Understanding the Links between Climate Change and Development

In about 2200 BCE a shift in the Mediterranean westerly winds and a reduction in the Indian monsoon produced 300 years of lower rainfall and colder temperatures that hit agriculture from the Aegean Sea to the Indus River. This change in climate brought down Egypt's pyramid-building Old Kingdom and Sargon the Great's empire in Mesopotamia.[1] After only a few decades of lower rainfall, cities lining the northern reaches of the Euphrates, the breadbasket for the Akkadians, were deserted. At the city of Tell Leilan on the northern Euphrates, a monument was halted half-built.[2] With the city abandoned, a thick layer of wind-blown dirt covered the ruins.

Even intensively irrigated southern Mesopotamia, with its sophisticated bureaucracy and elaborate rationing, could not react fast enough to the new conditions. Without the shipments of rainfed grain from the north, and faced with parched irrigation ditches and migrants from the devastated northern cities, the empire collapsed.[3]

Societies have always depended on the climate but are only now coming to grips with the fact that the climate depends on their actions. The steep increase in greenhouse gases since the Industrial Revolution has transformed the relationship between people and the environment. In other words, not only does climate affect development but development affects the climate.

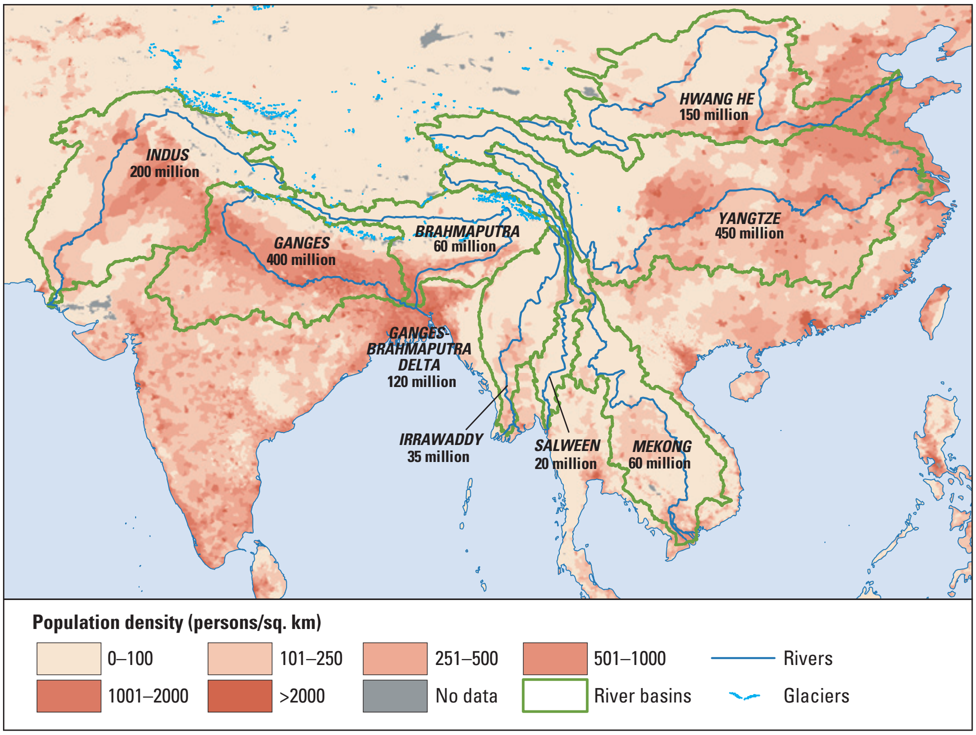
Left unmanaged, climate change will reverse development progress and compromise the well-being of current and future generations. It is certain that the earth will get warmer on average, at unprecedented speed. Impacts will be felt everywhere, but much of the damage will be in developing countries. Millions of people from Bangladesh to Florida will suffer as the sea level rises, inundating settlements and contaminating freshwater.[4] Greater rainfall variability and more severe droughts in semiarid Africa will hinder efforts to enhance food security and combat malnourishment.[5] The hastening disappearance of the Himalayan and Andean glaciers—which regulate river flow, generate hydropower, and supply clean water for over a billion of people on farms and in cities—will threaten rural livelihoods and major food markets (map 1.1).[6]

That is why decisive, immediate action is needed. Even though the debate about the costs and benefits of climate change mitigation continues, the case is very strong for immediate action to avoid unmanageable increases in temperature. The unacceptability of irreversible and potentially catastrophic impacts and the uncertainty about how, and how soon, they could occur

Key messages

Development goals are threatened by climate change, with the heaviest impacts on poor countries and poor people. Climate change cannot be controlled unless growth in both rich and poor countries becomes less greenhouse-gas-intensive. We must act now: country development decisions lock the world into a particular carbon intensity and determine future warming. Business-as-usual could lead to temperature increases of 5°C or more this century. And we must act together: postponing mitigation in developing countries could double mitigation costs, and that could well happen unless substantial financing is mobilized. But if we act now and act together, the incremental costs of keeping warming around 2°C are modest and can be justified given the likely dangers of greater climate change.

Map 1.1 More than a billion people depend on water from diminishing Himalayan glaciers



Sources: Center for International Earth Science Information Network, http://sedac.ciesin.columbia.edu/gpw/global.jsp (accessed May 15, 2009); Armstrong and others 2005; ESRI 2002; WDR team.

Note: The glaciers of the Himalayas and Tibetan Plateau regulate the supply of water throughout the year in major river basins supporting large agricultural and urban populations, with meltwater providing between 3 and 45 percent of river flow in the Ganges and Indus, respectively. Reduced storage as ice and snowpack will result in larger flows and flooding during rainy months and water shortages during warmer, drier months when water is most needed for agriculture. Glacier locations shown in the map only include glaciers larger than 1.5 sq. km in area. Numbers indicate how many people live in each river basin.

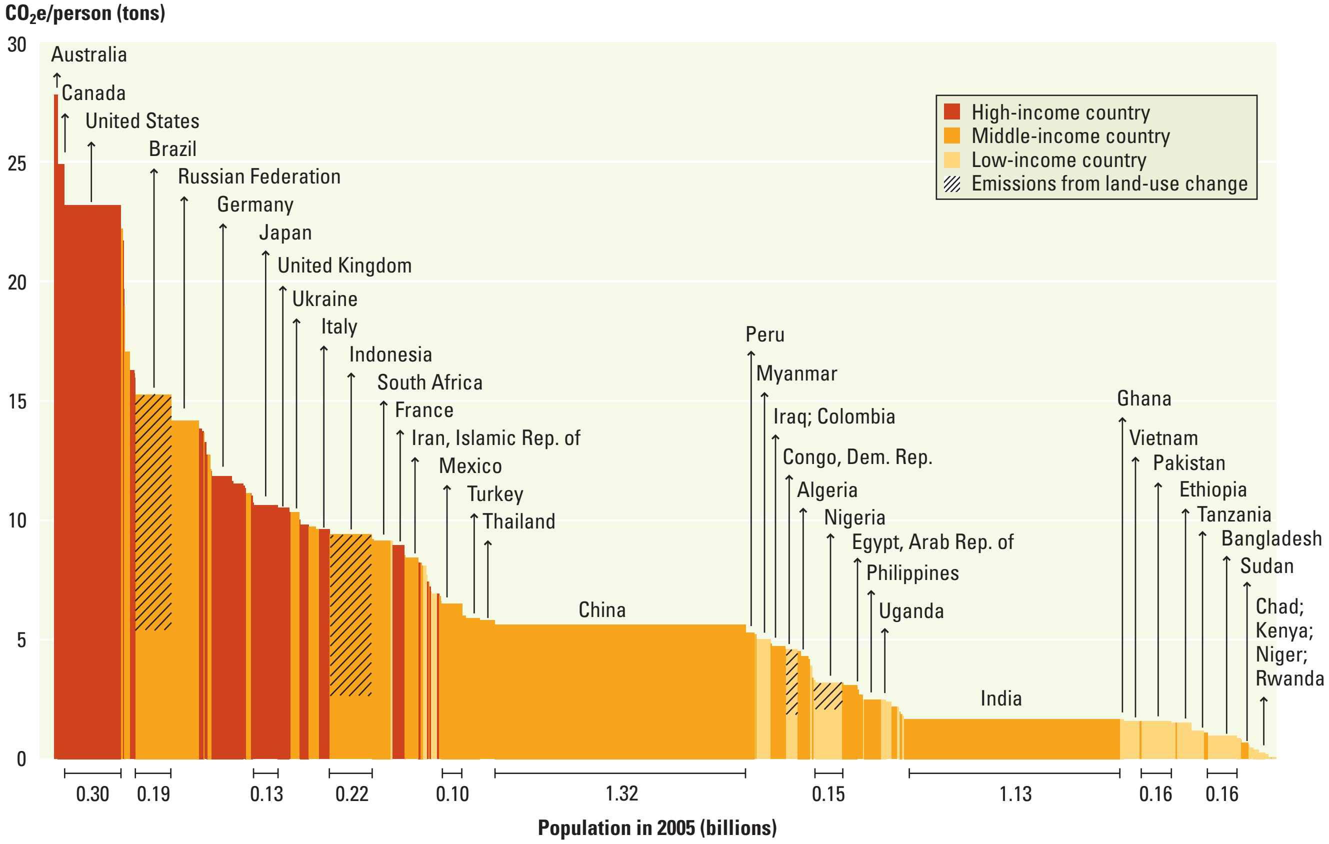
compel bold actions. The strong inertia in the climate system, in the built environment, and in the behavior of individuals and institutions requires that this action be urgent and immediate.

Over the past two centuries the direct benefits of carbon-intensive development have been concentrated largely in today's high-income countries. The inequity in the global distribution of past and current emissions, and in current and future damages, is stark (figure 1.1; see also focus A figure FA.6 and the overview). But if countries are willing to act, the economic incentives for a global deal exist.

The window of opportunity to choose the right policies to deal with climate change and promote development is closing. The further countries go along current emissions trajectories, the harder it will be to reverse course and alter infrastructures, economies, and lifestyles. High-income countries must face head-on the task of cutting their own emissions by reshaping their built and economic environments. They also need to promote and finance the transition to low-carbon growth in developing countries. Better application of known practices and fundamental transformations—in natural resource management, energy provision, urbanization, social safety nets, international financial transfers, technological innovation, and governance, both international and national—are needed to meet the challenge.

Increasing people's opportunities and material well-being without undermining the sustainability of development is still the main challenge for large swaths of the world, as a severe financial and economic crisis wreaks havoc across the globe. Stabilizing the financial markets and protecting the real economy, labor markets, and vulnerable groups are the immediate priority. But the world must exploit this moment of opportunity for international cooperation

Figure 1.1 Individuals' emissions in high-income countries overwhelm those in developing countries



Sources: Emissions of greenhouse gases in 2005 from WRI 2008, augmented with land-use change emissions from Houghton 2009; population from World Bank 2009c.

Note: The width of each column depicts population and the height depicts per capita emissions, so the area represents total emissions. Per capita emissions of Qatar (55.5 tons of carbon dioxide equivalent per capita), UAE (38.8), and Bahrain (25.4)—greater than the height of the y-axis—are not shown. Among the larger countries, Brazil, Indonesia, the Democratic Republic of Congo, and Nigeria have low energy-related emissions but significant emissions from land-use change; therefore, the share from land-use change is indicated by the hatching.

and domestic intervention to tackle the rest of development's problems. Among them, and a top priority, is climate change.

Unmitigated climate change is incompatible with sustainable development

Development that is socially, economically, and environmentally sustainable is a challenge, even without global warming. Economic growth is needed, but growth alone is not enough if it does not reduce poverty and increase the equality of opportunity. And failing to safeguard the environment eventually threatens economic and social achievements. These points are not new. They only echo what still is, after more than 20 years, perhaps the most widely used definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[7]

By definition, then, unmitigated climate change is incompatible with sustainable development.

Climate change threatens to reverse development gains

An estimated 400 million people escaped poverty between 1990 and 2005, the date of the latest estimate[8]—although the unfolding global financial crisis and the spike in food prices between 2005 and 2008 have reversed some of these gains.[9] Since 1990 infant mortality rates dropped from 106 per 1,000 live births to 83.[10] Yet close to half the population of developing countries (48 percent) are still in poverty, living on less than $2 a day.[11] Nearly a quarter—1.6 billion—lack access to electricity,[12] and one in six lack access to clean water.[13] Around 10 million children under five still die each year from preventable and treatable diseases such as respiratory infections, measles, and diarrhea.[14]

In the last half century the use of natural resources (among them fossil fuels) has supported improvements in well-being, but when accompanied by resource degradation and climate change, such use is not sustainable. Neglecting the natural environment in the pursuit of growth, people have made themselves more vulnerable to natural disasters (see chapter 2). And the poorest often rely more directly on natural resources for their livelihoods. Roughly 70 percent of the world's extremely poor people live in rural areas.

By 2050 the global population will reach 9 billion, barring substantial changes in demographic trends, with 2.5 billion more people in today's developing countries. Larger populations put more pressure on ecosystems and natural resources, intensify the competition for land and water, and increase the demand for energy. Most of the population increase will be in cities, which could help limit resource degradation and individual energy consumption. But both could increase, along with human vulnerability, if urbanization is poorly managed.

Climate change imposes an added burden on development.[15] Its impacts are already visible, and the most recent scientific evidence shows the problem is worsening fast, with current trajectories of greenhouse gas (GHG) emissions and sea-level rise outpacing previous projections.[16] And the disruptions to socioeconomic and natural systems are happening even now—that is, even sooner than previously thought (see focus A on science).[17] Changing temperature and precipitation averages and a more variable, unpredictable, or extreme climate can alter today's yields, earnings, health, and physical safety and ultimately the paths and levels of future development.

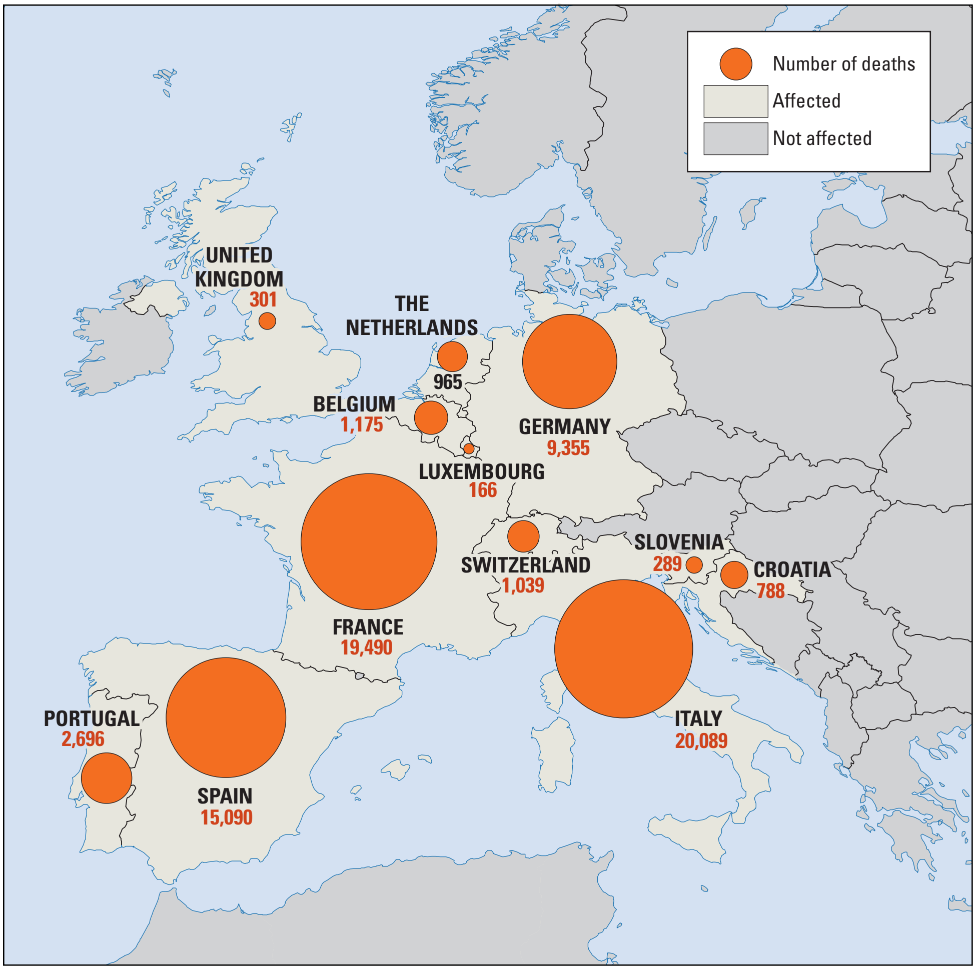
Climate change will affect numerous sectors and productive environments, including agriculture, forestry, energy, and coastal zones, in developed and developing countries. Developing economies will be more affected by climate change, in part because of their greater exposure to climate shocks and in part because of their low adaptive capacity. But no country is immune. The 2003 summer heat wave killed more than 70,000 people in a dozen European countries (map 1.2). The mountain pine beetle epidemic in western Canadian forests, partly a consequence of milder winters, is ravaging the timber industry, threatening the livelihoods and health of remote communities, and requiring millions in government spending for adjustment and prevention.[18] Attempts to adapt to similar future threats, in developed and developing countries, will have real human and economic costs even as they cannot eliminate all direct damage.

