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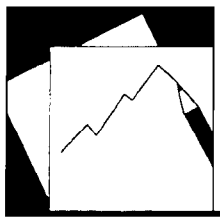

IMF Working Paper

Dealing with Increased Risk of Natural Disasters: Challenges and Options

Paul K. Freeman, Michael Keen, and Muthukumara Mani

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Dealing with Increased Risk of Natural Disasters: Challenges and Options

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Abstract

Natural disaster risk is emerging as an increasingly important constraint on economic development and poverty reduction. This paper first sets out the key stylized facts in the area—that the costs of disaster have been increasing, seem set to continue to increase, and bear especially heavily on the poorest. It then reviews the key economic issues at stake, focusing in particular on the actual and prospective roles of, and interaction between, market instruments and public interventions in dealing with disaster risk. Key sources of market failure include the difficulty of risk spreading and, perhaps even more fundamental, the Samaritan's dilemma: the underinvestment in protective measures associated with the rational expectation that others will provide support if disaster occurs. Innovations addressing each of these are discussed.

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I. Introduction

There are strong reasons to suppose that—as a result of both climate change and the increasing concentration of the world's population in vulnerable areas—natural disasters will become more frequent, more intense, and more costly in the coming years. Indeed, this may already be happening: in the last 10 years, economic losses from natural disasters have averaged about $40 billion a year, which is more than a sevenfold real increase in losses since the 1960s. Low-income and emerging economies, especially in Asia and South America, are particularly at risk; and within these countries, the poor stand to suffer most. Looking forward, the accelerating increase in surface temperatures suggests that natural disasters are likely to loom even larger as a source of macroeconomic disruption and an impediment to sustained growth in the years ahead. One estimate[2] is that global disaster costs will rise fivefold over the next fifty years.

The risk of a natural disaster is thus a significant issue for poverty reduction and development, and likely to become still more significant in the coming years. This paper reviews what is known about these risks and, especially, their implications for economic behavior and policy. It focuses, in particular, on the actual and proper roles of market instruments and public policy in dealing with these risks.

The paper is organized as follows. Section II summarizes the key stylized facts on the disaster risks in the years ahead and the economic vulnerabilities they imply, especially for poor countries. Section III considers the macroeconomic and developmental implications of natural disasters, and Section IV looks at the ways in which countries can prepare themselves to cope with these disasters. Section V discusses the implications for the role of the governments and the international community in addressing some of the existing constraints, and concluding remarks are presented in Section VI.

II. Disaster Risk in the Years Ahead

A. Natural Disasters Are Likely to Become More Frequent, Intense, and Damaging

There is reason to believe that the coming years will see an increase in the frequency and severity of natural disasters, especially extreme weather events. Indeed, a trend increase appears is apparent over the last few decades. Figure 1 shows a continued increase in the number of extreme weather events—such as floods, hurricanes, windstorms, and droughts—since 1950, and an even more marked increase in the direct losses[3] that they have

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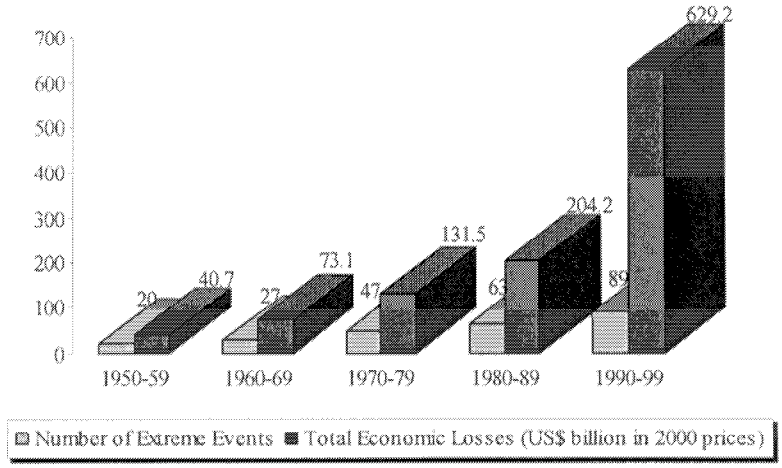
[2] ISDR, 2001.

[3] A distinction is conventionally made between the "direct" and "indirect" costs of a disaster (Anderson, 1991; OECD, 1994): the former are stock losses equivalent to the replacement cost of the physical assets destroyed (not including the loss of human life), the latter are flow losses relating to the consequent loss of income (which for some sectors—such as construction—can be negative). Unless otherwise stated, figures given in this paper

Figure 1. Frequency and Impact of Extreme Weather Events



Source: Munich Re, 2001.

Note: "Extreme weather events" as defined here include those in which thousands are killed, hundreds of thousands made homeless, and/or a country suffers substantial economic loss.

caused.[4] While world GDP per capita has increased by an annual average of 3.4 percent over this period, disaster costs rose by an average of 7.4 percent.

It is widely believed that climatic developments, coupled with the increased concentration of the world's population in vulnerable urban areas, pose an increasing risk from natural disasters. Broadly, the former is likely to increase the frequency and intensity of extreme weather events, and the latter to increase vulnerability to natural disasters.

A significant and immediate implication of global warming is that extreme weather events will happen more often and to be more damaging when they do occur.[5] The ultimate causes of this global warming remain somewhat contentious, but need not concern us here: the important point for present purposes is simply that, for whatever reason, average surface

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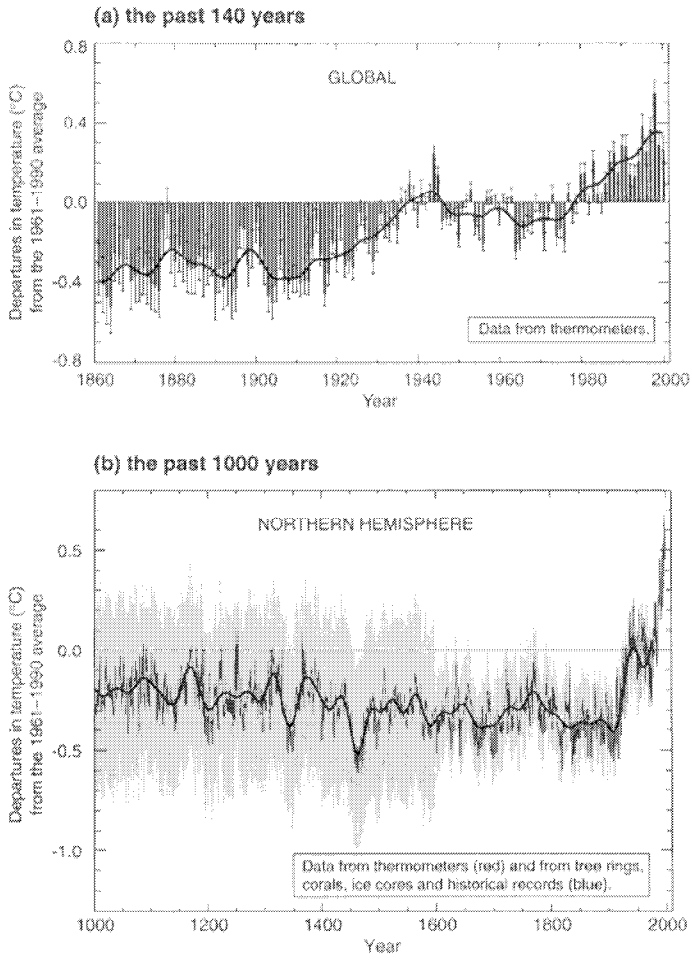
for the costs of disaster refer only to direct costs. Though hard to measure (Benson and Clay, 2000), indirect costs are commonly much larger: one estimate is that the loss of flows from infrastructure may be 2.5 times the cost of the direct losses (Shinozuka and Roth, 1998).

