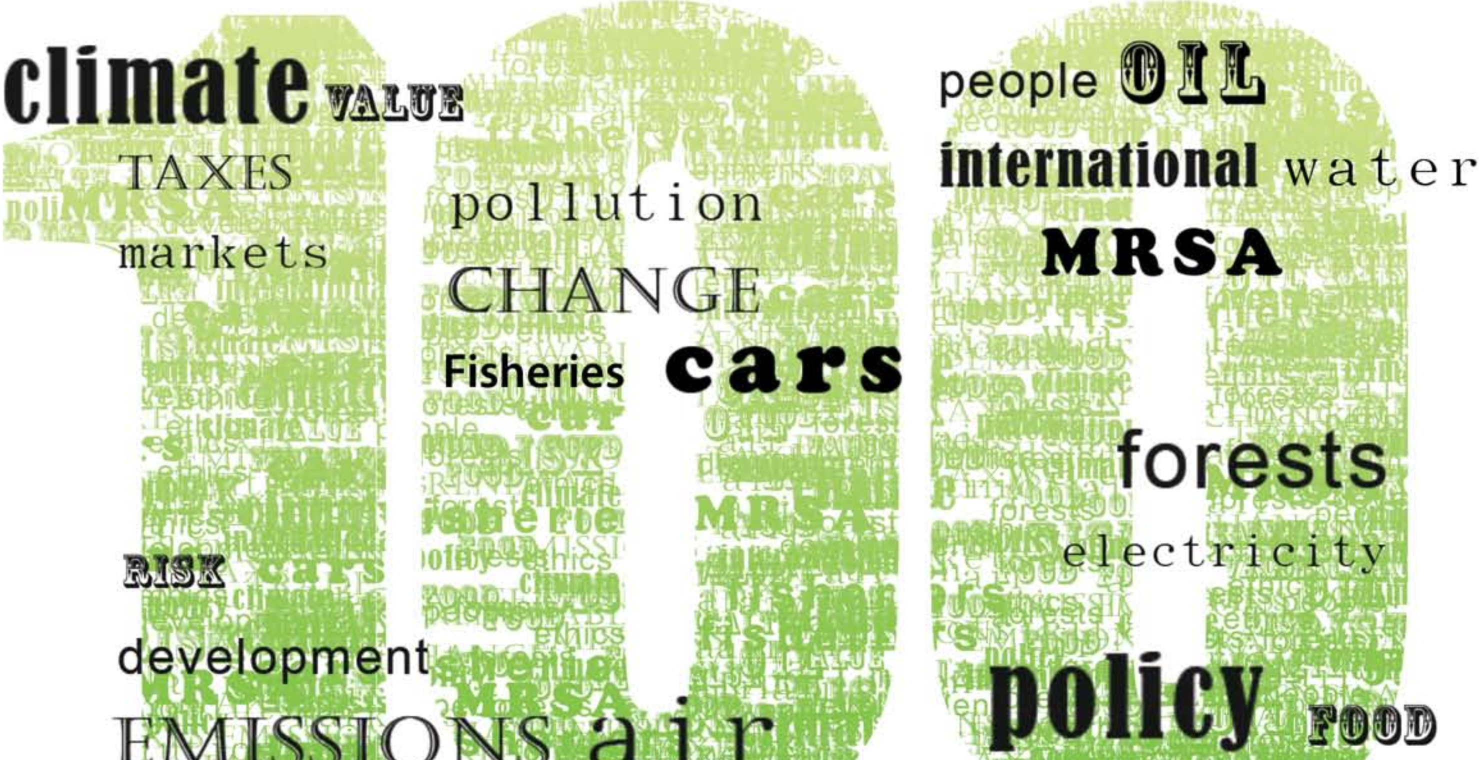
ISSUES OF THE DAY

100 Commentaries on Climate, Energy, the Environment, Transportation, and Public Health Policy



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PART 1

Global Environmental Challenges

It is difficult to imagine a more challenging policy problem than global climate change. The appropriate goals of climate policy, and which countries should be held the most responsible for reducing greenhouse gases, are highly contentious. On top of this, there are many complicated issues in the design of domestic climate policy for a country like the United States.

The commentaries in this first section touch on a variety of climate policy issues. At the international level, these include the implications of delayed participation by developing countries in international emissions control agreements, the design of globally efficient policy architectures that take into account political constraints, incentives to comply with international agreements, the monitoring of climate-related trends, lessons from emissions trading to date in Europe, and the successful phasing out of ozone-depleting chemicals.

At the domestic level, issues covered include design provisions in prospective U.S. climate legislation, the choice among emissions control instruments, to what extent supplementary policies to promote clean fuels and clean technology innovation are warranted, how allowance auctions in a cap-and-trade system might be designed, and measures to deal with the risk that energy-intensive capital will migrate to countries with no emissions controls.

Additional issues include the case for, and practicality of, incorporating the forestry sector into climate programs, and the possibility of allowing firms to offset their carbon dioxide emissions by funding projects to reduce greenhouse gases in other sectors of the economy or in other countries. Two commentaries discuss one of the most important issues in assessing the economically efficient stringency of climate policy, namely the rates at which future damages from climate change should be discounted. Also included is a discussion of the expected risks posed by sea-level rises and how to adapt to them.

1. STABILIZING ATMOSPHERIC CO_2 WITH INCOMPLETE INTERNATIONAL COOPERATION

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The urgency of bringing large emitters in the developing world into an international agreement to control greenhouse gases critically depends on the ultimate goals of climate policy. Under modest, rather than aggressive, climate stabilization targets, early participation is less critical as there is much greater scope to offset delayed participation through greater abatement in wealthy countries and more global abatement later in the century.

Most policymakers concerned about global warming have in mind some ultimate objective for limiting the amount of projected climate change, or atmospheric carbon dioxide (CO_2) accumulations. Much of the debate has focused on climate stabilization targets consistent with limiting CO_2 concentrations to either 450 parts per million by volume (ppmv) or 550 ppmv (currently, CO_2 concentrations are 385 ppmv, compared with preindustrial levels of about 280 ppmv). According to the Intergovernmental Panel on Climate Change, these stabilization targets are consistent with keeping eventual mean projected global warming to about 1.5°C and 2.5°C above current levels, respectively (this would be on top of temperature rises of about 0.75°C over the last century).

Economists and climate scientists have developed a number of models to estimate global emissions prices that are consistent with ultimately stabilizing atmospheric CO_2 concentrations at these target levels and minimizing the global burden of mitigation costs over time. To carry this out requires a uniform price on emissions from different regions within a given year (to equalize marginal abatement costs across different countries). The emissions price must also rise at roughly the rate of interest (about 5 percent) over time (to equate the discounted marginal abatement costs at different points in time).

However, it is unlikely that the world will address climate change in this wholly cooperative fashion—more likely, it will be years before developing countries are willing to comprehensively price their emissions, and even when they do, it may be at a lower rate than prevailing in the European Union and United States. How much of a problem is delayed participation by developing countries in terms of raising the overall burden of global mitigation costs, and what does this imply for appropriate near-term emissions pricing goals for the United States, if eventual targets for global stabilization are still to be met?

To explore these questions, we used our MiniCAM model and the following assumptions: that industrialized countries impose a common emissions price in 2012, China joins the agreement at a later date, and other countries join whenever their per capita income reaches that of China at the time of China's accession into the emissions control agreement. In one scenario, countries entering into the control regime would immediately price emissions at the same level as in industrialized nations, while in another case the emissions price for late entrants into the agreement converges gradually over time to the price in industrialized countries.

The model is designed to examine long-term, large-scale changes in global and regional energy systems in response to carbon policies. Given the many uncertainties—such as the costs of future emissions-reducing technologies (for example, nuclear power, carbon capture, and storage technologies) and emissions growth in the absence of controls (which is highly sensitive to assumed population and productivity growth)—the predictions should not be interpreted literally. But the results do provide some flavor for the proportionate increase in global abatement costs, and in required U.S. emissions pricing, due to delayed developing country participation.

We started with the more moderate climate stabilization target for CO_2 of 550 ppmv. In the ideal case, with full and early emissions pricing by all countries, global emissions and emissions in the United States rise above current levels before peaking around 2035 to 2050, and progressively decline thereafter. Global emissions prices rise to about $6 per ton of CO_2 (in current dollars) in 2025 and to about $20 per ton by 2050. By midcentury, annual global gross domestic product (GDP) losses are 0.2 percent (most other models also suggest global GDP losses of less than 1 percent by midcentury under this stabilization target).

With delayed participation, even if China joins between 2020 and 2035, the implications for emissions pricing in developed countries can be significant but are not that dramatic under the 550 ppmv stabilization goal. Compared with the globally efficient policy (with a globally harmonized emissions price at all times), near-term emissions prices in developed countries rise from between a few percent and 100 percent under the different scenarios, and discounted global abatement costs are higher by about 10 to 70 percent.

Emissions pricing policies implied by the 450 ppmv target are far more radical. Under globally efficient emissions pricing, CO_2 prices rise to about $35 per ton by 2025 and about $130 per ton by midcentury, while global and U.S. emissions are roughly 5 percent and 40 percent below 2000 levels in 2025 and 2050, respectively. Global GDP losses approach 2 percent by midcentury.

Moreover, the 450 ppmv concentration is so close to present-day levels, and demand for fossil fuels is rising so rapidly in developing nations, that delayed participation has severe consequences for early participants in this case. Developed countries would have to achieve a reduction of more than 85 percent (relative to 2005 emissions) in 2050 to stabilize CO_2 at 450 ppmv if developing countries don't begin participating until 2020. Even more drastic reductions would be required if the delay is longer. Discounted global abatement costs are anything from about 30 to 400 percent higher than under globally efficient pricing in most cases, and near- and medium-term emissions prices can be 10 times larger with China's accession delayed until 2035.

Why does delayed participation matter so much in one stabilization scenario, but not the other? Under the less stringent concentration target, there is much greater flexibility for offsetting delayed emissions reductions in developing countries through greater abatement by all countries later in the century. In contrast, to prevent CO_2 concentrations from rising above 450 ppmv (present levels are already more than 380 ppmv), the remaining emissions that can be released by all countries in the world, without exceeding that limit, are so limited that forgone emissions reductions in nonparticipating countries must be largely made up by far more aggressive reductions in participating nations. In other words, there is little opportunity to catch up later. The problem is compounded by emissions leakage as rapidly declining fuel demand in developed countries exerts downward pressure on global fuel prices, which in turn makes fuel use and emissions an economically more attractive option in countries without mitigation policies.

Perhaps not surprisingly, the urgency of widespread participation in international emissions agreements hinges critically on the appropriate long-term climate stabilization target. Unfortunately, there are also strong incentives for countries to be "free riders," to benefit from others' emissions mitigation efforts without undertaking their own mitigation.

In the globally efficient policy, developing countries bear about 70 percent of discounted abatement costs out to 2100 (as their emissions in the absence of controls expand rapidly relative to those in developed countries). However, developed countries bear "only" about 20 to 35 percent of global abatement costs when China's accession occurs in 2035 and new entrants face lower starting prices. Side payments and other types of compensation could create incentives for earlier actions in developing regions. However, agreeing on who gets what level of compensation will, almost certainly, be highly contentious.

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2. A PRAGMATIC GLOBAL CLIMATE POLICY ARCHITECTURE

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This commentary summarizes a proposed international architecture for global climate policy that takes into account a variety of likely political constraints. These include, for example, limits on the burden borne by individual countries and the reluctance of developing nations to make commitments without aggressive action to cut emissions in the United States.

Before the 15th Conference of the Parties took place in Copenhagen, many observers questioned the likelihood that much of substance would happen, much as they have many times before.

In fact, a key weakness of the first attempt to coordinate international climate policies was its lack of credible emissions targets—most countries failed to commit to emissions targets under the 1997 Kyoto Protocol, and many of those that did ratify are expected to exceed their targets for the first commitment period, 2008–2012. These considerations underscore the critical need to develop a global climate policy architecture that takes political realities into account.

Although there are many ideas for developing a successor to the Kyoto Protocol, the existing proposals are typically based on just one or two of the following factors: science (capping global carbon dioxide [CO_2] concentrations at 450 parts per million [ppm]); equity (allocating equal emissions per capita across countries); or economics (weighing the economic costs of aggressive short-term cuts against the, albeit speculative, long-term environmental benefits). Our proposal for emissions reductions takes these considerations into account but is more practical because it is based heavily on politics. Although it accepts the framework of national targets for emissions and tradable permits, it also attempts to solve the most serious deficiencies of the Kyoto agreement: the need for long-term targets, the absence of participation by the United States and developing countries, and the incentive for countries to fail to abide by their commitments.

POLITICAL CONSTRAINTS

In our judgment, any future climate agreement must comply with six important political constraints.

- First, aggressive targets to cut U.S. emissions will not be credible if China and other major developing countries do not commit to quantitative targets at the same time, due to concerns about economic competitiveness and the movement of energy-intensive industries to countries without emissions caps ("carbon leakage").
- Second, China and other developing countries will not make sacrifices different in character from those made by richer countries that have gone before them, taking due account of differences in per capita income, per capita emissions, and baseline economic growth.
- Third, in the long run, no country can be rewarded for having ramped up its emissions high above the levels of 1990 (the baseline year for emissions targets embodied in the Kyoto Protocol).
- Fourth, no country will agree to participate if the present discounted value of its future expected costs exceeds a threshold level, which, for illustration, we assume is 1 percent of GDP.