Warming can have a big impact on both the level and growth of gross domestic product (GDP), at least in poor countries. An examination of year-to-year variations in temperature (relative to a country's average) shows that anomalously warm years reduce both the current level and subsequent growth rate of GDP in developing countries.[19] Consecutive warm years might be expected to lead to adaptation, lessening the economic impacts of warming, yet the developing countries with more pronounced warming trends have had lower growth rates.[20] Evidence from Sub-Saharan Africa indicates that rainfall variability, projected to increase substantially, also reduces GDP and increases poverty.[21]

Agricultural productivity is one of many factors driving the greater vulnerability of developing countries (see chapter 3, map 3.3). In northern Europe and North America crop yields and forest growth might increase under low levels of warming and carbon dioxide (CO_2) fertilization.[22] But in China and Japan yields of rice, a major global staple, will likely decline, while yields of wheat, maize, and rice in Central and South Asia will be particularly hard hit.[23] Prospects for crops and livestock in rainfed semiarid lands in Sub-Saharan Africa are also bleak, even before warming reaches 2–2.5°C above preindustrial levels.[24]

India's post-1980 deceleration in the increase of rice productivity (from the Green Revolution in the 1960s) is attributable not only to falling rice prices and deteriorating irrigation infrastructure, as previously postulated, but also to adverse climate phenomena from local pollution and global warming.[25] Extrapolating from past year-to-year variations in climate and agricultural outcomes, yields of major crops in India are projected to decline by 4.5 to

Map 1.2 Rich countries are also affected by anomalous climate: The 2003 heat wave killed more than 70,000 people in Europe



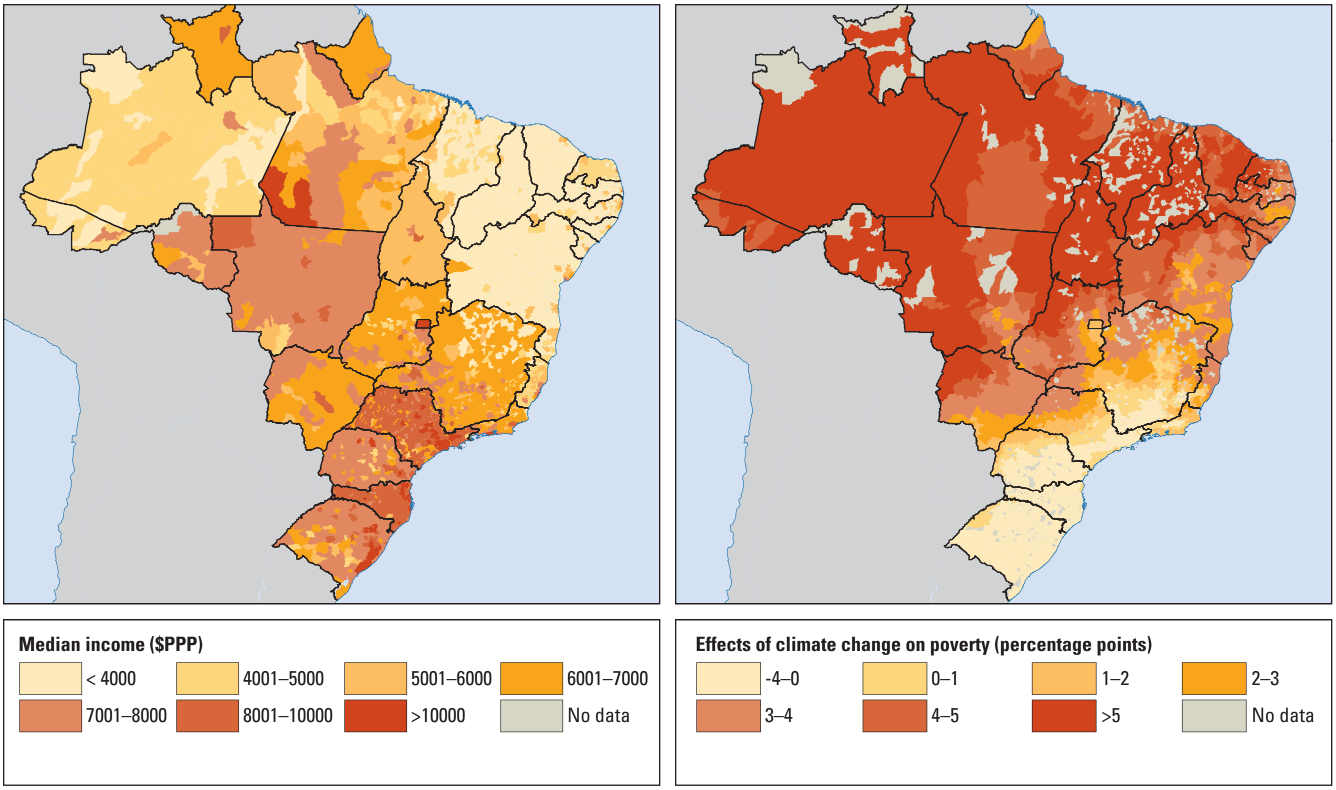
Source: Robine and others 2008.

Note: Deaths attributed to the heat wave are those estimated to be in excess of the deaths that would have occurred in the absence of the heat wave, based on average baseline mortality trends.

9 percent within the next three decades, even allowing for short-term adaptations.[26] The implications of such climate change for poverty—and GDP—could be enormous given projected population growth and the evidence that one percentage point of agricultural GDP growth in developing countries increases the consumption of the poorest third of the population by four to six percentage points.[27]

The impacts of climate change on health add to the human and economic losses, especially in developing countries. The World Health Organization estimates that climate change caused a loss of 5.5 million disability-adjusted life years in 2000—84 percent of them in Sub-Saharan Africa and East and South Asia.[28] As temperatures rise, the number of people exposed to malaria and dengue will increase, with the burden most pronounced in developing countries.[29] The incidence of drought, projected to increase in the Sahel and elsewhere, is strongly correlated with past meningitis epidemics in Sub-Saharan Africa.[30] Declining agricultural yields in some regions will increase malnutrition, reducing people's resistance to illness. The burden of diarrheal diseases from climate change alone is projected to increase up to 5 percent by 2020 in countries with per capita incomes below $6,000. Higher temperatures are likely to increase cardiovascular illness, especially in the tropics but also in higher-latitude (and higher-income) countries—more than offsetting the relief from fewer cold-related deaths.[31]

Map 1.3 Climate change is likely to increase poverty in most of Brazil, especially its poorest regions



Sources: Center for International Earth Science Information Network, http://sedac.ciesin.columbia.edu/gpw/global.jsp (accessed May 15, 2009); Dell, Jones, and Olken 2009; Assunçao and Chein 2008.

Note: Climate-change poverty impact estimates for mid-21st century based on a projected decline in agricultural yields of 18 percent. The change in poverty is expressed in percentage points; for example, the poverty rate in the northeast, estimated at 30 percent (based on $1 a day with year 2000 data), could rise by 4 percentage points to 34 percent. The estimates allow for internal migration, with the poverty outcomes of migrants counted in the sending municipality.

Adverse climate trends, variability, and shocks do not discriminate by income, but better-off people and communities can more successfully manage the setbacks (map 1.3). When Hurricane Mitch swept through Honduras in 1998, more wealthy households than poor ones were affected. But poor households lost proportionally more: among affected households, the poor lost 15 to 20 percent of their assets, while the richest lost only 3 percent.[32] The longer-term impacts were greater too: all affected households suffered a slowdown in asset accumulation, but the slump was greater for poorer households.[33] And impacts varied by gender (box 1.1): male-headed households, with greater access to new lodging and work, spent shorter periods in postdisaster shelters compared with female-headed households, which struggled to get back on their feet and remained in the shelters longer.[34]

A cycle of descent into poverty could emerge from the confluence of climate change, environmental degradation, and market and institutional failures. The cycle could be precipitated by the gradual collapse of a coastal ecosystem, less predictable rainfall, or a more severe hurricane season.[35] While large-scale natural disasters cause the most visible shocks, small but repeated shocks or subtle shifts in the distribution of rainfall throughout the year can also produce abrupt yet persistent changes in welfare.

Empirical evidence on poverty traps—defined as consumption *permanently* below a given threshold—is mixed.[36] But there is growing evidence of slower physical asset recovery and human capital growth among the poor after shocks. In Ethiopia a season with starkly reduced rainfall depressed consumption even after four to five years.[37] Instances of drought in Brazil have been

BOX 1.1 *Empowered women improve adaptation and mitigation outcomes*

Women and men experience climate change differently. Climate-change impacts and policies are not gender neutral because of differences in responsibility, vulnerability, and capacity for mitigation and adaptation. Gender-based patterns of vulnerability are shaped by the value of and entitlement to assets, access to financial services, education level, social networks, and participation in local organizations. In some circumstances, women are more vulnerable to climate shocks to livelihoods and physical safety—but there is evidence that in contexts where women and men have equal economic and social rights, disasters do not discriminate. Empowerment and participation of women in decision making can lead to improved environmental and livelihood outcomes that benefit all.

Women's participation in disaster management saves lives
Community welfare before, during, and after extreme climatic events can be improved by including women in disaster preparedness and rehabilitation. Unlike other communities that witnessed numerous deaths, La Masica, Honduras, reported no deaths during and after Hurricane Mitch in 1998. Gender-sensitive community education on early warning systems and hazard management provided by a disaster agency six months before the hurricane contributed to this achievement. Although both men and women participated in hazard management activities, ultimately, women took over the task of continuously monitoring the early warning system. Their enhanced risk awareness and management capacity enabled the municipality to evacuate promptly. Additional lessons from postdisaster recovery indicate that putting women in charge of food distribution systems results in less corruption and more equitable food distribution.

Women's participation boosts biodiversity and improves water management
Between 2001 and 2006 the Zammour locality in Tunis saw an increase in vegetal area, biodiversity preservation, and stabilization of eroding lands in the mountainous ecosystem—the result of an antidesertification program that invited women to share their perspectives during consultations, incorporated local women's knowledge of water management, and was implemented by women. The project assessed and applied innovative and effective rainwater collection and preservation methods, such as planting in stone pockets to reduce the evaporation of irrigation water, and planting of local species of fruit trees to stabilize eroded lands.

Women's participation enhances food security and protects forests
In Guatemala, Nicaragua, El Salvador, and Honduras women have planted 400,000 maya nut trees since 2001. Beyond enhanced food security, women and their families can benefit from climate change finance, as the sponsoring Equilibrium Fund pursues carbon-trading opportunities with the United States and Europe. In Zimbabwe, women lead over half of the 800,000 farm households living in communal areas, where women's groups manage forest resources and development projects through tree planting, nursery development, and woodlot ownership and management.

Women represent at least half of the world's agricultural workers, and women and girls remain predominantly responsible for water and firewood collection. Adaptation and mitigation potential, especially in the agriculture and forestry sectors, cannot be fully realized without employing women's expertise in natural resource management, including traditional knowledge and efficiency in using resources.

Women's participation supports public health
In India indigenous peoples know medicinal herbs and shrubs and apply these for therapeutic uses. Indigenous women, as stewards of nature, are particularly knowledgeable and can identify almost 300 useful forest species.

Globally, whether in Central America, North Africa, South Asia, or Southern Africa, gender-sensitive climate change adaptation and mitigation programs show measurable results: women's full participation in decision making can and will save lives, protect fragile natural resources, reduce greenhouse gases, and build resilience for current and future generations. Mechanisms or financing for disaster prevention, adaptation, and mitigation will remain insufficient unless they integrate women's full participation—voices and hands—in design, decision making, and implementation.

Sources: Contributed by Nilufar Ahmad, based on Parikh 2008; Lambrou and Laub 2004; Neumayer and Plumper 2007; Smyth 2005; Aguilar 2006; UNISDR 2007; UNDP 2009; and Martin 1996.

followed by significantly reduced rural wages in the short term, with the wages of affected workers catching up with their peers' only after five years.[38]

In addition limited access to credit, insurance, or collateral hampers poor households' opportunities to make productive investments or leads them to choose investments with low risk and low returns to guard against future shocks.[39] In villages throughout India poorer farmers have mitigated climatic risk by investing in assets and technologies with low sensitivity to rainfall variation but also with low average returns, locking in patterns of inequality in the country.[40]

Climate shocks can also permanently affect people's health and education. Research in Côte d'Ivoire linking rainfall patterns and investment in children's education shows that in regions experiencing greater-than-usual weather variability, school enrollment rates declined by 20 percent for both boys and girls.[41] And when coupled with other problems, environmental shocks can have long-term effects. People exposed to drought and civil strife in Zimbabwe during early childhood (between 12 and 24 months of age) suffered from a height loss of 3.4 centimeters, close to 1 fewer years of schooling, and a nearly six-month delay in starting school. The estimated effect on lifetime earnings was 14 percent, a big difference to someone near the poverty line.[42]

Balancing growth and assessing policies in a changing climate

Growth: Changing carbon footprints and vulnerabilities. By 2050 a large share of the population in today's developing countries will have a middle-class lifestyle. But the planet cannot sustain 9 billion people with the carbon footprint of today's average middle-class citizen. Annual emissions would nearly triple. Moreover, not all development increases resilience: growth may not happen fast enough and can create new vulnerabilities even as it reduces others. And poorly designed climate change policies could themselves become a threat to sustainable development.

But it is ethically and politically unacceptable to deny the world's poor the opportunity to ascend the income ladder simply because the rich reached the top first. Developing countries now contribute about half of annual greenhouse gas emissions but have nearly 85 percent of the world's population; the energy-related carbon footprint of the average citizen of a low- or middle-income country is 1.3 or 4.5 metric tons of carbon dioxide equivalent (CO_2e), respectively, compared with 15.3 in high-income countries.[43] Moreover, the bulk of past emissions—and thus the bulk of the existing stock of greenhouse gases in the atmosphere—is the responsibility of developed countries.[44] Resolving the threat of climate change to human well-being thus not only depends on climate-smart development—increasing incomes and resilience while reducing emissions relative to projected increases. It also requires climate-smart prosperity in the developed countries—with greater resilience and absolute reductions in emissions.