[4] Broadly consistent with the orders of magnitude in Figure 1, the Intergovernmental Panel on Climate Change, 2001 estimates that the global economic losses from catastrophic weather events increased in real terms tenfold in the last half century, from around US$3.9 billion annually in the 1950s to US$40 billion in the 1990s.

[5] Earthquakes and volcanic eruptions remain relatively stable, being apparently unaffected by climate change. It is the incidence of weather-related events that has accelerated.

Figure 2. Global Climate Change



Source: IPCC, 2001.

temperatures have been increasing for a century, and appear to be increasing at an increasing rate (Figure 2). These higher surface temperatures lead to increased absorption of water vapor into the atmosphere, and hence to an increase in the frequency and intensity of extreme and sudden onset weather events, such as floods and windstorms.

The increase in extreme weather events is expected to be particularly marked in Asia and Latin America. Annex 1 sets out the assessment of effects by region of the Intergovernmental

panel on Climate Change (IPCC).[6] While few places in the world will be spared from climatic disruptions, the Southern Hemisphere is likely to be especially strongly affected.[7] While the IPCC does not give precise probabilities for specific increases in extreme events (see Box 1) it attaches a 90 to 99 percent likelihood to, over the next 50 years; floods and droughts becoming more common in Latin America; sea-level rises impacting island states; and increased intensity of tropical cyclones.

Economic damage increases more than proportionately with the intensity of extreme events. At low levels of event intensity (as measured by precipitation rates, say, or wind speed), damage remains small if intensity increases somewhat; at extremely high levels of intensity, there is little more damage that can be done, so that the marginal damage from a increase in intensity is again low. At intermediate levels, however, marginal damage can be high (with small rises in flood levels, for instance, overcoming natural defenses).[8] The economic damage from extreme weather events is thus likely to increase more than proportionately with the number of events.

A second and independent reason to expect natural disasters to become more damaging is the increasing concentration of populations in urban areas, especially in megacities, that are particularly vulnerable to natural disaster. The damage caused by extreme weather events clearly depends not only on the intensity of the event, but also on where it strikes: even a small event striking a heavily populated region can cause significant damage. And the concern here is that many of the "megacities" in which the world's population is increasingly concentrated are particularly vulnerable to natural disasters, both extreme weather events of the kind discussed above and earthquakes or seismic activity.[9] For example, thirteen of the world's nineteen megacities—listed in Annex 2—are in coastal zones subject to increased sea level, flooding and windstorm damage. The proportion of people in developing countries who live in cities has doubled since 1960, with more than 40 percent now living in urban areas; and this is expected to rise to over 55 percent by 2030 (Freeman, 2002). Nearly half of

[6] The IPCC is a network of leading climate researchers assembled by the United Nations.

[7] Through a systematic analysis of the observed changes in temperature, precipitation patterns and intensity, sea level, snow and ice cover, ocean and atmosphere circulation patterns and ecosystems behavior, the report documents the worldwide fluctuation in weather events and makes some predictions for future trends. These include a probable increase in the frequency and the intensity of El Niño-like conditions that result in growing numbers of heavy rains and storms interspersed with short dry spells in some regions, and more prolonged droughts punctuated by heavy rain years in other parts of the world (IPCC, 2001).

[8] See, for instance, Freeman, and Warner, 2001.

[9] This is not simply coincidence: in many cases the same factors that made these attractive settlement areas—natural floodplains, alluvial soil, river or sea access, for example—are associated with high natural risk.

Box 1. Observed and Projected Changes in Extreme Weather and Climate Events

Changes in the Phenomenon	Confidence in Observed Changes (Latter Half of the 20th Century)	Confidence in Projected Changes (during the 21st Century)
More intense precipitation events	Likely, over many Northern Hemisphere mid-to high latitude land areas	Very likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, in a few areas	Likely, over most mid-latitude continental interiors
Increase in tropical cyclone peak wind intensities	Not observed	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities	Insufficient data for assessment	Likely, over some areas
Higher maximum temperatures and more hot days over nearly all land areas	Likely	Very likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely	Very likely
Reduced diurnal temperature range over most land areas	Very likely	Very likely
Increase of heat index over land areas	Likely, over many areas	Very likely, over most areas

Source: IPCC, 2001.

Note: Very likely =90–99 percent chance; likely=66–90 percent chance.

these cities are in geographic locations subject to extreme weather events; and over 70 of the world's 100 largest cities can expect a strong earthquake at least once every fifty years.[10] Even if the frequency and severity of climatic hazards were to remain constant, these trends suggest that the number and magnitude of natural disasters will continue to grow. Reflecting both climate change and patterns of urban concentration, losses from natural disaster losses are expected to increase dramatically over the next 50 years. The most comprehensive quantitative study of these issues—by the Munich Re, which specializes in disaster business—estimates that the global direct cost of natural disasters will top US$300 billion annually by the year 2050 (ISDR 2001), an increase in real terms relative to current levels of around 750 percent. Of these estimated losses, about US$47 billion per annum relate to the water sector, and US$42 billion to agriculture and forestry. GDP will also grow, of course, so that these absolute figures overstate the problem; but unless GDP grows at an annual average of 9 percent or more, disaster costs will absorb an increased fraction of real output. Munich Re estimate that most countries will experience average losses ranging from a few tenths of a percent to a few percent of GDP. Some, especially small island states, could face losses far exceeding 10 percent. It should be stressed that there appears to have been little systematic quantitative analysis of these trends. But it should be noted too that many regard these estimates, and the projections of the IPCC, as relatively conservative.

B. Low-Income Countries and Their Poor Are Especially Vulnerable

Many low-income countries are particularly at risk of natural disaster, and climate change is likely to reinforce this. Between 1990 and 1998, 94 percent of the world's major disasters were in developing countries.[11] Twenty-four of the 49 least-developed countries face a high-level of disaster risk, and 6 of them have been hit by at least 2 major disasters in each of the last 15 years.[12] Figure 3 shows that the frequency of disaster in the 77 PRGF-eligible countries is both high (with an average of nearly three disasters each in 2002) and apparently rising.

Small island developing states (SIDS) are especially at risk: a recent United Nations study has shown that at least 13 of the 25 countries most prone to disasters—particularly storm surges, landslides, extended droughts, and floods—are SIDS. They are particularly prone to extremely damaging natural disasters, Most small island states—and low-lying coastal states like Bangladesh—are prone to a range of disasters including storm surges, landslides,

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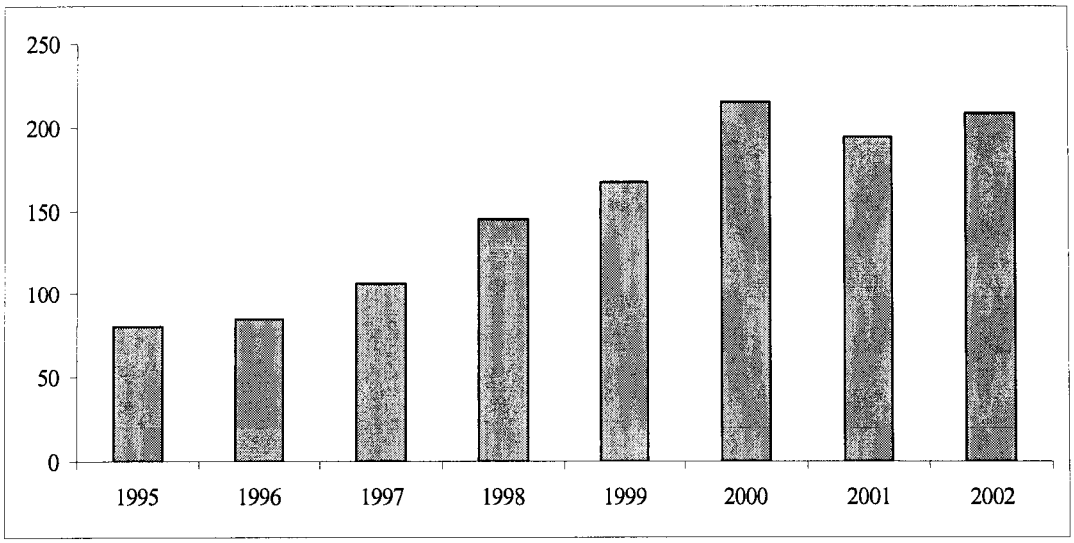
[10] Earthquake risk lies along well-defined seismic zones that incorporate a large number of developing countries. High-risk areas include the West Coast of North, Central, and South America, Turkey, Pakistan, Afghanistan, India, China, and Indonesia. The pattern of hurricanes in the Caribbean and typhoons in South Asia, Southeast Asia, and the South Pacific is well established. Floods occur in 1 percent of the worldwide landmass (Swiss Re, 1997).

