What Makes Greenhouse Sense?

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We have had "global warming" for more than a decade—the hottest decade on record worldwide. Is this the "greenhouse effect" that scientists have been warning about, i.e., a response to increased carbon dioxide in the atmosphere, or is it some natural, rather than man-made, climatic change?

The Intergovernmental Panel on Climate Change (IPCC) has cautiously proposed a "discernible" human influence. The IPCC is a cautious body not disposed toward outright conclusions. Actually, most of the several climate models do not predict the sudden increases in temperature of recent years.

Something is going on. What does it tell us about the need to curtail, drastically, carbon emissions during the coming century?

The popular guessing game—do we see a greenhouse "signature," can we identify a clear "signal" in the "noise"—is probably premature. (The metaphor of "signal to noise" is inappropriate here: noise is random, while the problem here is that there are several competing "signals" to sort out.)

The history of climate shows that sudden changes of global atmospheric temperature have occurred. There are random or chaotic influences on global climate. "El Niño" is an example, volcanic emissions are another. There are human influences besides greenhouse gases: aerosols of dust and, especially, sulfur emissions can block incoming sunlight; urbanization can produce "heat islands" that affect local temperature estimates. Finally, most of the globe is ocean. Relative to air the specific heat of water is great and the oceans act as a huge cooling reservoir that delays by probably decades the arrival of atmospheric warming.

So the recent temperature record is unlikely to be conclusive on the cause of the warming. Greenhouse warming is not clearly established by the temperature record, nor is it in any way ruled out. We may see the greenhouse "signal" clearly in another decade or two. Meanwhile we have to rely on what science can tell us.

There are a few indisputable facts about the "greenhouse" phenomenon. One, well understood for more than a century, is that a high density of greenhouse gases, as on Venus, can cause surface temperatures many times the boiling point of water, while the absence of such gases, as on Mars, makes surface temperatures too low for water to exist in liquid form. (Distance from the sun makes a difference but cannot account for the gross disparity.) Earth is unique in our solar system for its temperature range, and greenhouse gases are responsible.

Another well understood fact is that carbon dioxide molecules absorb infra-red radiation. This is easily measured in the laboratory. Carbon dioxide is transparent to incoming sunlight. But as the earth, warmed by daylight sun, radiates energy back into space it does so in the infra-red part of the electromagnetic spectrum, and the carbon dioxide in the air absorbs some of the

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energy and gets warm. (Citrus growers in California and Florida use smudge pots—ceramic tubes of burning crude oil—to produce on a clear still night a blanket of carbon dioxide that captures some of the heat radiating from the ground and keeps the fruit from freezing.)

Carbon dioxide is only one of several gases that have that property. The most important one is water vapor, and part of the estimated enhancement of temperature is the positive feedback of warming on absolute global humidity.

(Incidentally, actual greenhouses do not produce the "greenhouse effect." Rather, they mainly trap the air that is warmed by contact with the ground that is warmed by the sun. We should have called it the "smudge pot effect.")

I find the case for prospective greenhouse warming to be convincing. In large part the uncertainties are not about whether greenhouse warming is going to be real, but about the magnitude and speed of warming and about the variegated climatic effects—not just "warming," but all the changes in precipitation, humidity, sunlight and clouds, storms, and variations between night and day, summer and winter, polar regions and tropical, mountains and plains, and east and west coasts.

In the two major unspecialized scientific journals, *Science* and *Nature*, one has to go back a decade or two to find serious doubts about the basic science. Rarely is there such scientific consensus as there is on whether the greenhouse effect is real, even though it can not yet be uncontrovertibly detected in the recent climate record.

But the uncertainties are daunting. The best the IPCC can do—apparently the best anyone can do—is to give us a range of possible warming for any given increase in carbon dioxide. And the upper bound of that estimated range has been, for over twenty-five years, three times the lower bound!—an enormous range of uncertainty.

