible trading systems, which might, for example, cap the prices of emission allowances, rather than their quantities, thus reducing the uncertainty about the costs of emission reductions.

The Kyoto protocol can only be understood as a small first step toward addressing the problems of climate change. It is clear that its terms and likely even its fundamental policy instruments will need to be renegotiated, for example, when the emissions from countries such as China, which is currently exempt from the binding Kyoto targets, increase.

Enter George W. Bush. In his election campaign in 2000, President Bush promised to "establish mandatory reduction targets" for carbon dioxide, contrasting his pledge with that of Vice President Gore, who was advocating only voluntary reductions. In March 2001, writing in a letter to Republican Senators, Bush stated that he opposes the Kyoto Protocol and, reversing his position, that he does not believe "the government should impose on power plants [which produce about 40% of the U.S. carbon dioxide emissions] mandatory emissions reductions for carbon dioxide." Referring to a Department of Energy study that predicted increased electricity prices and shifts from coal use to natural gas use in power plants if carbon dioxide emission caps were introduced, he reasoned that, "At a time when California has already experienced energy shortages, and other Western states are worried about price and availability of energy this summer, we must be very careful not to take actions that could harm consumers. This is especially true given the incomplete state of scientific knowledge of the causes of, and solutions to, global climate change."

Citizens in the U.S. and foreign governments were angered and the Environmental Protection Agency Administrator Whitman, who just days before, according to a memo published in the New York Times last week, had urged the Administration "that global warming is an issue that must be addressed," was publicly embarrassed for her support of Bush's campaign pledge. March 2001 newspaper headlines called it "Bush's foolish flip-flop" (Denver Post) and the "Global flip-flop" (Boston Globe).

The California energy crisis soon disappeared as a justification for abandoning strategies to reduce greenhouse house gas emissions, if it ever did provide a justification. After all, no one on either side had suggested sudden changes in energy supply or pricing. Bush's comment about the "incomplete state of scientific knowledge" — despite the comprehensive IPCC report published earlier — led to public outcry, and so he commissioned the National Academy of Sciences (NAS) to evaluate the state of scientific knowledge about climate change.

The NAS report was published in June 2001 and reaffirmed the conclusions of the IPCC report. The NAS report began: "Greenhouse gases are accumulating in the Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed in the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability."

This left the Bush Administration unable legitimately to justify a wait-and-see approach to global climate change based on scientific uncertainty. Scientific uncertainties point toward early action to hedge our bets about climate change, for the risk of climate change having an adverse effect on the well-being of at least part of the world's population is clearly greater than zero. Adopting a wait-and-see approach posits certainty that future generations will be able to cope with climate change where, in fact, uncertainty about the extent of expected climate changes prevails.

But the NAS report did not sway the Bush Administration. The Administration has rejected the Kyoto Protocol but has not proposed an alternative. In 2002, Bush proposed to reduce the greenhouse gas intensity (ratio of greenhouse gas emission per unit economic output) by 18% by the year 2012, which would allow U.S. greenhouse gas emissions to grow by about 12% over 2002 levels or 30% over 1990 levels. This is a very modest goal at best. It would represent a slight improvement over the Administration's business-as-usual projections, but the intensity reduction merely continues long-term trends: according to Department of Energy data, the U.S. greenhouse gas intensity decreased by 21.4% (or by an average of 2% per year) between 1990 and 2002, in part because of the declining share in economic output of the emission-intensive manufacturing sector. The planned additional reduction is to be achieved by voluntary measures; no mechanism was established for ensuring that the target will be met.

When Science Magazine asked President Bush and Senator Kerry this summer to answer questions about their views on science, Bush selectively quoted from the NAS report from June 2001 to emphasize uncertainties about the science of climate change. In answer to the questions, "Is human activity increasing global temperatures? If so, should the United States set specific goals with respect to limiting or reducing greenhouse gas emissions by the end of the decade?", Bush wrote that "key uncertainties remain concerning the underlying causes and nature of climate change." To bolster his case, he quoted from the NAS report: "Because there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude of future warming should be regarded as tentative and subject to future adjustments upward or

downward. … Because of the large and still uncertain level of natural variability inherent in the climate record and the uncertainties in the time histories of the various forcing agents (and particularly aerosols), a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate changes during the 20th century cannot be unequivocally established." The selective quotation omits passages warning of the risks of climate change. For example, the sentence in the NAS report immediately preceding the sentence above quoted by Bush reads, "National policy decisions made now and in the longer-term future will influence the damage suffered by vulnerable human populations and ecosystems later in this century." In context, it is clear that the NAS wishes to convey that global climate change poses significant risks, uncertainties about the magnitude of future climate changes notwithstanding.