[11] (World Bank, World Development Report, 2000).

[12] Least-development countries defined as in World Bank's World Development Indicators (UNDP, 2001).

extended droughts, and extensive floods. Due to climate change, such events, including drought, are expected to occur with increased frequency and intensity. A recent UN study has shown that at least 13 of the 25 most disaster-prone countries are SIDS. Natural disasters are of special concern to SIDS because of their small size—dependence on agriculture and tourism, which are particularly vulnerable to natural and environmental disasters—narrow

Figure 3. Number of Extreme Weather Events in PRGF- Eligible Countries, 1995–2002



Sources: CRED/OFDA Natural Disasters database; and IMF staff calculations.

Note: Extreme weather events are here defined as the ones in which 10 or more people are killed and over 100 affected.

resource base; and the pervasive impact of such events on their economies. There is also an increasing danger of some of them physically disappearing.[13]

While the absolute monetary costs of natural disasters tend to be low in developing countries, their relative cost tends to be high. Although smaller in absolute terms—with the relatively low levels of infrastructure and capital stocks—economic loss relative to GDP is often far higher in developing than in developed countries (especially for SIDS). Between 1985 and 1999, the world's wealthiest countries sustained 57.3 percent of the measured economic losses to disasters, representing 2.5 percent of their combined GDP. Over the same period, the world's poorest countries endured 24.4 percent of the economic loss of disasters representing 13.4 percent of their combined GDP. That direct damages commonly impose

[13] The government of Tuvalu, for instance, has acknowledged that the island is doomed.

greater economic strain on developing than on developed countries can be seen from the examples in Table 1 compare, for instance, the experiences of the United States and Nicaragua in relation to the 1997–98 El Niño events; in absolute terms the damage was greater in the former, but relative to GDP the event was far more costly in the latter.

Table 1. Direct Damages from Some Recent Natural Disasters

Event (year)	Country	Damages (US$ billion)	Loss as a Percent of GDP
Earthquakes (1999)	Turkey	22	5
Floods (1998)	China	30	0.7
Hurricane Mitch	Ecuador	2.9	14.6
Hurricane Mitch	Honduras	3	20
Hurricane Mitch	Nicaragua	1	8.6
Hurricane Mitch	United States	1.96	0.03
Floods (1998)	Poland	3.5	3
Earthquake (1995)	Japan	95–147	2.5
Hurricane Andrew (1992)	United States	26.5	0.5
Cyclone/floods (1991)	Bangladesh	1	5

Sources: IIASA, 1999; and ECLAC, 2000.

Mortality losses from natural disaster, moreover, are far greater in developing countries. More than 97 percent of all deaths from natural disasters between 1990 and 1998 were in developing countries. Reflecting both their lesser preparedness and greater vulnerability, developing countries also tend to suffer more deaths per disaster: on average, 22.5 people die per reported disaster in highly developed nations and 145 die per disaster in nations of medium human development, while each disaster in countries of low human development claims an average of 1,052 people. Even apart from the human suffering this implies, such losses represent a loss of resources not captured in the monetary costs discussed above.

Within developing countries, the poor are especially vulnerable to natural disaster. They are more likely to live in areas known to be vulnerable—to landslides, for instance—as they may be priced out of safer areas. Disasters can severely impact the food production of the rural poor and so cause extreme hardship, especially for those living in or on the verge of destitution.[14] The assets of the poor, although less than those of the rich, are also more likely to be exposed to catastrophe risk. Although families with a stock of productive assets can protect themselves by drawing down savings or buffer stocks, these are unlikely to be sufficient in the event of a catastrophe, in which case real assets (including agricultural land

[14] For example, groups occupying semiarid lands, with marginal economies and a lack of effective preparedness, Blaike, and others, 1994.

and livestock) may be sold (Freeman and others, 2002). The poor may also be especially vulnerable to damage to water supply and transport infrastructures, since rural transport, electrification, and irrigation projects play a major role in poverty reduction. And, at the most general level, there is evidence that risk-sharing mechanisms, formal and informal, protect the poor less than the nonpoor. Certainly, disasters can substantially increase measured poverty. Thus one estimate is that in Ecuador, El Niño in 1998 may have increased poverty in affected areas (on a head count measure) by more than 10 percentage points[15] and in the Philippines, about 50 percent of the increase in head count poverty around the 1998 financial crisis has been attributed to El Niño events.[16]

III. The Macroeconomics of Disaster and Recovery

The macroeconomic and developmental implications of natural disaster can be both large and long lasting. The immediate impact effect of disaster is a destruction of part of the physical assets of an economy, including capital stocks, infrastructure, natural resources and, not least, labor. But being essentially an extreme form of supply shock, this also entails both short-and long-term impacts on the overall macroeconomic performance, including deterioration in output and production potential, and in trade and government budget balances, together with induced shifts in monetary and fiscal policies to contain the effects of increased disaster-induced inflation or to finance additional government expenditure. Worst-case scenarios would involve multiple, coincidental natural disasters, taking place during a time of weakness in financial markets.

While the effects of the shock naturally vary with the nature of the disaster and the structure of the economy affected, the broad contours of experience are reasonably common. The United Nations Economic Commission for Latin America and the Caribbean has quantified the direct losses from, and examined the macroeconomic consequences of 25 major disasters in the region over that period (ECLAC, 1999). These studies find that catastrophes can have serious long-term impacts on some countries while proving to be a only minor economic disruption for others. A key determinant is the socioeconomic condition of the country at the time disaster strikes: direct costs tend to be greater where initial conditions are worse.[17] As can be seen from the experiences reported in Table 2, natural disasters generally are associated with:

- **A worsening of the fiscal position,** as the domestic tax base contracts, and spending needs rise. When disasters are small relative to the national economy, there may be

[15] See Vos, Velasco, and Labadista, 1999.

[16] Datt and Hoogeveen, 1999.

[17] Other case studies UNDP, 2001; Benson, 1997a, 1997b, 1997c; and Albala-Bertrand, 1993, also support earlier findings of ECLAC.