Evidence shows that policy can make a big difference in how carbon footprints change when incomes grow.[45] The average carbon footprint of citizens in rich countries, including oil producers and small island states, varies by a factor of twelve, as does the energy intensity of GDP,[46] suggesting that carbon footprints do not always increase with income. And today's developing economies use much less energy per capita than developed countries such as the United States did at similar incomes, showing the potential for lower-carbon growth.[47]

Adaptation and mitigation need to be integrated into a climate-smart development strategy that increases resilience, reduces the threat of further warming, and improves development outcomes. Adaptation and mitigation measures can advance development, and prosperity can raise incomes and foster better institutions. A healthier population living in better-built houses and with access to bank loans and social security is better equipped to deal with a changing climate and its consequences. Advancing robust, resilient development policies that promote adaptation is needed today because changes in the climate, already begun, will increase even in the short term.

The spread of economic prosperity has always been intertwined with adaptation to changing ecological conditions. But as growth has altered the environment and as environmental change has accelerated, sustaining growth and adaptability demands greater capacity to understand our environment, generate new adaptive technologies and practices, and diffuse them widely. As economic historians have explained, much of humankind's creative potential has been directed at adapting to the changing world.[48] But adaptation cannot cope with all the impacts related to climate change, especially as larger changes unfold in the long term (see chapter 2).[49]

Countries cannot grow out of harm's way fast enough to match the changing climate. And some growth strategies, whether driven by the government or the market, can also add to vulnerability—particularly if they overexploit natural resources. Under the Soviet development plan, irrigated cotton cultivation expanded in water-stressed

Central Asia and led to the near disappearance of the Aral Sea, threatening the livelihoods of fishermen, herders, and farmers.[50] And clearing mangroves—natural coastal buffers against storm surges—to make way for intensive shrimp farming or housing development increases the physical vulnerability of coastal settlements, whether in Guinea or in Louisiana.

Climate shocks can strain normally adequate infrastructure or reveal previously untested institutional weaknesses, even in fast-growing and high-income countries. For example, despite impressive economic growth for more than two decades, and in part because of accompanying labor-market transitions, millions of migrant workers in China were stranded during the unexpectedly intense snow storms in January 2008 (map 1.4). The train system collapsed as workers returned home for the Chinese New Year, stranding millions, while the southern and central provinces suffered food shortages and power failures. Hurricane Katrina exposed the United States as unprepared and ill equipped, showing that even decades of steady prosperity do not always produce good planning (and by extension, good adaptation). Nor do high average incomes guarantee protection for the poorest communities.

Mitigation policies—for better or worse. Mitigation policies can be exploited to provide economic co-benefits in addition to emission reductions and can create local and regional opportunities. Biofuels could make Brazil the world's next big energy supplier—its ethanol production has more than doubled since the turn of the century.[51] A large share of unexploited hydropower potential is in developing countries, particularly in Sub-Saharan Africa (map 1.5). North Africa and the Middle East, with year-round exposure to sunlight, could benefit from increased European demand for solar energy (see chapter 4, box 4.15).[52] Yet comparative advantage in renewable energy production in many countries still is not optimally exploited, evidenced by the proliferation of solar power production in Northern Europe rather than North Africa.

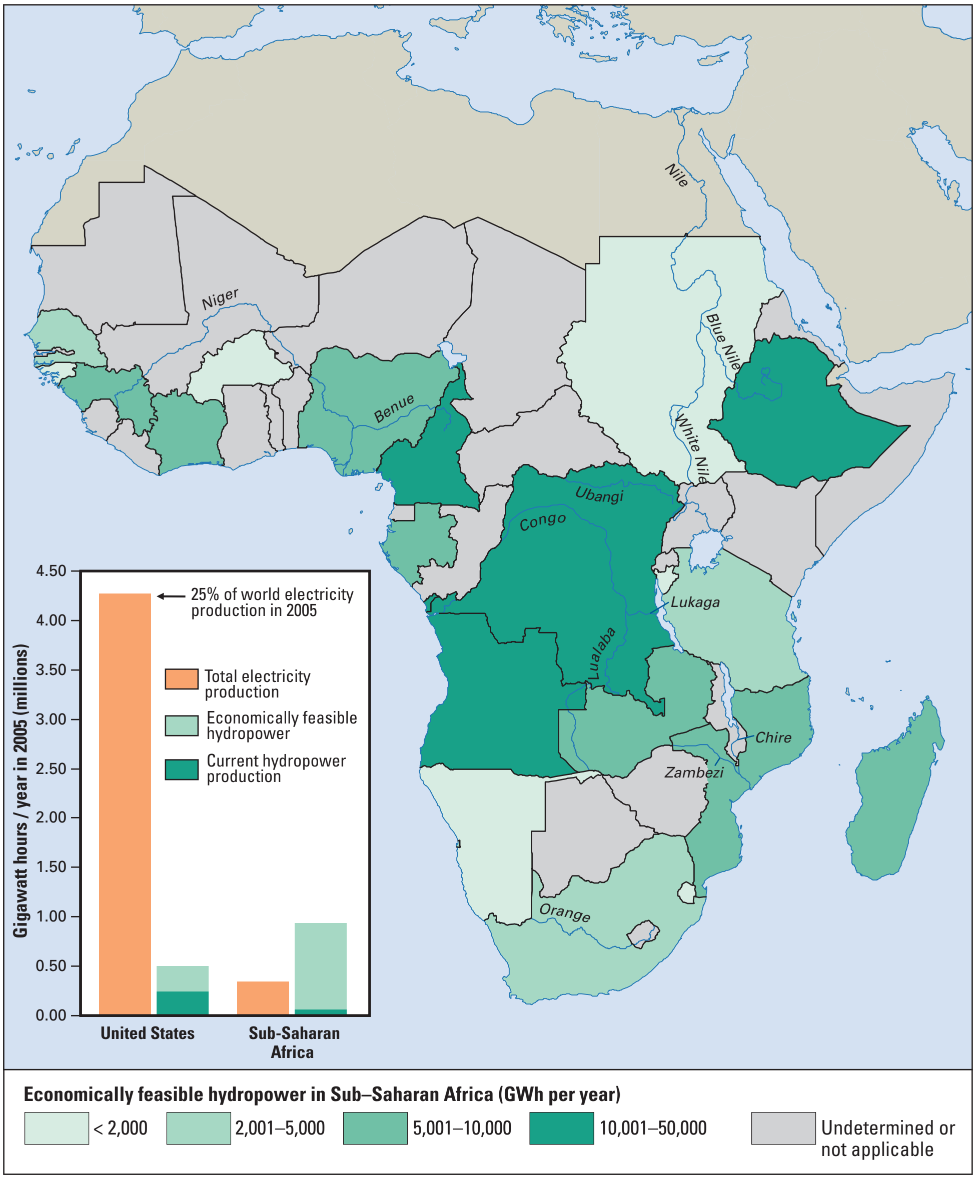
But mitigation policies can also go wrong and reduce welfare if ancillary effects are not considered in design and execution. Relative to cleaner cellulosic ethanol production and even gasoline, corn-based biofuel production in the United States imposes higher health costs from local pollution and offers only dubious CO_2 emission reductions (figure 1.2).[53] Moreover, biofuel policies in the United States and Europe have diverted inputs from food to fuel production and

Map 1.4 The January 2008 storm in China severely disrupted mobility, a pillar of its economic growth

Sources: ACASIAN 2004; Chan 2008; Huang and Magnoli 2009; United States Department of Agriculture Foreign Agricultural Service, Commodity Intelligence Report, February 1 2008, http://www.pecad.fas.usda.gov/highlights/2008/02/MassiveSnowStorm.htm (accessed July 14, 2009); Ministry of Communications, Government of the People's Republic of China, "The Guarantee Measures and Countermeasures for Extreme Snow and Rainfall Weather," February 1 2008, http://www.china.org.cn/e-news/news080201-2.htm (accessed July 14, 2009).

Note: Width of arrows reflects estimates of size of travel flows during the Chinese New Year holiday, based on reversal of estimated labor migration flows. Total internal migration is estimated between 130 million and 180 million people. Assessment of severity of the storm's impact is based on cumulative precipitation in the month of January and Chinese news and government communications at the time of the storm.

Map 1.5 Africa has enormous untapped hydropower potential, compared to lower potential but more exploitation of hydro resources in the United States



Sources: International Journal on Hydropower and Dams, World Atlas, 2006 (http://hydropower-dams.com, accessed July 9, 2009); IEA Energy Balances of OECD Countries 2008; and IEA Energy Balances of Non-OECD Countries 2007 (http://www.oecd.org/document/10/0,3343,en_21571361_33915056_39154634_1_1_1_1,00.html, accessed July 9, 2009).

Note: The United States has exploited over 50 percent of its hydropower potential, compared to only 7–8 percent in the countries of Sub-Saharan Africa. Total electricity production in the United States is shown for scale.

contributed to increases in global food prices.[54] Such food price hikes often increase poverty rates.[55] The overall impact on poverty depends on the structure of the economy, because net producers will benefit from higher prices, and net buyers will be worse off. But many governments in food-surplus countries, including Argentina, India, and Ukraine, have responded with export bans and other protectionist measures, limiting the gains for domestic producers, reducing grain supplies, and narrowing the scope for future market solutions.[56]

The interrelationship of trade and mitigation policies is not straightforward. It has been suggested that the carbon content of exports be counted in the carbon tally of the destination country, so that the exporting countries are not punished for specializing in the heavy industrial goods consumed by others. But if importers place a border tax on the carbon content of goods to equalize the carbon price, exporting countries would still bear some of the burden through a loss in competitiveness (see focus C on trade).

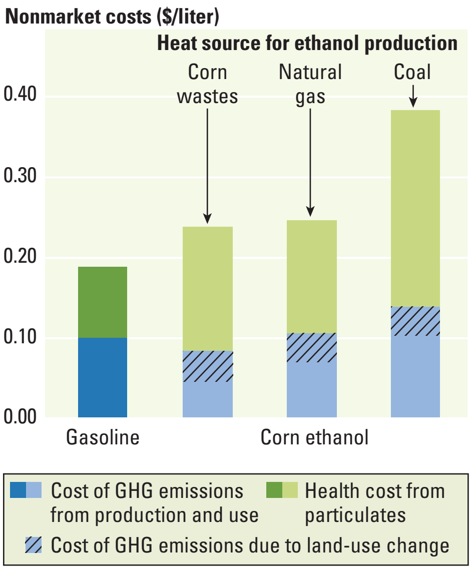
Green taxes. As outlined in chapter 6, carbon taxes can be an efficient instrument for controlling carbon emissions—but changes in the tax system to incorporate environmental costs (green taxes) could be regressive, depending on the country's economic structure, the quality of targeting, and the distribution of burden sharing. In the United Kingdom a carbon tax imposed equally on all households would be very regressive, consistent with findings from other OECD countries.[57] The reason is that spending on energy constitutes a larger share of total expenditures for poor households than for rich ones. But the regressive effect could be offset either through scaled tariff design or a targeted program based on existing social policy mechanisms.[58]

And green taxes in developing countries could even be progressive, as suggested by a recent study for China. Most poor households in China reside in rural areas and consume products much less carbon intensive than those consumed by generally better-off urban households. If revenues from a carbon tax were recycled into the economy on an equal per capita basis, the progressive effect would be larger still.[59]

Gaining political support for green taxes and ensuring they do not harm the poor will not be easy. Revenue recycling would be critical for Latin America and Eastern Europe, where a significant share of the poor live in urban areas and would be directly hurt by green taxes. But such revenue recycling, as well as the targeting suggested by the Great Britain study, would require a strong commitment to such a policy shift, difficult in the many developing countries where regressive subsidies for energy and other infrastructure services are politically entrenched. Without revenue recycling, the impact of carbon pricing or green taxes—even if progressive—is likely to harm the poor because poor households spend as much as 25 percent of their income on electricity, water, and transport. It is also likely to be politically difficult because even the average household spends about 10 percent of its income on these services.[60]

The real income of the poorest will also be reduced in the near term as the higher up-front costs of greener infrastructure construction, operation, and services hit the supply side of the economy.[61] A green tax could have a direct effect on households (caused by the increase in energy prices) and an indirect effect (on total household expenditure as a result of higher costs of production and thus prices of consumer goods). A study in Madagascar found that the indirect effects could represent 40 percent of the welfare losses through higher prices of food, textiles, and transport.[62] Despite the greater direct consumption of

Figure 1.2 Corn-based biofuels in the United States increase CO_2 emissions and health costs relative to gasoline



Source: Hill and others 2009.

Note: Costs are in terms of dollar per liter of gasoline or gasoline equivalent. Health costs (green) are estimated costs because of particulate matter emissions, from the production and end-use combustion of an additional liter of ethanol. Greenhouse-gas emission costs (blue) assume a carbon price of $120 a ton, based on the estimated price of carbon capture and storage. A portion (diagonal hatching in figure) of the greenhouse gas emissions associated with corn ethanol production comes from clearing, conversion, or cultivation of land.

infrastructure services by the middle class, the poorest quintile was projected to suffer the biggest loss in real income.

There is ample scope around the world for better energy tariff and subsidy design that both increases cost recovery and better targets benefits to the poor.[63] Climate change (and green tax proceeds) may make it worthwhile and feasible to expand income support programs to countries that now rely on energy and water pricing as part of their social policy. Greater energy efficiency reduces costs for everyone, while greener technologies can be less expensive than traditional carbon-intensive ones. For example, upgrading to improved wood-fired cook stoves in rural Mexico could reduce emissions by 160 million tons of CO_2 over the next 20 years, with net economic gains (from lower direct energy costs and better health) of $8 to $24 for each ton of avoided CO_2 emissions.[64]

Evaluating the tradeoffs

While few still debate the need for action to mitigate climate change, controversy remains over how much and how soon to mitigate. Holding the changes in global average temperatures below "dangerous" levels (see focus A on science) would require immediate and global actions—actions that are costly—to reduce emissions from projected levels by 50 to 80 percent by 2050.

A growing literature shows that the case for immediate and significant mitigation is stronger when taking into account the inertia in the climate system, meaning that warming and its impacts cumulate slowly but are to a considerable extent irreversible; the inertia of the built environment, which implies a higher cost of reducing emissions in the future if higher-emission fixed capital is put into place today; and the benefit of reducing the greater uncertainty and risk of catastrophic outcomes associated with higher temperatures.[65]

Any response to climate change involves some weighing of pros and cons, strengths and weaknesses, benefits and costs. The question is *how* this evaluation is to be undertaken. Cost-benefit analysis is a crucial tool for policy evaluation in the unavoidable context of competing priorities and scarce resources. But monetizing costs and benefits can too easily omit nonmarket environmental goods and services and becomes impossible if future risks (and attitudes toward risk) are highly uncertain.

Additional decision tools, complementing cost-benefit analysis, are needed to establish overall goals and acceptable risks. Multicriteria approaches can provide insights about tradeoffs that are not all expressed in monetary terms. In the face of risk aversion and uncertainty about future climate risks, the "tolerable windows" approach can identify emissions paths that stay within chosen boundaries of acceptable risk and then evaluate the cost of doing so.[66] "Robust decision making" can highlight policies that provide an effective hedge against undesirable future outcomes.[67]

The cost-benefit debate: Why it's not just about the discount rate

The economic debate about the cost-benefit analysis of climate change policy has been particularly active since the publication of the *Stern Review of the Economics of Climate Change* in 2007. That report estimated the potential cost of unmitigated climate change to be very high—a permanent annualized loss of 5–20 percent of GDP—and argued for strong and immediate action. The report's recommendations contradicted many other models that make an economic case for more gradual mitigation in the form of a "climate policy ramp."[68]

The academic debate on the appropriate discount rate—which drives much of the difference between Stern's result and the others—will most likely never be resolved (box 1.2).[69] Stern used a very low discount rate. In this approach, commonly justified on ethical grounds, the fact that future generations will likely be richer is the only factor that makes the valuation of future welfare lower than that of today; in all other ways, the welfare of future generations is just as valuable as the welfare of the current generation.[70] Good arguments can be presented in favor of both high and low discount rates. Unfortunately, intergenerational welfare economics cannot help solve the debate—because it raises more questions than it can answer.[71]

BOX 1.2 *The basics of discounting the costs and benefits of climate change mitigation*

The evaluation of resource allocation across time is a staple of applied economics and project management. Such evaluations have been used extensively to analyze the problem of costs and benefits of climate change mitigation. But big disagreements remain about the correct values of the parameters.