- Fifth, no country will abide by targets that cost it more than, say, 5 percent of GDP in any five-year budget period.
- Sixth, if one major country drops out, others will become discouraged and the system may unravel.

HOW IT WOULD WORK

Under our proposal, rich nations would begin immediately to make emissions cuts along the lines that their political leaders have already committed to (consistent with emissions targets in the European emissions trading scheme or in recent U.S. legislative proposals). Developing countries would agree to emissions caps that maintain their projected business-as-usual emissions in the first decades but, over the longer term, commit to binding targets that ultimately reduce emissions below business as usual. This approach prevents carbon leakage and gives industries a more even playing field. However, it still preserves developing countries' ability to grow their economies; they can also raise revenue by selling emissions permits. In later decades, the emissions targets asked of developing countries would become stricter, following a numerical formula. However, these emissions cuts are no greater than those made by rich nations earlier in the century, accounting for differences in per capita income, per capita emissions, and baseline economic growth.

Future emissions caps are to be determined by a formula that incorporates three elements. First is a progressivity factor that requires richer countries to make more severe cuts relative to their business-as-usual emissions. Second is a latecomer catch-up factor that requires nations that did not agree to binding targets under Kyoto to make gradual emissions cuts to account for their additional emissions since 1990. This prevents latecomers from being rewarded with higher targets, or from being given incentives to ramp up their emissions before signing the agreement. Finally, the gradual equalization factor addresses the fact that rich countries are responsible for most of the carbon dioxide currently in the atmosphere. From 2050 onward, this factor moves per capita emissions in each country in each period a small step in the direction of the global average of per capita emissions.

FINDINGS

We analyzed the numerical targets using an energy/climate model that represents emissions mitigation opportunities for different regions at different future time periods. Some of the main results include the following:

- The world CO_2 price reaches \$20–\$30 per ton in 2020, \$100–\$160 per ton in 2050, and \$700–\$800 per ton in 2100.
- According to the economic simulations, most countries sustain economic losses that are under 1 percent of GDP in the first half of the century, but then rise toward the end of the century.
- Atmospheric concentrations of CO_2 stabilize at 500 ppm in the last quarter of the century, implying a projected increase in world temperatures above preindustrial levels of about 3°C.

We have not been able to achieve year-2100 concentrations of 450 ppm or lower (to limit projected warming to about 2°C) without violating the same political-economic constraints.

CONCLUSION

The proposal calls for a successor international agreement that establishes a global cap-and-trade system. The emissions caps are set using formulas that assign quantitative emissions limits to countries in every five-year period from now until 2100. Three political constraints are particularly important in specifying the formulas. First, developing countries are not asked to bear any cost in the early years. Second, even later, developing countries are not asked to make any sacrifice that is different from the earlier sacrifices of industrialized countries, accounting for differences in incomes. Third, no country is asked to accept targets that cost it more than 5 percent of GDP in any given year.

The framework here allocates emissions targets across countries in such a way that every country is given reason to feel that it is only doing its fair share. Furthermore, the framework—a decade-by-decade sequence of emissions targets determined by a few principles and formulas—is flexible enough that it can accommodate major changes in circumstances during the course of the century.

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3. THINKING BEYOND BORDERS

Why We Need to Focus on Global Public Goods

Scott Barrett

is a professor in the School of International and Public Affairs at Columbia University. His research focuses on interactions between natural and social systems, especially at the global level. He is best known for his work involving international environmental agreements, such as the Kyoto Protocol.

Under what conditions has the international community dealt effectively with certain global problems, like smallpox eradication? The international response to other global problems—most notably climate change—has been ineffective so far; treaties cover only a limited number of countries, and even for those countries, incentives for complying with the agreement are too weak.

In Copenhagen in December 2009, governments met to discuss a road map for controlling global greenhouse gas emissions as a successor to the Kyoto Protocol, which expires in 2012. As we continue to contemplate a post-2012 future, it's worth reflecting on some basic economic concepts in order to better understand what it will take for that map to truly show us a way forward.

Global climate negotiators try to provide what economists call a public good. To prevent atmospheric greenhouse gas concentrations from rising, a substantial number of countries must act together. It is the total sum of emissions that affects concentrations, not the amounts emitted by individual countries. So each country has an incentive to let others act—one of the reasons so little has been achieved so far.

If each country's climate were shaped only by its own emissions, and not by the total of every country's emissions, the incentive would be different.

For example, national defense is a national public good. It is public in two senses. First, "consumption" of the good by one person does not reduce the amount available to others. Second, no citizen can be excluded from enjoying the benefit of national defense. This second attribute is particularly important: if beneficiaries do not have to pay, then why should they pay? But if no one pays, the good won't be provided—and everyone will be worse off.

This, then, is why government exists—to get around the free-rider problem and to supply public goods. Other examples of domestic public goods include clean air and water and the preservation of unique natural wonders.

But what about global public goods like climate change mitigation, nuclear non-proliferation, and disease eradication? These are harder to supply for the simple reason that there is no world government but, instead, 192 nation states. To supply these public goods, a different approach must be tried.

Imagine that we learn that Earth will be hit by a massive asteroid 25 years from now. If nothing is done to avert the collision, *Homo sapiens* will almost certainly become extinct. Engineers tell us that there are a variety of ways in which the asteroid's orbit could be altered. All it would take is a single best effort. Could we be confident that the money needed to deflect the asteroid would be raised?

The answer, fortunately, is yes. The incentives to act are so strong that we can be sure that the only real constraint on our ability to supply the global public good of asteroid protection is technical feasibility. Indeed, it would be in the interests of a single country to supply this global public good all by itself. International cooperation would not even be needed.

Perhaps the greatest global public good ever provided was the eradication of smallpox. When the world began this audacious effort, over a million people died every year from smallpox. Almost all of these people lived in poor countries, but the rich countries also gained from eradication. This is because the vaccine that offers protection from smallpox is costly and dangerous. Once the disease was eradicated, the need to vaccinate evaporated. Everyone gained.

What is novel about this global public good is that its supply requires the active cooperation of every country; success depends on the weakest link. The last case of endemic smallpox occurred in Somalia in 1977. Had this person not been isolated, had the people with whom he had come into contact not been vaccinated, and so on, smallpox would still be with us today.

Back then, Somalia had a government that could help in this effort. But in 1991, that government fell in a coup, and ever since, Somalia has been a "failed state." It is interesting to speculate whether smallpox could be eradicated today. I think the chances are good that it could not happen. Indeed, one of the reasons polio eradication has yet to succeed is that wild polioviruses still reside in trouble spots like the border region shared by Afghanistan and Pakistan.

Climate change mitigation is the hardest global public good to supply. In contrast to asteroid protection, it cannot be addressed by one huge project. Unlike eradication, it is not in the interests of each country to contribute, so long as all other countries do so. For climate change, the incentives are more challenging: success depends on the aggregate efforts of all countries.

An agreement to reduce greenhouse gas emissions must do three things. First, it must attract wide participation. Even the United States and China, the two largest emitters, are each responsible for no more than a quarter of the total problem. Also, should only a few countries act, carbon-intensive industries will likely shift production to other countries, causing their emissions to rise.

Unfortunately, the Kyoto Protocol failed to attract wide participation. True, China is a party; but China is not required to reduce its emissions. The United States, of course, is not a party. Kyoto is a failure if only because it has not provided incentives for both countries to change their behavior.

Second, the treaty must also provide incentives for compliance. Canada's emissions currently exceed the Kyoto limits by over 30 percent and are expected to rise even further. When a country like Canada, a Kyoto signatory and an upstanding member of the international community, fails to comply, then you know there are problems with the agreement itself. Kyoto provides no incentives for Canada to comply, just as it provides no incentives for the United States to join.

Finally, the treaty must get all countries to reduce their emissions by a very substantial amount—eventually by half and soon after that by much more. Even if Kyoto were implemented to the letter—if the United States were to ratify and all parties were to comply perfectly—global emissions would keep on rising.

Efforts may be made to get the industrialized countries to accept much tougher targets. This would go some way toward meeting the third requirement, but it will make no difference at all if the first two requirements are not also met. This has been the problem with the climate negotiations so far: they have avoided the hard but essential challenge of enforcement. Without that, targets are meaningless.

Lacking a world government, global public goods must usually be provided by international cooperation. The world has succeeded before—in eradicating smallpox, in vanquishing the Axis powers, in preventing nuclear war, and in protecting the ozone layer. There are reasons for this. They have to do with incentives and the ability of international institutions to change them. Climate change is a harder problem, but we will not make any progress in addressing it until we understand this. That is the main lesson to be learned from the study of global public goods.

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4. THE VALUE OF CLIMATE-RELATED SATELLITE DATA

William Gail

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Satellite-based climate-related data play a critical role in monitoring the impacts of climate change, perhaps giving early warning of possible instabilities in the climate system, and in validating emissions reduction policies, especially in regard to forest carbon sequestration.

Earth observations data collected from satellites (which include readings of atmospheric chemistry and temperature, in addition to Earth imagery) play a unique and critical role in supporting policy decisions related to global climate change. Perhaps surprisingly, our process for planning future capabilities of these satellites addresses only a limited aspect of the diverse policy needs society will have when these satellites become operational.

Satellite observations complement climate-related data collected from ground-based monitoring systems. Satellite data improve our ability to monitor and understand how atmospheric accumulations of greenhouse gases (GHGs) change over time, as well as reveal trends in global average and regional temperature. In this way, the data refine the forecast accuracy of scientific models that tell us how atmospheric GHG concentrations will change in response to future GHG sources, what portion of these gases might be absorbed by the oceans and other carbon sinks, and the sensitivity of global temperature to changes in GHG concentrations.

Equally important, the data provide critically needed knowledge about the risk of possible instabilities or "tipping points" in the climate system. Even though the risks might be very small, the potential for globally catastrophic outcomes is among the greatest concerns about warming the planet. One possibility is that higher temperatures could lead to emissions of methane (a potent GHG) from the melting of permafrost or from beneath the ocean floor, causing substantially greater warming than we currently forecast. Satellite observations of methane concentrations in the atmosphere can help us monitor the mechanisms by which these releases of underground methane might occur, allowing us to anticipate and respond to the problem.

Sea-level rise is a widely reported consequence of global warming. A significant portion is expected to come from the melting of ice sheets and glaciers. However, the extent to which higher temperatures will lead to melting is poorly understood. Empirical measurement, provided by satellite data, has already proven essential to understanding how ice sheets and glaciers are changing over time. Earth observations data also facilitate the monitoring of many other potential consequences of climate change, such as expansion of deserts, disappearance of freshwater sources, harm to sea life through acidification of the oceans as they absorb more carbon, biodiversity loss, and alterations to forests.

Beyond climate science, satellite data play a potentially critical role in the implementation of policies that address climate change. The trend to include forest carbon and land use within emissions trading programs for reducing GHGs is a particularly strong motivation for a robust satellite monitoring program. Satellite data are needed to measure changes in forest cover and are important, in particular, for monitoring issues such as emissions "leakage" (in which planting of forests in one region is offset by accelerated deforestation elsewhere).

Earth observations even play a role in the establishment of baselines by which to measure emissions reductions programs, as well as assist in evaluating the effectiveness of these programs. In particular, regional emissions of non–carbon dioxide (CO_2)

GHGs, like methane and nitrous oxides, are easier to track with satellite technologies than ground-based systems. Even space-based measurements of a country's CO_2 emissions are useful as a check on estimates built up from a country's fuel consumption (which may not be reliably measured for poorer countries with limited accounting systems).

Furthermore, by providing a picture of how resources and natural systems at the local level are impacted by climate change, satellite-based data help to pinpoint where adaptation policies are most needed. Examples include policies to promote the transition to hardier crops in areas at greater risk of drought and construction projects for valuable coastal regions most threatened by rising sea levels.

USING SATELLITE DATA TO ASSIST CLIMATE POLICY

Earth-based observations of climate-related phenomena are a public good. As the private market for this information is presently limited, its collection must be largely funded by the government. NASA is the only U.S. government entity with a portfolio of satellites capable of generating new scientific understanding of climate issues. Over the last 20 years, the United States has invested around $1 billion a year in expanding, maintaining, and operating satellites for climate-related monitoring. The most recent congressional stimulus package (as of this writing, HR1, The American Recovery Act of 2009) allocates a further $400 million to fund environmental satellites identified as vital by a 2007 National Academy of Sciences study.

NASA's data collection over the last two decades has laid the groundwork for understanding how Earth's complex natural variability—and human influence on it—impacts society. However, the next step is to ensure that this accumulating scientific knowledge is fully applied to improve critical policy and economic decisions. At present there is a fundamental and puzzling disconnect between those parties engaged in crafting domestic climate policy legislation and those responsible for choosing how to allocate NASA funding among alternative priorities so as to inform policy issues. Legislative proposals provide little detail on how information will be collected and used to monitor emissions control programs, particularly with regard to crediting of forest sequestration and reductions in non-CO_2 GHGs. NASA representatives need a more prominent place in deliberations over climate policy design, to ensure both that the best use is made of satellite information and that NASA focuses on the most pressing priorities for Earth observation.

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5. THE SUCCESSFUL INTERNATIONAL RESPONSE TO STRATOSPHERIC OZONE DEPLETION

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In what may have been the first successful international response to a global environmental threat, after the national spray can bans of the 1970s proved inadequate and the Antarctic ozone hole was discovered in the 1980s, the world community came together to limit, and ultimately eliminate, production of ozone-depleting substances.

