Climate Change and the Economy

Natalia Tamirisa

Policies to reduce the emission of greenhouse gases need not hobble the economy

Marr Ice Piedmont on Anvers Island, Antarctica.

ADDRESSING climate change and the economic damage it will likely bring presents policymakers with a dilemma. The benefits of policy action are uncertain and would accrue largely to future generations, whereas the costs of policies run the risk of being more immediate and extensive. At the same time, the costs of inaction are irreversible, potentially catastrophic, and likely to hit poorer countries harder than developed ones. Moreover, even if the greenhouse gas (GHG) emissions that accumulate in the atmosphere and warm the climate stopped immediately, temperatures would rise for some decades because of the emissions already accumulated.

For these reasons, economic policymakers increasingly recognize that policies will have to be adopted both to mitigate global warming, by slowing and ultimately reversing the growth of GHG emissions, and to adapt to the effects of the emissions that have already occurred and will occur in the coming decades. And they agree that mitigation policies in particular can have rapid and wide-ranging consequences.

To shed light on how mitigation policies would affect countries' economies, the IMF recently undertook a study comparing alternative policy designs—taxes on GHG emissions, emissions permit trading, and hybrid schemes combining elements of both policies. The encouraging news is that the analysis shows that climate change can be addressed without either hurting macroeconomic stability and growth or putting an undue burden on the countries least able to bear the costs of policies. In other words, if policies are well designed, their economic costs should be manageable.

Potential economic damage

Business-as-usual scenarios imply a sizable risk that the global climate will change dramatically by the end of the century. The Intergovernmental Panel on Climate Change (IPCC, 2007) projects that, in the absence of emissions control policies, global temperatures will increase by 2.8°C on average by 2100 (with best-guess increases ranging from 1.8°C to 4°C across scenarios from the *Special Report on Emissions Scenarios*). The probability of higher temperature increases is not negligible. Nicholas Stern (2008) points out that if business-as-usual concentrations of GHG stabilize at or above 750 parts per million (ppm) in CO_2-equivalent terms by the end of the century, as implied by the latest IPCC scenarios, there is at least a 50 percent chance that global temperatures will increase by more than 5°C, with potentially disastrous consequences for the planet.

A wide range of uncertainty surrounds any estimate of economic damage from climate change. The *Stern Review* estimates that the loss in GDP per capita by 2200 under his baseline scenario (with relatively high emissions and including market and nonmarket impacts and catastrophic risk) ranges from about 3 percent to 35 percent (90 percent confidence interval), with a central estimate of 15 percent (see Chart 1, panel 1). Uncertainty about damage from climate change stems from several sources. First, scientific knowledge about the physical and ecological processes underlying climate change is a work in progress. For example, it is unclear how rapidly GHGs will accumulate in the atmosphere, how sensitive climate and biological systems will be to increases in the concentration of those gases, and where the "tipping points" are, beyond which catastrophic climate events—such as the melting of the west Antarctic ice sheet or permafrost, a change in monsoon patterns, or a reversal of the Atlantic Thermohaline Circulation—would occur. Second, it is difficult to estimate how well people will be able to adapt to new climate conditions. And third, it is difficult to put a current value on damage that would be incurred by future generations.

Moreover, the low estimates of global damage mask a large variation across countries (see Chart 1, panel 2). Climate change will be felt earlier and much more acutely by less developed countries, at least in relation to the size of their economies. Such economies depend more on climate-sensitive sectors (such as agriculture, forestry, fishing, and tourism), have less healthy populations that are more vulnerable to changes in the environment, and offer fewer public services, which also tend to be of lower quality. The regions that are likely to be hurt the most by climate change include Africa, south and southeast Asia, and Latin America. India and Europe are exposed to catastrophic risk from a change in monsoon patterns and the reversal of the Atlantic Thermohaline Circulation, respectively. In contrast, China, North America, advanced Asian countries, and transition economies (especially Russia) are less vulnerable and may even benefit at low degrees of warming (for example, from better crop yields).

Facilitating adaptation

Of course, societies have historically shown an ability to adapt to changing environmental conditions, and individuals and firms can be expected to adjust their behavior—for example, by planting more drought-resistant crops and moving away from coastal areas exposed to increased flooding and hurricanes. But governments will also have to get involved because of possible market failures (individual firms and households unable to incorporate the full social benefits of adaptation into their decision making), the need for public goods and services to support adaptation, or limitations to the private sector's capacity to adapt—especially in poor countries.

Quantitative analyses of adaptation costs are scant, but studies focusing on public sector costs suggest that adaptation may put a strain on government budgets, especially in developing countries that have weak adaptation capacity and are likely to be severely affected by climate change. Cost estimates for developing countries run into tens of billions of dollars a year, comparable to estimates for advanced economies. Moreover, these estimates are likely to be low because they do not take into account some likely costs, such as those arising from greater volatility of weather patterns.

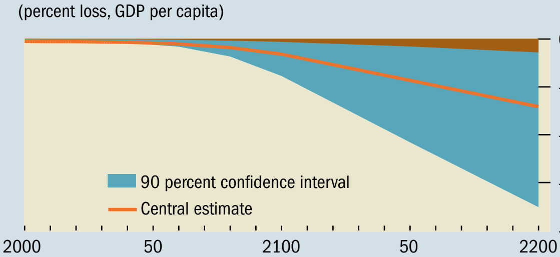
The best ways to improve a country's ability to adapt to climate change include the following:

Chart 1

Rising temperature, rising costs

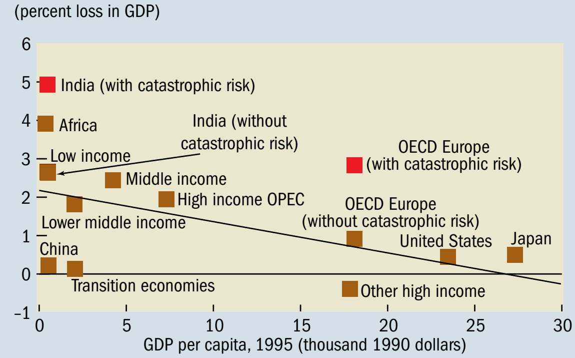
There is considerable uncertainty about the global economic impact of temperature increases that grows the farther the estimate is in the future . . .[1]

(percent loss, GDP per capita)



. . . but it is clear that the losses fall disproportionately on emerging and developing economies.[2]

(percent loss in GDP)



Sources: Stern (2007); Nordhaus and Boyer (2000).

[1]The chart plots estimates from the *Stern Report* for the baseline climate change scenario. The scenario assumes temperature increases of 3.9°C by 2100. Estimates cover market and nonmarket impacts, and the risk of catastrophe.

[2]Impact of a 2.5°C warming. Regression line includes only observations without catastrophic risk. See Nordhaus and Boyer (2000) for information on country group composition.

Economic and institutional development. Development helps countries diversify away from heavily exposed sectors; improves access to health, education, and water; and reduces poverty. Higher-quality institutions also strengthen countries' abilities to adapt to climate change.

Fiscal self-insurance. Government budgets must allow for adaptation expenditures, and social safety nets must be strengthened, especially in countries that will be severely affected. External financing may be needed to help poorer countries whose domestic resources are far short of what are needed—on this front, the UN has just launched an effort to provide such financing, a step in the right direction.

The choice of the exchange rate regime and labor market and financial sector policies. These choices can encourage firms and people to adjust to the abrupt shocks (such as extreme weather events) that are likely to accompany climate change. A flexible exchange rate regime and financial and labor market reforms that make capital and labor more adaptable may help reduce the macroeconomic cost of extreme weather shocks. Such shocks typically destroy capital investments and disrupt production, and adjusting to them requires moving people and capital across and within sectors. Many of these policies can be implemented fairly quickly and at a small cost to the budget.

Financial markets. These markets can reduce the macroeconomic costs of adapting to climate change by generating price signals that create incentives for people to move to lower-risk areas and reallocating capital to newly productive sectors and regions (see "The Greening of Markets" in this issue). The financial markets' capacity to diversify costs and spread the risks to those most willing and able to bear them will also help reduce the social costs of adaptation.

Curbing GHG emissions

But adaptation is not enough. To mitigate the consequences of global warming, GHG emissions must be reduced. If a price is put on GHG emissions commensurate with the damage they cause, consumers and businesses would have incentives to shift from producing and consuming goods that give rise to large quantities of emissions to creating clean goods and technologies. Such a price for GHG emissions is often called a carbon price, reflecting the fact that, among all GHGs, carbon dioxide is the main contributor to the climate problem.

Many policy instruments have been considered for mitigation purposes. They include, among other things, ***taxes on GHG emissions*** (carbon taxes); ***cap-and-trade*** schemes, in which the government restricts the quantity of emissions firms can produce but allows firms to trade their emissions rights; and ***hybrid policies*** combining elements of carbon taxes and cap-and-trade schemes.

Which mitigation policies are best? Carbon taxes have a big advantage over cap-and-trade schemes because they result in a stable price for emissions, which is critical for firms making long-term decisions about investment in low-emissions technologies. They also generate revenues that can be used to enhance efficiency (by lowering other taxes) or equity (by compensating groups disadvantaged by policy). However, under carbon taxes, the quantity of emissions reductions is uncertain, and taxes may be politically difficult to implement. That said, there are ways to reduce the disadvantages of cap-and-trade schemes—in the process, creating a hybrid instrument. Price volatility, for example, can be reduced by introducing safety valves that would allow the government to sell some temporary permits when prices exceeded some prespecified "trigger" level. Hybrid policies can also provide for a simultaneous targeting of emissions prices (over the short run) and emissions levels (over the long run).

Weighing mitigation policies

What will the economic costs of a given mitigation policy be for the global economy and individual countries' economies? The IMF examined this question using a global dynamic model—the 2007 version of the so-called G-cubed model (McKibbin and Wilcoxen, 1998) (see box).