On top of that are the uncertainties of what the changes in temperature will do to climates around the world, what those climate changes may do to the worlds we live in, and what peoples in different climates can do to adapt successfully.

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As a policy issue this is a new subject. Just as nuclear weapons required an unprecedented reorientation of military thinking, a reorientation that took some decades, and modern terrorism has recently required a reorientation of homeland security thinking, a reorientation that is barely begun, the prospect of possible changes in climate greater than any that have occurred in the past 10,000 years has had only a decade or two to generate ideas on how to cope with this ineluctably global problem.

I will illustrate from personal experience. In the 1970s, during what was called the "energy crisis," I was a member of two panels, each consisting of twenty experts from economics, petroleum engineering, nuclear engineering, public health, international relations, environmental science, and other pertinent disciplines. One panel had to do with the likely future of nuclear energy and the other was concerned with the future of energy policy in the United States. The

first published a book, *Nuclear Power: Issues and Choices* in 1977,[1] the second, *Energy: The Next Twenty Years* in 1979.[2] What could have been more pertinent to nuclear issues than the evident fact that nuclear fission produces no carbon dioxide? And what turned out to dominate energy and environmental disputes before the next twenty years had passed? And what did these two careful studies have to say about global warming? The nuclear book, out of 400 pages, had two pages on carbon dioxide. The 600-page book oriented toward the coming two decades had ten scattered references amounting to less than ten pages.

Thinking about warming and climate had not begun among "experts" concerned with energy policy nor had it yet attracted concerted attention among scientists in the several pertinent field of atmospheric chemistry and physics, meteorology, oceanography, agronomy, marine biology, glaciology, ecology, or paleoclimatology.

By 1992 the largest intergovernmental conference ever assembled, with heads of state from more than a hundred nations (including the United States), was focused on global environmental issues, with climate change at the center. In Rio de Janeiro the conference produced the "Framework Convention on Climate Change," promptly ratified by the United States.

Five years later, in Kyoto, a "protocol" to the Rio treaty was drafted (and signed by the United States), requiring very substantial reductions in CO_2 emissions for the developed countries over the next dozen years. It finally went into effect in February 2005, having been ratified as required by nations accounting for fifty-five percent of total world emissions of carbon dioxide. The Clinton administration let the Kyoto document languish for three years, and President Bush declared it unsuitable shortly after his inauguration. Russian ratification, which tipped the fifty-five percent threshold, was widely viewed as opportunistic, as the Russian economy's slump from 1990, the baseline from which reductions were to be measured, had made it likely that Russia would not need to restrict emissions and might even sell excess emission rights—dubbed "hot air" by commentators—to participating nations that could partially fulfill their obligations by such purchases.

While the Bush dismissal of "Kyoto" sounded harsh and unfriendly, compliance with what had been assented to in 1997 was almost certainly infeasible by 2001, nothing having been done to identify what policies, including new legislation, might be required to meet the U.S. obligation. Whether Kyoto will turn out to be a "first step" in an international effort to cope with climate change remains unclear.

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While the uncertainties about the magnitude of likely climate changes and their impact need not preclude precautionary steps to anticipate and to cope, they

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1. NUCLEAR ENERGY POLICY STUDY GROUP, NUCLEAR POWER: ISSUES AND CHOICES (1977).

2. HANS H. LANDSBERG, ENERGY: THE NEXT TWENTY YEARS (1979) (report by a study group sponsored by the Ford Foundation and administered by Resources for the Future).

certainly preclude any definitive regime of obligatory limits on national emissions of carbon dioxide (and other greenhouse gases) for some decades to come. Ultimately what matters is not any annual emissions rate but what the limit should be on the concentration of greenhouse gases in the atmosphere, i.e. on the cumulative emissions over all the decades to come minus what gets permanently absorbed in the oceans or somewhere else.