An international agreement dealing with climate change remains elusive, but as negotiators seek consensus, we can look back to the resolution of an earlier global environmental challenge: ozone. Although the ozone layer is not yet fully recovered, the international response to the discovery of stratospheric ozone depletion has been a remarkable success.

Chlorofluorocarbons (CFCs) were synthesized in the 1930s and initially used for refrigeration. By the 1970s, CFCs were used in aerosol spray cans; air-conditioning; foams for insulation, cushioning, and packaging; and as cleaning solvents. Although the number of firms using CFCs was large, production was restricted to a small number of firms, mostly in industrial countries.

Scientific studies in the mid-1970s suggested that CFCs might deplete stratospheric ozone. Because the compounds are chemically stable, they do not break down until they waft into the stratosphere and are exposed to intense ultraviolet radiation. The released chlorine catalyzes a reaction that converts ozone (O_3) to molecular oxygen (O_2). With less stratospheric ozone, more ultraviolet light penetrates to ground level and damages crops and plastics, causes skin cancer and cataracts, and harms phytoplankton, other plants and animals, and ecosystems.

North America and Europe took the lead in developing a global system to control CFC emissions, particularly after the surprise discovery of the Antarctic "ozone hole" in 1985. U.S. industry eventually supported international controls, partly because it feared that in the absence of international rules, new domestic rules would weaken its competitive position. The Montreal Protocol, signed in September 1987, set up an international framework to reduce CFCs and other ozone-depleting substances (ODS). Subsequent amendments nearly eliminated production of CFCs and similar compounds by the mid-1990s. HCFCs, which substitute for CFCs in some applications but are less potent ozone depleters, are regulated as transitional chemicals. Their use will be phased out by 2030.

ODS REGULATORY SYSTEMS

Although ODS are dangerous only if they are released to the atmosphere, the protocol regulates production and consumption because these are more easily monitored than emissions. Consumption is not measured but defined as production plus imports minus exports. For the United States, the limits apply at the national level; for the European Union, member states' production and consumption are not limited if the union as a whole complies.

U.S. implementation relies on tradable production and consumption permits, supplemented by excise taxes and end-use controls. The U.S. Environmental Protection Agency (EPA) issues annual permits for production (or import) and consumption to firms that manufacture or import ODS. Allocation is based on historical production or import shares. Permits are defined for each ODS, but intercompound trades based on ozone-depletion potential are allowed within ODS classes. The permits are tradable among firms without restriction and can be banked (saved for later use).

The U.S. command-and-control measures include prohibitions on ODS in certain applications, required equipment and training for refrigeration-service personnel, and prohibitions on selling small quantities of ODS. The "significant new alternatives policy" (SNAP) prohibits the replacement of an ODS with certain substitutes if alternative choices would better reduce overall environmental or health risk.

The initial EU regulation imposed a system of tradable production or import permits, similar to the U.S. system. These permits are tradable among firms within or between countries. A further regulation prohibits import of ODS and products containing ODS from countries outside the protocol and includes many end-use restrictions. Some EU member states adopted additional restrictions and economic incentives, such as taxes and deposit-refund schemes to encourage recovery of ODS in certain products.

ASSESSING THE RESULTS

EPA analysis of the rules implementing the Montreal Protocol in the United States estimated that the benefits of fewer fatal skin cancers alone would dwarf compliance costs. How well did the regulations work?

Effectiveness. Substantial reductions in CFC consumption were achieved with limited economic disruption. The concentration of ODS in the stratosphere peaked in the 1990s and is expected to fall to its prior level by midcentury, with ozone likely recovering to its prior levels around then.

Compliance costs. For the United States, compliance costs were comparable to EPA's estimates. The market price of CFCs appears to have been lower in the EU, suggesting smaller marginal compliance cost or more stringent command-and-control regulations there. The EU may have had lower costs because the Montreal Protocol required equal percentage reductions from a 1986 baseline. The United States had eliminated most of its aerosol use by then, but the EU had not and could achieve part of its compliance by limiting aerosol use at relatively low cost.

Administrative burden. Economic-incentive instruments make fewer information demands on regulators than command-and-control instruments. Ensuring compliance with the Montreal Protocol through end-use restrictions alone would have required information on the magnitude of ODS use and technological alternatives for reducing it in each application. EPA estimated that a traditional command-and-control approach would require 32 staff to administer and cost firms $300 million per year in reporting and recordkeeping. In comparison, the tradable-permit system required only 4 staff and cost firms just $2.4 million annually. Illegal imports, however, revealed limitations in monitoring and enforcement.

Burden on industry. U.S. tradable permits were allocated without charge to producers and importers based on their historical market shares. Because the permits were valuable, the allocation was a direct benefit, partially offsetting losses from restrictions on future sales. (Congress later imposed excise taxes, in part to capture some of these rents.) In contrast, ODS-user industries faced higher ODS prices.

Innovation. Information exchange among industries, governments, and international organizations helped minimize compliance costs and disruption. Producer and user industries collaborated internationally in safety and performance testing, and diffusion of alternatives was encouraged through trade shows, sometimes with government sponsorship.

Adaptability. The U.S. and EU tradable-permit systems easily incorporated changes each time the Montreal Protocol was amended. The permitted quantities could be reduced more easily and quickly than end-use restrictions could be tightened. In the United States, rulemakings to implement these amendments were completed within a year, substantially faster than most command-and-control rules.

PARALLELS WITH CLIMATE CHANGE

The issue of CFCs and stratospheric ozone shares some parallels with the problem of greenhouse gases. The effects of CFC emissions on stratospheric ozone are the same, regardless of which country releases them. Moreover, ODS and some of their substitutes are themselves greenhouse gases with long atmospheric lifetimes. Hence the benefits of reducing emissions span many future years, while control costs are borne up front. In contrast, negotiating an international regime to control CFCs was immeasurably easier than for greenhouse gases, given the small number of firms and countries involved.

Experience in resolving stratospheric ozone depletion shows that nations can work together to confront a global environmental threat, taking costly actions even before significant environmental damages result. The cap-and-trade mechanisms used in the United States and European Union proved effective and could be easily modified as international agreements required more stringent controls. Information sharing between producer and user industries accelerated and reduced the costs of transition.

While the response to ozone depletion provides a salutary model for how to respond to global warming, global warming is a much harder challenge: sources of greenhouse gases (notably fossil fuels) account for a vastly larger share of the world economy than did CFCs, and the number of firms and countries that contribute to global warming is far greater.

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6. EVALUATING EUROPE'S PLAN FOR REDUCING GREENHOUSE GASES

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The centerpiece of the European Union's effort to reduce greenhouse gases is the emissions trading scheme (ETS). As discussed in this commentary, plans for Phase 3 of the program resolve some serious design flaws that have characterized the ETS to date.

The European Union (EU) has mapped out its plan for the third phase of its carbon dioxide (CO_2) emissions trading scheme (ETS), which will begin in 2013. It is evident that lessons have been learned from the first two phases of the program. The EU has embraced a regulatory design that should enable substantial emissions reductions in the future, at least for the roughly 50 percent of total emissions covered by the trading program. This was not the case in the earlier design of the ETS.

The EU began a cap-and-trade program covering the power sector and major industrial sources in 2005, and the first phase of the program stretched through 2007. The program excludes transportation, small businesses, and direct fuel consumption by firms and households. The first phase has been maligned because after all the attention it received, in the end only minor emissions reductions were achieved, and the price for a tradable emissions allowance fell to near zero. But I see the situation somewhat differently. Much of the problem was that, when accurate inventories were taken for the first time, actual country emissions turned out to be lower than expected. The development of data systems, monitoring, and enforcement mechanisms form the infrastructure for subsequent phases of the program. Because the trading program is expected to last for decades, the initial emissions reductions will be relatively unimportant in the long run, when very substantial emissions reduction targets are possible.

More important than the emissions reductions that are achieved in the near term is the architecture of the program itself, specifically the incentives created under the program. The fact that the emissions cap in Phase 1 required few reductions should not be fatal in a well-designed program, because ideally the program would enable allowances to be banked for use in future compliance periods. This would provide firms with an incentive to harvest low-cost emissions reductions in the near term, because the allowances saved would have value in the future and the number of new allowances issued could be reduced accordingly. This approach also would provide a clear price signal to guide innovation and investment into the future. Unfortunately, the program did not allow for banking of allowances into Phase 2, but going forward, emissions allowances from Phase 2 can be carried over until Phase 3, so they will retain value and firms have an incentive to overachieve in the near term.

The weak environmental performance that characterized Phase 1 should not obscure the fact that there were important measures of success. The program was put together at a breakneck pace to demonstrate a commitment to the world that the EU would pursue climate policy goals. The first phase constituted a learning period for policymakers and stakeholders, with the introduction of emissions inventory and electronic reporting of environmental statistics in many of the 27 countries covered by the program.

Phase 2 of the program, which runs from 2008 to 2012, fixes two important problems. The cap is tightened, ensuring that meaningful emissions reductions will be achieved, and banking of allowances into the future is allowed. These changes create better incentives for innovation by supporting a higher allowance price, allowing investors to capitalize on low-hanging fruit in the near term, and by curbing allowance price volatility in the long run. In late 2009, the allowance price hovers around 14 euros per metric ton of CO_2 (about $21 per ton). Whether this is a reasonable price or not is not the question I mean to address here, but it is sufficient to provide meaningful incentives for reducing CO_2 emissions.

The major problem in Phase 1, however, also remains in Phase 2—namely, the initial distribution, or allocation, of allowances. In Phase 1, 99 percent of allowances were given away for free to emitters, and in Phase 2, this figure dropped slightly to 96 percent. But free allowances to emitters were not free to consumers—the regulated firms that received allowances for free increased the price of their products to reflect the opportunity cost of allowances (for example, their market value) because this is the value firms have to surrender in order to produce their goods.

Typically, firms have charged customers for allowances that they received for free, thereby leading to windfall profits, especially in the electricity sector, where power prices rose to incorporate allowance values. In the EU, those windfalls totaled many billions of euros, coming at the expense of consumers. Just as important, this revenue was not available for other purposes that would help reduce program costs, and the overall economic cost of the program was much higher as a consequence.

Phase 3 promises several important changes. First, the EU now embraces the principle of auctioning allowances rather than giving them away for free. The power sector will have to rely on auctions to obtain a majority of its allowances beginning in 2013. By 2020, the power sector will rely on full auctioning, and other covered sectors will have to rely on auctions for a majority of their allowances. Second, the compliance period lengthens to eight years, 2013 to 2020, providing a better planning horizon for investors. Third, the program's emissions targets are tighter and would ramp up significantly if there is expanded commitment from other nations to reduce emissions. Finally, there is a well-conceived effort to achieve equity among the EU member states by redistributing allowance allocations from wealthier states to poorer ones, which should help maintain support for the program.

The plan for the EU is part of an overall package of measures to implement climate and energy policy for Europe. The central aim is to reduce EU emissions by 20 percent from their 1990 levels by the year 2020 and by 30 percent if other industrialized countries agree to do the same. The policy governing sectors outside the trading program proposes a broad array of regulatory policies. These sectors are not directly covered by an emissions cap, and consequently the emissions target for these sectors is not as convincing as for those sectors covered by the trading program.

The intended reform for Phase 3 of the trading program addresses a variety of concerns head are on. Most significant of these the extended compliance period and the transition to auctioning. The result is a regulatory design that should enable substantial emissions reductions in the future in those sectors of the European economy. The encouraging result should attract the attention of U.S. policymakers.

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7. U.S. CLIMATE CHANGE POLICY

Previewing the Debate

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The United States may soon adopt limits on emissions of greenhouse gases (GHGs), particularly carbon dioxide (CO_2), most likely by putting an indirect price on emissions through marketable emissions allowances—a cap-and-trade program. This commentary reviews the five main policy design issues.

EMISSIONS TARGETS

Most policymakers think in terms of a target that would stabilize atmospheric GHG concentrations at some "safe" level. Many recent proposals aimed to reduce 2050 emissions by 50 to 80 percent below current levels, which could—given coordinated global action—achieve atmospheric stabilization at around double preindustrial levels. Energy models suggest that near-term emissions prices need to be about $5 to $50 per ton of CO_2 (rising at about 5 percent a year) to be consistent with such targets.

In contrast, economists typically think in terms of balancing the cost of additional emissions mitigation with the benefits of avoided future damage from climate change. This requires putting a price on emissions equal to an estimate of marginal benefits. The "right" price is considered to be between $5 and $30 per ton of CO_2 in the near term, although some say these studies give insufficient weight to distant future benefits and inadequately account for extreme risks.

ALLOWANCE ALLOCATION

How allowances are allocated—or how revenues from auctioning allowances are spent—will significantly influence the distributional effects of climate policy. Given the enormous wealth at stake—the value of allowances has been estimated at around $100 billion a year—it would be preferable for the government to auction all allowances and then make explicit, transparent decisions about how to use the revenues. Giving allowances away for free, on the other hand, would represent a large transfer of wealth to regulated firms.

Recent congressional proposals move toward auctioning a larger portion of allowances. But whether auction revenues will be used judiciously or fall prey to pork-barrel politics is another question. Some proposals would simply auction all allowances and return revenues to consumers through per capita rebates, an approach called "cap-and-dividend," that would make climate policy more equitable because the dividend, relative to income, would be higher for lower-income households. Alternatively, revenues could be used to cut taxes on labor and capital income and thereby reduce the economic distortions these taxes create. A typical estimate is that recycling $100 billion of revenue in income tax cuts would generate economic efficiency gains of around $25 billion or more.

