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Just Another Environmental Problem?

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Our scientific understanding of climate change, its causes, and its consequences for individuals, societies, and the world around us is becoming clearer with every year of research. As a result, the debate surrounding global warming and what to do about it has intensified over the past year or two, and a very wide range of opinions, as is typical where contentious issues are concerned, has been highlighted. Is climate change just another in a string of environmental challenges that have confronted contemporary societies, to be readily overcome by continued economic growth and clever technologies? Or is it the most serious threat ever to face humanity, one that will require fundamental changes in the values that underpin modern civilization if we are to avoid the risk of global collapse and descent into chaos and misery? Perhaps a look at the past can inform the debate.

Humans have coped, for better or for worse, with a wide range of environmental problems in the past, but to make use of insights from these experiences, we must first describe some of the characteristics of climate change that make it the unique and very controversial problem that it is.

The first point to note is that climate is not the same as weather. As one of my colleagues astutely commented: "Climate is what you expect; weather is what you get." Climate has to do with long-term averages and repeatable patterns, whereas weather varies enormously day to day. One never goes to a newspaper or the television for a climate forecast (although perhaps that will become common in the future), but we certainly pay close attention to weather forecasts. We have all grown up to expect a certain regularity—the changing of the seasons, the vagaries of rainfall and storms, and the ebbing and flowing of rivers—in the climatic environment around us. For some people it is virtually impossible to conceive of the possibility that mere mortals could influence something as vast and immutable as the earth's climate. Yet that is precisely what is happening.

The much longer timescale of climate compared to weather is part of the problem. It is hard to experience—hard to *feel*—a change in climate in one lifetime. Climate has certainly changed naturally in the past, and will continue to do so in the future, but in general such changes operate on geological timescales and are imperceptible in the span of a life.

Another sort of troublesome timescale dilemma lies at the heart of the climate change problem: The long timescales associated with the planet's climate system present severe problems not only for human perception but also for decision making. For example, largely because of the huge thermal inertia in the ocean, the momentum in the climate system means that we cannot stop the upward trend in global temperature for several decades even if we vigorously reduce greenhouse gas emissions during this period. We are committed to at least another 0.5°C of temperature increase no matter what we do.

DAUNTING DILEMMAS

So this presents a formidable policy dilemma. We will see absolutely no evidence for 30 or 40 years of the benefits of the difficult and probably painful policy decisions we make now or in the near future. What government of today would make such decisions, knowing that it will not be around when the benefits start to accrue? What citizenry is sophisticated and far-sighted enough not to punish at the polls a government that imposes deep cuts in greenhouse gas emissions in ways that might raise the price of fuel oil or limit economic growth today?

The nature of climate change also raises serious equity issues. Existing inequalities generated by forces such as colonialism and resource imbalances

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are being exacerbated by climate change. Because carbon dioxide is a nonreactive gas and has a long lifetime in the atmosphere, emissions generated by our forebears in the industrialized world continue to influence the climate today and will do so into the future. Although there is much concern today about future emissions from China and India, past emissions patterns and the long lifetime of CO_2 mean that, for decades into the future, the United States will remain by far the biggest single driver of climate change. Yet the impact of global warming will be felt disproportionately by poor people in the developing world.

When viewed on a per capita basis, such inequalities become even more pronounced. My own country, Australia, has one of the highest per capita rates of greenhouse gas emissions, along with the United States and Canada. Yet, because we have a population of only 20 million people, our aggregate emissions account for slightly less than 2 percent of the global total. Some of my countrymen use these numbers to argue that Australia need not do anything to reduce emissions, because our actions will not have a measurable effect on the global climate. But when national aggregates are reduced to the level of individuals, and when human rights are considered, the picture looks very different. Does an Australian citizen have more right to use the atmosphere as a dumping ground for the effluents of energy use than a Chinese citizen has?