As mentioned earlier, the average temperature change for any given concentration is uncertain by at least a factor of three, i.e., the upper estimate is at least three times the lower ("at least" because those estimates are not absolute bounds.) So even if we knew what the limit should be on the change in average global temperature, which we do not, we would still be wide by a factor of three. And how much of the emitted CO_2 will be absorbed by the oceans is a further uncertainty; currently it appears that something like two-fifths is being absorbed somewhere—in the oceans, in vegetation, in the soil—but whether the oceans will be as ready to absorb the gas when the oceans themselves have higher surface concentrations is not confidently predicted.

A further complication, as far as quota regimes are concerned, is that whatever may be the ultimate limit on the total carbon in the atmosphere, the trajectory of emissions should almost certainly—and differently from country to country—continue to increase for at least some decades before leveling off and eventually turning sharply down. There are several reasons.

One reason is that better and cheaper technologies for mitigation will become available, the longer we wait, especially if we invest heavily in the improved technologies to make sure they become available when we need them. A second reason is that anything we can postpone for twenty years becomes drastically cheaper if we can invest the equivalent cost at five or six percent and invest the proceeds in mitigation twenty years from now. A third reason is that postponement avoids the scrapping of costly capital assets that have substantial lifetimes left, like electric generating plants. A fourth reason is that later generations will almost certainly enjoy higher incomes than ours and be better able to afford any costs of switching to new energy sources. A fifth reason is that we should have a better understanding, in each successive decade, of what and how much needs to be done to slow down the global warming.

Kyoto focused on near-term emissions. That probably made sense. There undoubtedly is, as the U.S. National Academy of Sciences reported a decade ago, some "low hanging fruit" to be harvested—opportunities to reduce emissions significantly at little or no cost. They are mostly once-for-all, not indefinitely exploitable. These are things we know will eventually prove justified, and postponing them merely loses time.

A reasonable question is why, after more than a dozen years of intense investigation, the basic uncertainties about the magnitude of projected changes have not been reduced. Part of the answer is probably that no official body has been willing to commit itself to defending a quantitative challenge to the standing estimate. An important part is probably that climate science, like brain science or genetics, turned out to be much more complex than was originally appreciated, early in the recent concern with global warming. Twenty-five years ago the oceans were modeled mainly as cooling reservoirs. Now ocean currents are seen

as active participants in the circulation of heat, and that circulation depends on temperature and salinity at different depths and the turbulence on the surface due to winds. Clouds were little understood, and unable to play an active role; now clouds are understood to be reflectors of incoming radiation or absorbers of outgoing radiation depending on their altitude, density, droplet size, and geographical location. It was known that particles of dust in the atmosphere, and especially of sulfur (historically from some volcanic eruptions), could significantly reflect incoming sunlight; but there were no reliable studies of the amounts in the air, their geographical distribution, or their residence time.

A major scientific coincidence was the burgeoning availability of satellite reconnaissance of oceans, clouds, glaciers, forests, sea ice, airborne particles, and atmospheric temperatures that paralleled the concern for climate change. With the cascade of new knowledge came new appreciation of the complexity of interactions among atmospheric, oceanic, and terrestrial phenomena, including human activity.

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Without being able to forecast the speed or even the nature of climate change—"warming" is just a shorthand expression for what will motivate the changes—we can still try to foresee the kinds of impacts those changes may have. But here we must be careful: there is a strong temptation—I know because I have been experiencing it for twenty-five years—to think of changes in climate superimposed on life as we know it, or know of it. Climate change may become serious, if little or nothing is done about it, in the second half of this century and, even if substantial mitigating efforts are undertaken, toward the end of the century. To discern the likely effects we have to try to imagine the world as it may be in sixty, eighty, or a hundred years.

How do we do that? A possibility, just to acquire some perspective, may be to imagine how we might have reacted—"we" being our children's grandparents or great-grandparents—if, say, eighty years ago global warming and attendant climate changes of the kind now being discussed had been seriously considered. Several thoughts occur to me. One is that people in the United States, with "warming" on their minds, would have been more interested in milder winters than in hotter summers. A second is that, where summer was concerned, a major worry might have been mud. Automobile tires were skinny, hard as wood (with sixty pounds per square inch pressure), and absolutely no good in mud. Bicycles were no good in mud and walking was difficult. It might not have occurred to us (to them) that before the century was out the country would be paved almost solid.