COST CONTAINMENT

Cost containment is the fulcrum on which legislators hope to balance the ambition of emissions reductions with the economic impact. Cost containment itself, however, is not well defined. In practice, it conflates two issues: minimizing short-term allowance price volatility, and managing the long-term level of allowance prices. Several policy mechanisms have been proposed to accomplish one or both of these goals.

Banking and borrowing provide intertemporal flexibility and prevent allowance prices from being driven by year-to-year fluctuations in weather, economic growth, and other unrelated factors.

Allowance reserves are essentially institutionalized long-term borrowing by the government. The government brings some allowances forward from far-future caps and distributes them in the present.

Escalators and off-ramps kick in if allowance prices move outside a defined range. If prices are low, the emissions cap declines more quickly, but if prices are high, the cap stops declining or increases.

Price floors and ceilings allow legislators to select a range within which allowance prices will remain. Price floors can be implemented by incorporating a reserve price in allowance auctions. Price ceilings—often called a safety valve—are controversial, particularly among environmentalists, because the government's willingness to sell additional allowances at a prespecified price could compromise the emissions cap.

Independent oversight bodies would have authority to intervene in allowance markets with various policy mechanisms, much as the Federal Reserve oversees monetary policy.

Which policies merit enactment? Banking of allowances is uncontroversial and will certainly be included in legislation. Borrowing is likely to be allowed but limited in both volume and duration. Triggered mechanisms, which could abruptly cycle on and off or create odd incentives, are less than ideal. Price floors—minimum auction prices—should certainly be used. A price ceiling could increase the efficiency of a cap-and-trade program but may not be politically viable, making the idea of a reserve pool of allowances potentially attractive. A reserve might not alter long-term expectations, but in the short run it indicates a commitment to climate policy that may make a program more credible. To function well, independent oversight bodies need clear objectives combined with instrumental independence—characteristics largely lacking in the proposals to date.

More generally, Congress may find it useful to focus the discussion of cost containment on the question of short-term volatility, to help separate the question of good policy design from the broader scientific, economic, and political debate about emissions targets.

COMPETITIVENESS

Climate policy will raise the price of energy-intensive goods, perhaps disadvantaging domestic producers and shifting production and emissions to unregulated regions overseas. Policies to address competitiveness concerns must either lower the cost of domestic goods and exports or raise the cost of imported goods.

One proposal supported by some domestic industries would raise the cost of imports through border taxes on the "embodied emissions" in manufactured goods. Some argue that border adjustments would prompt trading partners to adopt climate policies of their own; others warn of poisoning multilateral negotiations and sparking retaliatory trade policies. Whether such policies would pass muster with the World Trade Organization is uncertain, and accurately determining embodied emissions would be challenging.

Other proposals would weaken regulatory requirements for domestic manufacturers, typically by exempting certain industries from the cap-and-trade program and instead using product standards to regulate the carbon intensity of manufactured goods. This would be good for exempted manufacturers but distortionary for the economy as a whole, pushing economic activity into lightly regulated sectors.

This leaves the option of subsidizing manufacturers' production costs by allocating some emissions allowances for free but (unlike grandfathering) updating them based on some metric of production. This implicit rebate keeps the playing field level at home (vis-à-vis imports) and abroad (vis-à-vis competitors in export markets). Around 15 percent of allowance revenues, provided on the basis of output, would compensate energy-intensive industries for abatement costs and mitigate leakage. An important question for competitiveness policies is how they respond as major trading partners take on comparable actions—for example, accelerating phaseout of free allocation to energy-intensive industries if developing countries enact their own climate policies.

INCORPORATING STATES

So far, the states have led on climate policy: California passed GHG legislation in 2006, and 10 northeastern states instituted the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program for electricity sector emissions, in January 2009. Will the federal program give credit to states for early actions or convert their allowances into federal allowances? Will states be allowed to go beyond the federal program? These considerations may become salient as political negotiations proceed; consider that 22 senators represent California and the RGGI states.

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8. WHICH IS THE BETTER CLIMATE POLICY?

Emissions Taxes versus Emissions Trading

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Whether the principle instrument to reduce greenhouse gases should be an emissions tax or a cap-and-trade system has been the subject of intense debate. Both instruments actually have considerable merit, though this hinges critically on key design features.

In many ways, tax and cap-and-trade systems to reduce carbon dioxide (CO_2) from fossil fuel combustion appear to be equivalent policy instruments. Either instrument can be levied upstream in the fossil fuel supply chain to encompass all potential emissions sources, with the tax or permit requirement proportional to a fuel's carbon content. In either case, the tax or allowance price is passed forward into higher fuel and energy prices, encouraging the adoption of energy-saving technologies, substitution away from high-carbon fuels to other fuels, and so on. However, the instruments may differ in two potentially important regards.

FISCAL ISSUES

One important way in which CO_2 taxes differ from "traditional" permit systems (where allowances are given away for free to firms) is that taxes raise revenue. For example, a \$20 CO_2 tax would initially raise around \$100 billion in revenue per year for the U.S. federal government. One way of using this revenue would be to finance a reduction in individual federal income taxes of around 10 percent, which would (moderately) alleviate various tax distortions in the economy. For example, by taxing away some of the returns to working and saving, income taxes deter some people from joining the labor force and encourage others to consume too much of their income. Income taxes also induce a bias away from ordinary spending toward items that are deductible or exempt from taxes (for example, owner-occupied housing and employer-provided medical insurance). Although subject to some dispute, research suggests that the economic efficiency benefits from recycling the revenues from a \$20 CO_2 tax are as high as \$40 billion a year, representing a substantial cost savings that would not be possible under a traditional permit system.

However, the answer to the question of whether a strong fiscal argument exists for CO_2 taxes over cap-and-trade lies in the details. If legislation accompanying the tax does not specify that revenues offset other taxes, then the new revenue sources might end up being wasted in special-interest spending. Alternatively, revenue might finance deficit reduction, but it is not clear whether this will ultimately lead to lower taxes in the future, or increased public spending.

Moreover, auctioning off the allowances in a cap-and-trade system, rather than giving them away for free, would generate the same amount of government revenue as an emissions tax for a given CO_2 price. So what matters is not so much the choice of emissions control instrument, but rather whether that instrument raises revenue (as both auctioned allowances and emissions taxes do) and uses that revenue productively.

PRICE VOLATILITY

A second potential argument for a CO_2 tax is that it fixes the price of emissions. In contrast, under a pure cap-and-trade system, emissions reductions are certain, but the CO_2 permit prices would vary over time with changes in energy demand, fuel prices, and so on. Volatility in permit prices may deter large investments in carbon-saving technologies (for example, carbon capture and storage) or major research and development programs (like hydrogen or plug-in hybrid vehicles), as it makes the long-term payoffs from these investments uncertain. Moreover, it makes economic sense to allow firms to produce more emissions in years when the costs of meeting a given emissions cap would otherwise be very high (a year of particularly high energy demand, for example), while encouraging extra abatement effort in years when the costs of meeting the cap are lower. An emissions tax provides this flexibility, and studies show that over time the expected environmental benefits, minus emissions mitigation costs, may be much greater than those under a fixed emissions cap.

But again, the distinction between taxes and permits may be more apparent than real, as cap-and-trade systems can be designed to limit the price volatility. For example, "safety valves" eliminate disruptive price spikes as the government steps in to sell extra allowances if permit prices reach a certain trigger point. Alternatively, allowing firms to borrow permits from the government during periods of high permit prices and bank permits when there is downward price pressure would help to smooth out sharp price fluctuations. In fact, some limited price flexibility might be desirable as it allows new information to be instantly reflected in market prices and abatement decisions. For example, if global warming occurs faster than expected, speculators would expect a tightening of the future cap, forcing permit prices both in the future and in the present higher; in contrast, it could take years to get a change in emissions tax rates enacted in response to new scientific information.

PRACTICAL ISSUES

In short, the key distinction is not really between CO_2 taxes and emissions trading schemes per se. Rather, it is between policies that raise revenues—and use revenues to enhance economic efficiency—and have limited price volatility (as with CO_2 taxes or auctioned permits with safety valves and emissions trading over time), versus non-revenue-raising instruments with no provisions to limit price variability (as in a traditional permit systems).

However, what would be the point of developing an elaborate emissions trading system if its main purpose is largely to mimic the effects of a (simpler) CO_2 tax?

One possibility is that policymakers may prefer the certainty of progressive emissions reductions over time provided under a cap-and-trade system. But this is no reason to reject the CO_2 tax out of hand, as the tax rate could always be raised in the future if targets for emissions reductions are not being met, perhaps due to unexpectedly rapid economic growth.

Another possibility is that policymakers may wish to provide temporary compensation for industries adversely affected by the emissions control program. Under a cap-and-trade system, granting some free allowances to those industries, which they might then sell to other firms, is a natural mechanism for such compensation, though at the cost of scaling back the potential efficiency benefits from recycling allowance auction revenues. However, compensation is also possible under a tax regime, perhaps by taxing firms only for their emissions over and above some threshold level that is exempt from the tax, or providing them temporary relief from, for example, corporate tax liabilities.

MOVING FORWARD

Broad-based, and appropriately scaled, federal action to begin a progressive transition away from a carbon-intensive economy is to be welcomed. However, achieving that with the best climate policy is also important, not just for minimizing transition costs, but also for increasing the prospects that the policy will be effective and sustained over time. Aside from the overall level of policy stringency, the two most important issues are the potentially large dividends to be reaped from raising and recycling revenue, and from containing emissions price volatility. Whether either emissions taxes or cap-and-trade systems are well designed in these regards is truly in the details of the legislation accompanying the policy.

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9. SHOULD CAP-AND-TRADE SYSTEMS BE SUPPLEMENTED WITH RENEWABLE PORTFOLIO STANDARDS?

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Cap-and-trade proposals to reduce greenhouse gas emissions are often supplemented with renewable portfolio standards (RPS) that regulate the share of renewables in power generation. How do RPS affect the costs of emissions control programs, is there an economic justification for these policies, and if implemented, how should they be designed?

Cap-and-trade systems have become a central pillar in existing and proposed U.S. and European policies to control carbon dioxide (CO_2) emissions. But that's not the only regulatory scheme being pursued both here and abroad: many policymakers are pushing for ambitious increases in the production of renewable energy. Are there any synergies between the two? Maybe, maybe not.

Federal production tax credits for renewable power have recently been expanded in the United States, and more than half of the states have established renewable portfolio standards (RPS). These require a certain share of power generation to come from renewable sources, providing a potential basis for a future federal RPS. The EU is even more ambitious, promising to increase its share of renewables in overall energy use to 20 percent by 2020, together with a 20 percent reduction in greenhouse gas emissions. Individual member states typically rely on either RPS or feed-in tariffs (which provide temporary subsidies to encourage market penetration of new technologies), or both, to stimulate renewable power production (in Europe, RPS is usually termed tradable green certificates).

RENEWABLE POLICIES AND THE COSTS OF CAP-AND-TRADE

If the only objective were to reduce CO_2 emissions, and there were no other market imperfections, then an appropriately scaled cap-and-trade system alone would be sufficient. The price on emissions would promote cost-effectiveness by equalizing the marginal costs of abatement through different options for reducing emissions, such as switching from coal to renewables and other low-carbon energy sources, adopting carbon capture and storage technologies at coal plants, reducing overall electricity use, reducing consumption of transportation fuels, and so on.

Under these conditions, supplementing a cap-and-trade system with an RPS would be counterproductive. If the emissions cap were binding, the RPS would have no effect on emissions (unless they become so stringent that the renewable policy stand-alone caused emissions to fall below the emissions target). At best, the RPS would be redundant if the renewable constraint is already met by the cap-and-trade system. But the more likely result would be to raise the overall costs of the emissions cap by inducing excessive abatement from expansion of renewables and too little abatement from other mitigation opportunities.

In a recent paper, we examined the implications of implementing RPS in addition to a cap-and-trade system in the context of the German electricity market. Using a numerical model of this market, we considered a cap-and-trade system that imposes a 25 percent emissions reduction below the business-as-usual level. An RPS that progressively forces up the share of renewables in the generation mix by 10 percentage points above the share with no RPS roughly doubles the overall costs of the emissions cap.

Under a binding emissions cap, an RPS benefits not just renewable producers but also the most CO_2-intensive power producers, while other low and zero carbon sources (like nuclear and coal with carbon capture and storage) lose out. The explanation for this presumably unintended effect of renewable policies is that the price of CO_2 allowances falls, which is especially beneficial for the most emissions-intensive power plants. According to our results, when emissions in the German power sector are reduced by 25 percent through a cap-and-trade system alone, lignite power production (the most CO_2-intensive power plants in Germany) falls by around 40 percent. Then, when the share of renewables is raised by 10 percentage points, production of lignite power increases by 17 percent (that is, to a level around only 30 percent instead of 40 percent below the business-as-usual level).

RATIONALES FOR RENEWABLES POLICIES

So is there a definitive case against portfolio standards and other renewables policies? The answer is not entirely clear, as there are other possible "market failure" arguments that might justify the use of these policies as a complement to a CO_2 cap-and-trade program.