The social discount rate expresses the monetary costs and benefits incurred in the future in terms of their present value, or their value to decision makers today. By definition, then, the primary tool of intergenerational welfare analysis—total expected net present value—collapses the distribution of welfare over time. Determining the appropriate value for the elements of the discount rate in the context of a long-term problem like climate change involves deep economic and ethical considerations (see box 1.4).

Three factors determine the discount rate. The first is how much weight to give to the welfare enjoyed in the future, strictly because it comes later rather than sooner. This pure rate of time preference can be thought of as a measure of impatience. The second factor is the growth rate in per capita consumption: if growth is rapid, future generations will be much wealthier, reducing the value assigned today to losses from future climate damages compared with costs of mitigation borne today. The third factor is how steeply the marginal utility of consumption (a measure of how much an additional dollar is enjoyed) declines as income rises.[a]

There is no universal agreement on how to choose the numerical values for each of the three factors that determine the social discount rate. Both ethical judgments and empirical information that attempt to assess preferences from past behavior are used, sometimes in combination. Because the costs of mitigation policies are borne immediately, and the possibly large benefits of such policies (avoided damages) are enjoyed far in the future, the choice of parameters for the social discount rate strongly influences climate-policy prescriptions.

Sources: Stern 2007; Stern 2008; Dasgupta 2008; Roemer 2009; Sterner and Persson 2008.

a. The marginal utility of consumption declines as income rises because an additional dollar of consumption provides more utility to a poor person than to a person already consuming a lot. The steepness of the change—known as the elasticity of the marginal utility of consumption with respect to changes in income level—also measures tolerance of risk and inequality.

Yet the call for rapid and significant action to mitigate greenhouse gas emissions is not solely dependent on a low discount rate. While its role in determining the relative weight of costs and benefits is important, other factors raise the benefits of mitigation (avoided damages) in ways that also strengthen the case for rapid and significant mitigation, even with a higher discount rate.[72]

Broader impacts. Most economic models of climate change impacts do not adequately factor in the loss of biodiversity and associated ecosystem services—a paradoxical omission that amounts to analyzing the tradeoffs between consumption goods and environmental goods without including environmental goods in individuals' utility function.[73] Although the estimated market value of lost environmental services may be difficult to calculate and may vary across cultures and value systems, such losses do have a cost. The losses increase the relative price of environmental services as they become relatively and absolutely scarcer. Introducing environmental losses into a standard integrated assessment model significantly increases the overall cost of unmitigated climate change.[74] In fact, factoring the loss of biodiversity into a standard model results in a strong call for more rapid mitigation, even with a higher discount rate.

More accurately modeled dynamics: Threshold effects and inertia. The damage function, which links changes in temperatures to associated monetized damages, is usually modeled in cost-benefit analysis as rising smoothly. But mounting scientific evidence suggests that natural systems could exhibit nonlinear responses to climate change as a consequence of positive feedbacks, tipping points, and thresholds (box 1.3). Positive feedbacks could occur, for example, if warming causes the permafrost to thaw, releasing the vast amounts of methane (a potent greenhouse gas) it contains and further accelerating warming. Thresholds or tipping points are relatively rapid and large-scale changes in natural (or socioeconomic) systems that lead to serious and irreversible losses. Positive feedbacks, tipping points, and thresholds mean that there might be great value to keeping both the pace and magnitude of climate change as low as possible.[75]

BOX 1.3 *Positive feedbacks, tipping points, thresholds, and nonlinearities in natural and socioeconomic systems*

Positive feedbacks in the climate system

Positive feedbacks amplify the effects of greenhouse gases. One such positive feedback is the change in reflectiveness, or albedo, of the earth's surface: highly reflective surfaces like ice and snow bounce the sun's warming rays back out to the atmosphere, but as higher temperatures cause ice and snow to melt, more energy is absorbed on the earth's surface, leading to further warming and more melting, as the process repeats itself.

Tipping points in natural systems

Even smooth, moderate changes in the climate can lead a natural system to a point beyond which relatively abrupt, possibly accelerating, irreversible, and ultimately very damaging changes occur. For example, regional forest die-off could result from the combination of drought, pests, and higher temperatures that combine to exceed physiological limits. A possible tipping point of global concern is the melting of the ice sheet that covers much of Greenland. Past a certain level of warming, summer melt will not refreeze in winter, dramatically increasing the rate of melting and leading to a sea-level rise of 6 meters.

Thresholds in socioeconomic systems

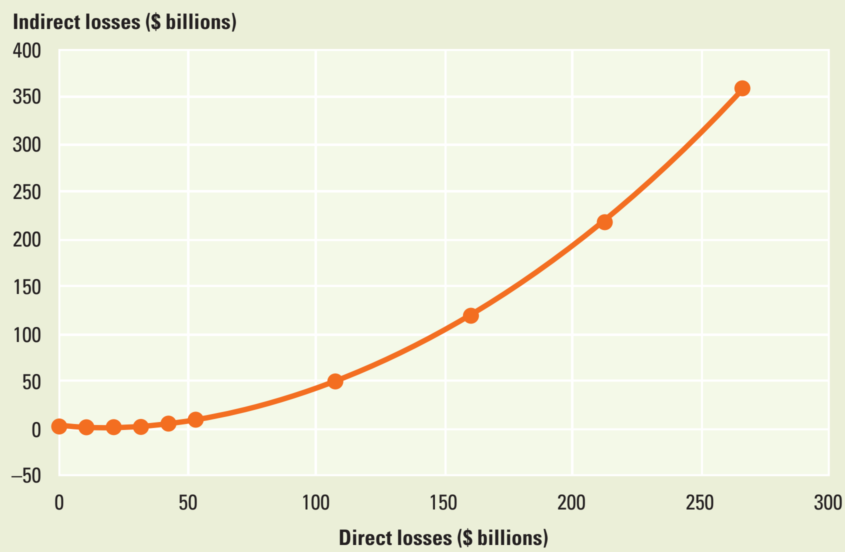
The economic cost of direct impacts could also present strong threshold effects—a result of the fact that current infrastructures and production practices are engineered to be robust only to previously experienced variation in weather conditions. This suggests that any increases in impacts will be driven primarily by rising concentrations of population and assets rather than by climate—so long as weather events remain within the envelope of past variations—but that impacts could increase sharply if climate conditions consistently exceed these boundaries in the future.

Nonlinearities and indirect economic effects

The economic response to these impacts is itself nonlinear, in part because climate-change impacts will simultaneously increase the need for adaptation and potentially decrease adaptive capacity. Direct impacts can also beget indirect effects (macroeconomic feedbacks, business interruptions, and supply-chain disruptions) that increase more than dollar for dollar in response to greater direct damages. This effect is evident in some natural disasters. Recent evidence in Louisiana shows that the economy has the capacity to absorb up to $50 billion of direct losses with minimal indirect losses. But indirect losses increase rapidly with more destructive disasters (figure). Direct losses from Hurricane Katrina reached $107 billion, with indirect losses adding another $42 billion; a simulated disaster with direct losses of $200 billion would cause an additional $200 billion in indirect losses.

Sources: Schmidt 2006; Kriegler and others 2009; Adams and others 2009; Hallegatte 2008; personal communication from Stéphane Hallegatte, May 2009.

Indirect losses increase even more steeply as direct damages rise: Estimates from Louisiana



Source: Data provided by Stéphane Hallegatte, based on Hallegatte 2008.

Substantial inertia in the climate system adds to the concern about positive feedbacks, threshold effects, and irreversibility of climate change impacts. Scientists have found that the warming caused by increases in greenhouse gas concentration may be largely irreversible for a thousand years after emissions stop.[76] Postponing mitigation forgoes the option of a lower warming trajectory: for example, a delay of more than 10 years would likely preclude stabilization of the atmosphere at any less than 3°C of warming.[77] In addition, the climate system will keep changing for several centuries even after concentrations of greenhouse gases stabilize (see overview). So only immediate mitigation preserves the option value—that is, avoids the loss of options in stabilization outcomes.

Inertia is also substantial in the built environment—transport, energy, housing, and the urban form (the way cities are designed). In response to this inertia, some argue for postponing mitigation investments to avoid getting locked into higher cost, lower-carbon investments unnecessarily, instead waiting until better, less expensive technology allows quick ramping up of mitigation and more is known about the risks societies will need to protect against.

But it is not possible in practice to postpone major investments in infrastructure and energy provision without compromising economic development. Energy demand is likely to triple in developing countries between 2002 and 2030. In addition, many power plants in high-income countries were built in the 1950s and 1960s so are coming to the end of their useful life, implying that many new plants will need to be built over the next 10–20 years even with constant demand. Currently, coal plants remain among the cheapest option for many countries—in addition to offering energy security for those with ample coal reserves. If all coal-burning power plants scheduled to be built in the next 25 years come into operation, their lifetime CO_2 emissions would be equal to those of all coal-burning activities since the beginning of industrialization.[78] Consequently, the absence of stronger emission reduction commitments by the power sector today will lock in relatively high emission trajectories.

Nor is it always possible to cost-effectively retrofit such investments on a large scale. Retrofits are not always possible, and they can be prohibitively costly. Staying with the coal example, carbon capture and storage—a technology that is being developed to capture the CO_2 produced by a fossil-fuel power plant and store it underground—requires that the plant be located within 50 to 100 miles of an appropriate CO_2 storage site or else the cost of transporting the carbon becomes prohibitively high.[79] For countries endowed with an abundance of potential storage sites, this is not an issue: about 70 percent of China's power plants happen to be close enough to storage sites and therefore could reasonably be retrofitted if and when the technology becomes commercially available. This is not the case in India, South Africa, or many other countries, where retrofits will prove unaffordable unless new plants are sited close to the few existing storage sites (see chapters 4 and 7).

Developing countries, with less existing infrastructure than developed countries, have a flexibility advantage and could potentially leapfrog to cleaner technologies. Developed countries must provide leadership in bringing new technologies to market and sharing knowledge from their experiences of deployment. The ability to change emissions trajectories depends on the availability of appropriate and affordable technology, which will not be in place at some future date without research and development (R&D) investment, dissemination, and learning-by-doing starting today.

Opportunities to shift from higher- to lower-carbon long-lived capital stock are not equally available over time.[80] The choice to switch to a more energy and economically efficient system realistically cannot be made in the future if the required technologies are not yet on the shelf and at sufficient scale to be affordable and if people do not yet have the know-how to use them (see chapter 7).[81] Effective, affordable backstop mitigation technologies for transforming energy systems will not be available in the future without active research and demonstration initiatives that move potential technologies along the cost and learning curves. To that end, developed countries need to provide leadership in developing and bringing new technologies to market and in sharing knowledge from their experiences of deployment.

Accounting for uncertainties. Economic assessments of climate change policies must factor in the uncertainties about the size and timing of adverse impacts and about the feasibility, cost, and time profiles of mitigation efforts. A key uncertainty missed by most economic models is the possibility of large catastrophic events related to climate change (see focus A on science), a topic that is at the center of an ongoing debate.[82] The underlying probability distribution of such catastrophic risks is unknown and will likely remain so. More aggressive mitigation almost surely will reduce their likelihood, though it is very difficult to assess by how much. The possibility of a global catastrophe, even one with very low probability, should increase society's willingness to pay for faster and more aggressive mitigation to the extent that it helps to avoid calamity.[83]

Even without considering these catastrophic risks, substantial uncertainties remain around climate change's ecological and economic impacts. The likely pace and ultimate magnitude of warming are unknown. How changes in climate variability and extremes—not just changes in mean temperature—will affect natural systems and human well-being is uncertain. Knowledge is limited about people's ability to adapt, the costs of adaptation, and the magnitude of unavoided residual damages. Uncertainty about the speed of discovering, disseminating, and adopting new technologies is also substantial.

These uncertainties only increase with the pace and amount of warming—a major argument for immediate and aggressive action.[84] Greater uncertainty requires adaptation strategies that can cope with many different climates and outcomes. Such strategies exist (and are discussed below), but they are less efficient than strategies that could be designed with perfect knowledge. So uncertainty is costly. And more uncertainty increases costs.

Without inertia and irreversibility, uncertainty would not matter so much, because decisions could be reversed and adjustments would be smooth and costless. But tremendous inertia—in the climate system, in the built environment, and in the behavior of individuals and institutions—makes it costly, if not impossible, to adjust in the direction of more stringent mitigation if new information is revealed or new technologies are slow to be discovered. So inertia greatly increases the potential negative implications of climate policy decisions under uncertainty. And uncertainty combined with inertia and irreversibility argue for greater precautionary mitigation.

The economics of decision making under uncertainty makes a case that uncertainty about the effects of climate change calls for more rather than less mitigation.[85] Uncertainty makes a strong argument for adopting an iterative approach to selecting targets—starting with an aggressive stance. This is not lessened by the prospect of learning (acquiring new information that changes our assessment of uncertainty).

Normative choices on aggregation and values. Climate change policies require tradeoffs between short-term actions and long-term benefits, between individual choices and global consequences. So climate change policy decisions are driven fundamentally by ethical choices. Indeed, such decisions are about concern for the welfare of others.

Directly including the benefits from nonmarket environmental goods—and their existence for future generations—in economic models of well-being is one approach for capturing these tradeoffs.[87] In practice the ability to quantify such tradeoffs has been limited, but this framework does provide a point of departure for further assessment of the increased value that societies assign to the environment as income increases, of possible tradeoffs between current consumption and costly efforts to safeguard the welfare—and existence—of future generations.[88]

Moreover, the way a model aggregates impacts across individuals or countries of different income levels significantly affects the value of estimated losses.[89] To capture a dimension of equity additional to the intergenerational concerns expressed in the discount rate, equity weights can be applied to reflect that the loss of a dollar means more to a poor person than to a rich one. Such an approach better captures human welfare (rather than just income). And because poor people and poor countries are more exposed to climate change, this approach substantially increases estimated aggregate losses from climate change. By contrast, summing up global damages in dollars and expressing them as a share of global GDP—implicitly weighting damages by contribution to total output—amounts to giving a much lower weight to the losses of poor people.

Value systems also play a role in environmental policy decisions. Recently climate change has emerged as a human rights issue (box 1.4). And most societies have ethical or religious systems that value nature and identify human responsibilities for the stewardship of the earth and its natural riches—though the results often fall short of the espoused ideals. In the first half of the 1600s, Japan was hurtling toward an environmental catastrophe through massive deforestation. But as early as 1700 it had an elaborate system of woodland management in place.[90] One reason the Tokugawa shogunate, the rulers at the time, decided to act was concern for future family generations—a concern that resulted from Confucian cultural traditions[91]—and a desire to maintain the hereditary political system. Today, Japan's territory is almost 80 percent forested.[92]

BOX 1.4 *Ethics and climate change*

The complexity of climate change highlights several ethical questions. Issues of fairness and justice are particularly important given the long temporal and geographical disconnect between greenhouse gas emissions and their impacts. At least three major ethical dimensions arise in the climate change problem: evaluating impacts, considering intergenerational equity, and distributing responsibilities and costs.

Evaluating impacts

Several disciplines, economics included, argue that welfare should be the overarching criterion in policy evaluation. But even within a "discounted utilitarianism" framework, there are large disagreements, most notably about which discount rate to use and how to aggregate welfare across individuals in the present and future. One common argument is that there is no sound ethical reason to discount economic and human impacts just because they are anticipated to happen 40—or even 400—years hence. A counterargument is that it is not equitable for the current generation to allocate resources to mitigating future climate change if other investments are seen to have a higher return, thus coming back to the problem of weighing costs and benefits of alternative uncertain options.