Pursuing this line of thought we could ask, if the climate change so predicted in 1925 had actually occurred by now, how might a farm boy of that time who stayed on the farm and lived to the present reflect on the changes that had occurred during his lifetime? Would the change in climate stand out?

My guess is that that now aged farmer would be more impressed with the disappearance of the horse; with the coming of electricity, telephone, and radio

(let alone television); with hybrid corn, antibiotics, and pesticides; with still having most of his original teeth; and with having college graduate grandchildren whom he could visit easily 2000 miles away. He might not notice milder winters: he has gloves and boots and parkas that did not exist when he was a boy, his car has a heater and, in case his road is not plowed, he has snow tires (and air conditioning for the summer). His agricultural technology has changed so much he is not sure what difference any change in climate may have caused to agricultural productivity.

Seventy years ago we did not have electronics, radioisotopes, nuclear energy, antibiotics, genetics, satellites, or even plastics—it was all silk, rayon, isinglass, and celluloid. How do we possibly foresee seventy years from now?

Still, we can assert a few things with some confidence. Most production for market in developed countries is substantially immune to climate. We can assemble automobiles, refine oil, transmit radio and TV, do open-heart surgery and banking and insurance, perform symphonies, manufacture pharmaceuticals, teach classes, operate airlines, and hold golf tournaments in Massachusetts, Washington, Texas, Georgia, or Michigan, even in Alaska as far as climate is concerned. Only agriculture and animal husbandry, forestry, fisheries, and outdoor recreation are susceptible to climate in the United States and in most developed countries. Agriculture, forestry and fisheries are no more than three percent of the U.S. gross domestic product. If the cost of producing raw food and lumber doubled over the next sixty or seventy years, it would reduce gross product by three percent while that same gross product doubled from ordinary productivity growth. We would double our per capita income in 2067 instead of 2065.

It is different for developing countries, many of whom depend on agriculture for a third or half of their gross product while as much as two-thirds of the population may depend on agriculture for a living. While it is not certain that the likely changes in climate would everywhere be adverse to farming, at least in those countries people are potentially vulnerable in a way that we in America are not. Additionally there could be serious health consequences: many vector-borne diseases become more virulent in hotter climates, and their prevalence could extend further as subtropical climates become more tropical.

I conclude that most, nearly all, of the adverse effects of likely climate change will accrue to the descendants of those living today in what we call "developing countries" (not all of which are actually developing). First, that is where the people are. Three quarters of them live there today, and it is predicted that seven-eighths of them will live there by the end of the century. Second, they are vulnerable in ways that we are not. Third, they do not have the resources to cope, to adapt, or to defend against adverse weather and climate and what it may do to health and productivity. The nations least able to afford to do anything to abate forthcoming changes in climate are the nations with the most at stake (whether their leaders realize that or not).

To draw this comparison between today's developed and undeveloped in their vulnerability to potential climate change, however, is also to identify what is likely to be the best defense against changing climate: development. Consider health, malaria in particular. That disease kills more than a million people every

year, a large proportion of them children. Malaria is no problem in the United States, Canada, or Western Europe. Climate does not altogether explain the lack of malaria; malaria got its name in ancient Italy and was serious in the United States a century ago. It is now associated with the tropics.

But consider Singapore and Malaysia, two nations separated by a kilometer of seawater. Their climates are identical. There is virtually no malaria in Singapore; malaria is serious in Malaysia. If anyone living in Singapore does get malaria (by spending a weekend in Malaysia) he or she is probably in good health to begin with and gets necessary medical care. Singapore of course has the advantage of being small and rich, so environmental measures can take care of any mosquitoes. But this is the point of the comparison: Singapore and Malaysia were identical not only in climate but in development forty years ago. Both have developed, but Singapore spectacularly. If Malaysia can reach, through a second forty years of development, where Singapore reached in its first forty years, it should no longer be at the mercy of the mosquito.