Table 2. Economic and Fiscal Impacts of Extreme Weather Events in Latin America and the Caribbean

Country/Event	Economic Performance	Fiscal Effects	Balance of Payments Effects
Nicaragua, 1972 Earthquake	GDP fell 15 percent and industrial productivity 46 percent	Tax revenue fell 39 percent	Sixfold increase in current account deficit
Honduras, 1974 Hurricane	GDP fell 6 percent and 23 percent in agriculture	Fiscal deficit grew 79 percent as tax revenue fell 15 percent and expenditure increased 65 percent	Threefold increase in current account deficit
Antigua and Barbuda, 1974 Earthquake	GDP fell 12 percent and in oil refining 30 percent	Fiscal deficit increased three times	Balance of payments deficit increased four times
Grenada, 1975 Tropical Storm	GDP fell 20 percent and agricultural production set back by 10 years	Fiscal deficit increased more than 60 percent	External imbalance grew 4 times
Dominican Republic, 1979, Hurricanes	GDP fell 8 percent	Fiscal deficit increased 8 times	External deficit increased 27 percent
El Salvador, 1982	GDP fell 2 percent	Fiscal deficit increased 30 percent	External deficit grew 25 percent
Ecuador, 1982–83 Several disasters	GDP fell 3 percent	Fiscal deficit increased 20 percent	Balance of payments increased 22 percent
Bolivia, 1982–83 Meteorological phenomena	GDP fell 10 percent and in agriculture 55 percent	Fiscal deficit increased 275 percent	External imbalance grew 30 percent
Peru, 1982–83 Meteorological phenomena	GDP fell 5 percent	Fiscal deficit increased 33 percent	Current account deficit increased 30 percent
Mexico, 1985 Earthquake	GDP fell 2.7 percent	Fiscal deficit increased 7 percent	Negligible
Nicaragua, 1988 Volcanic activity	GDP fell 2 percent and in agriculture 17 percent	Fiscal deficit increased 20 percent	Balance of payments deficit increased 10 percent
Nicaragua, 1992 Tsunami	GDP fell 1 percent	Fiscal deficits increased 5–10 percent	Balance of payments increased 24 percent

Source: Otero and Marti, 1995.

scope for increasing revenues by raising tax rates: thus the recent floods in central Europe, for instance, led to decisions to postpone tax cuts or impose temporary increases in both Austria and Germany. When disasters are large relative to the national economy, however, the immediate scope for increasing domestic revenues is likely to be small, at best. In the absence of external grants, governments must then either increase their borrowing or resort to monetization;

- **A weakening of the trade balance**, as the capacity to produce exports falls and reconstruction needs increase import demand and divert tradables produced domestically to the home market. While the reduction in income levels counteracts this to some extent by reducing import demand, experience suggests that this effect rarely dominates;

- **Downward pressure on the exchange rate**, reflecting both the weak trade balance and, potentially, concerns of foreign investors at their loss of potential future earnings and expectation of tax fiscal pressures ahead as a consequence of the worsening of the government's fiscal position. Foreign assistance can mitigate this effect, but is unlikely to offset it; and

- **Inflationary pressures**, reflecting an excess of money holdings in the face of reduced incomes and wealth, potential monetization of the increased deficit, and exchange rate depreciation.

Disasters worsen not only the immediate macroeconomic outlook, but also the balance sheet positions of key sectors. Public sector debt ratios are likely to worsen, for instance, as borrowing rises while both GDP and export capacity fall. A likely fall in domestic savings is likely to lead both private and public sectors to increase their borrowing abroad, perhaps in foreign-denominated forms.

Coping with disaster may lead to a reallocation of resources away from the support of long-term development and poverty relief. As an increasing share of donor assistance is devoted to disaster relief, preserving development expenditures requires expanding the total sums available.

The disruption of basic education and heath services can also have lasting impact. For example, nearly 10 percent of Peru's health facilities suffered damage as a result of El Niño events in 1997–98; and as a result of Hurricane Mitch in 1998, the water supply systems of 23 hospitals in Honduras were damaged or destroyed, and 123 health centers were affected (PAHO, 2000). With employment and hence the development of skills also likely to be disrupted, the quality of the work force may suffer permanent harm.

Prompt assistance can have a powerful effect in reducing the long-term macroeconomic damage caused by natural disasters. To the extent that the assets destroyed by disaster can be replaced, a full recovery is in principle possible. (Some physical losses, however, may be

permanent: for example, severe flooding can lead to irreversible soil erosion). Prompt assistance is important not only in speeding the economy's recovery, but in reducing the total costs of that recovery.[18] The quicker the recovery of output, the less the public sector will need to borrow and/or monetize to meet its fiscal shortfall in the interim. The sooner a supply of clean water is restored, the lower will be the morbidity impact.

IV. Preparing for Natural Disasters

There are three main ways in which countries can prepare themselves for natural disasters: by restructuring their economies away from disaster-prone activities (as market economies will naturally tend to do); by adapting their physical environment; and by purchasing insurance or similar risk-shifting assets. In the climate change context, there is widely believed also to be scope for taking measures—especially reducing CO_2 emissions—to reduce the probability of disaster. Such measures, commonly referred to as ones of "mitigation," are not addressed here. Nor do we address measures for adaptation to long-term climate change, though in practice these need to be integrated with those to deal with disaster.[19]

A. Adaptation

A variety of measures can be taken to reduce the physical destruction caused by natural disasters. These might include: land-use planning to reduce construction on seismic fault lines, coastal regions subject to storm damage, and river shorelines subject to frequent floods; building standards aimed at ensuring some level of robustness against earthquake or hurricane; mitigating environmental degradations, such as soil erosion, that can worsen the impact of disaster; and through engineering interventions, such as creation of dams for flood control, dikes to reroute flood waters, and seawalls to break storm surges. For example, the government of China recently approved a colossal scheme to counter increasing floods in the south (along the Yangtze River) and simultaneous drought in the north and the west. It plans to spend more than US$50 billion to dig three canals, each 375 miles long, that between them will carry 48 billion tons of water annually from Yangtze to the north. In its most recent World Disaster Report, the Red Cross indicates that investments of US$40 billion in disaster preparedness, prevention, and mitigation would have reduced global economic losses in the 1990s by US$280 billion (IFRC, 2001).

Structural measures might be necessary in sectors such as agriculture, water, and construction. In agriculture, this entails promoting farming practices that withstand climate variability—the use of drought-resistant crop varieties, for instance, or more efficient use of water resources—as well as building up farmers' capacity to adapt to long-term change. In

[18] A recent IDB study shows that on average 8.6 percent of direct disaster losses can be expected to be covered by international assistance, with a range from as little as 6 percent to as much as 25 percent (IDB, 2002).

[19] See Heller and Mani, 2002.

the most extreme cases, this might also entail moving labor and capital out of agriculture into more productive sectors with greater comparative advantage. Water supply infrastructure may need to anticipate increased seasonal variation and possibly greater frequency of both storms and dry periods. Proper building codes or construction techniques can substantially reduce the impacts from earthquakes and flooding.

Box 2. Disaster Preparedness in the United States

Spending by U.S. states on disaster preparedness increased steadily throughout the 1990s, which brought the worst and most expensive disasters in the nation's history. The National Emergency Management Association (2000) reports that states spent US$1.9 billion in fiscal 1999 on disaster preparedness, mitigation (prevention) response, and recovery. Of that, US$1.2 billion was spent on planning and prevention to reduce losses from disasters before they occurred—a marked change from previous years, when most state emergency management funds were spent on responding to and recovering from events.

The average per capita spending on comprehensive emergency management was US$8.50 in fiscal year 1999, up from US$4.64 in 1992. Only 24 percent of all emergencies declared by governors in fiscal year 1999 were declared federal disasters, suggesting that the large majority of disasters and emergencies are handled by state and local governments. State funding mechanisms for disasters vary. At least 28 state legislatures appropriate funds after each specific disaster. Nineteen states have a set-aside or rainy-day fund maintained at a particular level to cover disaster costs.

Source: NEMA Annual Report, 2000.

These structural developments will have significant fiscal consequences, as a result of both explicit public policy commitments and the implicit responsibilities of the state in the context of shocks (see Heller, 2002). Government thus has an important role to play in adaptation. This is so not only in terms of safeguarding its own property, but also in respect of adaptation measures with public good features, such as coastal defenses and alarm systems for developing weather risks, and the implementation of appropriate regulatory controls (on land use, for instance). Infrastructure planning too needs to be sensitive to risks of extreme weather events.[20]

There is a marked difference in the extent of adaptation in developed and developing countries. In the United States, in particular, the disaster-prone 1990s—which saw a federal emergency declared in every state—witnessed a significant increase in expenditure on preparedness and mitigation measures (see Box 2). In many developing countries, in contrast, the financial resources, technical knowledge and political will to mitigate physical

[20] Freeman and Warner, 2001, argue that, although this has been urged for years, the point is often ignored.

vulnerability are often absent.[21] In large measure, this seems to be because little incentive exists to mitigate damages with ex ante measures if the damages are largely paid for by someone else after the disaster—a point to which we return. In many other cases, moreover—especially for low-lying island countries, many of which are especially vulnerable—effective physical adaptation is inordinately expensive. In such cases a radical rethinking of the potential sources of growth and location of infrastructure may be required (Heller and Mani, 2002).