Carbon tax and a hybrid with a safety valve. The modeling exercise started by examining the macroeconomic effects of a global mitigation policy that requires countries to agree on a common carbon price: a uniform global carbon tax or a hybrid scheme whereby countries commit to a common safety valve (with the price of additional permits set to the rate of the carbon tax). All countries are assumed to introduce a common carbon price in 2013 and make a credible commitment to keep it in place over the long run, adjusting the rate as necessary to achieve a global emissions path that peaks around 2018 and then gradually declines to 40 percent of the 2002 levels by 2100. This profile is broadly consistent with stabilizing CO_2-equivalent concentrations at 550 parts per million (ppm) by

Why G-cubed?

The G-cubed model is well suited for evaluating how the effects of carbon pricing policies would unfold over time and across countries. Modeling of relative prices helps describe how rising carbon prices would encourage the substitution of cleaner technologies for carbon-intensive ones, affect the movement of spending away from emissions-intensive goods, and impact the terms of trade and the balance of payments. The latter reflects not only trade flows, but also international capital flows, which have received little emphasis in models used for climate policy analysis.

The eventual benefits of mitigation policies are not modeled in G-cubed, but this is not a major drawback of the analysis, which focuses on the costs of mitigation during the three decades following their introduction. Over such a horizon, the benefits of policies are expected to be small, given the slow feedback between changes in the flow of emissions and climate. G-cubed simulations are intended to illustrate the economic mechanisms at work following the introduction of mitigation polices and should not be taken as long-term macroeconomic forecasts. Although alternative sources of energy, such as biofuels, nuclear, and renewables, are not modeled explicitly, substitutions from fossil fuels into capital, as well as energy efficiency improvements, can be interpreted as substitution toward these sources of energy. Technology is assumed to be transferable across countries.

volume by 2100. To achieve such a profile, the carbon price would have to rise gradually over time, reaching $86 per ton by 2040 (an average annual rate of about $3 per ton of carbon). This corresponds to a 21 cent increase in the price of a gallon of gasoline by 2040 and a $58 increase in the price of a short ton of bituminous coal.

Faced with paying for their emissions of carbon, firms in all countries start changing technology, moving away from carbon-intensive inputs. Households alter their consumption patterns, also moving away from carbon-intensive goods. With higher carbon prices raising costs for firms, productivity and output fall. Aggregate investment falls because the average marginal product of capital is lower, and consumption follows declines in real incomes. To the extent that some firms and households are forward looking, they would react immediately to the anticipated future prices, which makes policy more effective. Although the levels of real activity fall permanently relative to the baseline, the shock has only a temporary effect on GNP growth rates: over time, they return to the baseline levels. Current accounts tend to improve in countries that considerably reduce emissions, because declines in investment in such countries outweigh declines in savings.

The total abatement costs vary across countries, depending on how efficient they are in reducing emissions and by how much they reduce them. In the G-cubed model, the costs are the highest for China—by far the least efficient economy in the use of energy (producing nine times more emissions per unit of output than Japan and five times more than the United States). China is assumed to be able to reduce emissions at the lowest incremental cost by improving the efficiency with which firms and households use energy. The net present value of consumption in China declines by about 2 percent from the baseline levels by 2040 (see Chart 2). For other economies, and the world as a whole, the decline in the net present value of consumption is about 0.6 percent for the same period. When measured in terms of the bundle of goods produced, the costs are higher, with the net present value of world GNP declining by about 2 percent from the baseline by 2040. But this would still leave world GNP 2.3 times higher in 2040 than in 2007. (The study focused on GNP as a measure of output because, in contrast to GDP, GNP takes into account the value of transfers between countries, which may occur particularly under the cap-and-trade policies.)

The total costs of mitigation in G-cubed are higher than in many other studies, but within the range of estimates reported by the IPCC. The main reason for higher estimates is that this study assumes relatively strong emissions growth in the baseline and uses conservative assumptions about the availability of the so-called backstop technologies, which allow output to be produced without any emissions of GHG.

Cap-and-trade policy. Next, the study compared the effects of the price-based policies to those of a global policy that requires countries to agree on an initial allocation of emissions rights and international trade of these rights. Each economy receives emissions rights for each year from 2013 onward, which are proportional to its share of global emissions in 2012. Emissions permits can be traded internationally, which establishes a common price. Economies with higher incremental (or marginal) abatement costs (MACs)—that is, the costs of an incremental reduction in emissions—buy permits from economies with lower MACs, compensating them for undertaking more abatement than implied by their share of emissions. Hence, the actual emissions paths of individual economies differ from their initial allocations of permits, whereas the world emissions path is consistent with the targeted profile.

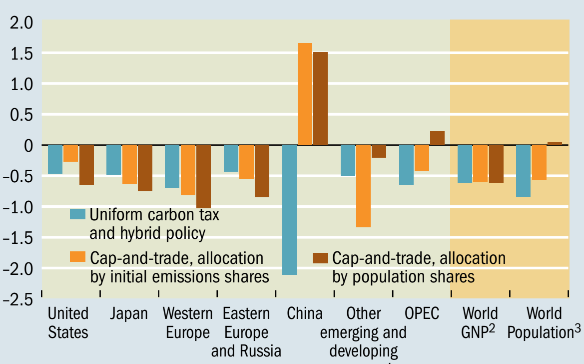
For most economies, transfers are small and the macroeconomic effects of the cap-and-trade policy are similar to those of the carbon tax and the hybrid. For China (a recipient), other emerging and developing economies (payers), and economies in the Organization of the Petroleum Exporting Countries (recipients), transfers reach 10 percent, –2 percent, and 1 percent of GNP, respectively, by 2040. China receives the largest transfers because it is comparatively inefficient in its use of energy and, hence, in G-cubed it is assumed to be able to reduce emissions at a much lower cost than other economies. Advanced economies, as well as other emerging and developing economies, buy emissions rights from China because emissions reductions are highly costly for these countries. The costs for economies paying transfers (Europe, Japan, Russia, and other emerging and developing economies) are higher under the cap-and-trade scheme than under the carbon tax and the hybrid policy, whereas the costs for the economies receiving transfers (China, OPEC, and the United States) are lower. The findings concerning the direction and magnitude of transfers are highly sensitive to assumptions about incremental abatement costs in individual economies, as well as to the specific design of cap-and-trade schemes, particularly the rule used for allocating permits across countries.

Chart 2

Costs of reducing carbon emissions

The global costs[1] of mitigation could be moderate between 2013 and 2040, but vary by country and by policy.

(deviation of consumption from the baseline, percent)



Source: IMF staff estimates.

[1]The costs are measured by the net present value of the difference between the path for consumption in the policy experiment and the path for consumption in the baseline, divided by the net present value of the path for consumption in the baseline. The discount rate is constant over time and across regions at 2.2 percent, which is the difference between long-term world interest rates and trend GNP growth rates. The net present value of consumption aggregates changes in consumption over time.

[2]Weighted by GNP shares in 2013.

[3]Weighted by population shares in 2013.

Although most studies predict that advanced economies—especially Western Europe and Japan—would have to pay for emissions permits, there is no consensus about international transfers for emerging market economies. Such countries have high growth potential, which implies high future demand for emissions rights, but they also emit a large amount of carbon dioxide per unit of output, suggesting much room for efficiency gains and the ability to sell emissions rights.

Alternative allocation rules. The pattern of international transfers and the macroeconomic effects of cap-and-trade schemes are highly sensitive to how emissions rights are allocated. Suppose each economy receives emissions rights not according to its initial share of emissions, but according to its share of world population in each year from 2013 onward. This would change the pattern of international trade in permits and the macroeconomic effects substantially, with other emerging and developing economies now selling permits and receiving transfers, in the amount of about 1 percent of GDP in 2020 and 2030, which reduces the cost of mitigation for these countries.

Guiding principles

What lessons can we glean for policymakers trying to contain the potentially adverse macroeconomic effects of mitigation? Carbon-pricing policies must

• ***Be long term and credible.*** It is important to establish a steadily rising time path for carbon prices that people and businesses believe in. Increases in world carbon prices then need not be large—say, a 1 cent initial increase in the price of a gallon of gasoline that rises by an additional two cents every three years. Such gradual increases, if started early, would allow the cost of adjustment to be spread over a longer period of time.

• ***Require all groups of countries—advanced, emerging market, and developing—to start pricing their emissions.*** Any policy framework that does not include emerging and developing economies (particularly, large and fast-growing economies such as Brazil, China, India, and Russia) in some way (for example, with a lag or with initially less stringent targets) would be extremely costly and politically untenable, because 70 percent of total emissions during the next 50 years are projected to come from these and other emerging and developing economies.

• ***Establish a common world price for emissions.*** This would ensure that emissions are reduced where it is least costly to do so. Emerging and developing economies, in particular, are likely to be able reduce emissions much more cheaply than advanced economies. For example, if China and India have access to technologies similar to those available in Japan and Europe, they can cut emissions dramatically by improving the efficiency with which they use energy and by reducing reliance on coal. The difference in costs can be significant—for the world as a whole, costs will be 50 percent lower if carbon prices are common across countries. Countries would have to harmonize the rate of carbon tax, coordinate trigger prices for the safety valve under a hybrid policy, or allow international trading of emissions permits under a cap-and-trade scheme.

• ***Be sufficiently flexible to accommodate cyclical economic fluctuations.*** In periods of high demand, it would be more costly for firms to reduce their emissions, whereas the opposite would be true when demand is low. Abatement costs would be lower if firms could vary their emissions over the business cycle. That would allow achievement of a given average level of emissions reductions over the medium term. In contrast to carbon taxes and hybrid policies, cap-and-trade could prove restrictive in periods of higher growth because of increased demand and prices for emissions permits, unless provisions are made to control price volatility.