Measles kills a million children a year in poor countries, not in the well-to-do. Vaccine is a great help; but what the poor children in developing countries need most, to reduce the impact of measles, is adequate nutrition and freedom from debilitating chronic illness. For that they need development. With development, countries can afford sanitation and safe drinking water, not to mention a public-health infrastructure. The worst effects of deteriorating climate on health can be avoided if poor countries can become non-poor in the coming half century.

Health is just one area in which development can significantly offset the adverse effects of climate change. Development means higher incomes, which in turn mean individuals and governments better able to adapt to changes, and governments better able to participate in global efforts at mitigation. Development also means shifting away from subsistence agriculture and into productive activities less dependent on the weather.

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A few years ago, two thousand American economists published a statement arguing that the nations of the world should adopt a rationing scheme under which every nation would be assigned a quota for carbon emissions, with strong sanctions for failing to meet quota obligations and with a trading system in which nations better able to come in under quota could "sell" unused emission rights to countries finding it more difficult to meet their quota obligations.

Few propositions appeal to economists more than that without clearly defined obligations backed up by the prospect of sanctions international cooperation involving potential major sacrifices cannot be sustained, and that without trading rights any regime will be hopelessly inefficient.

I did not sign the statement. I am an economist who believes in the essentiality of incentives, in clearly defined obligations, and in the virtues of trading. I cannot imagine such a regime for carbon emissions. I have several reasons.

Any serious regime would have to allocate emission rights over many

decades, not just a decade at a time but cumulatively. There is currently no possibility of reaching agreement on whether "acceptable" total emissions over the coming century should be 500 billion tons or 2000 billion tons; in any event, what is ultimately acceptable will depend on the costs of moderating emissions, and these costs are also extremely uncertain.

Because any economical trajectory of annual emissions should grow for some decades before leveling off and declining severely thereafter, with different trajectories for different nations, it would be almost impossible to determine, during the first half-century or so, whether a nation was on target to meet its ultimate cumulative limit. (It would likely be just as hard for the nation itself to know, as for any monitoring secretariat or judicial review body.)

Any stringent regime would involve allocating emission rights worth many trillions of dollars among rich nations and poor, rapidly growing nations and more mature economies, and countries with fossil fuels and countries without. I see no possibility of any such compact being arrived at. If there were such quotas they would certainly have to be renegotiated periodically as estimates changed and as nations experienced greater and lesser difficulties. Any nation that "sold" part of its unused quota would clearly be evidencing a too generous original quota.

Sanctions large enough to be effective deserve skepticism. Punishing poor countries will not be attractive; punishing rich countries, or large countries, or powerful countries, will not be attractive. I can imagine the United States agreeing to quotas it believes it can live with and making serious efforts to live within the quotas; it is hard to imagine any international body or consortium of nations imposing sanctions on the United States, or the United States accepting severe sanctions.

Granting, for argument, the apparent logic that nations will not make sacrifices in the absence of sanctions, there is no historical example of any international regime that could impose penalties on a scale commensurate with the magnitude of global warming. (It is notable that the current most legally cohesive regime, the European Union—certainly stronger than any greenhouse regime that one could imagine—calls for severe penalties on any nation that runs a deficit greater than three percent of gross domestic product for three years running; in 2004 both France and Germany violated the rule, and nothing was expected to happen to those two nations, and nothing did happen.)