B. Disaster Insurance

No matter what measures are taken to mitigate losses, there will still be damages. The issue is how to cope efficiently with the inevitable economic losses. In the developed world, historical risk transfer tools like insurance play a significant role in coping with disasters. A greater share of economic assets is held by the private sector and adequately insured against disaster.[22] Similarly, a higher proportion of damage sustained by individual households is covered by insurance. In many developing countries the insurance sector is only at nascent stage of development, and to a large extent does not have access to the latest financial structures and instruments.

There are important failures in the market for disaster insurance. Adverse selection may be less of an intrinsic problem than in other insurance markets, in that the likelihood of disaster occurring is in principle knowable to all parties with some accuracy, as is the value of the property at stake. In the San Francisco area, for instance, insurers are able to differentiate risk by zip code. While accuracy of prediction is lower in many developing countries, this reflects the thinness of existing markets rather than inherent technical constraints. This is not to say that assessing risk is always easy; and indeed climate change is in itself adding a further level of uncertainty in assessing the probability of extreme weather events.[23] Further difficulties may arise in providing insurance in developing countries from ill-defined property rights, with individuals and even firms lacking formal titles to their holdings. Nevertheless, two other problems appear more fundamental: those of risk-spreading, and the Samaritan's dilemma.

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[21] While 45 percent of the weather-related loss events occurring between 1985 and 1999 took place in wealthy countries, these countries represent 57 percent of the economic losses, and 92 percent of the insured losses. In contrast, 65 percent of the deaths took place in the poorest countries.

[22] Moreover, the disaster-vulnerable agricultural sector is much less important in developed economies, see Benson and Clay, 2000.

[23] One of the problems facing insurers is the difficulty of disentangling the causes (and hence probabilities) of weather-related events. This is especially true for those potentially related to human-induced climate change versus natural climate cycles, and those having to do with human activity that could accelerate or dampen the process (demographic trends, increasing property values, disaster mitigation efforts, and so on). In many cases, upward trends in losses have clearly been a product of both human and climatological factors, but in-depth understanding is hampered by technical complexity and insufficient information (Mills and others, 2001).

- **The sheer scale of potential losses from natural disaster can make risk-spreading difficult**. Since the costs of many disasters are large relative to the national economies affected, effective insurance requires some degree of international risk sharing. Some disasters—a large meteor strike, for instance—are so large as to be uninsurable relative to the global economy. Even for less dramatic events, however, insurance markets evidently have difficulty spreading risk. In the U.S., for instance, insurance companies shaken by the US$16 billion of claims following Hurricane Andrew and aware of the prediction of the National Oceanic and Atmospheric administration that a US$50 billion event is "only a matter of time"—appealed to Congress for backstop financial protection. While risk-spreading should in principle be less problematic for developing countries—since the losses they face are small relative to global resources[24]—this is not the case in practice. Insurance markets appear to be sufficiently segmented and shallow that the spreading of many of the risks faced by developing countries remains problematic. In the 1990s, for instance, Caribbean countries experienced insurance rate increases between 200–300 percent on account of shortages of insurance cover, due to indemnity payments made for large hurricane and earthquake losses worldwide (see Pollner, 2001).

- **Incentives to purchase insurance are blunted by the perception—rational, in many cases—that losses will be covered ex post by the national government or by donors**. Once disaster strikes, government will face strong pressures, and have a strong inclination, to meet uninsured losses. Knowing this, however, private firms and households have less incentive to purchase insurance or to undertake adaptive measures. This poses a "Samaritan's dilemma."[25] This is the problem that to the extent that households and businesses rationally expect national governments to come to their rescue in the event that disaster strikes, and that governments in developing countries believe they can rely on disaster relief from foreign donors, those at risk will underinvest in measures that could be taken before disaster strikes—whether physical or financial—to reduce the costs that arise when it does. And it is hard, for instance, for rich countries to credibly commit to scale down their ex post assistance unless significant ex ante protective measures are taken by poorer countries: the humanitarian urge to help, once disaster happens, is just too strong.

A range of new financial instruments tailored to extreme natural events are providing further risk management devices, but have as yet had relatively little impact. The last few years have seen the emergence of weather derivatives,[26] for instance, offering payoffs with the

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[24] There are of course exceptions: at US$30 billion, the cost of the Yangzte floods, for instance, approached that of the US$50 billion storm event for the U.S. that insurers so fear.

[25] The term originates with Buchanan, 1975, On its policy implications, see Bruce and Waldman, 1991, and Coate, 1995.

[26] For a discussion of these, and their pricing (See Zeng, 2000).

essentially the same structure as stock derivatives but written on underlying weather outcomes—temperature, wind speed, rain, or snowfall—rather than a stock price. These have been largely driven by the needs of utilities and other companies with weather exposure. A ski resort, for instance, might buy a put option written on the depth of snowfall, receiving a payment from the seller for each centimeter in excess of the strike value. The market in weather derivatives has grown rapidly in recent years, with a notional market value in the U.S. of around US$4.5 billion, and 4,000 contracts traded in 2001.

Potentially, the most important development has been the emergence of the catastrophe ("cat") bond. This instrument, now starting to be used in the United States, has the feature that some or all of the principal and interest on the bond is waived in the event that the specified catastrophe occurs.[27] By providing a way to securitize catastrophe risk, this enables risk to be spread beyond the insurance and reinsurance markets to the wider capital market. There are other possibilities one can imagine. For instance, although generally advocated as a means of easing the adjustment to more orthodox macroeconomic shocks, the GDP-indexed bond[28]—on which interest payments vary as GDP growth is above or below some reference value—could also provide some financial relief in times of natural disaster. There seems clear scope for further and deeper financial innovation to ease problems in this area: some aspects of climate change, for example, imply patterns of gain and loss that seem to offer opportunities for mutually advantageous swap arrangements.[29] The higher transactions costs—often because of the complexities of the securities market—makes these non-insurance hedges less attractive. By some estimates, they are twice as expensive (Swiss Re, 1999). For this reason, their application may be limited to very large transactions that may exceed the capacity of the insurance market to provide protection. These instruments remain, therefore, in their infancy (See Box 3 for a description of these and other new capital market instruments).[30]

While there is scope for governments to ease market failures in the provision of disaster insurance, they are generally not positioned to act as insurer of last resort. To the extent that adverse selection problems arise from insurers' difficulty in observing adaptation measures, for example, well-enforced building regulations and zoning rules may provide a cost-effective form of monitoring. Perhaps more important, governments can address their

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[27] These are bonds issued by an insurance or reinsurance company, which help in transferring their underwriting risk. Investors in Catastrophe Bonds will want to obtain a large enough return on their investment, in the form of higher than normal interest rates when no disaster occurs, to justify the risks of losing their principal and/or receiving a lower (or no) interest rate after a disaster.

[28] See Borzenstein and Mauro, 2002.

[29] For instance, El Niño events may simultaneously increase flood risk in California and reduce hurricane activity in the Atlantic.

[30] The reasons for this are explored by Froot, 2001.