• ***Distribute the costs of mitigation equitably across countries.*** Some mitigation policies—for example, a uniform tax, a cap-and-trade scheme where permits are allocated based on countries' share of emissions, or a hybrid policy—would impose high costs on some emerging market and developing economies. Substantial cross-border transfers may be needed to encourage them to participate and to help them deal with the negative impact. Using border tax adjustments to induce countries to join could elicit a protectionist response that would detract from mitigation efforts.

Countries may also need to complement carbon pricing with appropriate macroeconomic and financial policies. For example, under a global cap-and-trade regime, transfers from industrial countries that buy permits to emerging and developing economies that sell them could be potentially large. Such transfers would reduce the costs of carbon pricing policies for emerging and developing countries and would encourage them to participate. However, the transfers might also cause real exchange rates in the recipient countries to appreciate considerably, making some sectors of the economy less competitive. Such macroeconomic effects can be reduced if countries save a portion of these inflows; continue to improve the business environment; and, depending on their exchange rate regime, allow appreciation to take place at least partly through the nominal exchange rate rather than through inflation. ■

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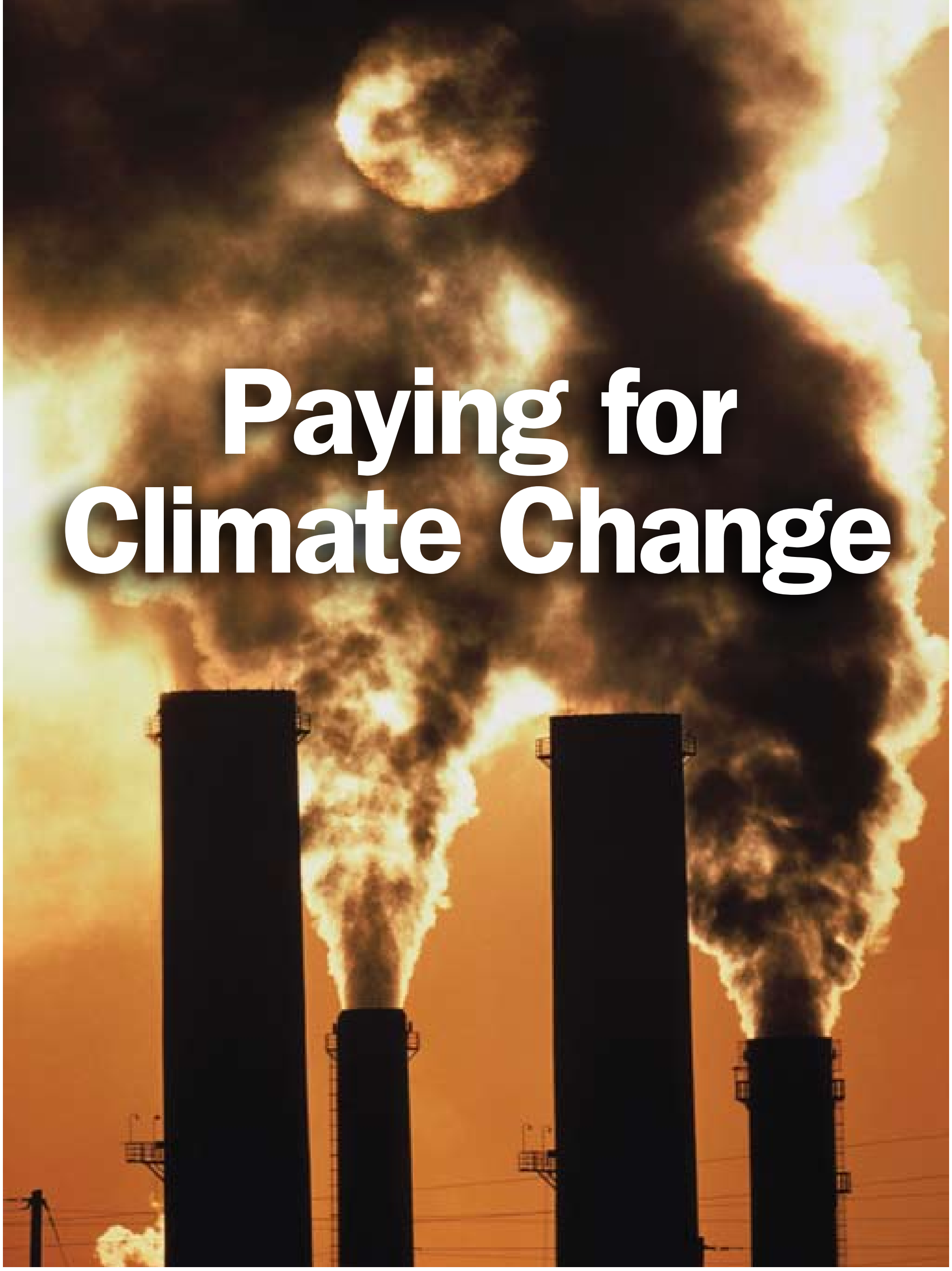
Paying for Climate Change

Governments must manage the incentives for households and firms to counter and adapt to climate change

Benjamin Jones, Michael Keen, and Jon Strand



Smokestacks in Eureka, California, United States.

CLIMATE science tells that the earth is warming as a result of human activities. But considerable uncertainty regarding the precise nature and extent of the risks remains. Economists are needed to develop sensible policies to address these risks, which account for the uncertainties. In particular, the world needs public finance economists to consider what role fiscal instruments—notably, taxing and public spending—have to play in dealing with climate change.

Country efforts to adapt to and mitigate climate change are interrelated—broadly speaking, they are substitutes—but differ in important respects. Most adaptation, often involving relatively modest changes in behavior, will be carried out through private markets, though policy interventions may be needed to facilitate it—for example, by improving weather forecasting.

Mitigation, by contrast, generally needs to be driven by deliberate policy to a greater extent. Much adaptation can, and should, wait until the climate process has evolved: it makes little sense to adapt now to changes that will materialize mainly in, say, 30–100 years. However, mitigation needs to start well in advance of the damage it seeks to avoid because damage arises not from current emissions but from the slow-moving stock of greenhouse gases (GHGs) cumulated in the atmosphere.

This article argues that the role of fiscal instruments is central—indeed indispensable—for both mitigating and adapting to climate change. It looks at how efficient fiscal policies can help minimize the negative effects of climate change and examines the policy options available to governments. Fiscal instruments cannot provide a complete solution. But taxes and public spending are key to getting the incentives right for households and firms, as well as to ensuring a fair distribution of the associated costs and benefits. They can help ensure that those whose GHG emissions affect climate developments pay a proper price for doing so, and they can provide the resources needed to pay for dealing with it.

Adaptation—how much could it cost?

Even with unchanged fiscal policies, climate change may have effects on both tax revenue (tax bases being eroded, perhaps, by declining agricultural productivity or by intensified extreme weather events, such as storms, flooding, and droughts) and public spending (perhaps to deal with increased prevalence of malaria). In some cases, the net effect might be beneficial, though the overall tendency is likely to amplify the problems faced by those countries—often among the poorest—most adversely affected in general by climate change.

The most likely negative effects of future climate change include sea-level rise, productivity losses in climate-exposed sectors such as tourism and agriculture, and more intense and perhaps more frequent and extreme weather events—all with potential adverse repercussions for fiscal positions and external stability.

Outside such catastrophic events as melting of the West Antarctic Ice Sheet, human societies are likely to adapt to most of these changes, although at a cost. How to minimize those costs, and how governments can best help, is not always clear. Typically, it will not be optimal to adapt so fully as to eliminate the entire climate effect: averting all damage may simply be too expensive. And difficult choices arise between taking early precautions and waiting for better information to become available. For example, whereas sinking costs into strengthening coastal defenses will seem a wise decision if future storm surge problems worsen, it will look like a white elephant if they do not.

Very little is known about the aggregate extent of the costs of adaptation, but there are some rough estimates. One survey concludes that these costs typically make up at most 25 percent of total climate impact costs (Tol, 2005). So if doubling GHG concentrations (a prospect under "business-as-usual" assumptions in this century) leads to an overall climate cost of 1–2 percent of world GDP, adaptation costs would be about 0.2–0.5 percent of world GDP, or about $70–150 billion a year. The World Bank (2006) also estimates adaptation costs for lower-income countries in the tens of billions of dollars annually.

Given the importance for adaptation of such public goods as coastal defenses and health provision, a substantial proportion of these costs can be expected to fall on the public sector, but how much that is likely to be is even less clear: the World Bank, for example, roughly estimated that about a third of adaptations costs could be public. However, a better understanding of the likely fiscal costs of adapting to climate change, at the country level, is urgently needed if the fiscal risks that it poses are to be properly prepared for.

Mitigation—dealing with market failures

Effective mitigation of GHG emissions is likely to require the use of fiscal instruments to overcome a deep market failure—a classic free-rider problem. The problem is simply that individuals, firms, and governments have insufficient incentives to limit their GHG emissions: whereas they incur the full costs of doing so, the benefits (from less global warming) accrue to the entire global community. The consequences are excessive emissions and too little effort in developing alternatives to fossil fuels.

At the local or national level, there may be some co-benefits from reduced burning of fossil fuels in the form of less local and regional pollution, but these do not eliminate the basic difficulty: everyone would prefer that others take the pain of reducing global emissions. Moreover, the benefits of current mitigation will accrue largely to future generations—so the extent to which the current costs are worth incurring depends on the weight one attaches to the well-being of future generations, and how much allowance to make for the likelihood that they will be better off than we are. The discount rate used to compare current costs and future benefits then proves critical in evaluating and forming climate-related policies—more so than in most other cost-benefit analyses because of the unusually long time horizons involved.