Nowhere are there any agreed criteria for allocating half a trillion tons, or a trillion, or two trillion, among almost 200 nations. Undeveloped nations demand the right to "catch up" to the developed in carbon emissions per capita or per unit gross product. Some argue for uniform emissions per capita. All may see carbon quotas as partly cash equivalents, via trading for money, and indeed there have been proposals for allocating carbon quotas as "foreign aid" precisely to facilitate conversion of carbon quotas to cash. Any "democratic" allocation of quotas would require negotiation among nearly 200 countries, some of whom are oil and gas producers that may object to any rationing. And how to penalize a poor country that fails to conform to its quota would require a judicial procedure to authorize sanctions and some enforcement mechanism, which would have to extract financial resources, embargo trade, restrict fossil fuel deliveries, or

otherwise impose penalties or fuel restrictions. Nothing like this has ever existed and it is even hard to conceive.

The World Trade Organization (WTO) might appear to be a model or precedent. It does entail penalties on infractions of the trading rules and it has a judicial body to hear complaints and authorize sanctions. It has worked, but as a model it is not a good fit. WTO is essentially a system of detailed reciprocal undertakings; infractions tend to be bilateral, and specific as to commodities. Offended parties can undertake retaliation and make the punishment fit the crime (thus exercising the principle of reciprocity). Fulfilling or failing WTO commitments is piecemeal, not holistic. There is no overall target to which a WTO member is committed. In contrast, if a greenhouse-regime nation fails to meet its target there is no particular offended partner to take the initiative and penalize the offender. There is no obvious formula to make the punishment fit the crime.

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Is there any precedent, or model, of international cooperation on a scale equivalent to what a greenhouse regime might entail? The North Atlantic Treaty Organization (NATO) is my candidate. NATO, as an organization, grew out of the Marshall Plan, which itself is a model. The division of Marshall-Plan aid was originally determined by the United States, the donor, after receiving tentative "plans" from Europe that amounted to more than was to be made available. Roughly five billion dollars was available for a fifteen month period. (The funds became available on April 1, not July 1.) Funds had to be distributed among countries as disparate as the United Kingdom, Turkey, Norway, Italy, Iceland, and the rest—disparate in their pre-war living standards, their wartime damage, their capacity for reconstruction, and their specific commodity needs. But through the Organization for European Economic Cooperation (OEEC, predecessor of the current OECD) the recipient nations were to negotiate later annual divisions of aid.

To that end, each country submitted detailed statements documenting their needs for hard currency during the coming fiscal year. They projected government expenditures civilian and military, private consumption—including rationed commodities like gasoline, meat, butter, and heating fuel—exports and imports by provenance and destination, feedstock requirements and projected growth in livestock populations, restoration of railroad beds and canals, housing repair and construction, machinery and equipment requirements, and finally, crucially, import requirements that had to be paid for in dollars. An ambitious effort by the Secretariat of the OEEC standardized the accounts and definitions. ("National economic accounts" were new and unfamiliar to several governments.)

Then began a process of reciprocal multilateral scrutiny. Each government was represented by a team of senior officials. Each government team was examined and cross-examined by the other government teams; each defended its projections and demands for aid, revised its claims and defended anew. More aid for one country meant less for the rest.

There was never any formula. "Relevant criteria" developed. The parties did not quite reach agreement, but were close enough that two people, the Secretary General of the OEEC and the representative of Belgium (which was not requesting any aid) offered a division that was promptly accepted. Of course, the U.S. government was insisting on agreement Today there is no such "angel" behind greenhouse negotiations. Still, this precedent offers encouragement.

NATO went through the same process in 1951-52, the "burden sharing exercise." The same people—by this time on a first-name basis—engaged in the same reciprocal scrutiny and cross examination. Military contributions such as conscription and training; procurement of weapons, ammunition, and vehicles; and contributions of real estate for pipelines, maneuvers, and housing were now crucially involved. U.S. aid was still involved and was the pressure to reach agreement, which was almost attained. This time three people, including the U.S. representative, offered up a proposal that was immediately accepted. U.S. aid tapered off, but the procedures and the teamwork remained.