Recent discussion has focused on human rights as the relevant criterion for evaluating impacts. Some human rights—particularly economic and social rights—will be jeopardized by climate-change impacts and possibly some policy responses. These include the right to food, the right to water, and the right to shelter. Climate impacts may also have direct and indirect effects on exercising and realizing civil and political rights. But establishing causation and attribution is a serious problem and may limit the scope for applying human rights law to international or domestic disputes.

Because the causes of climate change are diffuse, the direct link between the emissions of a country and the impacts suffered in another are difficult to establish in a litigation context. A further obstacle to defining responsibility and harm in legal terms is the diffusion of emissions and impacts over time: in some cases, the source of the harm has occurred over multiple generations, and the damages felt today may also by felt by many future generations.

Considering intergenerational equity

Intergenerational equity is an integral part of the evaluation of impacts. How intergenerational equity is incorporated in an underlying economic model has significant implications. As noted in box 1.2, standard present-value criteria discount future costs and benefits, collapsing the distribution of welfare over time to the present moment. Alternative formulations include maximizing the current generation's utility, incorporating its altruistic concerns for future generations, and taking into account the uncertainty of the existence of future generations.

Distributing responsibilities and costs

Probably the most contentious issue is who should bear the burden of solving the climate change problem. One ethical response is the "polluter pays" principle: responsibilities should be allocated according to each country's or group's contribution to climate change. A particular version of this view is that cumulative historical emissions need to be taken into account when establishing responsibilities. A counterargument holds that "excusable ignorance" grants immunity to past emitters, because they were not aware of the consequences of their actions, but this argument has been criticized on the grounds that the potential negative effects of greenhouse gases on the climate have been understood for some time.

A further dimension of responsibility concerns how people have benefited from the past emissions of greenhouse gases (see overview figure 3). While these benefits clearly have been enjoyed by the developed countries, which have contributed the bulk of atmospheric CO_2 so far, developing countries also gained some benefits from the resulting prosperity. One response is to ignore the past and allot equal per capita entitlements to all future emissions. Yet another view recognizes that what is ultimately important is not the distribution of emissions but rather the distribution of economic welfare, including climate change damages and mitigation costs. This suggests that in a world of unequal wealth, greater responsibility for bearing costs falls to the better off—although this conclusion does not preclude mitigation actions being undertaken in poorer countries with external finance provided by high-income countries (see chapter 6).

Sources: Singer 2006; Roemer 2009; Caney 2009; World Bank 2009b.

Alternative frameworks for decision making

Uncertainty, inertia, and ethics point to the need for caution and thus to the need for more immediate and aggressive mitigation, but the analytical debate over how much more continues among economists and policy makers. The conclusions of different cost-benefit analyses are very sensitive to initial assumptions such as the baseline scenario, the abatement and damage functions, and the discount rate, including implicit assumptions embedded in model formulations[93]—which can lead to decision-making gridlock.

Alternative decision-making frameworks that incorporate broader-based assessments of costs and benefits, allowance for risk aversion, and the implications of ethical judgments can more effectively support decision making in the face of numerous knowledge gaps and obstacles. Including some of the valuation issues noted above (option values, ecosystem services, risks of discontinuities) into a broader cost-benefit analysis is desirable (albeit difficult). More, however, is needed to make the normative consequences of policy choices as transparent as possible to inform decision makers aiming to establish concrete environmental and development targets and policies. That can help them win the support of the myriad stakeholders who will experience the real-world costs and benefits.

One alternative is a tolerable windows, or "guardrail," approach. A window of mitigation goals, or a range bounded by guardrails, is chosen to limit temperature change and the rate of change to what are considered—heuristically or on the basis of expert judgment—to be tolerable levels.[94] The window is defined by constraints derived from several climate-sensitive systems. One constraint could be determined by society's aversion to a given GDP loss, associated with a given amount and rate of temperature change. A second could be defined by society's aversion to social strife and inequitable impacts. A third could be concern about warming thresholds, beyond which certain ecosystems collapse.[95]

The guardrails approach does not require a monetary estimate of the damages, because the constraints are determined by what is judged to be tolerable in each system (for instance, it might be difficult to translate into GDP figures the number of people displaced after a severe drought). Drivers of the value of emission guardrails include scientific analysis of the potential for threshold effects, as well as nonmonetized judgments about residual risks and vulnerabilities that would remain under different mitigation and adaptation strategies. The costs of remaining within proposed sets of guardrails need to be considered in relation to the judgments surrounding the levels of climate safety provided by the different guardrails. On this sort of multicriteria basis, decision makers can make an informed and more comprehensive assessment of where it is best to set the guardrails (and this assessment can be periodically revisited over time).

This approach can be complemented by decision support techniques, such as robust decision making, to address difficult-to-evaluate uncertainties.[96] In the context of unknown probabilities and a highly uncertain future, a robust strategy answers the question, "What actions should we take, given that we cannot predict the future, to reduce the possibility of an undesirable outcome to an acceptable level?"[97] In the context of climate change, policy becomes a contingency problem—what is the best strategy given a variety of possible outcomes?—rather than a traditional optimization problem. The intellectual underpinnings of this approach are not new; they can be traced back to the work by Savage in the early 1950s on "minimizing the maximum regret."[98]

Looking for robust rather than just optimal strategies is done through what essentially amounts to scenario-based planning. Different scenarios are created, and alternative policy options are compared based on their robustness—the ability to avoid a given outcome—across the different scenarios. Such analysis includes "shaping actions" that influence the future, "hedging actions" that reduce future vulnerability, and "signposts" that indicate the need for a reassessment or change of strategies.

Robust decision analysis can also be done with more formal quantitative tools, in an exploratory modeling approach, using mathematical methods for characterizing decisions and outcomes under conditions of deep uncertainty.

Under robust decision making, costs, benefits, and the tradeoffs inherent in climate policies are assessed under all scenarios. The policy prescription is not to pursue an "optimal" policy—in the traditional sense of maximizing utility—that performs, on average, better than the others. Instead, sound policies are those that withstand unpredictable futures in a robust way. In this framing near-term policies can be understood as a hedge against the cost of policy adjustments—lending support to efforts to invest in R&D and infrastructure today to keep open the option of a low-carbon future tomorrow.[99]

The costs of delaying the global mitigation effort

Today's global warming was caused overwhelmingly by emissions from rich countries.[100] Developing countries are rightly concerned about the consequences of imposing limitations on their growth. This supports the argument, embodied in the principle of "common but differentiated responsibilities" in the United Nations Framework Convention on Climate Change (UNFCCC), which holds that high-income countries should lead in reducing emissions, given both their historical responsibility and their significantly higher per capita emissions today. Developed countries' much greater financial and technological resources further argue for their taking on the bulk of mitigation costs, regardless of where the mitigation occurs.

But emission reductions by rich countries alone will not be enough to limit warming to tolerable levels. While cumulative per capita past emissions are small especially in low-income but also in middle-income countries,[101] total annual energy-related CO_2 emissions in middle-income countries have caught up with those of rich countries, and the largest share of current emissions from land-use change comes from tropical countries.[102] More important, projected changes in fossil-fuel use in middle-income countries suggest that their CO_2 emissions will continue to increase and will exceed the cumulative emissions of developed countries in the coming decades.[103]

The implication, as stated in the UNFCCC and the Bali Action Plan,[104] is that all nations have a role in an agreement that reduces global emissions and that this role has to be commensurate with their development status. In this approach, developed countries take the lead in meeting significant reduction targets, and they assist developing countries in laying the foundations for lower-carbon growth pathways and meeting their citizens' adaptation needs. The UNFCC also calls for developed countries to compensate developing countries for the additional mitigation and adaptation costs developing countries will incur.

A critical component of global action is a global mechanism allowing those who mitigate to differ from those who pay (the subject of chapter 6). Negotiated international financial transfers can enable the direct financing—*by* high-income countries—of mitigation measures undertaken *in* developing countries. (In developing countries, mitigation will often entail reorienting future emission trajectories to more sustainable levels, not reducing absolute emission levels.) Unlocking large-scale finance from the high-income countries seems a great challenge. However, *if* high-income countries are committed to achieving lower total global emissions, it is in their interest to provide the financing to ensure that significant mitigation takes place in developing countries. Estimates of global mitigation costs usually assume that mitigation will happen wherever or whenever it is cheapest. Many low-cost measures to reduce emissions relative to projected trajectories are in developing countries. So global least-cost mitigation paths always imply that a large share of mitigation is in developing countries—regardless of who pays.[105]

Delayed action by any country to significantly lower emission trajectories implies a higher global cost for any chosen mitigation target. For example, delaying mitigation actions in developing countries until

2050 could more than double the total cost of meeting a particular target, according to one estimate.[106] Another estimate suggests that an international agreement that covers only the five countries with the highest total emissions (covering two-thirds of emissions) would triple the cost of achieving a given target, compared with full participation.[107] The reason is that shrinking the pool of mitigation opportunities available for reaching a set target requires pursuing not only the negative- and low-cost measures but also high-cost measures.

Although developed and developing countries have similar potential for negative cost (net benefit) measures and high-cost measures, the middle range of low-cost mitigation options is predominantly in developing countries (with many in agriculture and forestry). Exploiting all available measures will be crucial for achieving substantial mitigation. This point is illustrated by the McKinsey analysis (figure 1.3a), but the results are not exclusive to it. If developing countries do not reduce their emission trajectories, the total cost of any chosen amount of mitigation will be much higher (the marginal cost of abatement in developed countries alone—the red line in figure 1.3b—is always higher than if the global portfolio of options—the orange line in figure 1.3b—is considered). The decline in total mitigation potential and the increase in global mitigation costs stemming from an approach involving mitigation mostly in high-income countries do not depend on any particular model.[108] Nor do they depend on any differences in opportunities and costs between developed and developing countries: if the developed countries declined to reduce their emissions, similarly global costs would rise and some amount of potential abatement would be forgone (figure 1.3c).

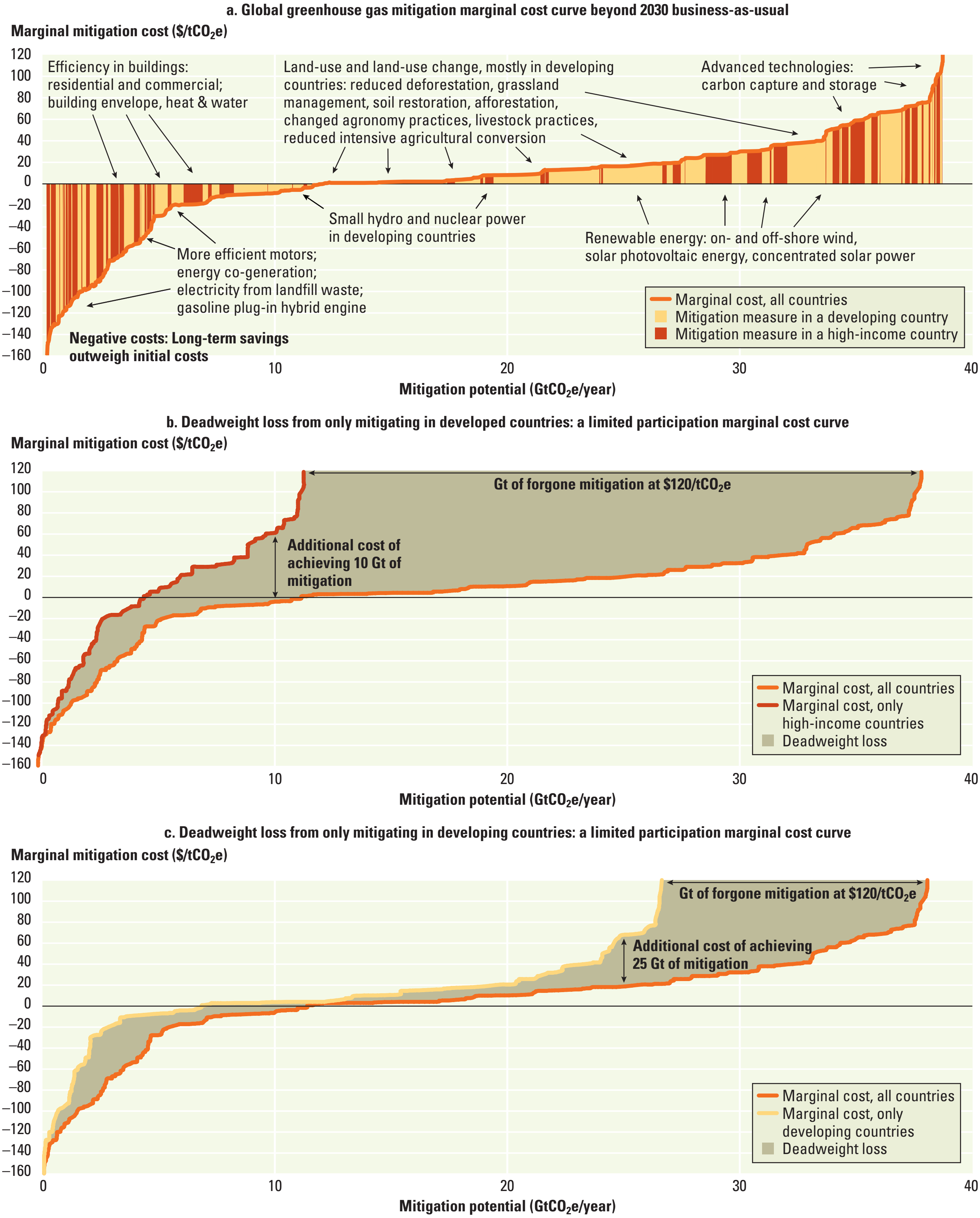
These increases in global abatement costs represent pure deadweight losses—wasted additional costs that yield zero welfare gains. Avoiding such losses (the shaded wedges between the marginal cost curves in figures 1.3b and 1.3c) creates plenty of incentives and space to negotiate the location and financing of mitigation actions while making all participants better off. It is much cheaper for the world as a whole to reach a given mitigation goal with a full portfolio of measures occurring in all countries. It is so much cheaper that, provided enough countries are committed to a global mitigation objective, all will be better off if the developed countries bear the cost of financing scaled-up measures in developing countries today.

Developed countries have the means and incentives to transfer enough finance to non-Annex I countries[109] to make them at least as well off by receiving transfers and scaling up their mitigation efforts immediately, compared with delaying commitment a decade or more before phasing in their own national targets and policies. For a given mitigation target, each dollar transferred to that end could yield an average of three dollars in welfare gains by eliminating deadweight losses—gains that can be shared according to negotiated terms. In other words, the participation of developing countries in reaching a global target is worth a lot. Sharing the large recovered deadweight losses can form a strong incentive for universal participation in a fair deal. It is not a zero-sum game.[110]

That said, it is crucial not to underestimate the difficulties of reaching agreement on global emissions targets. The reason is that such agreement suffers from a kind of international "tragedy of the commons": all countries can benefit from global participation, but unilateral incentives to participate are weak for most countries. This is the case not only because all countries would like to free ride, enjoying the benefits without bearing the costs.[111] Most countries are small enough that if one decided to defect from a global agreement, the agreement would not unravel. When applied to all countries, however, this reasoning undermines the possibility of reaching a deal in the first place.[112]

In fact, simulations exploring a variety of coalition structures and international resource transfers to persuade reluctant participants to stay in the coalition reveal the difficulty in reaching a stable agreement (one that is consistent with self-interest) to undertake deep and costly cuts in global emissions. Stable and effective coalitions

Figure 1.3 Assessing deadweight losses from partial participation in a climate deal



Source: McKinsey & Company 2009 with further data breakdown provided for WDR 2010 team.