The second market failure relates to the development of new energy technologies that will permit substantial reductions in GHG emissions. Most such research and development (R&D) activity will—and, from efficiency considerations, probably should—be undertaken by individuals and businesses in pursuit of commercial gain. But they will typically not be able to appropriate all the social benefit of their innovations, so there is a risk of underinvestment in climate-related R&D.

The same considerations also apply, of course, to much R&D that has nothing to do with climate change, and many governments already offer generous tax breaks and other forms of fiscal support for commercial R&D. However, the importance now attached to climate- and energy-related research, including energy security considerations, and the particularly high risks for individual developers (in particular, related to developing more fundamental, "breakthrough" technologies—such as the capture and storage of CO_2 emissions and geo-engineering techniques for offsetting climate modifications), may argue for additional support of climate-related research. In practice, however, energy-related R&D remains well below its peak in the 1970s.

Pricing emissions

Another complex issue is how to price emissions. In principle, optimal policy to reduce GHG emissions is simple: every emitter should be charged a price per unit of emissions, equal to the (net present value of) damage it causes (this in addition to the price paid for the coal or other underlying resource). That is, to ensure that the cost of reducing emissions is minimized, the charge should be the same for all emissions, wherever and however they arise. The use of fossil fuels, for example, should be charged at a rate—a "carbon price"—that reflects the carbon content of each and, hence, the CO_2 that they emit when burned.

Though the principle is simple, its application is complex. Deciding the "correct" value of marginal damage from emissions—we shall speak of the carbon price, although the same principles apply to all GHGs—requires taking a view on matters ranging from the highly speculative (such as the likely pace and nature of technical progress) to the philosophical (in the choice of discount rate).

And it is not just (or even mainly) today's carbon price that matters. Investments decisions made today in risky R&D, or in developing power stations that will last decades, require some view on future fossil fuel prices, including carbon prices.

The carbon price is likely to increase over time in real terms, at least for the foreseeable future: as the time of most intense damage comes nearer, the carbon price rises in present value and, hence, so too does the charge. It may not be wise for the carbon price to increase too fast, however, because that could create an incentive for owners of fossil fuels to extract more rapidly now, when the charge is low, making future problems worse (Sinn, 2007). Although the appropriate rate of increase remains an open question, a key challenge for policymakers, which they are far from solving, is to find ways of making credible the expectation of reasonably rising carbon prices.

Chart 1 illustrates some of the ambiguities and uncertainties related to the correct emissions price path and is based on simulations under the U.S. Climate Change Science Program. It uses two integrated assessment models applied in that work: the IGSM model developed by the Massachusetts Institute of Technology, and the MiniCAM model, developed by teams at the Pacific Northwest National Laboratories and University of Maryland.

The assessment of future emissions prices varies widely—both for a given year and by time frame, across models and long-run GHG concentration targets. (In 2040, for example, the price will range from $13 per ton of carbon (tC) for MiniCAM given a long-run target of 650 parts per million (ppm) for atmospheric carbon to $562/tC for IGSM under a 450 ppm target.)

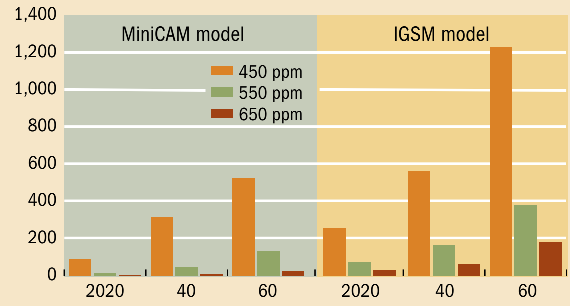
Differences between models represent uncertainties about such factors as mitigation costs and baseline energy use; the "correct" emissions target is also uncertain. Some types of uncertainty are not modeled: assumptions about discounting, for example, are the same in all these calculations (4 percent a year). For comparison, most assessments of the current "correct" emissions price are in the range $15–$60/tC (with the value proposed by the Stern Review at about $330/tC, something of an outlier).

Chart 1

Different rates

The IGSM model, which assumes a higher baseline growth in emissions than the MiniCAM model, requires higher tax rates to achieve targeted emissions levels.

(global carbon tax rates, dollars per ton of carbon)



Source: IMF staff calculations using MiniCAM output.

Carbon taxes, cap-and-trade, and all that

Further issues arise in implementing carbon prices. There are two archetypal market-based methods: carbon taxation and cap-and-trade schemes (under which rights to emit are issued—either sold or given away—up to some fixed amount and then bought by those who find abating relatively hard from those who find it relatively easy). Most schemes proposed in practice are hybrids: they may involve, for instance, permit trade but with the government ready to issue enough permits to keep the price above some floor. But these two polar forms illustrate many of the key choices to be made.

In the simplest case, no choice need be made. If all emission quotas under a cap-and-trade arrangement are auctioned to the highest bidders, and with full certainty about emissions (and the emissions price), the two mechanisms are equivalent: replacing a cap-and-trade scheme with a carbon tax at a rate equal to the market-clearing permit price, emissions, and government revenue will be exactly the same.

But in the presence of uncertainty, the equivalence breaks down. Cap-and-trade provides certainty on aggregate emissions; carbon taxes provide relative certainty on prices. In the face of uncertainty as to how costly reducing emissions will be, taxes may have some advantage as a mitigation device because they better match the marginal costs and benefits of mitigation.

Suppose, for example, that abatement proves much more costly than expected. Under cap-and-trade, emissions would be unaffected, but the necessary abatement would be very costly. Under a carbon tax, those costs would be avoided, but emissions would be higher than desired. Such a surge in emissions may be of relatively little concern, however, because emissions over any short period matter little to atmospheric concentrations, which are what really matter.

The equivalence will also fail if—as has often happened in practice—emissions rights under cap-and-trade are not auctioned, but given away. For example, under the current phase of the European Union Emissions Trading Scheme (EU-ETS), set up to help implement the EU's Kyoto Protocol commitments, no more than 10 percent of emissions quotas may be auctioned. This leads to an implicit revenue loss of about €40 billion a year and to a substantial and opaque measure of redistribution.

Such "grandfathering" of emissions rights can have other adverse effects too. Firms may expect future allocations to depend on current emissions, thereby blunting their incentive to abate now. Entry and exit rules also matter. If exiting firms lose their rights, for instance (rather than being able to sell them), they may be less likely to exit, making abatement more difficult. Grandfathering may have been reasonable for investments sunk before carbon pricing was even imaginable. But that is no longer the case. And, indeed, the European Commission proposes to eliminate grandfathering during the third phase of the EU-ETS, from 2013 to 2020—a firm step in the right direction, and an example for others.

What to do with the revenue?

How much money optimally imposed emissions taxes will raise for governments is an important fiscal issue. Chart 2 shows projected revenues from charges on carbon emissions in percent of world GDP by 2020, 2040, and 2060, with projected tax rates and emissions calculated by the integrated assessment models used in that exercise. We see that these numbers range from totally insignificant (0.1 percent of income under MiniCAM in 2020 with a 650 ppm target), to substantial (more than 3 percent of income under IGSM in 2060 with a 450 ppm target). While regional distributions are not given here, the share of total emissions for lower-income countries is projected to increase gradually (more so under the MiniCAM model), implying that these countries also will collect a greater share of overall tax revenue (exceeding 65 percent for non-OECD countries by 2060 under MiniCAM).

When equivalence of the kind described above holds, the same total revenue could also be achieved under a cap-and-trade arrangement with full auctioning of emissions rights. But the revenue distribution across countries could be quite different.

The widespread presumption under carbon taxation is that revenues would accrue to the country in which the carbon is used (although this would not prevent subsequent international transfers). Under cap-and-trade, however, some rule must be adopted for allocating the total emissions rights across countries. And how that is done—in proportion to emissions under business as usual, for instance, or in proportion to population—can have powerful implications for the direction and extent of international trade in permits.

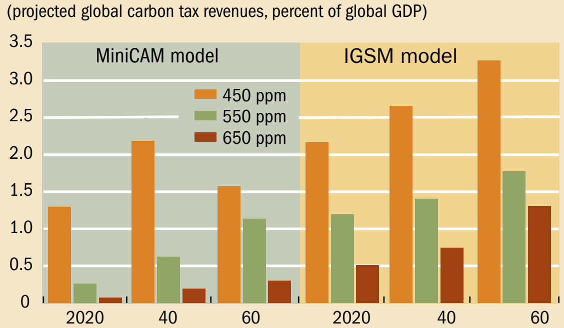
Different exercises give somewhat different results but tend to agree that Africa and India would likely be sellers of permits (forcing them with an incentive to participate in the scheme), whereas the industrial countries would be buyers. Such schemes, on top of having deterrent effects on emissions, would imply an effective resource transfer from high-income to lower-income countries. Clearly, the implementation of such transfers would raise difficulties: it would need, in particular, some agreed system by which each country can be assured that others are indeed emitting no more than allowed by the permits they hold.

Chart 2

Money maker

The IGSM model produces higher revenues than the MiniCAM model, mainly due to higher tax rates on emissions.

(projected global carbon tax revenues, percent of global GDP)



Source: IMF staff calculations using MiniCAM output.

For cash-strapped governments, the potential revenue from carbon pricing would seem to provide at least one benefit from climate change. And, indeed, it would enable them to make less use of more distortionary taxes and deal more confidently with the potential revenue challenges arising from trade liberalization and globalization. (Some, of course, will worry that they will instead simply waste this additional revenue.)