NATO, for which the Marshall Plan provided the congenial social infrastructure, is the only non-wartime institution in which so many countries cooperated over such high economic stakes. The procedures were not aesthetically satisfying; no formulae were developed, just a civilized procedure of argument and accommodation. Additionally, two of the participating nations, Italy from the outset and Germany soon after, were former enemies of the rest.

NATO nations undertook commitments, heavy commitments, arrived at through the process I described, and generally met their commitments. There were no sanctions on non-performance other than diplomatic argument. By any measure NATO was a success. The camaraderie and tradition of cooperation engendered by the Marshall Plan were immensely helpful. We have no such auspicious tradition to undergird the international greenhouse effort, but NATO is the only historical model I can find.

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A striking difference between commitments under NATO, or under WTO, and commitments under the Kyoto Protocol (or almost any other greenhouse regimes that have been proposed) is the difference between commitment to actions and commitment to results. NATO governments argued over what they would actually do: raise troops, train and deploy them; procure vehicles, arms, and ammunition; submit to an international command structure; and, if it came to that, to defend each other's territory as if it were their own.

The expected results were deterrence of attack or, if deterrence failed, defense. There was no way to measure how much added deterrence the Dutch contributed, or the Norwegians, or the British. The only way to assess how much the Dutch would, in the event, have contributed to slowing down a Soviet-bloc attack would be to count their troops and weapons. Essentially, "inputs" were visible and measurable; "outputs" in the form of deterrence or successful defense were conjectural, judgmental, not measurable.

As in NATO, commitments in WTO were to what nations would do, or refrain from doing. There are no commitments to particular consequences. No

WTO member nation is committed to imports of any sort from anywhere; it is committed only to actions, or abstentions, regarding tariffs and other restrictions, subsidies, and tax preferences.

In the Kyoto Protocol, commitments were not to actions but to results that were to be measured after a decade or more. A disadvantage is that no one can tell, until close to the target date, which nations are on course to meet their commitments. More important, nations undertaking results-based commitments are unlikely to have any reliable way of knowing what actions will be required, i.e., what quantitative results will occur on what timetable for various actions. The Kyoto approach assumed without evident justification that governments actually knew how to reach ten or fifteen year emissions goals. (The energy crisis of the 1970s did not last long enough to reveal, for example, the long-run elasticity of demand for motor fuel, electricity, industrial heat, etc.) A government that commits to actions at least know what it is committed to, and its partners also know and can observe compliance. In contrast, a government that commits to the consequences of various actions on emissions can only hope that its estimates, or guesses, are on target, and so can its partners.

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Comprehensive estimates of climate change are invariably gradual. That is mainly because climate-change models reflect, naturally, what is known about the behavior of climate, and what is not known, of course, is not known. Are there potential abrupt, large-scale transitions that can be realistically imagined. Are there potential catastrophes that should be gripping our attention?

Two have been seriously studied. One is the possible attenuation of the oceanic circulation involving the downward plunge of ocean-surface water in the northern Atlantic near the arctic circle and the corresponding northward surface flow of the Gulf Stream that warms Western Europe. (Madrid shares its latitude with Cape Cod, Copenhagen with Hudson Bay.) There is some evidence that in earlier geological eras the Gulf Stream may not have existed, or was substantially attenuated. There are some estimates that global warming may influence the temperature and salinity of northern Atlantic waters and reduce the circulation on which the Gulf Stream depends. That could mean a severe cooling of western Europe as a result of global warming.

The other, more ominous, possibility relates to a body of ice known as the West Antarctic Ice Sheet. This is "grounded" ice, attached to Antarctica and secured by several islands, essentially an iceberg so thick that it rests on the bottom and extends a kilometer or more above sea level. If it should glaciate or otherwise move to sea it would sink and raise sea level drastically. (Floating ice, like the Arctic sea ice, does not affect sea level; the grounded ice would.) The estimate of potential sea-level rise is on the order of twenty feet. That would put major coastal cities, like New York or London, under water. They might be preserved with dikes—Amsterdam is about fourteen feet below sea level—but huge areas of nations like Bangladesh could not be protected. (Not only would the coastline of Bangladesh be prohibitively long to protect with levees but there would be no way for fresh water—already a source of severe flooding—to reach

the sea.)