One possibility is that the market penetration of renewable fuels, even under a cap-and-trade system, may otherwise be too limited, due to technology spillovers. In particular, an early adopter of a new technology may find ways to lower the costs of using that technology through "learning by doing." Later adopters benefit from the knowledge created through earlier learning by doing at other firms, but they do not have to pay for it. Correspondingly, early investment in a technology may therefore be too low, because early adopters do not take into account the knowledge spillovers to other firms. In principle, this market imperfection may justify the use of a technology-forcing policy like an RPS.

However, at present there is little evidence available on the magnitude of these knowledge spillovers for relatively new technologies like wind and solar, so it is difficult to judge to what extent, if any, an RPS is justified as a complementary measure. A similar example would be the tax credit for hybrid cars in the United States; the question of whether that credit made sense on the grounds of learning-by-doing spillovers has never been thoroughly studied either.

Another possible rationale for using RPS is energy security interpreted as reduced import dependence for oil and gas. Increased production of renewable power will typically suppress gas power production, and therefore reduce the demand for imported gas from "unstable" sources like Russia. This is presumably a more important issue in Europe than in the United States. With a cap-and-trade system in place, this effect might be strengthened because, as noted above, introducing RPS will expand both renewable and coal power production, partly at the expense of gas power. The effect of RPS on oil imports is more modest and indirect, because oil is only marginally used in the power sector. Again, it is difficult to translate energy security in terms of reduced import dependence on fossil fuels into monetary economic benefits that may offset the additional cost of RPS.

DESIGN ISSUES

The economists' case for cap-and-trade has largely been made, but the jury is still out when it comes to renewables policies. Given that these policies are becoming increasingly prevalent for many other reasons, it behooves us to recommend design features to contain the costs of these policies.

With a cap-and-trade system in place, designing renewable policies should focus on other issues than CO_2 emissions, such as the potential market failures referred to above. If these are supposed to be equally important across renewable technologies, a market-based RPS, where firms are allowed to trade credits derived from renewable production, may be a proper instrument. It stimulates the cheapest renewable options, and so the renewable target is reached in a cost-effective way. As long as RPS are implemented at the state and not the federal level, overall costs can be further contained by also allowing trade in credits across states. Banking and borrowing can reduce costs even further, and also help smooth the price of credits, and consequently the price of electricity. Broadening the coverage of RPS to include large-scale hydro power (which is often excluded), nuclear, and coal power with carbon capture can also bring down costs. However, the choice of technologies covered by the RPS as well as the specific design should be driven by the market failure(s) it is supposed to confront.

In the case of import dependence, for example, it is reasonable to consider the market failure to be of equal importance for all renewables. The answer is less clear when it comes to technology spillovers. If these are believed to be largest for the most immature renewable technologies, which are often the least competitive ones, other instruments than RPS may be more appropriate. This could, for instance, be technology-specific subsidies that are reduced over time as the technology matures.

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10. INDUCING INNOVATION FOR CLIMATE CHANGE MITIGATION

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Stabilizing global climate change at acceptable levels will require the development and wide diffusion of transformative technologies to substantially lower the emissions intensity of economic activity. What is the best long-term strategy for promoting such technological change?

Fossil fuels provide for over 80 percent of U.S. and global energy use, but unfortunately also contribute the majority of greenhouse gas (GHG) emissions. Achieving the very significant reductions in GHGs that are now widely regarded as necessary would require innovation and large-scale adoption of GHG-reducing technologies throughout the global energy system. Alongside policies aimed directly at mandatory GHG emissions reductions—such as a cap-and-trade system or a carbon tax—much discussion has surrounded policies targeted at technology R&D activities and technology-specific mandates and incentives. The resulting debate is therefore not so much over the importance of new technology per se, but rather over which policies and institutions will be the most effective and efficient for achieving the technological changes and associated emissions reductions necessary for stabilizing GHG concentrations.

When considered alongside policies that impose mandatory GHG-reduction requirements, additional technology policies may not seem necessary or desirable. After all, the point of market-based approaches is to establish a price on GHG emissions. Just as people will consume less of something that carries a price than they will of something that is given away for free, attaching a financial value to GHG reductions should induce households and firms to buy technologies with lower GHG emissions the next time they are in the market (for example, a more efficient car or appliance). This market-demand pull should in turn encourage manufacturers to invest in R&D efforts to bring new lower-GHG technologies to market, just as they do for other products and processes. That is why many experts and most economists—including this one—think that establishing a market-based price for GHG emissions is the single most important policy for encouraging the innovation and adoption of GHG-reducing technologies.

But is a GHG price the *only* useful policy, or should we have other arrows in our quiver? There are, in fact, several motivations for including additional R&D policies as complements to a pricing policy in a comprehensive strategy to address climate change. The economics literature on R&D points to the difficulty firms face in capturing all the benefits from their investments in innovation, which tend to "spill over" to other technology producers and users. This market reality can lead to underinvestment in innovative efforts—even given intellectual property protection—potentially warranting policies that directly target R&D. The problem of private-sector underinvestment in technology innovation may be exacerbated in the climate context, where the energy assets involved are often very long-lived and where the incentives for bringing forward new technology rest heavily on domestic and international policies rather than on natural market forces. Put another way, the development of climate-friendly technologies has little market value absent a sustained, credible government commitment to reducing GHG emissions.

If more stringent emissions constraints will eventually be needed, society will benefit from near-term R&D to lower the cost of achieving those reductions in the future. An emissions price that is relatively low in the near term may be inadequate to induce such innovative efforts absent very credible expectations that the policy will indeed be tightened in the future. If the politically feasible near-term emissions price (or the expected long-term emissions price) is lower than what would be best for society, market inducements for R&D on GHG-reducing technologies will also be insufficient. These motivations provide compelling rationales for public policies targeted at the R&D phases of the technology innovation process, including efforts that lower the cost and expand our options for low-GHG renewable energy, energy efficiency, nuclear power, and carbon capture and storage.

What specific policies might be useful in this regard? The R&D tax credit against corporate income has been the historical means for encouraging greater private sector R&D—in general, not just for energy or climate. Making the R&D tax credit permanent would help to further strengthen private-sector incentives that would be induced by a price on GHG emissions—currently the credit expires and then is extended every few years. Targeting the tax credit specifically at GHG-reducing technologies would be difficult, however. Another worthwhile option is to use innovation-inducement prizes to encourage GHG-reducing innovation, by offering financial or other rewards for achieving specific technology objectives that have been specified in advance.

While increased private-sector R&D is an essential part of the solution, private R&D tends to be focused on applied research and especially development. Publicly funded contracts and grants for clean energy R&D—which focuses on strategic basic research and precommercial applied research—are therefore important additional parts of the overall strategy. By virtue of its critical role in the higher education system, public R&D funding will continue to be important in training researchers and engineers with the skills necessary to work in both the public and private sectors to produce GHG-reducing technology innovations. This linkage has led to a recent increase in political support for expanded spending—particularly on physical sciences and engineering.

Overall, public funding for research tends to receive widespread support based on the significant positive spillovers typically associated with the generation of new knowledge. Many experts have advocated at least doubling relevant energy R&D over the next several years in order to help accelerate climate technology innovation. Translating this support into real increases in funding is more of a challenge—a challenge that could potentially be met through funds arising from a carbon tax or from a cap-and-trade system with allowance auctions.

Agreement over the appropriate role of public policy in technology development tends to weaken, however, when it comes to directed technology support for widespread technology deployment. Most economists and many other experts think that a broad-based, technology-neutral emissions price stands the best chance of guiding deployment among the wide variety of technological options at the lowest possible cost. To date, however, almost all technology-focused funding in proposed climate legislation is targeted at deployment rather than R&D.

In sum, climate technology policies are best viewed as a *complement to* rather than a *substitute for* an emissions pricing policy. But they are an important part of the climate policy portfolio, particularly if we hope to lower the cost and expand the options for significant future GHG reductions both in the United States and abroad.

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11. HOW SHOULD EMISSIONS ALLOWANCE AUCTIONS BE DESIGNED?

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Policymakers are increasingly interested in auctioning at least some of the emissions allowances in cap-and-trade systems, rather than giving them all away for free. What considerations should be taken into account for the efficient design of allowance auction markets?

As more and more governments, both here and abroad, start to implement cap-and-trade programs to reduce emissions of carbon dioxide (CO_2), interest in emissions allowance auctions is growing. Several of the states involved in the Regional Greenhouse Gas Initiative (RGGI) are auctioning 100 percent of their allowances under this cap-and-trade program. And the European Commission is now proposing that a majority of the CO_2 allowances allocated to electricity generators be sold in an auction, starting in 2013, with a phase-in to 100 percent auctioning by 2020. Auctioning is also a central component in the national cap-and-trade proposals currently before the U.S. Congress. The Kerry-Boxer bill (S. 1733), includes a provision to auction over 20 percent of the allowances initially, growing to over 70 percent by 2030. Several other federal bills envision a similar increasing reliance on auctions over time.

Policymakers are seeking an approach that will achieve a number of policy objectives, including a competitive market with no collusion and good price discovery, an efficient allocation of emissions allowances, minimal interference with operation of the secondary allowance market, minimal price volatility, and low administrative and transaction costs. Maximizing revenue—a common goal in most government auctions of public assets, like drilling rights for oil—is not a priority here.

Given these diverse needs, what's the best approach to designing an auction? Research, including economic experiments conducted to guide the design of the RGGI allowance auction, suggests that the most effective design is a sealed-bid, uniform price auction where all winning bidders pay the first rejected bid. This way, auction participants who place a high value on allowances can feel free to bid their true value, knowing that they will only have to pay the highest rejected bid (the market-clearing price) for the allowances that they win. Uniform price auctions do a better job at tracking changes in market conditions and revealing the true market price. Simplicity also suggests that a one-round auction is preferable to a more complicated multi-round approach, which is both time-consuming and more susceptible to collusion.

However, this approach could yield inconsistent prices. If allowances from more than one year are auctioned at the same time, the price of the later vintage (for example, 2010) could potentially exceed the price of the earlier one (2009). (The vintage of an allowance defines the first year or time period when it can be used for compliance with the emissions cap.) One possible solution is a combined vintage auction, based on the idea that allowances are bankable and that a bid for a later vintage should be treated as a request to purchase either that vintage or an earlier one, whichever is less expensive.

Allowance auctions should be held frequently enough to maintain liquidity in the allowance market, but not so often as to raise administrative and transaction costs unnecessarily. Having large infrequent auctions could pose a financial challenge to firms that need to acquire large quantities of allowances at each auction and consequently must put up substantial amounts of capital to participate. Such auctions also could disrupt secondary market trading because large quantities of allowances would be introduced at the time of the auction.

Well-designed auctions should include a minimum, or reserve, price below which no allowances would be sold (reserve prices are common in auctions like those on eBay). This feature helps to limit the gains to bidders from collusion and could be used to prevent allowances from being sold for less than the minimum value that regulators or society places on a ton of CO_2 emissions. Reserve prices must be backed up by a commitment not to sell allowances for less and a rule about whether and how unsold allowances could be reintroduced into the market. Reserve prices could be set at some absolute level that would presumably grow over time as CO_2 caps grow tighter or, after a secondary market has developed, at some fraction of a well-established index of recent prices in the secondary market.

Auctions should be open to all qualified participants, namely any entity that can provide assurance of the financial resources to follow through on its bid to purchase allowances. Restricting participation will limit competition in the auction and could help facilitate collusive behavior, driving a wedge between prices in the auction and the true market price of allowances.

Contrary to the open auction principle, some have tried to argue that restricting participation in allowance auctions to entities that are required to comply with the cap-and-trade regulation will have several beneficial effects. For example, advocates of this line of thinking suggest that restricting participation would prevent a large bidder with no CO_2 emissions from hoarding allowances in the auction. Limiting auction participation is also seen as a way to prevent outside entities from purchasing allowances for use as CO_2 emissions offsets in other voluntary or regulatory programs.

However, this line of argument is not sufficient. Restricting access to the auction will not by itself limit access to the allowance market, and hoarding behavior could be effected in the secondary market as well. Opportunities for hoarding can be reduced through other design features, such as frequent small auctions, and limits on the proportion of allowances in a single auction that can be purchased by a single entity. The fact that hoarding or cornering the market is likely to be an expensive and risky strategy is perhaps the greatest deterrent.

On March 17, 2008, the states participating in RGGI released a synopsis of the design elements for their allowance auctions, and the first auction took place in September 2008. The RGGI auction design is largely consistent with that recommended here. That historic event began the real world test of how well the auction design elements adopted by RGGI work in practice for CO_2 allowances. Stay tuned for the rest of the story.

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12. COMPETITIVENESS, EMISSIONS LEAKAGE, AND CLIMATE POLICY

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One of the obstacles to implementing climate policy in the United States has been the worry that domestic firms competing in global markets will be disadvantaged. How serious are these concerns?

In the debate over mandatory federal carbon pricing policies, the potential for adverse effects—on energy-intensive, import-sensitive industries, on domestic jobs, and on the nation's trade balance—consistently emerges as a significant concern. Equally important is the potential for erosion of the environmental benefits if an increase in domestic production costs shifts production to nations with weaker climate mitigation policies, or none at all.

COMPETITIVENESS

With regard to competitiveness issues, recent analyses by Ho et al. (2008) have considered the kinds of adjustments to climate policy that firms can make over different time scales.

- In the very short run, firms cannot adjust prices or production techniques, and profits fall accordingly.
- In the short run, firms can raise prices to reflect higher energy costs but lose sales as a result of product or import substitution.
- In the medium run, in addition to changing output prices, firms can change the mix of energy, labor, and other inputs in their production processes, but capital remains in place; economywide effects are considerable.
- In the long run, capital may also be reallocated across the economy.