Note: The bars in (a) represent various mitigation measures, with the width indicating the amount of emission reduction each measure would achieve and the height indicating the cost, per ton of avoided emissions, of the measure. Tracing the height of the bars creates a marginal mitigation cost curve. Panels (b) and (c) show the marginal mitigation cost curve if mitigation only takes place in high-income countries (b) or only in developing countries (c), as well as the resulting deadweight losses associated with these scenarios. Such deadweight losses could be avoided or minimized through financial mechanisms that allow a separation between who pays and who mitigates, and ensure the most cost-effective mitigation measures are adopted.

are possible for milder and less costly global emissions cuts, but such cuts do not sufficiently address the threats to sustainability of greater climate change.[113]

Seizing the moment: Immediate stimulus and long-term transformations

In 2008 the global economy suffered a dramatic shock, triggered by disruptions in the housing and financial markets in the United States and eventually encompassing many countries. The world had not experienced such a financial and economic upheaval since the Great Depression. Credit markets froze, investors fled to safety, scores of currencies realigned, and stock markets dropped sharply. At the height of the financial volatility the stock market in the United States lost $1.3 trillion in value in one session.[114]

The ongoing consequences for the real economy and development indicators around the world are huge—and continue to unfold. The global economy is projected to contract in 2009. Unemployment is on the rise around the world. The United States alone had lost almost 5 million jobs between December 2007, when the recession began and March 2009.[115] Some estimates suggest 32 million job losses in developing countries.[116] Between 53 million and 90 million people will fail to escape poverty because of the fallout during 2009.[117] Official development assistance—already well below the committed targets for several donor countries—is likely to decline as public finances in developed countries worsen and attention shifts toward domestic priorities.

Some regions are becoming more vulnerable to future challenges as a consequence of the economic downturn: Sub-Saharan economies grew rapidly in the first years of the 21st century, but the collapse of commodity prices and global economic activity will test this trend. Countries and communities around the world that rely on remittances from nationals working in developed countries are severely affected as these financial transfers fall.[118] In Mexico remittances fell by $920 million in the six months leading up to March 2009—a decline of 14 percent.[119]

The financial crisis presents an added burden to development efforts and a likely distraction from the urgency of climate change. Individual, community, and country vulnerability to the climate threat will increase as economic growth slows down, revenues disappear, and assistance shrinks. While the economic slowdown will be matched by a temporary deceleration in emissions, people remain vulnerable to the warming already in the pipeline; and without concerted efforts to decouple emissions from growth, emissions will again accelerate as economic recovery takes hold.

Governments in many developed and developing countries are responding to the crisis by expanding public spending. Spending proposed in several national and regional stimulus plans totals $2.4 trillion to $2.8 trillion.[120] Governments expect that this spending increase will protect or create jobs by increasing effective demand—one of the main priorities for halting the downturn. The World Bank has proposed that 0.7 percent of high-income countries' stimulus packages be channeled into a "vulnerability fund" to minimize the social costs of the economic crisis in developing countries.[122]

The case for a green stimulus

Despite the economic chaos the case for urgent action against climate change remains. And it becomes more pressing given the increase in poverty and vulnerability around the world. Thus recent public debates have focused on the possibility of using fiscal packages to push for a greener economy, combating climate change while restoring growth.

How can both the economic slump and climate change be tackled with the fiscal stimulus? Solving the climate change problem requires government intervention, not least because climate change is created by a large-scale negative externality. And the once-in-a lifetime crisis in the financial markets and the real economy calls for public spending.

Investment in climate policy can be an efficient way to deal with the economic crisis in the short term. Low-carbon technologies could generate a net increase in jobs, because they can be more labor intensive than high-carbon sectors.[122] Some estimates suggest that $1 billion in government spending on green projects in the United States can create 30,000 jobs in a year, 7,000 more than generated by traditional infrastructure.[123] Other estimates suggest that spending $100 billion would generate almost 2 million jobs—about half of them directly.[124] But as with any short-term stimulus, the job gains might not be sustained in the long run.[125]

Green spending around the world

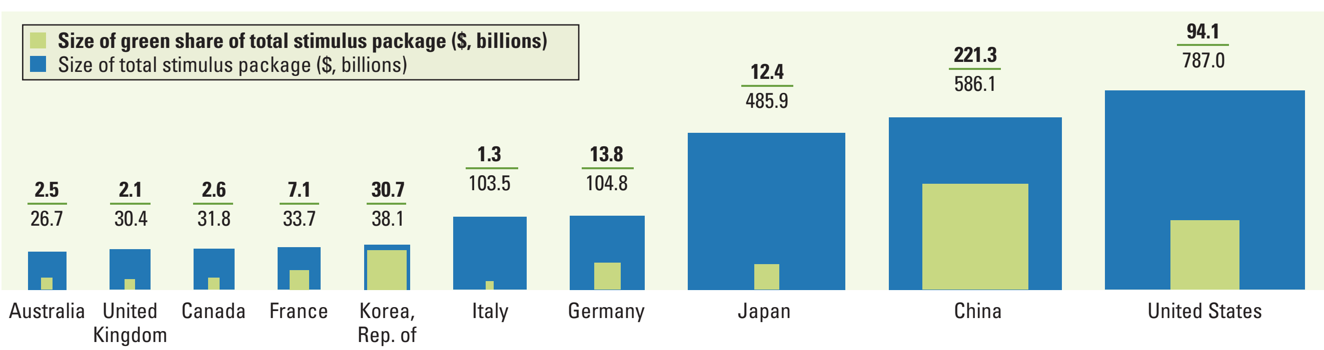
Several governments have included a share of "green" investments in their stimulus proposals—including low-carbon technologies, energy efficiency, research and development, and water and waste management (figure 1.4). The Republic of Korea will devote 80.5 percent of its fiscal plan to green projects. Some $100 billion to $130 billion of the U.S. stimulus package has been allocated to climate-change-related investments. Overall, some $436 billion will be disbursed in green investments as part of fiscal stimuli around the world, with half expected to be used during 2009.[126]

The efficiency of these investments will depend on how quickly they can be implemented; how well targeted they can be in creating jobs and utilizing underused resources; and how much they shift economies toward long-lived, low-carbon infrastructure, reduced emissions, and increased resilience.[127] Investments in energy efficiency in public buildings, for instance, are appealing because they are usually "shovel ready," are very labor intensive, and generate long-term savings for the public sector.[128] Similar virtues can be found in helping to finance other energy-efficiency measures that reduce the social cost of energy in private buildings, as well as in water and sanitation facilities and in improved traffic flows.

In each country the portfolio of projects and investments varies widely, according to the specific conditions of the economy and the needs for job creation. Most stimulus packages in Latin America, for instance, will be spent on public works—including highways—with limited mitigation potential.[129] In the Republic of Korea, where 960,000 jobs are expected to be created in the next four years, a large part of the investment—$13.3 billion of $36 billion—will be allocated to three projects: river restoration, expansion of mass transit and railroads, and energy conservation in villages and schools, programs projected to create 500,000 jobs.[130] China will devote $85 billion to rail transport as a low-carbon alternative to road and air transport that can also help alleviate transportation bottlenecks. Another $70 billion will be allocated for a new electricity grid that improves the efficiency and availability of electricity.[131] In the United States two fairly inexpensive projects—$6.7 billion for renovating federal buildings, and another $6.2 billion for weatherizing homes—will create an estimated 325,000 jobs a year.[132]

In most developing countries the projects in stimulus packages do not have a strong emission-reduction component, but they could improve resilience to climate change

Figure 1.4 Global green stimulus spending is rising



Source: Robins, Clover, and Singh 2009.

and create jobs. Improving water and sanitation networks in Colombia, for example, is estimated to create 100,000 direct jobs per $1 billion invested while reducing the risk of water-borne illnesses.[133] Both developing and developed countries should consider adaptation measures such as streambed and wetland restoration, which can be particularly labor intensive and thus reduce both the physical and financial vulnerability of some groups. The challenge would be to ensure that the adaptation measures are sustained after the expenditure program ends.

These preliminary figures will likely change as the crisis unfolds. There is no guarantee that the green elements of the fiscal stimulus will succeed in either generating jobs or changing the carbon mix of the economy. And even in the best-case scenario, the fiscal interventions will not be enough to eliminate the risk of high-carbon lock-in and climate vulnerability. But the opportunity to jump-start green investments and lay the foundation for low-carbon economies is real and needs to be seized.

Fundamental transformations in the medium and long term

Incorporating sound low-carbon and high-resilience investment components in fiscal expansions to combat the financial crisis will not be enough to thwart the long-term problems posed by climate change. Fundamental transformations are needed in social protection, in carbon finance, in research and development, in energy markets, and in the management of land and water.

Over the medium and long terms the challenge is to find new paths to reach the twin goals of sustaining development and limiting climate change. Reaching an equitable and fair global deal would be an important step toward avoiding worst-case scenarios. But it requires transforming the carbon-intensive lifestyles of rich countries (and rich people everywhere) and the carbon-intensive growth paths of developing countries. This in turn requires complementary socioeconomic changes.

Modifications in social norms that reward a low-carbon lifestyle could prove a powerful element of success (see chapter 8). But behavioral change needs to be matched with institutional reform, additional finance, and technological innovation to avoid irreversible, catastrophic increases in temperature. In any case and under any scenario, strong public policy can help economies absorb the shocks of unavoidable climate impacts, minimize net social losses, and protect the welfare of those who most stand to lose.

The response to climate change could generate momentum to improve the development process and promote welfare-enhancing reforms that need to happen anyway. For example, the joint efforts to increase energy efficiency and promote development could find a policy—and physical—expression in greener, more resilient cities. Improving urban design to promote energy efficiency—through, say, more public transportation and a congestion charge—can increase physical security and the quality of life. Much depends on the degree to which existing inadequate institutional mechanisms and policies can be strengthened or replaced thanks to greater political space for change brought about by the threat of global warming and to increased international technical and financial assistance.

Individual citizens will have a large role in the public debate and implementation of solutions. Opinion surveys show that people around the world are concerned about climate change, even in the recent financial turmoil[134] (though evidence on recent trends in the United States is mixed).[135] Most governments also recognize, at least in discourse, the enormity of the danger. And the international community has acknowledged the problem, as exemplified by the 2007 Nobel Peace prize awarded for the scientific assessment and communication to the public of climate change.

The challenge for decision makers is to ensure that this awareness creates the momentum for reform of institutions and behavior and serves the needs of those most vulnerable.[136] The financial crises of the 1990s catalyzed the revamping of social safety nets in Latin America, giving birth to Progresa–Oportunidades in Mexico and Bolsa Escola–Bolsa Familia in Brazil, among the best innovations in social policy in decades.[138]

The current crisis has eroded faith in unregulated markets. As a consequence, better regulation, more intervention, and greater government accountability are expected. For dealing with climate change, additional climate-smart regulation is needed to induce innovative approaches to mitigation and adaptation. Such policies create an opening for the scale and scope of government interventions needed to correct climate change—the biggest market failure in human history.

Notes

1. Weiss and Bradley 2001.
2. Ristvet and Weiss 2000.
3. Weiss 2000.
4. Harrington and Walton 2008; IWM and CEGIS 2007.
5. Schmidhuber and Tubiello 2007.
6. Bates and others 2008.
7. WCED 1987.
8. Chen and Ravaillon 2008.
9. World Bank 2009a.
10. United Nations 2008.
11. Chen and Ravaillon 2008.
12. IEA 2007.
13. United Nations 2008.
14. United Nations 2008.
15. UNDP 2008.
16. IARU 2009.
17. Smith and others 2009.
18. Patriquin and others 2005; Patriquin, Wellstead, and White 2007; Pacific Institute for Climate Solutions 2008.
19. Note that this relationship holds even when controlling for the fact that poorer countries tend to be warmer on average. Dell, Jones, and Olken 2008.
20. Dell, Jones, and Olken 2008.
21. Brown and others 2009.
22. IPCC 2007b.
23. Cruz and others 2007.
24. Easterling and others 2007.
25. Auffhammer, Ramanathan, and Vincent 2006.
26. Guiteras 2007.
27. Ligon and Sadoulet 2007.
28. Campbell-Lendrum, Corvalan, and Pruss-Ustun 2003.
29. Among the many diverse regions and countries affected are Colombia (Vergara 2009), the Caucasus (Rabie and others 2008), Ethiopia (Confalonieri and others 2007), and the islands of the South Pacific (Potter 2008).
30. Molesworth and others 2003.
31. Confalonieri and others 2007.
32. Confalonieri and others 2007; Morris and others 2002.
33. Carter and others 2007.
34. World Bank 2001.
35. Azariadis and Stachurski 2005.
36. Lokshin and Ravallion 2000; Jalan and Ravallion 2004; Dercon 2004.
37. Dercon 2004.
38. Mueller and Osgood 2007.
39. Azariadis and Stachurski 2005.
40. Rosenzweig and Binswanger 1993.
41. Jensen 2000.
42. Alderman, Hoddinott, and Kinsey 2006.
43. Figures include all greenhouse gases but do not include emissions from land-use change. If estimates of land-use change emissions are added, the share of developing countries in global emissions is closer to 60 percent.
44. WRI 2008.
45. Chomitz and Meisner 2008.
46. Authors' calculations, based on data from CAIT (WRI 2008). Greenhouse gas emissions (excluding land-use change) per capita range from 4.5 to 55.5 metric tons CO_2e (7 to 27, if small-island states and oil producers are excluded) among high-income countries. Emissions per $1,000 of output at market exchange rates range from 0.15 to 1.72 metric tons in high-income

"Take care of your earth,
Look after its creatures.
Don't leave your children,
A planet that's dead."

—Lakshmi Shree, India, age 12

countries; measuring output at purchasing power parity, the range is 0.20 to 1.04 metric tons.

47. Marcotullio and Schulz 2007.

48. Rosenberg 1971.

49. IPCC 2007a.

50. Lipovsky 1995.

51. "Annual Brazilian Ethanol Exports" and "Brazilian Ethanol Production," http://english.unica.com.br/dadosCotacao/estatistica/ (accessed December 2008).

52. Ummel and Wheeler 2008.

53. Hill and others 2009.

54. Mitchell 2008.

55. Ivanic and Martin 2008.

56. Ng and Aksoy 2008; World Bank 2008.

57. Cramton and Kerr 1999.

58. Ekins and Dresner 2004.

59. Brenner, Riddle, and Boyce 2007.

60. Benitez and others 2008.

61. Estache 2009.

62. Andriamihaja and Vecchi 2007.

63. Komives and others 2005.

64. Johnson and others 2008.

65. Pindyck 2007; Weitzman 2009a; Hallegatte, Dumas, and Hourcade 2009.

66. Yohe 1999; Toth and Mwandosya 2001.

67. Lempert and Schlesinger 2000.

68. Nordhaus 2008a. For a discussion of models and their results, see, for example, Heal 2008; Fisher and others 2007; Tol 2005; and Hourcade and Ambrosi 2007.

69. The 5 percent estimate is largely driven by the discount rate, but the margin between 5 percent and 20 percent is based on the inclusion of nonmarket impacts (health and environment), possibly higher sensitivity of the climate to greenhouse gases, and the use of equity weighting. Stern 2007; Dasgupta 2007; Dasgupta 2008.

70. For a discussion, see Dasgupta 2007; Dasgupta 2008; and box 1.4.

71. Dasgupta 2008.

72. Heal 2008; Sterner and Persson 2008.

73. Guesnerie 2004; Heal 2005; Hourcade and Ambrosi 2007.

74. Sterner and Persson 2008.

75. Hourcade and others (2001) explore the sensitivity of seven different integrated assessment models to the shape of the damage function and find that optimal concentration trajectories can imply significant departure from current emission trends if significant damages occur with warming of 3°C or 500 parts per milion (ppm) CO_2 concentration. More generally, they note that early action can be justified if a nonzero probability is assigned to damages increasing very rapidly with warming, so that damages grow more rapidly than the rate at which discounting shaves down their weight.