But carbon pricing may well worsen the distortions caused by the existing tax systems, tending, broadly, to reduce the level of economic activity and so exacerbate marginal disincentives caused by the tax system. So it is generally a good use of the revenue from carbon pricing to shift away from more distorting tax instruments. Exactly what those other instruments are may vary across countries. Several European countries, for example, have sought to alleviate labor market problems by using increased energy taxes to reduce social contributions. Others might see the corporate tax as a prime candidate for reduction.

Participation and fairness

Not the least of the potential roles for fiscal design is to encourage wide participation in mitigation—to limit emissions at least possible cost—and, a related challenge, to help spread the burden of climate change in ways that are perceived to be fair. This means, for example, using other instruments to soften the distributional impact of carbon pricing within countries (which can be particularly difficult when it comes to raising unduly low energy prices in low-income countries) and addressing such controversial issues as the potential use of border tax adjustments if neighboring countries do not have similar carbon tax rates.

Thus, it is increasingly clear that fiscal design issues will be central to any effective response to the difficulties posed by climate change. ■

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Rising Temperatures, Rising Risks

A dry lake bed in Hubei Province, China.

Mohan Munasinghe

GLOBAL warming is already taking its toll. In Darfur, where several hundred thousand people have died in recent years from the internal conflict, climate change has exacerbated water and land shortages (because of growing desertification), undermined agriculture, and fueled conflict over these scarce resources among the poor. On the opposite side of the globe, many Pacific islands (and the Maldives) that are often only centimeters above sea level are threatened with inundation by rising seas. In the distant north, melting of the sea ice is affecting polar wildlife and undermining the already precarious livelihoods of native peoples.

These grim harbingers of climate change underline the need to better understand the phenomenon and address the consequences. The latest report of the UN's Intergovernmental Panel on Climate Change (IPCC) says that global warming is a reality and has almost certainly been caused by recent human activities that have increased greenhouse gas (GHG) emissions. It also indicates that climate change (characterized by temperature increase, sea level rise, and precipitation changes) will continue into the foreseeable future and intensify (see Box 1), with potentially disastrous consequences for the planet and its inhabitants.

The most vulnerable groups will be the poor, the elderly, and children, including those living in rich countries. The most affected regions will be the Arctic, sub-Saharan Africa, small islands, and Asian megadeltas. High risks will be associated with low-lying coastal areas, water resources in dry tropics and subtropics, agriculture in low-latitude regions, key ecosystems (such as coral reefs), and human health in poor areas. Moreover, extreme weather events will worsen, especially tropical cyclones and heat waves. The result is that prospects for achieving many of the eight 2015 Millennium Development Goals—which include poverty reduction, better health and education, gender equality, and saving the environment—will become even more remote.

How can this destructive cycle be broken? The best hope lies in crafting strategies that address climate change and sustainable development simultaneously. This is because the two issues are highly interconnected: climate change affects development prospects and development paths determine the future climate. At the global level, countries need to act in a concerted fashion to reshape human activities on an unprecedented scale although, sadly, current trends are not at all promising (see Box 2). At the national level, however, the outlook might be more hopeful, given that practical methods now exist for integrating

Making development more sustainable will help address climate change

climate change responses into sustainable development strategies. Indeed, the existence of these tools should help to dispel the concern of many policymakers that tackling climate change might divert resources that are sorely needed to deal with more immediate development problems, such as growth, poverty, food security, ill health, unemployment, and inflation.

How humans can cope

The two specific ways that humans can respond to climate change are through adaptation and mitigation. Adaptation tries to reduce the vulnerability of human and natural systems to the stresses of climate change, whereas mitigation aims to lower, or even remove, GHG emissions.

Adaptation responses. Adaptation efforts need to be stepped up, given that long-term, unmitigated climate change is likely to exceed the adaptive capacity of natural, managed (agricultural), and human systems. Natural organisms and ecosystems tend to adapt autonomously (for example, migration of animals as habitats change, and growth-cycle changes in plants), but many may not survive if the rate of temperature rise is too rapid. Humans are capable of preplanned (or anticipatory) adaptation, although reactive measures are often necessary. Proven adaptation methods exist—including building dikes against sea level rise, developing temperature- or drought-resistant crops, and widening hazard insurance coverage—but they need to be disseminated more widely and implemented by governments, businesses, and civil society. Take coastal areas threatened by flooding and storms as temperatures rise. With constant expenditures on coastal protection, about 55–90 million people will be affected annually by a 2°C warming. However, these numbers may be drastically cut (to 2–10 million) by marginally raising annual coastal protection spending to match GDP growth rates.

Mitigation responses. Current mitigation efforts—primarily, reducing the emission intensity of energy use and increasing carbon dioxide absorption by planting forests—similarly need to improve. The result would be lower GHG concentrations, along with other benefits, such as better health, lower energy demand leading to greater energy security, and greater energy availability for poor and rural areas. At this point, we know the technological and policy options that could stabilize GHG concentrations in the range of 450–550 parts per million by volume (ppmv) within the next 100 years. The estimated median costs of mitigation measures to achieve 550 ppmv might amount to about 1.3 percent of world GDP by 2050 (equivalent to an annual reduction of GDP of less than 0.1 percent a year up to 2050), although the cost of stabilization at the 450 ppmv level may exceed 3 percent of 2050 GDP.

> **"Although per capita emissions will remain far lower in developing nations than in industrial countries for the foreseeable future, total emissions in the more populous countries will become increasingly significant."**

Box 1

The scientific facts

For decades, the public debate over global warming boiled down to a little science and a lot of conjecture. But in recent years, the world's scientists have found their voice, and in the 2007 *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC)—which was founded 20 years ago by the UN to provide an authoritative review of climate change information—many of the world's leading scientists spoke with one voice. Their message was a grim one.

What we know. For more than 10,000 years, carbon dioxide concentrations in the atmosphere were stable at about 280 parts per million by volume (ppmv), but, following the industrial revolution, these concentrations rose rapidly and now exceed 380 ppmv. As a result—and with the help of other minor greenhouse gases (GHGs), such as methane and nitrous oxide—over the past 100 years, the planet's surface has warmed by an average of 0.75°C, and the rate is accelerating. Other evidence of global climate change includes a systematic rise in the mean sea level (about 16 centimeters during the past century), the melting of ice in polar areas and glaciers, increased damage caused by extreme weather events, less precipitation in dry areas and more precipitation in wet areas, and significant shifts in ecological cycles and animal behavior.

The IPCC predicts that in the absence of a serious effort to curb emissions, by 2100 carbon dioxide concentrations will be about twice the preindustrial level (550 ppmv), the average global temperature will increase by about 3°C above current levels (the range being 1.1–6.4°C), and the mean sea level will rise 35–40 centimeters. Extremes of climate and precipitation will worsen, and the melting of ice will accelerate because of the greater warming of polar regions. Even if emissions were sharply curbed, the IPCC estimates that temperatures would rise at least 1.5°C more by 2100.

What we don't know. The IPCC is continuing to work on some important gaps in knowledge. For example, the level at which GHG concentrations are dangerous is not scientifically certain, although the European Union has made a value judgment that 2°C (corresponding to 450–500 ppmv) is the tolerable risk threshold. One key parameter, to be determined more accurately, is the sensitivity of climate to GHG concentrations. The accuracy of the economic costs of impacts also needs to be increased, especially since many of them will occur in the distant future. Because of time lags, often involving decades or even centuries, catastrophic outcomes such as the melting of polar ice or changes in oceanic circulation are hard to predict.

How would this mitigation take place? A key way is through the flexibility mechanisms in the 1997 Kyoto Treaty to combat global warming—such as the Clean Development Mechanism, Joint Implementation, and Emissions Trading—which permit industrial countries to transfer part of their Kyoto emissions-reduction obligations to other nations in exchange for payment. Consider a Clean Development Mechanism project implemented in a developing country, where the incremental cost of planting a forest to absorb carbon would be only $10 a ton of carbon. The absorbed carbon would be credited to an industrial country and set off against the industrial country's mitigation obligations under the Kyoto Protocol—which might otherwise have involved retrofitting an existing power plant at a cost of $50 a ton of carbon. This process would be efficient because mitigation is done at the lowest cost. Further, the money transfer from a rich to a poor country would be equitable, provided the developing country received more than the minimum payment of $10 a ton (to cover costs)—that is, it shared the $40 cost saving. Recent compensation levels have ranged from $5 to $10 a ton in developing countries to about $50 in Europe.

Box 2

A snapshot of global efforts

The 1992 UN Framework Convention on Climate Change (UNFCCC), accepted by 190 countries, is the guiding document for international actions. It seeks "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" . . . "on the basis of equity and in accordance with [nations'] common but differentiated responsibilities and respective capabilities." It notes that developed countries "should take the lead in combating climate change" and recognizes "the specific needs and special circumstances" of developing countries. While accepting the "right to promote sustainable development," the UNFCCC invokes the precautionary principle that "where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason" for postponing measures to prevent climate change.

In an effort to implement the UNFCCC, participating countries agreed in late 1997 on the Kyoto Protocol, which came into force in February 2005. It specifies that, by 2012, Annex I (industrial) countries will collectively reduce their emissions by 5 percent relative to 1990 levels, and Non-Annex I (developing) countries are exempt from mandatory emissions reductions. Currently, 174 countries have ratified this agreement, although the United States (the largest greenhouse gas (GHG) emitter) has rejected it.

Nevertheless, global GHG emissions rose by more than 70 percent from 1970 to 2004, with major increases since Kyoto. The road map agreed at the UNFCCC Bali meeting in December 2007 set out the agenda and timetable to craft a post-Kyoto mitigation agreement—along with helping poor countries adapt to climate change (with improved financial and technical help)—but participants failed to agree on specific mitigation targets, mainly because of U.S. reluctance.