Based on modeling results using an assumed carbon dioxide price of $10 per ton, several findings emerge. Measured by the reduction in domestic output, several industries are at greatest risk of contraction over both the short and the long terms: chemicals and plastics, primary metals, and nonmetallic minerals. Another hard-hit industry, petroleum refining, will likely be able to pass along most cost increases. Output reductions shrink over time, however, as firms adjust inputs and adopt carbon- and energy-saving strategies. Industries that continue to bear the impacts are generally the same ones affected initially, albeit at reduced levels. As profits drop in the short term, competitive markets adjust to ensure market rates of return in the longer run.

In the near term, the largest cost increases are concentrated in particular segments of affected industries: petrochemical manufacturing and cement see very short-run cost increases of more than 4 percent, while iron and steel mills, aluminum, and lime products see cost increases exceeding 2 percent.

Overall production losses also decline over time in most nonmanufacturing sectors, although a more diverse pattern applies. The initially significant impact on electric utilities does not substantially change, whereas mining experiences a continuing erosion of sales as broader adjustments occur throughout the economy. Agriculture faces modest but persistent output declines due to higher prices for fertilizer and other inputs.

Short-term losses in employment are roughly proportional to those of output. Over the longer term, however, after labor markets adjust, the remaining, relatively small job losses are fully offset by gains in other industries, leaving no net change in employment.

POLICY TOOLS

The best solution to addressing climate change, most experts agree, involves binding international agreements that create parity in carbon markets. But in the interim, unilateral actions must be taken. A consequence is emissions "leakage"—domestic reductions are offset by increases abroad as production, demand, and energy supplies are reallocated globally. Over the long term, the leakage rate for the few most vulnerable industries could be as high as 40 percent in the case of a unilateral $10 per ton CO_2 price.

Displacement of production through lost competitiveness is not the only source of carbon leakage—and may not even be the main source. A large-scale drop in U.S. demand for carbon-intensive energy will drive down fossil fuel prices globally and expand consumption elsewhere. Coal and oil will become cheaper, making electricity and steel in China less expensive and more carbon intensive. The only way to address such leakage is to ensure that all major countries adopt comparable carbon policies and prices.

Climate policy must be cost-effective: it must ensure access to inexpensive mitigation opportunities throughout the United States (and potentially around the world), minimizing the expense of achieving the emissions target. Beyond that, policymakers have several options.

A weaker overall policy—less stringent emissions caps and/or lower emissions prices—would offer relief to all industries, not just those facing increased competition. But environmental benefits and incentives for technology innovation would be smaller. Exempting certain sectors provides more targeted relief but eliminates incentives to deploy even inexpensive measures. Traditional forms of regulation, such as emissions standards, could deliver some emissions reductions while avoiding the added burden of allowance purchases (under auctioned cap-and-trade programs) or taxes on remaining emissions. However, the overall cost to society will tend to be higher than under an economywide pricing policy.

Trade-related "border adjustment" policies would require importers to purchase allowances based on actual or estimated embodied emissions, leveling the playing field at home between imported and domestic consumer goods. It would have the same effect on our exports and foreign goods, by adding an export rebate based on average emissions payments in the sector. Such adjustment policies may raise concerns within the World Trade Organization, however.

An allocation policy that keeps domestic costs from rising in the first place would also do the same thing. Allowance allocation would need to be updated in accordance with output, and the value of that allocation would function like a domestic production rebate. This type of benchmarking with ongoing adjustments stands in contrast to the fixed allocations used in Title IV of the Clean Air Act.

Fischer and Fox have examined the options and found different economic trade-offs. Although all the options promote domestic production to some extent, none would necessarily be effective at reducing leakage because while they reduce emissions abroad, they expand the emissions of domestic firms. The net effects depend on the relative responses of domestic and foreign producers to carbon price changes and on the relative emissions intensity of production at home and abroad. It seems likely that for most U.S. sectors, a full border adjustment—combining an import adjustment based on actual embodied carbon emissions with an export rebate—is most effective at reducing global emissions. But if for reasons of avoiding trade disputes import adjustments are limited to a weaker standard, the domestic rebate can be more effective at limiting emissions leakage and encouraging domestic production.

QUALIFICATIONS

Now, some caveats. First, although an emissions cap can limit domestic emissions, awarding additional allowances to certain sectors to compensate for competitiveness concerns will tend to raise allowance prices overall and shift costs among sectors. For energy-producing sectors like electricity or petroleum refining, a production rebate undermines incentives for cost-effective conservation efforts. Second, border adjustments risk providing political cover for unwarranted protectionism and may provoke trade disputes. Third, many of our largest trading partners—including the European Union—are implementing emissions pricing. And for most energy-intensive manufacturing, these partners represent a quarter or more of the leakage from lost competitiveness. Thus, actual leakage is less of a concern, and any allocation scheme must consider how preferential treatment will be phased out.

Overall, sector-specific policies are more difficult to implement than economywide approaches and can require hard-to-obtain data. Furthermore, they create incentives for rent seeking as industries seek special protection without necessarily being at significant competitive risk. Nonetheless, a unilateral or near-unilateral domestic carbon mitigation policy could in fact cause adverse impacts on certain energy-intensive, import-sensitive industries, particularly in the short to medium term, justifying some kind of policy response.

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13. ADDRESSING BIODIVERSITY AND GLOBAL WARMING BY PRESERVING TROPICAL FORESTS

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Environmentalists have long been exasperated by the loss of biodiversity from the progressive destruction of tropical forests. Global warming policies at last offer some hope of slowing deforestation, as firms in developing countries have incentives to partly offset their emissions mitigation obligations through the purchase of credits to maintain the carbon stored in tropical forests. Tropical forests have long been recognized as providing habitat for a huge share of the world's wildlife and plant species. For decades, however, concern has been mounting that these sensitive ecosystems, which constitute over 50 percent of the planet's forested area, are in peril. The clearing of large tracts of tropical forests and conversion of that land for other uses destroys habitats and threatens many species with extinction.

Why should tropical forests be protected? One long-standing argument is that governments should protect these areas, rich in biodiversity, because of their untapped potential for the pharmaceutical industry. For example, a plant currently undiscovered, deep in the forest, could one day prove helpful in the fight against HIV/AIDS. However, this reasoning has not held up over time. A famous project saw Merck & Co., Inc., one of the world's largest pharmaceutical companies, providing $1 million dollars to Costa Rica in return for 1,000 plants collected from its forests. Although the Merck project successfully raised money for Costa Rican biodiversity research, few, if any, drugs have been developed, and the model has not been transferred elsewhere.

However, a new justification is emerging. Real hope lies in the idea of protecting forests for their value in the fight against global warming. Forests contain huge amounts of carbon, and are often referred to as carbon "sinks," for they absorb and store carbon dioxide from the atmosphere. As concerns about the consequences of global warming grow, and as more people understand how carbon dioxide contributes to that warming, it is possible not only to estimate the value of a forest for sequestering carbon, but also to provide landowners with incentives to avoid deforestation. Simply put, by controlling deforestation we can significantly affect our carbon emissions. Studies suggest that halting deforestation in the tropics and other judicious uses of forestland for carbon control and storage could substantially reduce the costs of mitigating global warming.

Recent market transactions on the European Climate Exchange place the value of carbon somewhere between $10 and $100 per ton (the price of carbon dioxide = 12/44 the price of carbon). Furthermore, the exchange provides a vehicle to allow landowners to capture the value of the carbon benefits. Even if we use what seems like a fairly conservative price of $80 per ton, that means that the almost two billion hectares of tropical forests currently hold captive a whopping 300 billion tons of carbon, worth about $6 trillion.

If we add the 140 billion tons of carbon in the dead wood, litter, and soils on the forest floor, the additional value is $2.8 trillion, meaning an impressive total value of $8.8 trillion for the globe's tropical forests.

Sorting out the value and benefits of these forests is one thing. Next we need to work out how much we're willing to pay to keep them intact.

For a landowner, one study suggests the value of cleared land works out to $300 per hectare, on average (Pearce 1996). So let's assume that governments will need to pay $500 per hectare to stop them from felling their trees. That adds up to a $1 trillion cost across all of the world's tropical forests. Yet the benefits of sequestered carbon in those forests, even at modest prices, are about 8.8 times as great as the costs.

The difficult question remains, however, as to who will pay to sustainably maintain these forests. Until now, no one has come forward with the requisite large amounts. However, with carbon credits selling for up to $100 per ton, tropical countries may find it in their interest to take heed. The concept is that countries that can reduce or eliminate high rates of deforestation could receive carbon credits that would be recognized and could be transacted in the carbon markets. Countries that found it difficult to meet their carbon emissions targets under the Kyoto Protocol or subsequent climate agreements could purchase the credits generated by avoided deforestation to meet those targets. Thus, benefits would accrue to both buyers and sellers of carbon credits, and the benefits of tropical forests could be preserved for humankind. Another approach would be to focus on the tropical lands that are particularly subject to deforestation. Most of the world's tropical deforestation takes place in eight countries, with 50 percent occurring in Brazil and Indonesia. So, in order to maximize efficiency at the start, an initial approach might be to focus "avoided" deforestation strategies and funds on these countries. Studies estimate that in order to substantially reduce tropical deforestation, annual expenditures of $2.2 to $5 billion would be needed for an extended period.

Protecting tropical forests will not be easy. Measurement, monitoring, and an administrative and regulatory structure would be required. Efforts would need to be made to ensure that deforestation activities are not simply deflected to other regions or countries with less stringent governance. Such enforcement would be complicated, but is possible if satellites and density-measuring lasers are employed (DeFries et al. 2007). The compensation costs and outlays for monitoring would still be far less than the economic benefits of carbon capture, even without considering the other environmental benefits of the forests. Even though a system of forest protection might not be easily implemented, the potential total benefits of protection are great. Halting deforestation would be a powerful tool to help humans effectively address the peril of climate change.

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14. FORESTS IN A U.S. CLIMATE PROGRAM

Promising, but the Key Is Implementation

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Ideally, the forest sector would be included in a domestic program to reduce greenhouse gases, as studies suggest there is potential to sequester in trees a substantial amount of carbon at relatively modest cost. Unfortunately, however, there are challenging design issues that need to be overcome before an effective forest sequestration policy can be implemented.

As the U.S. government develops a program to reduce the country's net emissions of greenhouse gases, it will be important to consider the role that forests and the forestry sector can play. Through photosynthesis, trees act as biological scrubbers for carbon dioxide, removing the gas from the atmosphere, storing the carbon as biomass, and returning the oxygen to the atmosphere.

Many forestry practices contribute to this carbon sequestration, including preventing deforestation, modifying harvest practices to reduce soil disturbance, reforesting harvested timberland, implementing new management methods such as extended rotations, and managing fire more effectively to avoid catastrophic loss. Perhaps more important, converting marginal or abandoned cropland and pastureland to forest stands can contribute significantly to increased carbon sequestration.

Although carbon sequestration alone will not drastically mitigate our carbon emissions, it can serve as a significant and cost-effective component. A 2005 study by the Pew Center for Climate Change reviewed nearly a dozen studies of the cost of carbon sequestration in the United States. Once the individual studies were adjusted for comparability, the results suggested that as much as 500 million tons of carbon per year—about 30 percent of national emissions—could be sequestered at a cost of $25 to $75 per ton of carbon ($7 to $21 per ton of carbon dioxide). With carbon capture and geological storage costs approaching $150 per ton, forest carbon sequestration appears quite cost-effective.

Several of the climate change bills introduced in Congress over the past few years have addressed various aspects of forest carbon sequestration. Most prominently, the 111th Congress passed HR 2454, commonly known as the Waxman-Markey bill, which includes provisions for substantial forest carbon offset projects and programs, both domestic and international.

The challenge for promoting forest carbon sequestration is designing a program that reliably induces landowners to protect and expand their forest carbon inventories. There are two basic approaches to encourage forestland owners to sequester more carbon: results-based programs and practice-based incentive systems. Each has its virtues and limitations.

RESULTS-BASED APPROACH

The results-based approach focuses on the amount of carbon actually sequestered by individual landowners and allows for innovative strategies customized to local circumstances. It would create incentives that closely coincide with the sought-after outcomes. The incentives might take the form of payments or subsidies from the government or offset credits under a cap-and-trade program.

Under a results-based approach, the government and program participants must employ some mechanism to estimate, report, and verify the actual carbon sequestration achieved by forest management changes. To win popular and political support—

particularly if credits that can be used to meet obligations under a cap-and-trade program are allocated to individual landowners—it will be necessary to develop procedures that assure the public that estimates of carbon gains are accurate.

The first and perhaps most challenging element of estimating the impact of a carbon sequestration project is developing a reference case—that is, estimating how much carbon would have been stored on a site in the absence of the program. Most of the practices that increase forest carbon sequestration are familiar activities that are already integral to land-use management. For a particular area of land, it can thus be difficult to say which practices would have been used anyway, even if government policy had not influenced management decisions. The requirement that the project go beyond the reference case is sometimes referred to as "additionality." Since the reference case cannot be observed—after all, it did not happen—sequestration project evaluators have to rely on professional judgment to estimate business-as-usual carbon sequestration.