In the Science questionnaire, Bush went on to describe the goal to reduce greenhouse gas intensity and various climate change science and technology programs. He did not provide a response to Science's question whether he is in favor of a cap-and-trade program for greenhouse gas emissions.

In response to the same questions, Kerry provided few details. "The scientific evidence is clear that global warming is already happening and rising levels of global warming pollution are making the problem worse. … President Bush rejected the Kyoto Protocol, stubbornly walking away from the negotiating table altogether and eroding our relations with global allies. John Edwards and I will take the United States back to the negotiating table. … As [we] work to rejoin the international community on global warming, we will work at home to take concrete steps to reduce greenhouse gas emissions. … John Edwards and I support a similar approach [to cap-and-trade systems] to global warming, setting concrete limits to reverse the growth in global warming pollution but letting industry find the best path for getting there." One would like to see a more concrete proposal.

Devising global warming policies is a challenge that requires courageous leadership and a willingness to confront both the socio-economic and the scientific risks and uncertainties, without positing certainty about either costs of emission reductions or risks of climate change where uncertainty reigns.

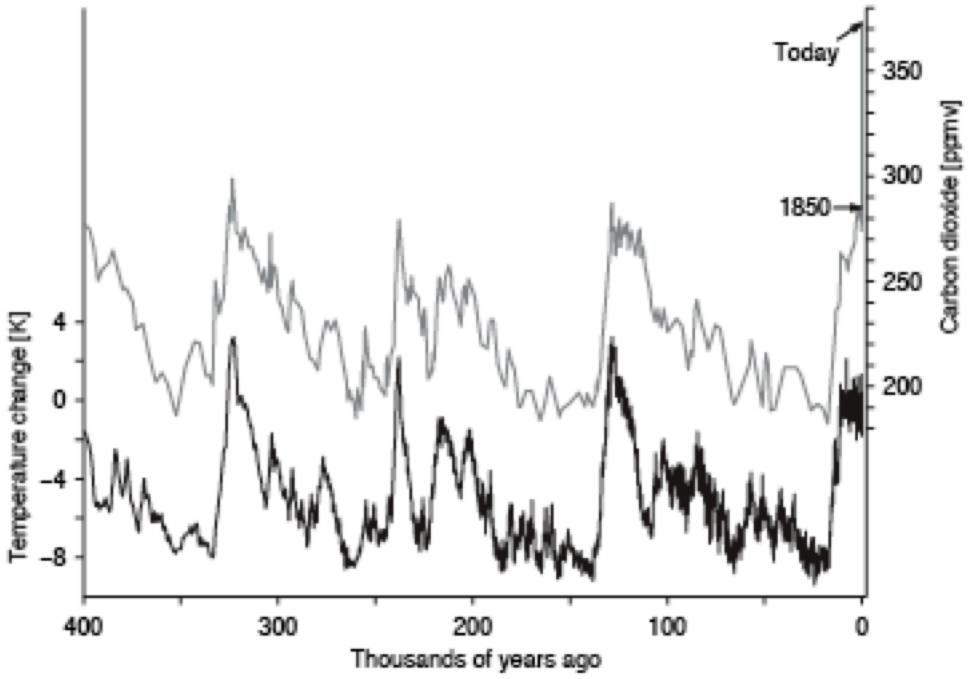

Figure caption: Temperature variations (black line, left axis) and carbon dioxide concentrations (gray line, right axis) inferred from Antarctic ice cores. The 100,000-yr ice age cycle is clearly recognizable. Carbon dioxide concentrations today are higher than they were at any time in at least the past 400,000 years. [Data from Etheridge et al. 1998, Petit et al. 1999, and Keeling and Whorf 2004.]