These are two phenomena that will need watching and study. Either, by the time it manifests itself, may be beyond prevention: the warming built into the system of greenhouse gases, delayed by the "thermal inertia" of the oceans—their capacity to delay the actual warming of the atmosphere—may be sufficient to continue the process.

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An interesting policy option, probably only for the far future, gets remarkably little attention, possibly because it sounds too much like science fiction, possibly because it scares people who do not want it discussed. It has attracted the name "geo-engineering"—changing something about the earth. (Actually, with global warming, we are already geo-engineering, just not purposely.) The specific proposal would be to increase the earth's albedo, its reflection of incoming sunlight. It is now known, and somewhat measurable, that aerosols—fine solid or liquid particles in the atmosphere, especially those of sulfur—reflect sunlight. Volcano eruptions that put lots of sulfur in the atmosphere have had this effect famously. Today's pollution, especially industrial but also windblown dust and sand, is thought to be reflecting enough sunlight to mask somewhat the greenhouse effect.

Why not do this purposefully one may ask? If we are putting things in the atmosphere, the various greenhouse gases that absorb outgoing radiation, why not put things in the atmosphere that reflect incoming radiation—just "preserve the balance?" We could not use sulfur, it is too unhealthful to people and wildlife. Instead, we could spend a few decades experimenting to find something cheap and innocuous that may stay in the stratosphere long enough to be a partial solution to the greenhouse problem. The amount of incoming sunlight that would have to be kept out is small enough to be not noticeable. A report of the National Academy of Sciences mentioned the possibility a dozen years ago.

The idea has some attractions. It reduces the need to change the way people all over the world cook their meals, drive their cars, light and cool and warm their homes, grow their rice—rice paddies are a source of methane, a greenhouse gas—and produce their electricity. Instead of negotiating a complex regime of emission quotas, nations would negotiate shares in the costs of the program, a kind of negotiation with which they have had experience at least since the first U. N. budget. Diplomatically and administratively, it would drastically simplify the greenhouse issue. But for the time being this possibility is not visible on anybody's agenda. It certainly deserves research into the possibilities for small-scale reversible experiments in case the greenhouse problem begins to appear diplomatically intractable some time in the decades to come.

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What should be the role of developing countries, especially the major ones—China, India, Indonesia, Brazil, South Korea—but also more than a hundred others, some of them oil-exporting members of OPEC? The U.S. Senate

overwhelmingly passed a resolution, in relation to the Kyoto treaty, calling for the full participation of the main developing countries in any treaty that the United States might join. Perhaps for some senators the resolution was a gentle way of disposing of the treaty. The developing nations were on record, unambiguously, as having no intention of participating. (A hundred of them actually ratified the Kyoto treaty, but their participation was ceremonial; the treaty excluded them from any obligation.)

Certainly the larger developing nations must eventually be brought into some form of cooperation to reduce emissions. China's emissions of carbon dioxide are already one-half the United States' and growing at a rate to surpass U.S. emissions in another two or three decades. Two motives make them uneager to join. A main motive is their correct perception that rapid development will reduce their vulnerability to climate, and suppressing energy use is likely to hinder development. Another is that the developed nations, especially the United States, having developed industrially through uninhibited exploitation of fossil fuels over the past century and a half, and less in need of rapid further development to escape the dangers of climate change, should lead the way and demonstrate a serious commitment to emissions reduction. They probably do not yet perceive such leadership or commitment.

If Western Europe, Japan, and the United States manage to demonstrate over the coming decade that they are serious about the climate issue, China, India, and others can probably be induced to take the subject seriously. At that time the wealthy nations can engage in planning how to help the developing world afford to join a global effort.