Project evaluation is also vexed by problems with leakage—that is, countervailing off-site effects that decrease the true carbon sequestration gains of a project. For example, a project developer might protect a particular area of forest from harvest to reduce the release of carbon from the site. But if, in response to market demand, a timber company simply cuts elsewhere instead, the carbon sequestration gains of the project have been lost. Also problematic is the fact that forest carbon can be released back into the atmosphere if the wood decays or burns; it is not necessarily as permanent as other kinds of emissions reductions.

Yet another problem involves verification. Project evaluation is hard enough when the professional has no financial or personal interest in the project. But when the individual developing the sequestration project is also charged with evaluating it, as is often the case, there is an inherent conflict of interest.

The methods used to evaluate carbon offsets are supposed to lead to results that are additional, verifiable, permanent, and enforceable. Although this may sound like a demanding standard, it is not enough. What is really needed is an approach that is independently reproducible—that is, the results of the analysis do not vary with the analyst. None of the current protocols or estimation procedures has been tested to see whether it complies with this standard. Senator Boxer's bill from the 110th Congress, S 3036, is the only one introduced in Congress to require that the methods used to assess offsets be tested and verified by teams of independent experts before the methods can be used to earn allowances.

PRACTICE-BASED APPROACH

An alternative to the results-based approach is a practice-based incentive system, similar to the programs that have been used for environmental stewardship under the Farm Bills. Under this scheme, landowners are paid for adopting specific practices that are thought to be correlated with high levels of carbon sequestration—for example, converting highly erodible cropland to forest stands. The advantage of this approach is that it avoids potentially costly and contentious carbon measurement issues. The disadvantage is that the incentives for carbon sequestration are dulled; landowners' first priority is implementing the practice, not sequestering carbon.

GOVERNMENT PRODUCTION APPROACH

A more radical option that has received virtually no attention is for the government (federal or state) itself to acquire land and adopt carbon-sequestering practices. This is what the government has done in many hazardous waste cleanups. Although there may be substantial political resistance to the government's expanding its holdings of land, the "government production" approach offers the advantage of practicality. It reduces problems of asymmetry of information, makes it easier for the government to pursue multiple objectives such as biodiversity and recreation, and allows the government to adjust its practices without extensive renegotiation of terms with private parties. The disadvantage, of course, is that a government production approach dulls incentives for efficiency and innovation.

We have been working for a decade and a half to overcome the challenges of a results-based offset program, but the issues persist. While we may be able to overcome these difficulties with additional experience and experimentation, it is likely that policymakers should consider alternatives. Further developing programs that use the input-based and government production approaches may well prove more fruitful in the long run. In any case, forest carbon sequestration is so promising, we must make a continued, diligent effort to find workable systems.

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15. EMISSIONS OFFSETS IN A GREENHOUSE GAS CAP-AND-TRADE POLICY

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A key issue in the design of a cap-and-trade (or tax-based) system to reduce U.S. greenhouse gas emissions is to what extent covered sectors may offset some of their abatement obligations by paying for lower-cost emissions reductions in other countries, or in domestic sectors (such as agriculture) that might not be formally regulated. Some important pitfalls need to be addressed if offset provisions are to work effectively, without undermining overall emissions reduction targets.

Emissions offsets have received much attention, both positive and negative, as a policy option to mitigate climate change. Simply put, an offset is an agreement between two parties under which one party voluntarily agrees to reduce its emissions (or increase carbon storage in forests or agricultural soils) in exchange for a payment from another party. For this discussion, the paying party is mandated via regulation to reduce emissions, but the selling party is not. The underlying premise is that the offset seller can cut emissions less expensively than the offset buyer can, and will do so if paid more than the action costs.

The most well-known climate policy offset program is the Clean Development Mechanism (CDM). Under that arrangement, countries that have agreed to binding greenhouse gas (GHG) reduction commitments under the UN's Kyoto Protocol can meet their commitments through focusing on internal emissions reductions, trading emissions rights with other countries facing Kyoto emissions targets, or relying on the CDM itself, obtaining emissions reductions credits generated through offset projects in developing countries not bound by Kyoto targets.

One of the newest programs is the Regional Greenhouse Gas Initiative, which recently launched a mandatory program to reduce GHGs from the electric power sector in 10 northeastern states with offsets from the uncapped sectors allowed as a compliance option. In mid-2009, the U.S. House of Representatives passed cap-and-trade legislation to cut GHG emissions approximately 80 percent by 2050, with domestic and international offsets as a significant component of the policy's cost containment design. As of this writing, the legislation is now being considered by the U.S. Senate.

WHY OFFSETS?

The economic argument in favor of offsets is straightforward to anyone familiar with emissions trading principles. Rather than designate which parties must undertake which reductions to achieve a collective target, it is more efficient to allow parties to contract among themselves to find who can achieve these reductions at the lowest cost. This is true for emissions trading in general and for offsets in particular. Empirical evidence bears this out. A recently published study by EPA of the cap-and-trade bill that passed in the House of Representatives in 2009 found that allowing offsets even subject to quantitative limits on their use reduces marginal compliance costs by about half. In addition to cost containment, offsets are seen as a potential source of economic stimulus, delivering much-needed resources and efficient technologies to sectors and countries outside the cap that are economically disadvantaged. They can also be a source of environmental cobenefits through the deployment of less-polluting technologies and protecting forests and other ecosystems that sequester carbon.

POTENTIAL PROBLEMS

Two common criticisms of offsets are that they deflect effort from abatement in the capped sectors and generate credit for reductions that may not be real. But the former criticism is misdirected. Deflecting abatement from the capped sectors is exactly how offsets work to reduce costs. It should be the overall reductions we are interested in, not where they occur. However, if offset credits are being given for reductions that do not actually occur, the transaction and the cap are illusory.

The validity of offset reductions is called into question because they are generated from sources that do not face an emissions mandate. This makes it difficult to determine how to give credits for emissions reductions—reductions compared to what? The answer typically comes in the form of a baseline that captures what the emissions level would be under a "business-as-usual" scenario. Reducing emissions below this baseline can be considered additional to reductions that would have occurred anyway.

"Additionality" is a necessary condition for the reductions to be real. Additionality may be more readily apparent in some cases such as methane capture from livestock operations or afforestation of cropland because these are not prevalent practices for farmers under business as usual. But in practice it can be difficult to determine additionality because once a project starts, the baseline is a counterfactual event that is unobservable. This can become a matter of guesswork that varies in sophistication—from complex data analysis to simply asking the party to provide evidence the project is additional. If a party has too much freedom to set its own baseline, there is legitimate concern about its validity and whether the reductions are therefore truly additional.

Another potential problem with offset transactions is "leakage," which occurs when emissions reductions generated by the project simply lead to emissions being shifted to some ungoverned source, such as another uncapped entity not engaged in an offset project, thereby counteracting the project's reductions. A third problem, "permanence," comes specifically from offsets generated by biological sequestration of carbon in forests and agricultural soils, which have the highest physical and economic potential in a domestic U.S. program. These projects create value by removing CO_2 from the atmosphere and storing it in biomass and soils. The stored carbon, however, can be re-emitted by natural disturbances, such as fire, or intentional management actions. If this occurs, the original benefits of the project have been negated and the offset accounting shortfall needs to be addressed.

POSSIBLE SOLUTIONS

Offset policy has focused on addressing additionality, leakage, and permanence issues in two ways.

Quality standards. Each of the problems identified here can be dealt with by imposing standards to protect offset quality. This follows the CDM approach, which restricts the activities eligible for offsets and requires an executive board to approve all projects. All CDM projects must meet standards for additionality, address leakage, and require all biological sequestration projects to accept temporary payments rather than risk impermanence. This was deemed necessary to get political buy-in from parties who were skeptical of offset integrity. The results have been mixed. Indeed, it has been challenging to get many CDM projects approved, thereby restricting supply. But the logjam is loosening, and some projects that have been approved have been criticized for generating dubious reductions despite quality standards.

Quantitative restrictions. Policymakers have tended to couple quality standards with quantitative restrictions on the use of offsets for compliance. For example, the EU limits the share of compliance commitments that can be met with offset credits to approximately 10 percent (with some variation across countries within the EU). The U.S. House bill would have similarly placed compliance limits on offsets. These restrictions implicitly suggest that policymakers are lured by the appeal of offsets, but they only trust them so far.

SUMMARY

Offsets are neither a panacea nor a pox. Done well, they expand emissions reduction opportunities and lower the cost of achieving the cap, but they create a number of accounting problems for a cap-and-trade program. Rigorous standards for their inclusion are essential if the system is to have integrity. Nonetheless, some flexibility is necessary to ensure that high-quality offsets are not left out of the system because of overly burdensome requirements. This trade-off is as much art as science. Quantitatively limiting offsets for compliance is not an ideal solution, but it may be necessary, at least at first when offset quality is highly uncertain. Even with quality standards and quantitative restrictions in place, the CDM has generated a substantial flow of potential credits (3.8 billion tons in the pipeline) redeemable in the Kyoto system. Clearly, the current system, warts and all, has at least passed the first test of viability. Whether or not offsets are a critical element of the post-2012 Kyoto framework and the U.S. compliance market remains for policymakers to decide.

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16. ETHICS AND DISCOUNTING GLOBAL WARMING DAMAGES

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One of the most contentious issues in assessing what price to put on greenhouse gas emissions is the rate at which global warming damages to future generations should be discounted. How can we think about the discount rate, and is there any possibility for reconciling different views?

Over the past few years, great debates have erupted over discounting, stimulated by the economic analysis of climate change. One of the more controversial, the 2006 report by Nicholas Stern, *The Economics of Climate Change: The Stern Review,* employed a much lower discount rate—around 1.4 percent—than had previously been used. Partly for this reason, the *Stern Review* recommended more rapid reductions in greenhouse gas emissions, with carbon dioxide (CO_2) concentrations peaking at 450–550 ppmv (parts per million by volume). Stern's implicit carbon price along a business-as-usual pathway was roughly $85 per ton of CO_2, though the damages from today's emissions (and hence the appropriate price on CO_2) would be substantially lower if atmospheric stabilization targets were achieved.

In contrast, much (but not all) previous economic analysis had used market interest rates of well above 2 percent, with concentrations reaching around 700 ppmv and carbon prices of considerably less than $20 per ton of CO_2, and often single digits. By way of comparison, current carbon prices in the European greenhouse gas emissions trading scheme are around $20 per ton, and have been as high as around $40 per ton.

The discounting debate is certainly a critical issue for all of the economists now engaged in climate change policy discussions. But before engaging with the debate, it is helpful to clarify some key ideas. To start with, a discount rate is a rate of change of the price of one good relative to another. Under idealized circumstances, the discount rate for all goods could be identical. But the world is not ideal, so different goods have different appropriate discount rates. So when economists refer to "the" discount rate, we are referring to a general, economywide discount rate, which can roughly be applied to aggregate consumption in the economy. This general discount rate represents our collective willingness to trade off aggregate present for future consumption. The discount rate reflects changes in real, not just nominal, prices and is not merely an adjustment for inflation.

Economists make an important distinction between the discount rate for consumption versus utility (or well-being). We might discount expected utility in the future because, for instance, there is a risk of dying beforehand. We might discount future generations because we care less about their welfare than we care about our own. In addition to discounting utility, a further discount component is applied to future consumption, if higher living standards are anticipated in the future. This reflects the rate at which the value of additional consumption declines as consumption increases—represented by a parameter called the "elasticity of marginal utility" with respect to consumption. In total, the consumption discount rate comprises two parts: the utility discount rate and the elasticity of marginal utility multiplied by the consumption growth rate. Even with a zero utility discount rate, if aggregate consumption is expected to keep growing, then a positive consumption discount rate is appropriate.

The discount rate is a function of how we expect consumption to change in the future. Greater optimism (pessimism) about future consumption growth implies a higher (lower) consumption discount rate. In rare cases, where large-scale investment changes consumption growth, the investment will also change the appropriate consumption discount rate. Climate change, and/or our response to it, may be large enough to change the underlying growth rate, and hence also the discount rate.

So why is there such a difference between the *Stern Review* and most previous research? Stern adopts a "prescriptive" approach, explicitly considering the ethics of climate change, and his modeling treats the utility of everyone equally: individuals are not discounted just because they are born in the future. The average global per capita consumption growth was set at around 1.3 percent (although consumption growth varies from region to region and from each of the many thousand model runs to the next). With an assumed elasticity of marginal utility equal to one, this implied a global average consumption discount rate of 1.4 percent. As noted, Stern's carbon prices were higher than in earlier work, and his recommendation is to reduce emissions rapidly.

In contrast to Stern's prescriptive approach, previous research tended to be "descriptive" in assumptions about discounting, focusing on what we actually do, rather than what we ought to do from an ethical point of view. The focus was on market interest rates, which reflect the sum of many individual choices. Historic market interest rates (ignoring past and present financial crises) have averaged around 6 percent, so most previous research applied consumption discount rates at roughly this level. As such, utility discount rates were around 1–3 percent, the elasticity of marginal utility was set at 1–2 percent, and consumption growth rates were around 2 percent. With these higher discount rates, much more gradual emissions reductions are recommended, with atmospheric concentrations reaching or exceeding 700 ppmv.

TOO STERN ABOUT STERN?

Several arguments have been advanced against Stern's approach. We consider two of the more powerful. Stern's utilitarian ethics is not the only, or even the predominant, ethical outlook. For instance, "agent-relative" ethical ideas advanced by philosopher David Hume in the 18th century suggest that it is legitimate to care about those closer to us (by genetic proximity, or space or time) than those farther away. Also, if our ancestors had adopted Stern's perspective, they would have had to devote more resources (by way of savings and investment) for our benefit, reducing their own consumption, and hence also their welfare. This seems unfair given that our ancestors were significantly poorer than we are today.