Box 3. New Financial Instruments for Managing Weather and Disaster Risks

The new capital market instruments on the market fall in six broad categories:

- **Catastrophe Bonds**. These pay high yields, but are subject to default if a defined catastrophe occurs during the life of the bond. Funds obtained from the sale of the bonds are normally invested in risk free instruments, and the interest earned reduces the net cost of the bond to the issuer.
- **Contingent Surplus Notes**. These are essentially "put" rights that allow the owner of the note to issue debt to prespecified buyers in the event of a catastrophic event. The owner of the note pays a fee to the potential debt buyers for their commitment to buy the debt.
- **Exchange Traded Catastrophe Options**. The property claims service (PCS) options that trade on the Chicago Board of Trade provide for the purchaser of the option to demand payment under an option contract if the claims index surpasses a prespecified level. The indexes used cover different areas of the United States and reflect insurance industry aggregate reported claims.
- **Catastrophe Equity Puts**. Equity puts permit the insurer to sell equity shares on demand after a major disaster, in return for an up-front fee.
- **Catastrophe Swaps**. These derivatives use capital market players as counter parties. An insurance portfolio with potential payment liability is swapped for a security and its associated cash flow payment obligations. An insurer would take on the obligation to pay an investor periodic payments on a specified portfolio of securities that the investor was originally liable to pay, while the investor assumes the liability of the insurer to make payments in the event of a catastrophe.
- **Weather Derivatives**. These provide payouts in the event of more than some specified number of days occurring with temperatures or rainfall above or below a specified trigger point.

Source: Pollner, 2001.

Samaritan's dilemma problem by making the purchase of insurance compulsory (which may in some cases also serve to thicken markets enough for insurers to cover their fixed costs), or perhaps providing some form of premium subsidy. In some cases—in France and Japan, for example—the government has responded to the unavailability of catastrophe insurance by providing it directly. In others, governments have established public-private collaborative schemes to insure catastrophic cover through risk pooling, coupled with group reinsurance arrangements and last resort credit back-up (CII, 2000). While such measures can be an efficiency-enhancing response to market failure, they run the danger of perpetuating inadequate adaptation. It is widely believed, for instance, that government support for inexpensive insurance (as well as relief when disaster struck) encouraged inefficient migration in the U.S. towards disaster-prone coastal areas on the eastern seaboard.

While disaster insurance is fairly extensive in developed countries, it remains very limited in developing countries. In the U.S., for example, more than 50 percent of the risk of loss from catastrophes is insured. Coverage appears to be rather less in other developed countries: in Germany, Austria, and the Czech Republic, for instance, only about 10–20 percent of the

losses from the floods in 2002 were insured.[31] In countries with per capita income less than about US$10,000, insurance cover is less than 10 percent; and in those with per capita income under US$760, it is about 1 percent. Asia, which accounted for half of all the damage caused by natural catastrophes and two-thirds of all the casualties from catastrophic events in 1997, owned only 8 percent of the insurance coverage for catastrophes purchased in the world market, whereas the United Kingdom, United States, and Japan together accounted for 55 percent of the total while representing less than 2 percent of the total market (Freeman, 2000).[32] In many developing countries, disaster insurance seems to be confined to relatively wealthy individuals and to large enterprises having particular exposure to weather conditions, such as utilities and hotels. Even where they have existed, insurance schemes—usually offered by the public sector—have often failed due to high administrative costs, inefficient loss calculation, and inadequate premium charges (Hazell, 1992). Also in many countries, governments have crowded out such market development by operating highly-subsidized public crop insurance programs, stifling the development of innovative insurance products (Vatsa and Krimgold, 1999). One would, of course, expect a far lower take-up of insurance in developing countries, reflecting lower income levels and in some cases less clear property rights. Whatever the reason, however, their exposure is clearly considerable—and perhaps, given the potential capacity of global insurance and capital markets, unnecessarily so.

Governments of developing countries rarely take out disaster insurance, even for their own property. When risks are small relative to the aggregate economy, it may indeed be optimal for governments to self-insure, relying on their tax and borrowing powers to meet emergencies if they arise. [33] In many cases, however, the potential losses are not small in this sense. They are small, however, relative to world capital markets, so that one might expect the governments of small developing countries to seek to insure themselves in global markets. While few data appear to be available, it seems clear that most do not do so to any significant extent.[34] This no doubt reflects, and sustains, the segmentation of insurance markets referred to above. It may also be a matter of political economy, with a reluctance to

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[31] *The Economist*, August 22, 2002, Germany delayed personal income tax cuts and temporarily increased the rate of corporation tax from 25 to 26.5 percent.

[32] There is, however, a danger, even in developed countries, that increased losses will lead to pressure on insurance reserves and prices, and to insolvencies. For example, in its annual report on reinsurance released on September 9, 2002, Moody's Investors Service says the outlook for the industry is negative in the near term, citing unprecedented catastrophe losses, poor investment returns, and the consequences of the previous low level of premiums. Large and small insurers alike have been impacted by weather extremes and will be more so in the future if the frequency or intensity of weather-related events increases. Some have already reacted by increasing their premiums, excluding more risks and tightening terms and conditions on contracts (Mills and others, 2001).

[33] Arrow and Lind, 1970.

[34] A somewhat similar puzzle is posed by the apparent underuse of hedging devices by countries exposed to commodity price risk: for discussion of this in relation to oil exports, see Daniels, 2001.

forego other and more visible kinds of spending now in order to ease the future position of perhaps different politicians. It seems too to be a sign that the Samaritan's dilemma looms large.

V. Policy Implications

A. The Need for New Approaches

The trends described in Section II make it clear that natural disasters are likely to figure increasingly prominently on the development agenda. Indeed, there are already signs that increased disaster spending is putting significant pressure on donor spending. In the past decade, the amount of ODA has dropped in real terms by 11 percent from US$61.6 billion to US$54 billion. Of that amount, an increasing portion (from about 3 percent to 8 percent) has been allocated to post disaster funding. In 1999, emergency relief from DAC donors increased by 56 percent in real terms, to US$4.4 billion in 1999 (IFRC 2001). Recognizing these pressures, a recent World Bank review of its policy in this area set out to "lay the groundwork for a new paradigm of natural disaster management," emphasizing a proactive effort to reduce disaster losses and shift financing from reactive borrowing to a more efficient use of cost sharing and risk transfer tools (World Bank, 1999). Through its disaster management facility, the Bank has advocated market mechanisms as a viable alternative to relying on post disaster reconstruction (Pollner, 2000; Kreimer, 1999; World Bank, 2001).The Inter-American Development Bank—which has increased its funding for post disaster reconstruction by a factor of 10 over the previous 15 years (IDB 2000)—is working to develop regional catastrophe insurance markets for Central America as a component of the Puebla to Panama initiative sponsored by Mexico. To the extent that less immediate support is forthcoming from these sources, the Fund may feel the demand for emergency assistance more keenly.

B. What Can be Done?

Both ex ante and ex post responses are required to address the likely developments outlined above—with an important moral hazard problem linking the two. Prudence and efficiency both require that the countries at risk themselves take measures to prepare for the natural disasters likely, at some point, to befall them. Once the event has occurred, calls for the support of the international donor community can be expected. These circumstances create, however, a "Samaritan's dilemma" while the donor community is likely to wish to provide ex post support, and come under pressure to do, knowledge of this mitigates the incentive that countries have to expend resources to prepare for the disaster.

Natural Disaster as a Contingent Liability

In considering the proper response to this, it is useful to think of natural disaster as creating a contingent liability for the national government: should disaster occur, costs will be incurred. And the catastrophic nature of the event—a low-probability of an extremely high cost—can make this a particularly difficult kind of contingent liability to deal with.

A significant part of this contingent liability can arise from implicit guarantees given to—or at least perceived by—the private sector. As seen in Section IV, insurance—even for routine losses, let alone catastrophic events—is not widely demanded or available in many developing countries. In most countries, the government assumes substantial risk for the reconstruction of private housing after a disaster. More generally, the protection of those affected by disaster is widely seen as a basic duty of government. This makes the assumption of risk by the government after disaster strikes politically inevitable, the difficulty being that this sets a precedent that can create substantial future contingent liability. For example, in both Colombia and El Salvador, governments have "implicitly" increased the obligation to provide housing after a disaster (IDB, 2002). Given a commitment by the government, whether explicit or not, to underwrite any disaster loss, individuals and firms have little interest in investing in protective measures.