76. Solomon and others 2009.

77. Mignone and others 2008.

78. Folger 2006; Auld and others 2007.

79. Carbon capture and storage technology is described in chapter 4, box 4.6.

80. Shalizi and Lecocq 2009.

81. For a general discussion, see Arthur 1994; for a more specific application of increasing returns and the need to invest in innovation in the area of energy efficiency, see Mulder 2005.

82. Weitzman 2007; Weitzman 2009a; Weitzman 2009b; Nordhaus 2009.

83. Gjerde, Grepperud, and Kverndokk 1999; Kousky and others 2009.

84. Hallegatte, Dumas, and Hourcade 2009.

85. See Pindyck (2007) and Quiggin (2008) for recent reviews.

86. O'Neill and others 2006.

87. In their model, Sterner and Persson (2008) include environmental goods in the utility function.

88. Portney and Weyant 1999.

89. Fisher and others 2007; Hourcade and Ambrosi 2007; Tol 2005.

90. Diamond 2005.

91. Komives and others 2007; Diamond 2005.

92. Diamond 2005.

93. Hof, den Elzen, and van Vuuren 2008.

94. Bruckner and others 1999.

95. Yohe 1999.

96. Toth and Mwandosya 2001.

97. Lempert and Schlesinger 2000.

98. Savage 1951; Savage 1954.

99. Klaus, Yohe, and Schlesinger 2008.

100. IPCC 2007a.

101. See overview figure 3 for cumulative emissions relative to population share.

102. According to the IEA (2008), non-OECD (Organisation for Economic Co-operation and Development) countries reached the same level of annual energy-related emissions as OECD countries in 2004 (approximately 13 gigatons of CO_2 a year). The World Resource Institute's CAIT emission indicator database suggests the same conclusion using the World Bank's definition of developed and developing countries; WRI 2008.

103. Wheeler and Ummel 2007.

104. Chapter 5, box 5.1, describes the Bali Action Plan in detail.

105. For 2030, this has been estimated at 65–70 percent of the emission reduction, or 45–70 percent of the investment cost. Over the course of the century (using net present value to 2100) the estimated share of investments that should take place in developing countries is 65–70 percent. See overview note 47 for sources.

106. Edmonds and others 2008.

107. Nordhaus 2008b.

108. See, for example, Edmonds and others 2008.
109. See note 108 above and chapter 5, box 5.1.
110. Hamilton 2009.
111. Barrett 2006; Barrett 2007.
112. Barrett and Stavins 2003.
113. Carraro, Eykmans, and Finus 2009; personal communication with Carlo Carraro, 2009.
114. Brinsley and Christie 2009.
115. Bureau of Labor Statistics 2009.
116. ILO 2009.
117. World Bank 2009a.
118. Ratha, Mohapatra, and Xu 2008.
119. Banco de México, http://www.banxico.org.mx/SieInternet/consultarDirectorioInternetAction.do?accion=consultarCuadro&idCuadro=CE99&locale=es (accessed May 15, 2009).
120. Robins, Clover, and Singh 2009.
121. Robert B. Zoellick, "A Stimulus Package for the World," *New York Times*, January 22, 2009.
122. Fankhauser, Sehlleier, and Stern 2008.
123. Houser, Mohan, and Heilmayr 2009.
124. Pollin and others 2008.
125. Fankhauser, Sehlleier, and Stern 2008.
126. Robins, Clover, and Singh 2009.
127. Bowen and others 2009.
128. Bowen and others 2009; Houser, Mohan, and Heilmayr 2009.
129. Schwartz, Andres, and Dragoiu 2009.
130. Barbier 2009.
131. Barbier 2009.
132. Authors' calculations based on Houser, Mohan, and Heilmayr 2009.
133. Schwartz, Andres, and Dragoiu 2009.
134. Accenture 2009.
135. Pew Research Center for People and the Press 2009.
136. Ravallion 2008.
137. These programs pioneered the use of incentive-based transfers to poor households to supplement incomes while directly encouraging poverty-combating behaviors. In contrast to traditional income support, these programs provide cash to poor househods conditional on their participation in nutrition and health programs (immunizations, pre-natal care) or on their children's school attendance. Fiszbein and Schady 2009.

References

ACASIAN (Australian Consortium for the Asian Spatial Information and Analysis Network). 2004. "China Rail Transport Network database." Griffith University, Brisbane.

Accenture. 2009. *Shifting the Balance from Intention to Action: Low Carbon, High Opportunity, High Performance*. New York: Accenture.

Adams, H. D., M. Guardiola-Claramonte, G. A. Barron-Gafford, J. C. Villegas, D. D. Breshears, C. B. Zou, P. A. Troch, and T. E. Huxman. 2009. "Temperature Sensitivity of Drought-Induced Tree Mortality Portends Increased Regional Die-Off under Global-Change-Type Drought." *Proceedings of the National Academy of Sciences* 106 (17): 7063–66.

Aguilar, L. 2006. "Climate Change and Disaster Mitigation: Gender Makes a Difference." International Union for Conservation of Nature, Gland, Switzerland.

Alderman, H., J. Hoddinott, and B. Kinsey. 2006. "Long-Term Consequences of Early Childhood Malnutrition." *Oxford Economic Papers* 58 (3): 450–74.

Andriamihaja, N., and G. Vecchi. 2007. "An Evaluation of the Welfare Impact of Higher Energy Prices in Madagascar." Working Paper Series 106, World Bank, Africa Region, Washington, DC.

Armstrong, R., B. Raup, S. J. S. Khalsa, R. Barry, J. Kargel, C. Helm, and H. Kieffer. 2005. "GLIMS Glacier Database." National Snow and Ice Data Center, Boulder, CO.

Arthur, W. B. 1994. *Increasing Returns and Path-Dependence in the Economy*. Ann Arbor, MI: University of Michigan Press.

Assunçao, J. J., and F. Chein. 2008. "Climate Change, Agricultural Productivity and Poverty." Background Paper for de la Torre and others, 2008, *Low Carbon, High Growth: Latin America Responses to Climate Change*. Washington, DC: World Bank.

Auffhammer, M., V. Ramanathan, and J. R. Vincent. 2006. "Integrated Model Shows that Atmospheric Brown Clouds and Greenhouse Gases Have Reduced Rice Harvests in India." *Proceedings of the National Academy of Sciences* 103 (52): 19668–72.

Auld, G, S. Bernstein, B. Cashore, and K. Levin. 2007. "Playing It Forward: Path Dependency, Progressive Incrementalism, and the 'Super Wicked' Problem of Global Climate Change." Paper presented at the International Studies Association annual convention, February 28, Chicago.

Azariadis, C., and J. Stachurski. 2005. "Poverty Traps." In *Handbook of Economic Growth, vol. 1,* ed. P. Aghion and S. Durlauf. Amsterdam: Elsevier.

Barbier, E. B. 2009. *A Global Green New Deal*. Nairobi: United Nations Environment Programme.

Barrett, S. 2006. "The Problem of Averting Global Catastrophe." *Chicago Journal of International Law* 6 (2): 1–26.

———. 2007. *Why Cooperate? The Incentive to Supply Global Public Goods*. Oxford, UK: Oxford University Press.

Barrett, S., and R. Stavins. 2003. "Increasing Participation and Compliance in International Climate Change Agreements." *International Environmental Agreements: Politics, Law and Economics* 3 (4): 349–76.

Bates, B., Z. W. Kundzewicz, S. Wu, and J. Palutikof. 2008. "Climate Change and Water." Technical Paper, Intergovernmental Panel on Climate Change, Geneva.

Benitez, D., R. Fuentes Nieva, T. Serebrisky, and Q. Wodon. 2008. "Assessing the Impact of Climate Change Policies in Infrastructure Service Delivery: A Note on Affordability and Access." Background note for the WDR 2010.

Bowen, A., S. Fankhauser, N. Stern, and D. Zenghelis. 2009. *An Outline of the Case for a "Green" Stimulus*. London: Grantham Research Institute on Climate Change and the Environment and the Centre for Climate Change Economics and Policy.

Brenner, M. D., M. Riddle, and J. K. Boyce. 2007. "A Chinese Sky Trust? Distributional Impacts of Carbon Charges and Revenue Recycling in China." *Energy Policy* 35 (3): 1771–84.

Brinsley, J., and R. Christie. 2009. "Paulson to Work Quickly with Congress to Revive Plan (Update 1)." Bloomberg, September 29.

Brown, C., R. Meeks, Y. Ghile, and K. Hunu. 2009. "An Empirical Analysis of the Effects of Climate Variables on National Level Economic Growth." Background paper for the WDR 2010.

Bruckner, T., G. Petschel-Held, F. L. Toth, H.-M. Füssel, C. Helm, M. Leimbach, and H.-J. Schellnhuber. 1999. "Climate Change Decision Support and the Tolerable Windows Approach." *Environmental Modeling and Assessment* 4: 217–34.

Bureau of Labor Statistics. 2009. "Employment Situation Summary." Washington, DC.

Campbell-Lendrum, D. H., C. F. Corvalan, and A. Pruss-Ustun. 2003. "How Much Disease Could Climate Change Cause?" In *Climate Change and Human Health: Risks and Responses,* ed. A. J. McMichael, D. H. Campbell-Lendrum, C. F. Corvalan, K. L. Ebi, A. Githeko, J. D. Scheraga, and A. Woodward. Geneva: World Health Organization.

Caney, S. 2009. "Ethics and Climate Change." Background paper for the WDR 2010.

Carraro, C., J. Eykmans, and M. Finus. 2009. "Optimal Transfers and Participation Decisions in International Environmental Agreements." *Review of International Organizations* 1 (4): 379–96.

Carter, M. R., P. D. Little, T. Mogues, and W. Negatu. 2007. "Poverty Traps and Natural Disasters in Ethiopia and Honduras." *World Development* 35 (5): 835–56.

Chan, K. W. 2008. "Internal Labor Migration in China: Trends, Geographical Distribution and Policies." Paper presented at the Proceedings of United Nations Expert Group Meeting on Population Distribution, Urbanization, Internal Migration and Development, New York.

Chen, S., and M. Ravaillon. 2008. "The Developing World Is Poorer than We Thought, But No Less Successful in the Fight against Poverty." Policy Research Working Paper 4703, World Bank, Washington, DC.

Chomitz, K., and C. Meisner. 2008. "A Simple Benchmark for CO_2 Intensity of Economies." Washington, DC: Background Note for the World Bank Internal Evaluation Group on Climate Change and the World Bank Group.

Confalonieri, U., B. Menne, R. Akhtar, K. L. Ebi, M. Hauengue, R. S. Kovats, B. Revich, and A. Woodward. 2007. "Human Health." In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Cambridge, UK: Cambridge University Press.

Cramton, P., and S. Kerr. 1999. "The Distributional Effect of Carbon Regulation: Why Auctioned Carbon Permits Are Attractive and Feasible." In *The Market and the Environment,* ed. T. Sterner. Northampton, UK: Edward Elgar Publishing.

Cruz, R. V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li, and N. Huu Ninh. 2007. "Asia." In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Cambridge, UK: Cambridge University Press.

Dasgupta, P. 2007. "Comments on the Stern Review's Economics of Climate Change." *National Institute Economic Review* 199: 4–7.

———. 2008. "Discounting Climate Change." *Journal of Risk and Uncertainty* 37 (2): 141–69.

Dell, M., B. F. Jones, and B. A. Olken. 2008. "Climate Change and Economic Growth: Evidence from the Last Half Century." Working Paper 14132, National Bureau of Economic Research, Cambridge, MA.

———. 2009. "Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates." *American Economic Review* 99 (2): 198–204.

Dercon, S. 2004. "Growth and Shocks: Evidence from Rural Ethiopia." *Journal of Development Economics* 74 (2): 309–29.

Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed*. New York: Viking.

Easterling, W., P. Aggarwal, P. Batima, K. Brander, L. Erda, M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber, and F. Tubiello. 2007. "Food, Fibre and Forest Products." In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. M. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Cambridge, UK: Cambridge University Press.

Edmonds, J., L. Clarke, J. Lurz, and M. Wise. 2008. "Stabilizing CO_2 Concentrations with Incomplete International Cooperation." *Climate Policy* 8 (4): 355–76.

Ekins, P., and S. Dresner. 2004. *Green Taxes and Charges: Reducing their Impact on Low-income Households*. York, UK: Joseph Rowntree Foundation.

ESRI (Environmental Systems Research Institute). 2002. "ESRI Data and Maps." Redlands, CA.

Estache, A. 2009. "How Should the Nexus between Economic and Environmental Regulation Work for Infrastructure Services?" Background note for the WDR 2010.

Fankhauser, S., F. Sehlleier, and N. Stern. 2008. "Climate Change, Innovation and Jobs." *Climate Policy* 8: 421–29.

Fisher, B. S., N. Nakićenović, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J.-C. Hourcade, K. Jiang, M. Kainuma, E. La Rovere, A. Matysek, A. Rana, K. Riahi, R. Richels, S. Rose, D. van Vuuren, and R. Warren. 2007. "Issues Related to Mitigation in the Long-Term Context." In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer. Cambridge, UK: Cambridge University Press.

Fiszbein, A., and N. Schady. 2009. *Conditional Cash Transfers: Reducing Present and Future Poverty*. Washington, DC: World Bank.

Folger, T. 2006. "Can Coal Come Clean? How to Survive the Return of the World's Dirtiest Fossil Fuel." December. *Discover Magazine.*

Gjerde, J., S. Grepperud, and S. Kverndokk. 1999. "Optimal Climate Policy under the Possibility of a Catastrophe." *Resource and Energy Economics* 21 (3–4): 289–317.

Guesnerie, R. 2004. "Calcul Economique et Développement Durable." *La Revue Economique* 55 (3): 363–82.

Guiteras, R. 2007. "The Impact of Climate Change on Indian Agriculture." Department of Economics Working Paper, Massachusetts Institute of Technology, Cambridge, MA.

Hallegatte, S. 2008. "An Adaptive Regional Input-Output Model and its Application to the Assessment of the Economic Cost of Katrina." *Risk Analysis* 28 (3): 779–99.

Hallegatte, S., P. Dumas, and J.-C. Hourcade. 2009. "A Note on the Economic Cost of Climate Change and the Rationale to Limit it to 2°K." Background paper for the WDR 2010.

Hamilton, K. 2009. "Delayed Participation in a Global Climate Agreement." Background note for the WDR 2010.

Harrington, J., and T. L. Walton. 2008. "Climate Change in Coastal Areas in Florida: Sea Level Rise Estimation and Economic Analysis to Year 2080." Florida State University, Tallahassee, FL.

Heal, G. 2005. "Intertemporal Welfare Economics and the Environment." In *Handbook of Environmental Economics, Vol. 3,* ed. K.-G. Maler and J. R. Vincent. Amsterdam: Elsevier.

———. 2008. "Climate Economics: A Meta-Review and Some Suggestions." Working Paper 13927, National Bureau of Economic Research, Cambridge, MA.

Hill, J., S. Polasky, E. Nelson, D. Tilman, H. Huo, L. Ludwig, J. Neumann, H. Zheng, and D. Bonta. 2009. "Climate Change and Health Costs of Air Emissions from Biofuels and Gasoline." *Proceedings of the National Academy of Sciences* 106 (6): 2077–82.

Hof, A. F., M. G. J. den Elzen, and D. P. van Vuuren. 2008. "Analyzing the Costs and Benefits of Climate Policy: Value Judgments and Scientific Uncertainties." *Global Environmental Change* 18 (3): 412–24.

Houghton, R. A. 2009. "Emissions of Carbon from Land Management." Background note for the WDR 2010.