Of course, these mitigation and adaptation efforts raise tough questions about equity and burden sharing, which often dominate global debates. To date, the bulk of greenhouse gases—chiefly carbon dioxide from the burning of fossil fuels and deforestation—have been emitted by the rich countries (in 2004, average per capita GHG emissions in industrial countries were four times greater than those in developing countries).

But as the years progress, developing countries will need to boost their energy use (often relying heavily on coal) to alleviate poverty and promote development. Although per capita emissions will remain far lower in developing nations than in industrial countries for the foreseeable future, total emissions in the more populous countries will become increasingly significant. The International Energy Agency estimates that by 2015, China will take over from the United States as the world's top carbon dioxide emitter, and India will move up from fifth to third place. And, further complicating matters, the poor countries will be the ones hardest hit by climate change. For now, developing countries should focus on adaptation, especially to protect their poor, whereas rich countries (which are better endowed financially and technically) should lead the mitigation effort and also assist poorer countries in both their adaptation and mitigation work. Meanwhile middle-income countries need to join the mitigation effort over time as they become richer.

A framework for action

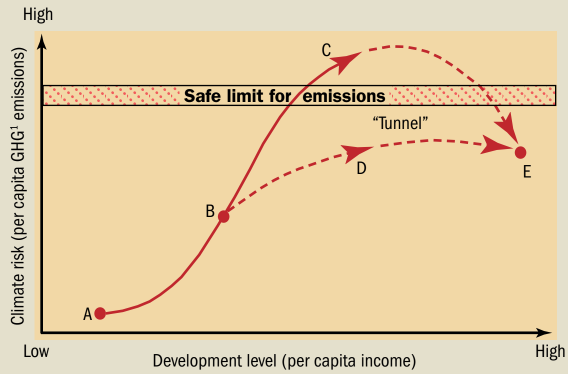
What will it take for global warming to grab the attention of policymakers, who are invariably preoccupied with the problems of today? The answer lies in convincing them to integrate climate change policies into each country's national sustainable development strategy. And the good news is that many practical ways to do just that have been developed and used over the past 15 years. One promising framework—known as "sustainomics"—offers some initial practical steps to help make the transition from the risky business-as-usual scenario to a safer and more sustainable future. It draws on three basic principles:

- First, the main goal must be to make development more sustainable. This step-by-step approach is more practical and permits us to address urgent priorities without delay, because many unsustainable activities are easier to recognize and implement (for example, conserving energy). Sustainable development is defined here as a process (rather than an end point).
- Second, the three elements (or vertices) of the sustainable development triangle need to be given balanced treatment. That means weighing ***social*** (inclusion, empowerment, and governance), ***economic*** (growth, efficiency, and stability), and ***environmental*** (biodiversity, natural resources, and pollution) dimensions.
- Third, deliberations should transcend traditional boundaries (involving academic disciplines, space, time, and stakeholders). Transdisciplinary analysis is essential, because issues and solutions cut across conventional disciplines. Problems such as climate change also span the planet, play out over centuries, and concern every human being.

These principles could help guide policymakers trying to shape a long-term consensus on reconciling mitigation costs

Tunneling through

Developing countries need to avoid the carbon-intensive path of industrial countries.



Source: Munasinghe (2007).
[1]Greenhouse gas.

and development aspirations. As the chart shows, a country's level of environmental risk (represented by GHG emissions per capita) varies with its level of development (measured by GNP per capita). A typical developing country might lie along the curve AB, whereas an industrial nation might be at C. Ideally, industrial countries (exceeding safe limits for "dangerous" climate change) should mitigate and follow the future growth path CE by restructuring their development patterns to delink carbon emissions and economic growth. Developing countries could adopt innovative policies to "tunnel" through (along BDE) by learning from the experiences of the industrial world—thus, the tunnel would lie below the safe limit. That way, they could simultaneously continue to develop (and grow) more sustainably, follow a less carbon-intensive growth path, and reduce their climate vulnerability.

The framework also provides policymakers with a variety of practical tools—both new and conventional methods applied innovatively. At the national level, tools include macro and sectoral modeling, environmentally adjusted national income accounts, poverty analysis, and the Action Impact Matrix. At the project level, they include cost-benefit analysis, multicriteria analysis, and environmental and social assessment.

Useful policy instruments include pricing, taxes and charges, regulations and standards, quantity controls, tradable permits, financial incentives, voluntary agreements, information dissemination, and research and development. These tools help to identify and implement the most desirable "win-win" climate policies that simultaneously yield economically, environmentally, and socially sustainable paths. They also help resolve trade-offs among conflicting goals.

Ensuring food security

Among the various sustainomics tools, the Action Impact Matrix (AIM) excels in its ability to show how to integrate climate change and sustainable development—making it an extremely useful tool for decision making at the national, sectoral, and project levels. It identifies and prioritizes how the main national development policies and goals affect the key adaptation and mitigation options, and vice versa. It analyzes key economic-environmental-social interactions to identify potential barriers to making development more sustainable. And it helps determine the key macro policies and strategies that would facilitate the implementation of adaptation and mitigation to overcome the effects of climate change.

Take the case of the 2006 AIM for Sri Lanka, as illustrated in Table 1. The cells with values of –3 and –2 indicate the more adverse effects and should have the greatest priority. Conversely, cells with values of 0 or –1 may effectively be ignored because the effects are small. Consider the row marked "(S1) Status," where the cell (S1, 6) has a value of –3, indicating that climate change will have a severe negative impact on future water resources. Looking down column (6), we note that cell (C6) also has a value of –3, showing that this lack of water resources will severely affect food security. Similarly, looking down column (1), we see that climate change will also have highly negative effects on food

Table 1

Identifying climate-development links in Sri Lanka

An Action Impact Matrix helps pinpoint impacts of key climate change vulnerabilities on major development goals and policies, determines "win-win" policies, and resolves trade-offs.

Notation:
+ Beneficial
– Harmful
3 High
2 Moderate
1 Low
0 No impact

	Key vulnerabilities: economic sectors and ecosystems	(1) Agricultural output	(2) Hydro power	(3) Deforestation	(4) Biodiversity (flora and fauna)	(5) Wetlands and coast ecosystems	(6) Water resources	(7) Poor communities	(8) Human health	(9) Infrastructure	(10) Industries and tourism
(S0)	Status (natural variability)	-1	0	-2	-1	-1	-2	-1	0	2	2
(S1)	Status (+climate change impacts)	-2	-1	-2	-2	-2	-3	-2	-1	-1	-1
Major development goals/policies											
(A)	**Growth**	-1	-1	-1	-1	-1	-2	-2	-1	-1	-1
(B)	**Poverty alleviation**	-2	0	-1	-1	-1	-2	-2	-2	-1	-1
(C)	**Food security**	-3	0	-1	-1	-1	-3	-1	-1	0	0
(D)	**Employment**	-1	0	-1	0	-1	-2	-1	-2	-1	-2
(E)	**Trade and globalization**	-2	-1	0	0	0	-1	-1	0	-2	-1
(F)	**Budget deficit reduction**	-1	-1	0	0	0	0	0	-2	0	-1
(G)	**Privatization**	0	1	1	0	0	1	0	0	-1	-1

Source: Munasinghe (2007).

security through the agriculture sector, as indicated by the –3 in cell (C1). Each such cell is linked to a separate detailed description—for example, the description for cell (C1) describes outputs of all major crops in different parts of Sri Lanka, under different temperature and rainfall conditions.

In light of the very high AIM priority assigned to food security, agriculture, and water, a more detailed study of this issue was quickly undertaken. A Ricardian agriculture model was applied to identify how past output changes in important crops such as rice, tea, rubber, and coconut had depended on natural variations in climate (mainly temperature and rainfall). Then, a downscaled regional climate model was used to make detailed temperature and precipitation predictions specific to Sri Lanka. The combined results of both models showed that the impact on future rice cultivation would be negative and significant (almost 12 percent yield loss by 2050) and would affect poor farmers in the dry zone, where incomes are lowest. Meanwhile, some areas in the wet zone, where tea is grown and incomes are higher, would experience gains (+3.5 percent yield by 2050).

These findings raise several important policy issues. First, given that rice is the staple food and a large portion of the population depends on rice farming, adaptation measures are essential to protect national food security, protect livelihoods, and reduce the vulnerabilities of the rural poor in the dry zone. Second, the different effects of climate change on poor farmers and richer landowners have income distribution and equity implications that also need to be addressed. And third, population movements from dry to wet zones are a potential risk that policymakers will need to deal with.

Encouraging renewable energy

At the project level, another AIM was generated to study Sri Lanka's links between mitigation and development goals. Small hydropower was identified as a promising renewable energy option, and that, in turn, raised the question of which small hydropower sites should be selected. In an effort to assess social, economic, and environmental indicators, a multicriteria analysis was undertaken. Its advantage was that it allowed policymakers to look at all of these spheres in a balanced manner—in large part, by quantifying and displaying trade-offs that had to be made between conflicting objectives that are difficult to compare directly. The multicriteria analysis thus provided useful additional information to supplement the economic data from a cost-benefit analysis.

As in all sustainable development studies, the indicators chosen were crucial. In this case, the economic indicator was cost, the social indicator was number of people resettled, and the environmental indicator was a biodiversity loss index. All indicators were measured per ton of carbon mitigated at each site (because fossil fuel use was displaced by the hydroelectric energy generated).

Which hydropower projects ranked highest? It was those that provided the most balanced path for integrating mitigation with national sustainable development objectives. Table 2 shows the top 10 sites (out of 22 examined) based on their high score on a simple composite sustainability criterion, which gave equal weight to the economic, social, and environmental indicators. The best 2, Projects E and V, also scored highest on the economic indicator, but third-place Project R managed to edge out Project H, even though the latter scored higher on economic terms alone.

Table 2

Prioritizing small hydropower projects in Sri Lanka

A multicriteria analysis offers policymakers a way to pick the best mitigation projects that make development more sustainable.