The first thing to do with a contingent liability is to identify and acknowledge it. This requires assessing the probabilities and associated costs of the various natural disasters that might befall a country. Clearly there is a considerable degree of uncertainty as to, for example, the maximum loss that might be suffered. On the other hand, there is considerable historical information to build on in gauging the likelihood of disaster. Combining this with evidence on current trends of the kind reported in Chapter I, at least a rough estimate—or range of estimates—should be feasible. Even this in itself is likely to focus attention on possible policy responses.

A recent study undertaken jointly by the World Bank, Swiss Re, and the International Institute for Applied Systems Analysis (IIASA), illustrates how this can be done, integrating natural catastrophe loss calculations into the World Bank's macroeconomic planning model for countries (also called the Revised Minimum Standard Model). Applying this model for Honduras, for example, the study estimates an annual contingent exposure of US$82 million in lost capital stock due to natural catastrophe exposure. Further, the study shows that based on its assumptions, Honduras needs an average of US$170 million annually in additional external funding requirements to meet expected direct and indirect losses, or nearly twice the annual expected direct loss.[35] If this foreign funding is not available, the study predicts that another natural catastrophe could significantly damage growth prospects for Honduras over the next eight years; it would, of course, take even longer for income levels to return to their initial path. Similar estimates for Nicaragua and Argentina reveal an additional annual contingent exposure of US$20 million and US$650–950 million respectively in lost capital stock due to natural catastrophe risk. Incorporating these annual contingent exposures into the planning process could substantially alter macroeconomic projections for both the countries.

[35] To finance additional post-catastrophe consumption and full restoration of productive capacity after a 1-in-100-year storm in 2000, Honduras would need US$ 2 billion from foreign sources (IDB, 2002).

Though desirable in principle, it is probably not feasible in practice, especially in the low-income countries most at risk, to incorporate the contingent liability of natural disaster explicitly into the government's accounts. As with other contingent liabilities that governments face—loan guarantees, price support schemes, and so on—the expected loss from natural disasters could, in principle, be calculated and added to the liability side of the government's balance sheet.[36] But this is rarely done even in the most developed economies, and even for relatively straightforward liabilities (which could be valued, for instance, by standard option pricing formulae), presumably because it is felt that such methods are less transparent than simpler, but essentially arbitrary methods. For the kind of catastrophic risk associated with natural disasters, moreover, it is not clear that valuing the risk at its expected cost properly captures the extent of exposure: the potential loss is so large that the government cannot plausibly be supposed to be risk-neutral in face of the uncertainties posed.[37] A simple statement of the maximum possible loss as a memorandum item—the approach sometimes adopted for other contingent liabilities—together with some broad statement of the likelihood of occurrence (identifying, for instance, if this is a one-in-ten year event, or a one-in-twenty), could clearly be informative in assessing the sustainability of a government's fiscal position.

Provisioning and the Fiscal Stance

Some provisioning against the risk of disaster may be appropriate. While governments typically set aside a contingency reserve to deal with unanticipated spending needs, it is not clear that the possibility of natural disaster features systematically in calculating the sums set aside. A number of countries have, however, been exploring the use of explicit reserve funds as a means to provide post disaster funding. In Mexico, for example, FONDEN is an annual budgetary allocation for natural disaster expenditures. While it is evidently impossible to set aside enough to meet the costs of all conceivable disasters, the importance of meeting the immediate costs of disaster makes it prudent to adopt a fiscal stance that provides some degree of self-insurance. This may also provide some incentive to undertake mitigation activities, which will in turn provide some reassurance to potential insurers and donors.

The degree to which disaster risk makes it appropriate to adopt a tighter fiscal stance than would otherwise be the case requires further study. In general, one would expect the appropriate set aside to be higher (relative to the expected loss): the larger the potential loss relative to national income; the more likely disaster is to occur; the more expensive is insurance; and the more risk-averse and prudent is the government. Annex 3 examines these

[36] The IMF's fiscal transparency code, for instance, advocates reporting on government financial assets and disclosure on contingent liabilities irrespective of the accounting standards and policies adopted.

[37] One would imagine, for instance, that many countries would rather have the risk of disaster eliminated than receive a lump sum payment equal to its expected cost.

issues in detail.[38] For the special case of constant absolute risk aversion, a simple rule of thumb emerges: in each period it is optimal to set aside an amount equal to half the expected value of the disaster cost net of the amount previously set aside.

Encouraging Mitigation

Mitigation measures can play an important role, but cannot eliminate the bulk of the risk. An important role can be played by such measures as land-use planning, strictly enforced building codes, expansion of disaster-proof agricultural practices and so on. At a deeper level, action can be taken to reduce CO_2 emissions. Much of the risk stems, however, from the concentration of population in disaster-prone areas, which is hard to reverse.

Governments, especially in developing countries, may take measures to mitigate failures of local insurance markets. This might involve, for instance, allowing tax deductibility for disaster insurance premiums, though the effectiveness at individual level may be blunted by the narrow reach of the income tax. Subsidizing premiums would have a more extensive reach, though it may be administratively more convenient to offer such support at the level of the insurer. This in turn leads to a wider range of possible measures, such as the issuance of guarantees to insurers and reinsurers; guarantees that might themselves be hedged on world reinsurance and capital markets. There may also be scope for simply mandating particular levels of insurance. Not least, governments might do more to insure their own property.

Market and policy failures leave many countries underprepared for natural disaster. There are good reasons to suppose that many countries do less to prepare for disasters than they should. Emergency assistance loans commonly focus on rehabilitation following the last disaster, with little done to protect against the next one. Some may simply not appreciate, or have the capacity to analyze, the risks to which they are exposed. Even if aware of the issue, cash-strapped governments faced with other pressing needs may be reluctant to divert resources towards mitigation measures and the purchase of insurance, especially if the event is of sufficiently low probability that the political consequences of underpreparation are likely to be borne by a subsequent government. And this inclination will be reinforced—and hence natural disasters more costly than they need be—to the extent that donors are believed to stand ready to bear part of the cost in the event that disaster occurs—the Samaritan's dilemma noted above.

Dealing with the Samaritan's Dilemma

One general response to the class of problems described by the Samaritan's dilemma is to require or encourage those at risk to take ex ante measures that will reduce the harm they suffer if the event at issues arises. In this way, the potential additional burden on the

[38] Somewhat surprisingly, calculations for the CARA case suggest that provisioning, relative to the expected loss, is lower the more likely the event is to occur.

Samaritan is reduced and, at the same time, those at risk are better protected. In the context of natural disasters, such encouragement might be given by donors committing to provide emergency assistance on a concessional basis to countries deemed to have undertaken appropriate measures to mitigate their exposure to disaster risk.[39] These measures might be physical (sea wall protection, for instance), regulatory (a clear statement, for example, that the government will not replace housing built in clearly identified areas of risk), and/or financial (the purchase of insurance). Precisely which measures are deemed appropriate, of course, would naturally be expected to vary across countries—with the extent and nature of their vulnerabilities, and perhaps too with their income levels.

Conditioning ex post assistance on ex ante measures in this way would not eliminate the Samaritan's dilemma, as the strength of the humanitarian imperative once disaster strikes make it extremely hard for donors to credibly limit the assistance that they then provide. But measures of this kind may have some role in addressing a basic inefficiency in dealing with disaster risk, and so free resources for other development needs.