Several features of the climate system—thresholds, nonlinear impacts, abrupt changes, and so on—bedevil humanity's attempts to deal with global warming. Take the North Atlantic region as an example. Ice core records show that the climate in that region has swung wildly and quickly in the past, with temperature changes of up to 10°C in just a decade. Such climatic shifts would certainly be noticeable in one human lifetime! The processes that lie behind such abrupt shifts (for example, the influx of freshwater into the North Atlantic Ocean) are becoming better understood, and they could indeed be triggered by contemporary, human-driven climate change if critical thresholds are crossed. Dramatic shifts of this sort remain low-probability but potentially very high-impact events. How can our current decision-making processes deal with such unlikely but potentially cataclysmic climatic changes?

Perhaps the ultimate climate catastrophe would be an irreversible shift in the earth's climate to another state, one much less amenable to human life on the planet. Does discussing this represent wild and irresponsible speculation, or could such a disaster actually occur? The earth has existed in very much warmer states in the past, and twice has virtually frozen over. Humans, of course, did not exist during those planetary environmental extremes, and would have had extraordinary difficulty in merely surviving them. Interestingly, the warm extremes were associated with very high concentrations of greenhouse gases in the atmosphere (as is the case with Venus, which has a surface temperature of hundreds of degrees).

Modern climate science is not yet up to the task of determining what climatic states might exist beyond the two that humans have experienced during our time on earth (ice ages and intervening warm periods), how conducive such states might be to human life, and whether human influence on climate could trigger a rapid shift to a significantly different planetary state. This is the ultimate risk that humanity faces in perturbing its own life support system, and it is one for which we have virtually no scientific information to inform debate. How should such a risk be factored into decision-making?

At its most fundamental level, the climate problem can be described as a clash between, on one hand, the centrality that fossil fuel–based energy systems have for economic growth and the continued development of contemporary civilization and, on the other hand, the centrality that a stable and amenable climate has for human well-being and societal viability. Which should have the higher priority—or can we find clever ways to balance a thriving global economy with a healthy global environment?

QUICK FIXES

The second half of the twentieth century saw an explosion of activity in the human enterprise. Population soared, the global economy grew even more rapidly, technological development accelerated sharply, communication and transportation linked people and societies around the world as never before, and the notion that individual consumption means progress spread like wildfire around the planet. Resource use also grew exponentially during this period, and this, along with decidedly non-green technologies, put unprecedented pressures on the environment. The last few decades of the twentieth century marked the beginning of the contemporary environmental movement, often associated with the publication of Rachel Carson's landmark book *Silent Spring*. What insights can we glean from the "Great Acceleration" of the twentieth century, and from the environmental campaigns, battles, and successes that it spawned?

Silent Spring focused attention on the deleterious effects of chemical pollutants in the biosphere. This was a serious problem, but it was confined to local or regional (rarely global) scales because many of these pollutants, such as DDT, do not have a long lifetime in the atmosphere. This meant that in many cases the solutions to chemical pollution could be developed within individual countries, which eased (but certainly did not eliminate) the jurisdictional and institutional issues that plague the climate change challenge. In addition, many of these chemical pollutants, although important for certain industries, were not central to contemporary economies. Alternative management strategies were devised and, eventually, less damaging chemicals were produced to greatly ease the chemical burden on the environment without a significant effect on economies.

The acid rain problem of the 1980s in eastern North America and Western Europe brought a new dimension to environmental issues. Sulphate aerosols (small particles) emitted into the atmosphere as a by-product of burning fossil fuels react with water droplets in the atmosphere to form sulphuric acid; when the acids fall in rain, they damage life in lakes and terrestrial ecosystems. Because sulphate aerosols have a lifetime of a week or two in the atmosphere, they can travel a thousand or so kilometers along with weather systems, meaning that pollution emitted in one country can cause environmental damage in another. That clearly complicated the political and institutional approaches to dealing with this form of pollution.

A techno-economic solution was found based on new technology that scrubbed smokestack effluent to remove sulphur compounds. The solution was driven by a cap-and-trade permit system that, at a minimal economic cost, greatly reduced the aggregate amount of sulphur that could be emitted.

However, no direct analogy exists between the acid rain problem and climate change. Sulphate is a minor combustion product from the burning of fossil fuels (carbon dioxide and water vapor are the major products), and it can be removed from the effluent at low cost. This is not the case for carbon dioxide. Also, because of the limited lifetime of sulphate aerosols in the atmosphere, the acid rain problem has not and will not become global, even as Asian nations industrialize rapidly.