Indicator	Project rank									
	1	2	3	4	5	6	7	8	9	10
Sustainability[1]	**E**	**V**	**R**	**I**	**P**	**J**	**U**	**L**	**H**	**S**
Social[2]	L	O	P	Q	R	V	M	I	C	E
Environmental[3]	G	R	I	O	Q	L	E	V	S	T
Economic[4]	E	V	H	R	I	P	J	U	L	S

Source: Munasinghe (2007).

Note: Individual letters stand for individual projects, which are ranked by social, environmental, and economic impact.

[1]The sustainability index is a composite that gives equal weight to the social, economic, and environmental indicators.

[2]Measured by number of people displaced.

[3]Measured by a composite biodiversity loss index.

[4]Measured by cost.

A higher profile

In recent months, three developments—the release of the IPCC Fourth Assessment Report, the awarding of the 2007 Nobel Peace Prize to the IPCC and Al Gore, and the December 2007 Bali conference of the UN Framework Convention on Climate Change—have combined to raise the profile of climate change and helped to highlight the difficulties that policymakers face in coming to grips with this important challenge. Although there is a growing consensus worldwide on the need to take early action on climate change, important practical issues remain unresolved, including burden sharing and equity.

Nevertheless, one can conclude on an optimistic note. Although climate change and sustainable development are complex, interlinked problems that pose a challenge to humanity, they could be solved together by integrating adaptation and mitigation response measures into the broader rubric of sustainable development strategies. We know enough already to immediately take the first step toward making development more sustainable—helping to usher in a safer and brighter future. ■

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The Greening of Markets

Financial markets can play a valuable role in addressing climate change

Paul Mills

IT IS not immediately obvious what role financial markets can play in addressing climate change. Climate change happens slowly and has a global impact on the physical environment, whereas financial markets react to news in fractions of a second and are almost liberated from specific physical locations. The low energy intensity of the financial sector means that reductions in greenhouse gas (GHG) emissions would have little impact on the physical operations of financial markets and institutions (unlike, for instance, their effects on electricity production or transport).

Nevertheless, financial markets potentially play two important roles in the policy response to climate change (see table). First, they foster mitigation strategies—that is, the steps taken to reduce GHG emissions for a given level of economic activity—by improving the efficiency of schemes to price and reduce emissions (for example, carbon permit trading) and the allocation of capital to cleaner technologies and producers. Second, financial markets can cut the costs of adaptation—that is, how economies respond to climate change—by reallocating capital to newly productive sectors and regions and hedging weather-related risks.

In recent years, markets in carbon permit trading, weather derivatives, and catastrophe (CAT) bonds have seen sharp increases in activity and innovation, which bodes well for the future. But if a basic understanding of finance is not reflected in policy design, climate change policy can suffer setbacks. Hence, recognizing how financial markets will react to climate change initiatives, and how they can best promote mitigation and adaptation, will become crucial to shaping future policy and minimizing its costs.

Reducing GHG emissions

On the mitigation front, a large number of countries have committed, or are likely to commit, to targets to curb GHG emissions by 2012 under the Kyoto Protocol or its successor arrangement. In addition to regulatory restrictions, this policy goal can be achieved through either emissions taxes or schemes to cap emissions and allow trading of permits. In such an environment, financial markets can reinforce commercial pressures on firms to reduce emissions.

One such mechanism is the ***"green" investment fund***. Originally part of the movement for "socially responsible" or "ethical" investment, such funds were established in the 1980s to invest only in companies working to limit the environmental damage they caused. Since then, more specialist funds have been launched that invest in companies, projects, and technologies involved in reducing GHG emissions. In fact, some recently launched equity indices comprise only shares of companies that have low GHG emissions or are investing in abatement technologies. The amounts invested in green funds are as yet too small to have a significant impact on overall equity performance. But if the post-Kyoto settlement results in a sig-

Identifying the right tools

Financial instruments can help minimize the costs of reducing greenhouse gas emissions and adapting to climate change.

Emissions trading	Climate change–related investments	Market for catastrophe and weather risks
Mitigation strategies		**Adaptation strategies**
Instruments		
Tradable emissions permits	Investment funds in sectors that could profit from climate change (for example, water and nuclear)	Catastrophe risk transfer instruments (for example, CAT bonds and swaps)
Futures and options on emissions permits	Investment funds dedicated to clean technologies	Weather and crop insurance
Funds investing in emission permits	Projects earning carbon credits	Derivatives for hedging weather risk
Intended effects		
Minimization of costs of given level of reduction of greenhouse gas emissions	Efficient reallocation of capital in response to climate change	Risk sharing of natural catastrophe and weather-related risks
	Provision of new capital for financing climate change mitigation	Maintenance of insurability of weather risks and reduction in premiums
		Provision of price signals of weather-related risks and costs

Source: Deutsche Bank (adapted).

nificant tax on, or price for, GHG emissions, then companies with low current emissions or investments in abatement technologies should outperform the market. Indeed, this already seems to have been anticipated by equity investors. When launched in October 2007, the 300 stocks comprising the HSBC Global Climate Change Index had outperformed the MSCI World Index by 70 percent since 2004.

More generally, as GHG emissions are taxed or rationed, to the extent that companies are unable fully to pass on these costs, the cost of capital for heavy emitters will suffer relative to their competitors. Such price signals will reallocate capacity to sectors and regions in which production, investment, and research are most profitable, given a higher price for emitting GHGs.

A second mechanism is the Kyoto Protocol's ***Clean Development Mechanism (CDM)***, which allows cheaper emissions reductions in emerging markets and low-income countries to be certified by the UN and then sold as credits to offset emissions in cap-and-trade schemes in high-income countries. Substantial funds have been raised to invest in projects to benefit from certified emissions reductions under the CDM. Credits worth €12 billion were sold into the European Union's Emissions Trading Scheme (ETS) in 2007, and funds dedicated to carbon reduction projects now exceed €10 billion. However, the CDM's effectiveness is limited by slow project accreditation and concerns about both project quality and whether they make any appreciable difference to GHG emissions growth in emerging economies.

A third mechanism—and the clearest example of a financial market playing a central role in climate change mitigation policy—is ***carbon emissions trading***. Following the precedent of the U.S. market for sulphur dioxide (SO_2) permits—which reduced SO_2 emissions at low cost—provision for permit trading was included in the Kyoto Protocol, and trading schemes have been developed in the European Union, Australia, and the United States.

Heavy EU trading

The European Union ETS is the largest such market, with €9.4 billion in EU allowances traded in 2005, €22.4 billion in 2006, and €28 billion in 2007. In volume terms, trading has grown considerably since 2005 (see Chart 1). The European Union ETS began in 2005 with a trial phase, and in early 2008 it moved into Phase II—which is designed to implement the European Union's Kyoto Treaty emissions reduction target from 2008 to 2012. Futures trading in EU allowances started in 2004, and futures and spot EU allowances are now traded on five exchanges and by seven brokers, concentrated in London. Weekly turnover has grown to more than 20 million tonnes of carbon dioxide (CO_2) equivalent, roughly 70 percent of which is traded through brokers. Liquidity has improved substantially, with instantaneous trades now possible at tight bid-offer spreads. Initially, energy companies were the primary market participants, but investment banks and hedge funds have also become active traders.

Such cap-and-trade schemes are intended to minimize the cost of a given level of pollution abatement by creating property rights to emit, administratively limiting the supply of permits to the target level, distributing permits (either by auction or by direct allocation), and allowing them to be traded so that emitters short of permits are forced to buy them from those that are "long" because of abatement. Theoretically, this should result in the marginal cost of abatement equaling the price of a permit within the scheme, with emissions being cut by the most cost-efficient producers—a result that is equivalent to an optimal GHG emissions tax (see "Paying for Climate Change" in this issue).

Has the European Union ETS proved successful? A liquid market for carbon has been created whose price has reflected changing market fundamentals. The significant price of emissions permits has generated some incentives toward abatement. Nevertheless, some lessons have been learned.

First, ***price volatility has been higher than necessary***. Most notably, permit prices in April 2006 dropped sharply because of rumors and selective publication of information by some EU members, indicating that permits had been overallocated in Phase I (see Chart 1). Subsequent confirmation that the scheme as a whole was net "long" resulted in the collapse of the Phase I price to close to zero. Allowing unused Phase I permits to be banked for use in Phase II would have limited price sensitivity and reduced reputational damage to the scheme. In addition, more frequent and careful release of market-sensitive data would have reduced unnecessary volatility and increased confidence in price reliability.

Second, ***so far the European Union ETS has fostered trading of EU allowances with little impact on long-term investment.*** When the price of EU allowances was at the higher end of its range, some energy companies reportedly switched marginal production from dirtier coal to cleaner, gas-fired power stations. Some producers also say that a significant price for carbon is encouraging energy-saving investment. However, attention has focused on buying credits from outside the EU scheme (principally from China), where abatement costs are substantially lower. In addition, Phase II of the scheme is insufficiently long lived to provide credible incentives for investment in cleaner energy technologies. Consequently, the fall in EU carbon intensity has slowed, despite the ETS, and recent performance has been worse than in the United States.

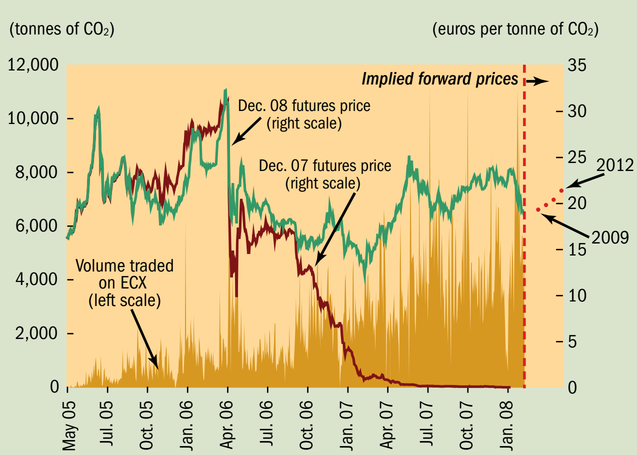
"Perhaps the clearest way in which financial markets can help with adaptation to climate change is through the increased ability to trade and hedge weather-related risk."