There are two corresponding replies. First, it is true that utilitarianism is not the only viewpoint. But for a global issue like climate change, our analysis should be impartial, not favoring the Chinese over the Americans, say, or people alive today ahead of those alive in 2050. Many of the greatest economists and philosophers have specifically endorsed an impartial approach, and recommended a zero utility discount rate, which implies a low consumption discount rate, as in the *Stern Review*. Furthermore, the "prescriptive" school argued that there are at least three reasons for being cautious about using market prices to reveal ethical attitudes: markets do not always work properly, as we have seen in recent years; market interest rates can aggregate the choices only of those alive today, and do not represent the wishes of future generations; and interest rates reveal only one discount rate—yet, as discussed, in the real world different goods will have different discount rates.

Second, lower discount rates would indeed have compelled our ancestors to have saved more, but not ruinously so, once we account for the fact that we are so much better off than our ancestors were (as a result of impressive technological progress).

SO, WHAT TO DO?

There are several pragmatic routes to reconciling the approaches. One is to explicitly take into account uncertainty over the discount rate. For example, suppose we crudely assume that Stern is as likely to be correct as his critics, such that a 1.4 percent discount rate is as likely to be correct as a 6 percent discount rate. In this case, over a 100-year period, the discount rate that yields global warming damages equal to the average of damages under a 1.4 percent rate and under a 6 percent rate is 2 percent. In other words, the logic of uncertainty makes the arguments about ethics less significant.

Accounting for "unknown unknowns," by assuming the probabilities are themselves uncertain, further bridges the divide between the discount rate of the *Stern Review* and higher market interest rates. Also, it may be consistent to apply high discount rates for aggregate consumption, and low discount rates for (increasingly scarce) natural capital. If climate change disproportionately damages natural capital, a lower discount rate may be justified.

Finally, social institutions, beyond the market for government bonds, might be investigated with a view to backing out implicit long-term ethical preferences. This would avoid the need for a priori ethical assumptions, such as those made in the *Stern Review*, and would also avoid the problems with relying on market prices to derive ethical positions. Such research may reveal that the apparent chasm between prescriptive and descriptive approaches is narrower than it seems.

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17. CLIMATE CHANGE ABATEMENT

Not "Stern" Enough?

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If the value of environmental resources potentially at risk from climate change is rising over time relative to the value of ordinary market consumption, the future nonmarket impacts of climate change should be discounted at a lower rate. Accounting for this possibility increases the likelihood that more aggressive near-term actions to cut greenhouse gas emissions are justifiable on economic grounds.

That Earth is undergoing anthropogenically induced climate change is no longer in dispute, yet uncertainties abound—concerning cloud formation, feedback from methane in melting permafrost, and ecosystem responses to rapid change, to mention just a few. There are also economic uncertainties: what will the physical effects of climate change mean for the global economy, and how will that affect the world's societies?

As the nations of the world consider actions to mitigate a changing climate, the crucial policy issue boils down to this: what level of investment in climate change abatement should we make today to avoid costs associated with climate change in the future?

The Economics of Climate Change: The Stern Review recommended that 1 percent of global GDP be invested each year to avoid the economic consequences and the unprecedented risks from climate change. That was in 2006. In June 2008, looking at faster-than-expected climate change, Nicholas Stern doubled the estimate, to 2 percent of GDP.

Critics are divided, some calling it too pessimistic or too optimistic, depending on one's proclivities. A central issue in the debate has been the discount rate that Stern used to calculate the future benefits and costs of climate change. Because the impacts of climate change will continue to be felt in the distant future, the rate at which we "discount" the future critically affects the level of emissions reductions that is economically warranted today. For example, at a discount rate of 1 percent, the discounted value of $1 million 300 years hence is around $50,000 today. But if the discount rate is 5 percent, the discounted value is less than a mere 50 cents.

Economists disagree about what value to choose for the discount rate when determining an appropriate level of investment in climate change abatement. Stern used an unusually low rate, motivated by ethical arguments, uncertainty, and the exceptionally long time horizon. This leads to very high damage figures. Hence, his call for a high level of investment in climate change abatement today.

Among the most prominent economists studying the costs and benefits of climate change is William Nordhaus, who has argued for using a higher discount rate and therefore arrives at less startling results with respect to an economic estimate of the damages from climate change, and with respect to the measures we should take in the near term to mitigate negative impacts.

We would point out that most previous investigations (including the *Stern Review* and those by Nordhaus and others) do not consider the effects of the changing composition of economic well-being and changing relative prices. These changes can have an effect on the calculation of the present value of costs of climate change that is as substantial as the choice of discount rate.

Any discount rate assumes a growing economy. But it is unrealistic to assume constant, unwavering growth, equal for all sectors. Both logic and history indicate that growth tends to be concentrated in some sectors, depending on resources, technical innovations, and consumer preferences. If the output of some material goods (such as mobile phones) increases, but the availability of environmental goods and services (like clean water and biodiversity, or rain-fed agricultural production) declines, then the relative prices (or willingness to pay) for the environmental amenities should rise over time, a fundamental point first made by John Krutilla some 40 years ago.

Because of rising relative prices, the environmental sector could see its share of the economy grow in value even as it becomes physically smaller relative to a growing conventional sector. This has consequences for discounting itself that have been overlooked. In a multisector model, discount rates will not generally be constant—nor will they be the same for each sector. There will be a change in the relative prices for goods and services from sectors that grow at different rates.

Accounting for relative price changes can dramatically increase the abatement necessary to mitigate climate change. Using Nordhaus's integrated assessment model for climate change, Sterner and Persson show that even with the relatively high discount rate parameters assumed by Nordhaus but also modeling changes in relative prices yields results that are similar to the conclusions of the *Stern Review* and differ greatly from previous work by Nordhaus and others. If one were to use both low discount rates and changing relative prices, one would find even stronger support for strict and immediate abatement measures than did the *Stern Review.*

We also have a second concern with the *Stern Review*—that it may not give sufficient weight to nonmarket damages.

The nonmarket impacts of climate change are at center stage, because it is precisely the prices of these goods and services that we expect to rise over time. Nonmarket impacts from climate change include biodiversity and ecosystem loss, the effects of air pollution on human health, and damage from extreme hurricanes, droughts, and floods. The *Stern Review* does a great job of presenting many of these, the costs of which could be very high over the coming century: billions of people could suffer water shortages, and tens to hundreds of millions are at risk of hunger, diseases like malaria, and coastal flooding.

Those impacts could also have extreme social consequences if droughts force mass migrations, coastal inundation drives environmental refugees inland, and conflicts erupt over increasingly scarce resources. Such social problems have the potential to make the already serious climate damages much worse. However, social impacts are not included in the Stern analysis, nor have they been included in most other economic analyses. To give a full picture of the costs of climate change and the benefits of mitigation, these impacts should also be taken into account, together with their expected increase in relative value over time.

We believe that it is exactly the nonmarket effects of climate change that are the most worrisome. Given the risk of catastrophes, the main effect of climate change will be not to stop growth in conventional manufacturing, but rather to damage some vital ecosystem services, making them relatively scarcer and raising their relative prices.

In a thorough evaluation of the effect of relative prices, one would assess changes by sector. Clean water, rain-fed agriculture, and some other ecosystem services have particular importance for the very poor, and the climate change damages suffered by the poor are particularly important for human welfare. The extent of the price effect depends heavily on the elasticity of substitution, which measures the change in the composition of willingness to pay for goods and services when relative prices change.

In the meantime, analyses of abatement costs and benefits need to take into account the content of future growth. Future scarcities, whether caused by the changing composition of the economy or by climate change, will lead to rising prices for certain goods and services. Escalating prices for environmental goods and services raise the estimated damage of climate change, counteracting the effect of discounting.

Future scarcity values for nonmarket environmental assets are likely to generate high damage figures, even assuming high discount rates. Combining the low discount rates in the *Stern Review* with rising relative prices could lead to support for even higher levels of abatement than Stern recommended. This would mean that society should consider atmospheric greenhouse gas concentration targets that Stern deems unrealistic: a target below 450 ppm of CO_2 equivalents and consequently even more restrictive stabilization scenarios.

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18. EVALUATING CLIMATE RISKS IN COASTAL ZONES

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Rising sea levels as a result of climate change pose complex risks for developed and developing nations alike. Local policies for adapting to higher sea levels need to be crafted, even if the international community is successful in controlling greenhouse gas emissions.

Coastal zones around the world have already experienced some of the most adverse consequences of climate change. Global sea-level rise over the last century has, for example, contributed to increased coastal flooding and erosion as well as widespread ecosystem loss. Extreme weather events have done much of the damage. About 120 million people were exposed to tropical cyclones between 1980 and 2000, and more than 250,000 of them died as a result. The U.S. State Department estimated that close to 100,000 people died as a direct result of the cyclone that stuck Myanmar in May 2008.

Future climate change will produce more of the same over the coming decades. We can expect increased risks from coastal storms, higher sea surface temperatures, altered precipitation and runoff patterns, and more acidic oceans. It is important to note that these impacts will vary considerably across regions—and with increasing unpredictability. Consider the plight of corals scattered around the globe. They are all vulnerable to thermal stress and most have low adaptive capacity. This is not really news, but the increased pace at which corals around the globe have been affected is surprising.

Coastal wetland ecosystems, such as salt marshes and mangroves, are especially threatened where they are sediment starved or constrained on their landward margin by development; here we are learning more about these systems' amplified vulnerabilities as they face multiple stresses from humans and other natural sources. Changes to coastal ecosystems also have serious implications for the societies whose welfare and livelihoods depend on the services that they provide. Indeed, we are only now beginning to understand the degree to which the associated socioeconomic costs will escalate as a result of climate change.

To be sure, the impact of climate change on coasts is exacerbated by elevated pressures from human activities, especially when they are concentrated in populated deltas (and even more so in Asian megadeltas), other low-lying urban areas, and narrow atolls. The enormous loss of life in Myanmar can, for example, be attributed in large measure to degraded mangroves that could have provided some protection from the enormous storm surge. While physical exposure can significantly influence vulnerability for both human populations and natural systems, diminished or nascent adaptive capacity is often the most important factor in creating a hot spot of human vulnerability.

The traditional view holds that adaptive capacity is largely dependent upon development status. However, there are many other underlying determinants of adaptive capacity that are only now being explored: the availability of social and political capital, the ability to manage risk, the ability to separate signal from noise in support of response decisions. Developing nations may have the political or societal will to protect or relocate people who live in low-lying coastal zones, for example, but their vulnerabilities could be much greater without the necessary financial and decision-support capacities, as well as widespread recognition of a causal link between human activity and climate-borne risk.

Adaptation costs for climate change are much lower than the damage costs that would result if no adaptive measures were taken for most developed coasts. Indeed, coastline protection decisions in developed countries can, if exercised properly, reduce economic risk by as much as 75 percent. Conversely, high-end sea-level rise scenarios, combined with other climate changes (like increased storm intensity) and insufficient adaptive capacities, will make some islands and low-lying areas completely uninhabitable. Over the long term, unmitigated climate change could overwhelm the adaptive capacities of even the wealthiest coastal communities.

Coastal vulnerabilities clearly make the point that risk can increase over time for one of two reasons (or both). On the one hand, assessed risk may grow over time because evolving scientific knowledge supports increased confidence that an impact will occur. On the other, even if science has nothing new to say about relative likelihood of a particular impact or manifestation of climate change, risk can also grow because recent research and experiences have shown that consequences have heretofore been understated. Take, for example, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change on increased risk from coastal storms. The natural science community was, in 2006 (and still is, for that matter), debating whether or not a warming planet will mean an increase in the intensity and frequency of extreme storms. The social science community meanwhile learned from Hurricane Katrina (among others storms) that the assessed consequences of such storms have grown, because multiple stresses have been recognized and because even potentially strong adaptive capacity (such as that available to a big city in a wealthy country) is not always utilized to even a fraction of its full potential. Clearly, the risk of coastal storms can be assessed even higher than when the Third Assessment Report was released in 2001.

Our growing understanding of coastal vulnerabilities also supports the inclusion of "sustainability, equity, and attitudes to risk" in the iterative climate response plan described above. Development pathways matter because they dictate in large measure potential progress in building adaptive capacity and placing sustainability on par with economic growth in the calculus of development planning. But like everything else in the climate game, these connections do not work in only one direction; sustainability can affect climate impacts, and climate impacts can affect sustainability. Nor are they "linear"; these associations can have kinks and curves that cause abrupt disconnects, or at least alter the strength of the connection. And they always work together; sometimes good ideas on one side of the connection are counterproductive when their effects are evaluated on the other.

Finally, the research and policy communities are now coming to grips with the notion that increased risks associated with coastal vulnerabilities are not confined to the developing world. Even absent any change in storm frequency, sea-level rise can portend dire consequences for major cities in the developed world. For example, the likelihood that the current "every 100 years" flooding event in New York City will become the "every 25 years" event by 2035 is now assessed to be greater than 50 percent.

It is practically impossible to understate the climate risks that coastal zones will face as the future unfolds, almost irrespective of global mitigation efforts over the short to medium run. That said, the research and assessment communities continue to see them as nearly perfect laboratories within which to study the complexity of the interactions of human beings with their environments.

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