Arguably the first truly global environmental problem was the ozone hole episode. It is often cited as an analog for climate change, with the implication that the successful resolution of the ozone hole problem provides a readily replicable model for the climate change problem. On the surface, this is an attractive analogy. Both problems are indeed global in scale, arising from millions of individual actions (emissions of gases) around the planet. Both are based on changes in the composition of the atmosphere. And in both cases, because of the mixing power of the atmosphere, the consequences of the problem do not correlate with its geographic sources—a characteristic that poses significant challenges to the institutional and political fabric of the international order.

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As it happens, the ozone hole problem is well on the way to being solved. Why? The reasons for ozone depletion over Antarctica in springtime became well understood scientifically and were eventually agreed on by all parties. The associated threat to human and ecosystem health was also clear and well understood. In addition, a consensus on an international protocol to rapidly cut and then eliminate emissions of the offending gases (CFCs—chlorofluorocarbons) was quickly reached. The agreement included provisions to meet the needs of developing countries. And implementation was rapid, in part because monitoring of emissions could be carried out easily.

A critical difference exists, however, between the ozone hole and climate change that makes this analogy far from perfect. The gases causing the hole in the ozone—CFCs—were used primarily as refrigerants and aerosol propellents. Although useful, these products are not central to the functioning of contemporary societies, in contrast to the generation of energy by the combustion of fossil fuels. Furthermore, the handful of chemical companies (less than 10) that manufactured CFCs quickly found substitute chemicals that had the beneficial characteristics of CFCs but were benign in terms of stratospheric chemistry. This produced a win-win situation. CFCs could be phased out quickly and virtually completely without any damage to economies or even to individual companies. Unfortunately, there is no such quick fix—or direct win-win pathway—for the rapid phasing-out of fossil fuel–based energy systems.

LUCKY ESCAPE

Much less known, meanwhile, are two fascinating aspects of the ozone hole story that may provide lessons for the climate change debate. First, the scientific detective story that first blew the whistle on the ozone hole threat was not as straightforward as it appears in retrospect. The British Antarctic Survey had been monitoring the level of stratospheric ozone since the mid-1950s, primarily to use as a baseline value for future comparisons because the level of stratospheric ozone over Antarctica was assumed to be the most stable on the planet. Around the mid-1970s, however, the measurements began to show a decrease in stratospheric ozone concentration. The British scientists discounted the measurements at first, assuming that the ozone level was stable and therefore something must have gone wrong with the instruments. A wide range of tests was performed on them. Nearly a decade passed before the scientists finally agreed that there was nothing wrong with the instruments and that, for some inexplicable reason, atmospheric ozone concentrations were indeed dropping quickly.

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It is rather common for scientists to discard "outliers" in an observation series, but this case shows that outliers can contain critical information and are discounted or discarded at considerable risk. Could a similar situation arise with climate change, especially as we obtain more measurements of extreme events and other outliers? For example, by some measures the destructiveness of hurricanes has risen sharply over the past few decades, much more rapidly than predicted by models. Are these observations a consequence of poor measurements, or are we really seeing a more deadly threat to tropical and sub-tropical coastlines?

The second, and even more frightening, aspect of the Antarctic ozone hole story is the saga of a global catastrophe that was quite fortunately avoided. As the name indicates, CFCs contain chlorine atoms; bromine, though, could easily have been used instead and would have produced a compound equally useful for the tasks for which CFCs were designed. Once up in the atmosphere, however, bromine atoms are about 100 times more reactive than chlorine atoms. Had bromine been used to make refrigerants and aerosol propellents, we would now be facing a stratospheric ozone hole not just over Antarctica but everywhere around the Earth, and at all seasons of the year, not just in the austral spring. We could not venture outside without wearing strong sunglasses and covering our skin at all times and in all seasons. The consequences for other forms of life are hard to imagine. It would have been a global environmental disaster of great magnitude.