Hourcade, J.-C., and P. Ambrosi. 2007. "Quelques Leçons d'un Essai à Risque, l'evaluation des Dommages Climatiques par Sir Nicholas Stern." *Revue d'economie politique* 117 (4): 33–46.

Hourcade, J.-C., M. Ha-Duong, A. Grübler, and R. S. J. Tol. 2001. "INASUD Project Findings on Integrated Assessment of Climate Policies." *Integrated Assessment* 2 (1): 31–35.

Houser, T., S. Mohan, and R. Heilmayr. 2009. "A Green Global Recovery? Assessing U.S. Economic Stimulus and the Prospects for International Coordination." Policy Brief PB09-03, World Resources Institute, Washington, DC.

Huang, Y., and A. Magnoli, eds. 2009. *Reshaping Economic Geography in East Asia.* Washington, DC: World Bank.

IARU (International Alliance of Research Universities). 2009. "Climate Change: Global Risks, Challenges and Decisions." IOP Conference Series: Earth and Environmental Science. Copenhagen.

IEA (International Energy Agency). 2007. *World Energy Outlook 2007*. Paris: IEA.

———. 2008. *World Energy Outlook 2008*. Paris: IEA.

ILO (International Labour Organization). 2009. *Global Employment Trends: January 2009.* Geneva: ILO.

IPCC (Intergovernmental Panel on Climate Change). 2007a. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva: IPCC.

———. 2007b. "Summary for Policymakers." In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Cambridge, UK: Cambridge University Press.

Ivanic, M., and W. Martin. 2008. "Implications of Higher Global Food Prices for Poverty in Low-Income Countries." Policy Research Working Paper 4594, World Bank, Washington, DC.

IWM (Institute of Water Modelling) and CEGIS (Center for Environmental and Geographical Information Services). 2007. *Investigating the Impact of Relative Sea-Level Rise on Coastal Communities and Their Livelihoods in Bangladesh*. Dhaka: IWM, CEGIS.

Jalan, J., and M. Ravallion. 2004. "Household Income Dynamics in Rural China." In *Insurance against Poverty,* ed. S. Dercon. Oxford, UK: Oxford University Press.

Jensen, R. 2000. "Agricultural Volatility and Investments in Children." *American Economic Review* 90 (2): 399–404.

Johnson, T., F. Liu, C. Alatorre, and Z. Romo. 2008. "Mexico Low-Carbon Study—México: Estudio Para la Disminución de Emisiones de Carbono (MEDEC)." World Bank, Washington, DC.

Klaus, K., G. Yohe, and M. Schlesinger. 2008. "Managing the Risks of Climate Thresholds: Uncertainties and Information Needs." *Climatic Change* 91: 5–10.

Komives, K., V. Foster, J. Halpern, Q. Wodon, and R. Abdullah. 2005. *Water, Electricity, and the Poor: Who Benefits from Utility Subsidies?* Washington, DC: World Bank.

Komives, K., V. Foster, H. Halpern, Q. Wodon, and R. Krznaric. 2007. *Food Coupons and Bald Mountains: What the History of Resource Scarcity Can Teach Us about Tackling Climate Change*. New York: United Nations Development Programme.

Kousky, C., O. Rostapshova, M. A. Toman, and R. Zeckhauser. 2009. "Responding to Threats of Climate Change Catastrophes." Background paper for the *Economics of Natural Disasters,* Global Facility for Disaser Reduction and Recovery, World Bank, Washington, DC.

Kriegler, E., J. W. Hall, H. Held, R. Dawson, and H. J. Schellnhuber. 2009. "Imprecise Probability Assessment of Tipping Points in the Climate System." *Proceedings of the National Academy of Sciences* 106 (13): 5041–46.

Lambrou, Y., and R. Laub. 2004. *Gender Perspectives on the Conventions on Biodiversity, Climate Change and Desertification*. Rome: Food and Agriculture Organization.

Lempert, R. J., and M. E. Schlesinger. 2000. "Robust Strategies for Abating Climate Change." *Climatic Change* 45 (3–4): 387–401.

Ligon, E., and E. Sadoulet. 2007. "Estimating the Effects of Aggregate Agricultural Growth on the Distribution of Expenditures." Background paper for the WDR 2008.

Lipovsky, I. 1995. "The Central Asian Cotton Epic." *Central Asian Survey* 14 (4): 29–542.

Lokshin, M., and M. Ravallion. 2000. "Short-lived Shocks with Long-lived Impacts?

Household Income Dynamics in a Transition Economy." Policy Research Working Paper 2459, World Bank, Washington, DC.

Marcotullio, P. J., and N. B. Schulz. 2007. "Comparison of Energy Transitions in the United States and Developing and Industrializing Economies." *World Development* 35 (10): 1650–83.

Martin, A. 1996. "Forestry: Gender Makes the Difference." International Union for Conservation of Nature, Gland, Switzerland.

McKinsey & Company. 2009. *Pathways to a Low-carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*. McKinsey & Company.

Mignone, B. K., R. H. Socolow, J. L. Sarmiento, and M. Oppenheimer. 2008. "Atmospheric Stabilization and the Timing of Carbon Mitigation." *Climatic Change* 88 (3 -4): 251–65.

Mitchell, D. 2008. "A Note on Rising Food Prices." Policy Research Working Paper 4682, World Bank, Washington, DC.

Molesworth, A. M., L. E. Cuevas, S. J. Connor, A. P. Morse, and M. C. Thomson. 2003. "Environmental Changes and Meningitis Epidemics in Africa." *Emerging Infectious Diseases* 9 (10): 1287–93.

Morris, S., O. Neidecker-Gonzales, C. Carletto, M. Munguia, J. M. Medina, and Q. Wodon. 2002. "Hurricane Mitch and Livelihoods of the Rural Poor in Honduras." *World Development* 30 (1): 39–60.

Mueller, V., and D. Osgood. 2007. "Long-term Impacts of Droughts on Labor Markets in Developing Countries: Evidence from Brazil." Earth Institute at Columbia University, New York.

Mulder, P. 2005. *The Economics of Technology Diffusion and Energy Efficiency*. Cheltenham, UK: Edward Elgar.

Neumayer, E., and T. Plumper. 2007. "The Gendered Nature of Natural Disasters: The Impact of Catastrophic Events on the Gender Gap in Life Expectancy, 1981–2002." *Annals of the Association of American Geographers* 97 (3): 551–66.

Ng, F., and M. A. Aksoy. 2008. "Who Are the Net Food Importing Countries?" Policy Research Working Paper 4457, World Bank, Washington, DC.

Nordhaus, W. 2008a. *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press.

———. 2008b. "The Role of Universal Participation in Policies to Slow Global Warming." Paper presented at the Third Atlantic Workshop on Energy and Environmental Economics, A Toxa, Spain.

———. 2009. "An Analysis of the Dismal Theorem." Cowles Foundation Discussion Paper 1686, New Haven, CT.

O'Neill, B. C., P. Crutzen, A. Grübler, M. Ha-Duong, K. Keller, C. Kolstad, J. Koomey, A. Lange, M. Obersteiner, M. Oppenheimer, W. Pepper, W. Sanderson, M. Schlesinger, N. Treich, A. Ulph, M. Webster, and C. Wilson. 2006. "Learning and Climate Change." *Climate Policy* 6: 585–89.

Pacific Institute for Climate Solutions. 2008. "Climate Change and Health in British Columbia." University of Victoria, Victoria.

Parikh, J. 2008. *Gender and Climate Change: Key Issues*. New Delhi: Integrated Research and Action for Development.

Patriquin, M., A. M. Wellstead, and W. A. White. 2007. "Beetles, Trees, and People: Regional Economic Impact Sensitivity and Policy Considerations Related to the Mountain Pine Beetle Infestation in British Columbia, Canada." *Forest Policy and Economics* 9 (8): 938–46.

Pindyck, R. 2007. "Uncertainty in Environmental Economics." *Review of Environmental Economics and Policy* 1 (1): 45–65.

Pollin, R., H. Garrett-Peltier, J. Heintz, and H. Scharber. 2008. *Green Recovery: A Program to Create Good Jobs and Start Building a Low Carbon Economy*. Washington, DC: Center for American Progress.

Portney, P. R., and J. P. Weyant. 1999. *Discounting and Intergenerational Equity*. Washington, DC: Resources for the Future.

Potter, S. 2008. *The Sting of Climate Change: Malaria and Dengue Fever in Maritime Southeast Asia and the Pacific Islands*. Sydney: Lowy Institute for International Policy.

Quiggin, J. 2008. "Uncertainty and Climate Policy." *Economic Analysis and Policy* 38 (2): 203–10.

Rabie, T., S. el Tahir, T. Alireza, G. Sanchez Martinez, K. Ferl, and N. Cenacchi. 2008. "The Health Dimension of Climate Change." Background Paper for *Adapting to Climate Change in Europe and Central Asia,* ed. M. Fay, R. I. Block, and J. Ebinger, 2010, World Bank, Washington, DC.

Ratha, D., S. Mohapatra, and Z. Xu. 2008. *Outlook for Remittance Flows 2008–2010*. Washington, DC: World Bank.

Ravallion, M. 2008. "Bailing Out the World's Poorest." Policy Research Working Paper 4763, World Bank, Washington, DC.

Ristvet, L., and H. Weiss. 2000. "Imperial Responses to Environmental Dynamics at Late Third Millennium Tell Leilan." *Orient-Express* 2000 (4): 94–99.

Robine, J.-M., S. L. K. Cheung, S. Le Roy, H. Van Oyen, C. Griffiths, J.-P. Michel, and F. R. Herrmann. 2008. "Death Toll Exceeded 70,000 in Europe during Summer of 2003." *Comptes Rendus Biologies* 331 (2): 171–78.

Robins, N., R. Clover, and C. Singh. 2009. *A Climate for Recovery: The Colour of Stimulus Goes Green*. London: HSBC.

Roemer, J. 2009. "The Ethics of Distribution in a Warming Planet." Cowles Foundation Discussion Paper 1693, New Haven, CT.

Rosenberg, N. 1971. "Technology and the Environment: An Economic Exploration." *Technology and Culture* 12 (4): 543–61.

Rosenzweig, M. R., and H. P. Binswanger. 1993. "Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments." *Economic Journal* 103 (416): 56–78.

Savage, L. J. 1951. "The Theory of Statistical Decision." *Journal of the American Statistical Association* 46 (253): 55–67.

———. 1954. *The Foundations of Statistics*. New York: John Wiley & Sons.

Schmidhuber, J., and F. N. Tubiello. 2007. "Global Food Security under Climate Change." *Proceedings of the National Academy of Sciences* 104 (50): 19703–08.

Schmidt, G. 2006. "Runaway Tipping Points of No Return." Real Climate, July 5, 2009.

Schwartz, J., L. Andres, and G. Dragoiu. 2009. "Crisis in LAC: Infrastructure Investment, Employment and the Expectations of Stimulus." World Bank, LCSSD Economics Unit, Washington, DC.

Shalizi, Z., and F. Lecocq. 2009. "Economics of Targeted Mitigation Programs in Sectors with Long-Lived Capital Stock." Policy Research Working Paper 5063, World Bank, Washington, DC.

Singer, P. 2006. "Ethics and Climate Change: Commentary." *Environmental Values* 15: 415–22.

Smith, J. B., S. H. Schneider, M. Oppenheimer, G. W. Yohe, W. Hare, M. D. Mastrandrea, A. Patwardhan, I. Burton, J. Corfee-Morlot, C. H. D. Magadza, H.-M. Füssel, A. B. Pittock, A. Rahman, A. Suarez, and J.-P. van Ypersele. 2009. "Assessing Dangerous Climate Change through an Update of the Intergovernmental Panel on Climate Change (IPCC) 'reasons for concern.'" *Proceedings of the National Academy of Sciences* 106 (11): 4133–37.

Smyth, I. 2005. "More than Silence: The Gender Dimensions of Tsunami Fatalities and Their Consequences." Paper presented at the WHO Conference on Health Aspects of the Tsunami Disaster in Asia, Phuket, Thailand.

Solomon, S., G.-K. Plattner, R. Knutti, and P. Friedlingstein. 2009. "Irreversible Climate Change due to Carbon Dioxide Emissions." *Proceedings of the National Academy of Sciences* 106 (6): 1704–09.

Stern, N. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

———. 2008. *Key Elements of a Global Deal on Climate Change*. London: London School of Economics and Political Science.

Sterner, T., and U. M. Persson. 2008. "An Even Sterner Review: Introducing Relative Prices into the Discounting Debate." *Review of Environmental Economics and Policy* 2 (1): 61–76.

Tol, R. S. J. 2005. "The Marginal Damage Cost of Carbon Dioxide Emissions: An Assessment of the Uncertainties." *Energy Policy* 33: 2064–74.

Toth, F., and M. Mwandosya. 2001. "Decision-making Frameworks." In *Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, ed. B. Metz, O. Davidson, R. Swart, and J. Pan. Cambridge, UK: Cambridge University Press.

Ummel, K., and D. Wheeler. 2008. "Desert Power: The Economics of Solar Thermal Electricity for Europe, North Africa, and the Middle East." Working Paper 156, Center for Global Development, Washington, DC.

UNDP (United Nations Development Programme). 2008. *Human Development Report 2007/2008. Fighting Climate Change: Human Solidarity in a Divided World*. New York: UNDP.

———. 2009. *Resource Guide on Gender and Climate Change*. New York: UNDP.

UNISDR (United Nations International Strategy for Disaster Risk Reduction). 2007. *Gender Perspective: Working Together for Disaster Risk Reduction. Good Practices and Lessons Learned*. Geneva: UNISDR.

United Nations. 2008. *The Millennium Development Goals Report 2008*. New York: UN.

Vergara, W. 2009. "Assessing the Potential Consequences of Climate Destabilization in Latin America." Sustainable Development Working Paper 32, World Bank, Latin America and Caribbean Region, Washington, DC.

WCED (World Commission on Environment and Development). 1987. *Our Common Future*. Oxford, UK: WCED.

Weiss, H. 2000. "Beyond the Younger Dryas: Collapse as Adaptation to Abrupt Climate Change in Ancient West Asia and the Eastern Mediterranean." In *Environmental Disaster and the Archaeology of Human Response,* ed. G. Bawden and R. M. Reycraft. Albuquerque: Maxwell Museum of Anthropology.

Weiss, H., and R. S. Bradley. 2001. "What Drives Societal Collapse?" *Science* 291: 609–10.

Weitzman, M. 2007. "A Review of the *Stern Review on the Economics of Climate Change*." *Journal of Economic Literature* 45 (3): 703–24.

———. 2009a. "On Modeling and Interpreting the Economics of Catastrophic Climate Change." *Review of Economics and Statistics* 91 (1): 1–19.

———. 2009b. "Reactions to the Nordhaus Critique." Harvard University. Cambridge, MA.

Wheeler, D., and K. Ummel. 2007. "Another Inconvenient Truth: A Carbon-Intensive South Faces Environmental Disaster, No Matter What the North Does." Working Paper 134, Center for Global Development, Washington, DC.

World Bank. 2001. "Hurricane Mitch: The Gender Effects of Coping and Crises." Notes of the Development Economics Vice Presidency and Poverty Reduction and Economic Management Network 56, Washington, DC.

———. 2008. "Double Jeopardy: Responding to High Food and Fuel Prices." Working Paper 44951, Washington, DC.

———. 2009a. *Global Monitoring Report 2009: A Development Emergency*. Washington, DC: World Bank.

———. 2009b. "World Bank Statement to the Tenth Session of the United Nations Human Rights Council." Geneva.

———. 2009c. *World Development Indicators 2009*. Washington, DC: World Bank.

WRI (World Resources Institute). 2008. "The Climate Analysis Indicators Tool (CAIT)." Washington, DC.

Yohe, G. W. 1999. "The Tolerable Windows Approach: Lessons and Limitations." *Climatic Change* 41 (3–4): 283–95.