These lessons have prompted a comparison with the prerequisites for successful emissions trading and those for credible monetary policy. For a cap-and-trade scheme to develop long-term credibility, authority should be delegated to an independent central bank–type institution that is given a politically driven target to abate emissions at the lowest cost. This institution would be charged with the transparent and careful release of data, enforcement of long-term property rights, and discretion to change bankability and safety valve provisions to keep the price of permits within a set range to achieve its goal.

Chart 1

Active green trading

Carbon trading in the European Union has been growing, despite price volatility.



Source: European Climate Exchange (ECX).
Note: Data as of February 5, 2008.

Adapting to climate change

On the adaptation front, financial markets can help to reduce the costs of climate change in several ways. First, markets should generate price signals to reallocate capital to newly productive sectors and regions. By shifting investment to sectors and countries with higher rates of return (for example, water and agricultural commodities), the costs of adaptation would be reduced below those that would arise from an inflexible capital stock.

For instance, climate change is likely to change the dispersion and intensity of rainfall, leading to greater conservation investment in newly arid regions and in crops that use less water. The recent outperformance of companies specializing in water purification and distribution suggests that such factors are beginning to be reflected in equity prices.

But perhaps the clearest way in which financial markets can help with adaptation to climate change is through the increased ability to trade and hedge weather-related risk, which, some meteorologists believe, will increase as a result of climate change.

Weather derivatives offer producers whose revenue is vulnerable to short-term fluctuations in temperature or rainfall a way to hedge that exposure. Exchange-traded weather derivatives focus primarily on the number of days that are hotter or colder than the seasonal average within a defined future period. For instance, if there are more cold days than average over the contract period, those that have bought the "cooling degree day" future will enjoy a payout proportionate to the excess number of cold days. Futures enjoy low transaction costs and often relatively high liquidity. However, the parameter used to determine the futures contract payout may not be correlated exactly with a firm's actual losses if extreme weather occurs. Hence, trading such derivatives often provides only an approximate hedge for firms' weather-related exposures.

After a slow start in the late 1990s, the exchange-traded weather derivatives and insurance markets have grown strongly in recent years (see Chart 2), with a reported turnover of weather contracts exceeding $19 billion in 2006–07, from $4–5 billion in 2001–04. Exchange-traded contracts have focused primarily on short-term trading of temperature in selected U.S. and European cities, with liquidity now concentrating in near-term contracts as hedge funds and investment banks take a larger share of turnover.

Weather derivatives are complemented by weather swaps and insurance contracts that hedge adverse weather and agricultural outcomes. For instance, insurance contracts are being sold that pay out if temperature or rainfall in a specified area exceeds the seasonal average by a sufficient margin. Governments in some lower-income countries (for example, India and Mongolia) are offering crop and livestock insurance as a way to protect their most vulnerable farmers. Ethiopia pioneered drought insurance in 2006.

Governments can assist in developing weather derivatives and insurance by providing reliable and independent data on weather patterns. These data enable market participants to model weather risk at a particular location with greater accuracy and so offer a lower price for insurance. Similarly, neutral tax, legal recognition, and regulatory treatment of weather derivatives and insurance are necessary to ensure that artificial barriers to the market do not arise unintentionally.

Given that climate change is predicted to produce more extreme weather events, ***CAT bonds*** offer a new way for financial markets to disperse catastrophic weather risk (Hofman, 2007). At their simplest, CAT bonds entail the proceeds of the bond issue being held in an escrow account and surrendered to the issuer if a parameter(s) measuring an extreme natural catastrophe, such as a hurricane or an earthquake, breaches a specified trigger level. For this insurance, bond investors are paid a yield premium, and the principal is returned if the trigger is not breached by the time the bond matures.

The results are potentially profound for the continuing supply (or extension) of weather catastrophe insurance and the protection of vulnerable sectors, such as agriculture and coastal property. They offer insurers many more flexible ways to access the global capital markets to undertake catastrophe risk, thus allowing insurance to continue to be provided despite climate change.

CAT bonds were devised in the early 1990s, following the large payouts resulting from Hurricane Andrew in 1992, to enable reinsurance companies to divest themselves of extreme CAT risk and economize on capital. Until 2005, CAT bond issuance was less than $2 billion a year. But after Hurricane Katrina depleted industry capital, issuance has risen dramatically, with $4.9 billion in 2006 and $7.7 billion in 2007 (see Chart 3). Demand for CAT bonds has been strong from hedge funds and institutional investors looking for higher yields uncorrelated with other bond markets.

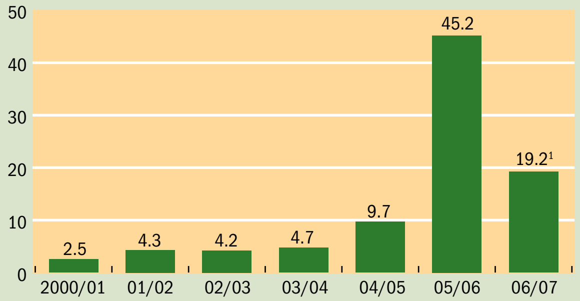
Although CAT bonds and other innovative ways of raising capital for weather-related reinsurance constitute only about 10–15 percent of global reinsurance capacity for extreme weather risk, their establishment as a global asset class should ensure that, if weather catastrophes do deplete the capital of the reinsurance industry in the future, it can be replenished

Chart 2

Blowing hot and cold

The demand to trade contracts providing protection against excessive temperature and rainfall has grown considerably.

(weather derivatives: notional value traded, billion dollars)



Source: PricewaterhouseCoopers.

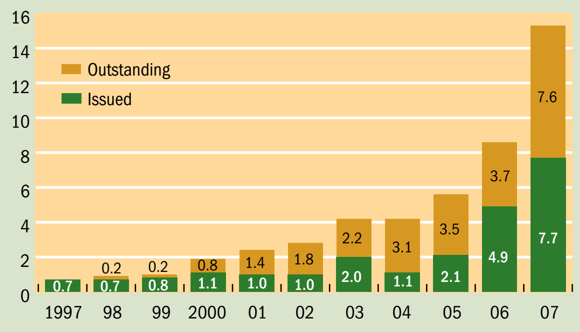
[1]Reduction in notional value traded in 2006/07 is largely the result of a move to monthly, rather than seasonal, contracts on the Chicago Mercantile Exchange.

Chart 3

Weathering the storms

Demand for catastrophe (CAT) bonds has accelerated in recent years as investors search for risks that aren't correlated with other financial markets.

(catastrophe bond issuance and amounts outstanding, billion dollars)



Source: Swiss Re Capital Markets.

more rapidly through the global capital markets. Premiums for weather risk insurance are already more stable following extreme weather events, and future insurability should be maintained at a reasonable cost, even if climate change results in their greater intensity.

How can governments respond to maintain insurability of weather-related risks despite climate change? First, authorities can restrict development in areas vulnerable to flooding or wind damage. Second, they can invest in flood defenses or water conservation measures to help private insurers continue to provide flood or drought coverage at a reasonable cost. Third, governments should refrain from subsidizing or capping flood or hurricane insurance premiums, because doing so encourages risky behavior and prevents the private insurance market from generating price signals to smooth adaptation to climate change. Higher premiums, or the withdrawal of insurance coverage, will provide incentives to curtail risky behavior and exposure to extreme weather. Permitting vulnerable property developments can make weather catastrophes an unnecessarily large fiscal threat—perhaps even for high-income countries.

Governments could consider hedging their fiscal exposures to catastrophes by directly issuing CAT bonds (as Mexico did in 2006 to provide earthquake insurance) or by participating in collective schemes to pool their weather-related risks, such as of hurricanes (as 16 Caribbean countries did in conjunction with the World Bank in 2007 through the Caribbean Risk Insurance Facility—a $120 million regional disaster insurance facility).

Demand for new CAT risks for diversification is exceptionally strong in the CAT bond market at present, so the insurance offered for new risks should be of relatively good value. Rating agencies could consider raising the credit ratings of low-income sovereign borrowers vulnerable to weather-related catastrophes if they cap their extreme fiscal risks through insurance. As with weather derivatives, providing longer runs of reliable and independent weather data enables insurance modelers to project weather patterns with greater confidence, thereby reducing the cost.

Benefiting from innovations

It seems likely that financial markets will play an integral role in climate change mitigation and adaptation in the future. Securities markets will reward those companies that successfully develop or adopt cleaner technologies. Cap-and-trade seems to be becoming the mitigation policy of choice in high-income countries, in which case the global market in permits for GHG emissions is likely to become the largest global commodity market.

Although weather derivatives and CAT bonds do not offer a complete panacea—as yet, only hedges against weather and catastrophe risks are available out to five years—recent rapid innovation and deepening in these markets prompt optimism that they will continue to innovate and further help adaptation to climate change. The growth of hedge funds and the appetite for risks that are uncorrelated with other financial markets mean that there is likely to be continuing demand for financial instruments that provide investors a premium to assume weather risk despite climate change. The ingredients for innovation exist, and governments should consider ways in which they can foster and take advantage of such innovations. ■

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G.Total nonrequested distribution (sum of D, E, and F)	40,672	40,209
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I. Copies not distributed	3,607	4,383
J. Total (sum of H and I)	50,475	50,800
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