That such a disaster was avoided was certainly not a result of foresight. The ozone-destroying properties of chlorine and bromine atoms were completely unknown at the time the decision to use chlorine was made. A more likely explanation for the choice is that an engineer or middle-level manager decided on a chlorine-containing compound because it was marginally cheaper or perhaps easier to obtain in sufficient quantities.

Lessons can be drawn from this episode. One concerns the nature of the "earth system" (a term increasingly used to describe the systemic nature of the global environment). As with any complex system, small changes can cause large and unexpected responses in the environment. Many of these strongly nonlinear impacts—that is, effects out of proportion to the causal agents—are virtually impossible to predict a priori. In terms of climate change, we are only now moving beyond consideration of direct effects, like heat waves and sea level rise, to explore possible abrupt or highly nonlinear impacts.

A second lesson is that the small changes that produce dramatic outcomes can be triggered by random or chance events. These include actions carried out by human agents that have no logical or predictable precursors yet can influence the course of history. A political assassination sparking a world war, or a stock market crash triggered by a few individuals' decision to sell off a large number of shares, are examples of such events in the non-environmental realm. The point is that even inadvertent actions could have catastrophic consequences for the global environment.

As the human enterprise grows in power vis-à-vis the rest of the natural world, such chance events, coupled with the nonlinear features of the earth system, could lead to some very surprising outcomes. The decision to use chlorine instead of bromine in the production of refrigerants and propellants was one such event. Had the decision gone the other way, it would be seen today as a turning point in the evolution of humans' relationship to the environment.

SAVED BY TECHNOLOGY?

The design and use of new technologies, with the phasing-out of CFCs as one example, have been an important strategy in solving many contemporary environmental problems. Can technology also solve the climate change challenge? The jury is still out, but there is little doubt that technology will be a central player in the search for an effective solution. However, the nature of the strategies by which technology might be deployed has been a subject of intense, sometimes vitriolic, debate in the research community. Two fundamental approaches toward deploying technology can be identified.

First, technologies can be used to reduce or eliminate the source of the environmental problem. The obvious example in the climate change area is the development and deployment of energy systems that are not based on fossil fuels—such as nuclear energy, solar and wind power, biologically produced liquid fuels, and so forth—or the removal and storage, in the ocean or in geological formations, of carbon dioxide from the effluent of fossil fuel–based energy systems. These strategies reduce the amount of carbon dioxide that is emitted into the atmosphere and therefore reduce the rate of climate change at its source. Controversies surrounding this technological approach are primarily associated with the other environmental impacts of various energy options and the economic cost of developing and deploying alternative systems.

The second approach is often termed "geo-engineering." Rather than trying to reduce the emissions of greenhouse gases, geo-engineering attempts to manipulate the functioning of the earth system itself to counteract the effects of a changing climate. Examples of geo-engineering solutions that have been proposed include the injection of sulphate aerosols, which cool the climate, into the stratosphere; the orbiting of giant mirrors around the earth to reflect some of the incoming solar radiation; and the iron fertilization of plankton in the ocean to stimulate growth and draw down carbon dioxide from the atmosphere. Such suggestions are highly controversial, in part because they employ simple cause-and-effect logic to attack a problem deeply embedded in a complex system. Like all complex systems, the earth's environment is subject to thresholds, abrupt changes, nonlinear effects, and irreversible changes, which could trigger unwanted and unanticipated consequences as damaging as climate change itself.

DEEP HISTORY

Proposals to use global-scale technology to geo-engineer the planet raise fundamental questions that go beyond unwanted side effects. Even the suggestion that we manipulate the earth's environment raises ethical concerns for a wide range of cultures and belief systems. It also brings analysis of past human-environment interactions squarely into the center of the research arena, a kind of analysis popularized in Jared Diamond's book *Collapse: How Societies Choose to Fail or Survive.*

Societies have faced serious environmental challenges in the past, often associated with natural climate variability. Intense drought or long dry periods are features of climate variability that have caused considerable stress to humans throughout our existence on the earth. Famous cases such as the collapse of the Akkadian empire in the Middle East some 4,000 years ago, or the disappearance of the classic Mayan civilization around A.D. 1000, are often used to illustrate how environmental change can drive societies into decline and collapse. However, other societies, when faced with similar environmental pressures, have responded with innovation and have transformed themselves into different and even more resilient societies. An example is the development of sophisticated irrigation systems by several Asian societies in response to a drying climate.

These examples and counterexamples focus less on the nature of environmental stress than on the nature of affected societies. Why do some societies adapt well to severe change, reinvent themselves, innovate, and thrive, while others are unable to cope and go into rapid and uncontrollable decline? Many ideas have been put forward by scholars to explain collapse or transformation; it is clear that issues involving institutional structures, complexity and resilience, and centralized systems versus distributed networks are all significant. What stands out as critically important, however, is whether societies are capable of questioning and rethinking the fundamental values and principles on which they are based and, if necessary, radically changing them to confront and overcome the challenges they are face.

What are the implications of all this for the increasingly globalized society of the twenty-first century? Will technological solutions solve the climate change problem, or is a more fundamental shift in societal values required? Although lessons from the past are useful, climate change presents a unique set of challenges. And, in the meantime, another critical feature of the environmental challenges facing twenty-first century society compounds the difficulty: Climate change is not the only global environmental problem. In addition to modifying the earth's climate, humans have transformed 50 percent of the land surface, appropriated more than half of all accessible freshwater, fully exploited or depleted most fisheries, and perturbed the earth's nitrogen cycle even more than the carbon cycle. We also are driving the sixth great extinction event in the earth's history.

The twenty-first century appears likely to mark a turning point in the evolution of humanity's relationship with the environment.

Considering climate change in the context of all the global environmental and socioeconomic changes that are occurring casts the "technological fix" solution in a different light. Focusing solely on climate change could well lead to approaches and technologies that would not address, or would even worsen, other global environmental problems. A thought experiment can illustrate the potential trap. Assume that we somehow develop a clean, affordable, inexhaustible, nonpolluting energy source but do not simultaneously consider the possible ramifications for the environment. Such a new energy source powering new technologies could well lead to the continuation, or even acceleration, of other environmental pressures such as the clearing of tropical rainforests, the over-exploitation of fisheries, the production of even more pesticides and other chemical pollutants, and the mixing of species and ecosystems through greater travel and transport.

In short, the twenty-first century appears likely to mark a turning point in the evolution of humanity's relationship with nature. Either we deal with each of a burgeoning number of environmental problems, one by one, using cause-and-effect logic, or we use more holistic, system-oriented approaches that will no doubt lead to a fundamental reanalysis of our role in the planetary environment.

SURVIVING THE ANTHROPOCENE

The demonstrable impact of human activities on the global-scale functioning of many of the earth's environmental processes—including climate—has prompted Paul Crutzen, the 1995 recipient of the Nobel Prize in chemistry, to argue that we have entered the Anthropocene, a new geological era. The advent of the Anthropocene challenges us to think about the types of knowledge required to deal with climate change and the scores of other environment-society problems confronting us.

Indeed, perhaps surprisingly to some, history and other disciplines that inform the present by examining the past are rapidly becoming central fields of endeavor—along with the natural sciences and engineering—in dealing with the Anthropocene and its consequences. Understanding how humans have interacted, for better or for worse, with the environment in the past will not offer direct analogies for climate change and other contemporary challenges. But it can provide critical insights into how we have conceived of our place in the rest of nature and how we have acted on these perceptions.

Above all, scholarship for the Anthropocene demands that we take a hard look at the very ways in which we generate knowledge. Western educational systems have, since medieval times, been based on a disciplinary approach, with a premium placed on ever more detailed understanding of ever narrower topics. In the natural sciences, this usually means taking pieces of a system out of the system and studying their behavior in isolation, using cause-and-effect logic. Perhaps this approach to knowledge generation is itself a problem, and is thus not likely to be part of the solution.

What we lack is a more integrated, holistic way of looking at how the complex world around us really works, and our role in it. Climate change may just be the issue that triggers a fundamental reexamination of our place in the natural world. Such a reexamination may determine how successfully we deal with the consequences of the Anthropocene. ■