VI. Concluding Remarks

It is increasingly evident that the scale and prospective increase in natural disaster risk, and the particular vulnerability of poor countries, calls for more than the simple provision of humanitarian assistance once disaster strikes. Potential efficiency gains could be realized—to the benefit of both those directly affected and those in a position to help—if more effective protective measures, both physical and financial, were put in place. For this, three main obstacles need to be overcome:

- Insurance markets have difficulty dealing with risks that, though large even relative to developed economies, are small relative to the global economy;

- Developing economies may not have the resources to take protective measures and, in many cases, face few insurance opportunities; and

- The prospect of support being provided by others dulls the incentive of those at risk to protect themselves.

There are signs that market instruments are emerging to address the first of these. Dealing with the second and third, however, may require a sharper focus on disaster risk in the

[39] A facility of this kind would have similarities to the IMF's Contingent Credit Line: in each case the intention is, at least in large part, to induce desirable ex ante measures and to verify for other parties that such measures are indeed in place. There would not, however, be any signaling problem of the kind some have seen in the CCL (with application for the facility perhaps signaling some additional information private to the authorities), since the probability of disaster is essentially public information.

formation of policies both at the national level and within the international community, and perhaps a more innovative structuring of the support provided by the latter.

APPENDIXES

I. IPCC Assessment of Regional Impact of Climate Change

Region	Expected Impacts of Climate Change[a]
Africa	* Adaptive capacity[b] of human systems in Africa is low due to lack of economic resources and technology, and vulnerability[c] high as a result of heavy reliance on rain-fed agriculture, frequent droughts and floods, and poverty. * Grain yields are projected to decrease for many scenarios, diminishing food security, particularly in small food-importing countries (*medium to high confidence*). * Major rivers of Africa are highly sensitive to climate variation, average runoff, and water availability would decrease in Mediterranean and southern countries of Africa (*medium confidence*). * Extension of ranges of infectious disease vectors would adversely affect human health in Africa (*medium confidence*). * Desertification would be exacerbated by reductions in average annual rainfall, runoff, and soil moisture, especially in Southern, North, and West Africa (*medium confidence*). * Increases in droughts, floods, and other extreme events would add to stresses on water resources, food security, human health, and infrastructures, and would constrain development in Africa (*high confidence*). * Significant extinctions of plant and animal species are projected and would impact rural livelihoods, tourism, and genetic resources (*medium confidence*). * Coastal settlements in, for example, the Gulf of Guinea, Senegal, Gambia, Egypt, and along the East-Southern African coast would be adversely impacted by sea-level rise through inundation and coastal erosion (*high confidence*).
Asia	* Adaptive capacity of human systems is low and vulnerability is high in the developing countries of Asia; the developed countries of Asia are more able to adapt and less vulnerable. * Extreme events have increased in temperate and tropical Asia, including floods, droughts, forest fires, and tropical cyclones (*high confidence*). * Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea level-rise, floods and droughts, and tropical cyclones would diminish food security in many countries of arid, tropical, and temperate Asia; agriculture would expand and increase in productivity in northern areas (*medium confidence*). * Runoff and water availability may decrease in arid and semi-arid Asia, but increase in northern Asia (*medium confidence*). * Human health would be threatened by possible increased exposure to vector-borne infectious diseases and heat stress in parts of Asia (*medium confidence*). * Sea-level rise and an increase in the intensity of tropical cyclones would displace tens of millions of people in low-lying coastal areas of temperate and tropical Asia; increased intensity of rainfall would increase flood risks in temperate and tropical Asia (*high confidence*). * Climate change would increase energy demand, decrease tourism attraction, and influence transportation in some regions of Asia (*medium confidence*). * Climate change would exacerbate threats to biodiversity due to land-use and land-cover change and population pressure in Asia (*medium confidence*). Sea-level rise would put ecological security at risk, including mangroves and coral reefs (*high confidence*). * Poleward movement of the southern boundary of the permafrost zones of Asia would result in a change of thermokarst (a land-surface configuration that results from the melting of ground ice) and thermal erosion with negative impacts on social infrastructure and industries (*medium confidence*).

IPCC Assessment of Regional Impact of Climate Change (continued)

Region	Expected Impacts of Climate Change[a]
Europe	* Adaptive capacity is generally high in Europe for human systems; southern Europe and the European Arctic are more vulnerable than other parts of Europe. * Summer runoff, water availability, and soil moisture are likely to decrease in southern Europe and would widen the difference between the north and drought-prone south; increases are likely in winter in the north and south (*high confidence*). * Half of alpine glaciers and large permafrost areas could disappear by the end of the century (*medium confidence*). * River flood hazard will increase across much of Europe (*medium to high confidence*); in coastal areas, the risk of flooding, erosion, and wetland loss will increase substantially with implications for human settlement, industry, tourism, agriculture, and coastal natural habitats. * There will be some broadly positive effects on agriculture in northern Europe (*medium confidence*); productivity will decrease in southern and eastern Europe (*medium confidence*). * Upward and northward shift of biotic zones will take place. Loss of important habitats (wetlands, tundra, isolated habitats) would threaten some species (*high confidence*). * Higher temperatures and heat waves may change traditional summer tourist destinations and less reliable snow conditions may impact adversely on winter tourism (*medium confidence*).
Latin America	* Adaptive capacity of human systems in Latin America is low, particularly with respect to extreme climate events, and vulnerability is high. * Loss and retreat of glaciers would adversely impact runoff and water supply in areas where glacier melt is an important water source (*high confidence*). * Floods and droughts would become more frequent (*high confidence*) with floods increasing sediment loads and degrading water quality in some areas. * Increases in intensity of tropical cyclones would alter the risks to life, property, and ecosystems from heavy rain, flooding, storm surges, and wind damages. * Yields of important crops are projected to decrease in many locations in Latin America, even when the effects of CO_2 are taken into account; subsistence farming in some regions of Latin America could be threatened (*high confidence*). * The geographical distribution of vector-borne infectious diseases would expand poleward and to higher elevations, and exposure to diseases such as malaria, dengue fever, and cholera will increase (*medium confidence*). * Coastal human settlements, productive activities infrastructure, and mangrove ecosystems would be negatively affected by sea-level rise (*medium confidence*). * The rate of biodiversity loss would increase (high confidence).

IPCC Assessment of Regional Impact of Climate Change (continued)

North America	* Adaptive capacity of human systems is generally high and vulnerability low in North America, but some communities (e.g., indigenous peoples and those dependent on climate-sensitive resources) are more vulnerable; social, economic, and demographic trends are changing vulnerabilities in subregions. * Some crops would benefit from modest warming accompanied by increasing CO_2, but effects would vary among crops and regions (*high confidence*), including declines due to drought in some areas of Canada's Prairies and the U.S. Great Plains, potential increased food production in areas of Canada north of current production areas, and increased warm-temperate mixed forest production (*medium confidence*). However, benefits for crops would decline at an increasing rate and possibly become a net loss with further warming (*medium confidence*). * Snowmelt-dominated watersheds in western North America will experience earlier spring peak flows (*high confidence*), reductions in summer flows (*medium confidence*), and reduced lake levels and outflows for the Great Lakes-St. Lawrence under most scenarios (*medium confidence*); adaptive responses would offset some, but not all, of the impacts on water users and on aquatic ecosystems (*medium confidence*). * Unique natural ecosystems such as prairie wetlands, alpine tundra, and cold water ecosystems will be at risk and effective adaptation is unlikely (*medium confidence*). * Sea-level rise would result in enhanced coastal erosion, coastal flooding, loss of coastal wetlands, and increased risk from storm surges, particularly in Florida and much of the US Atlantic coast (*high confidence*). * Weather-related insured losses and public sector disaster relief payments in North America have been increasing; insurance sector planning has not yet systematically included climate change information, so there is potential for surprise (*high confidence*). * Vector-borne diseases—including malaria, dengue fever, and Lyme disease—may expand their ranges in North America; exacerbated air quality and heat stress morbidity and mortality would occur (*medium confidence*); socioeconomic factors and public health measures would play a large role in determining the incidence and extent of health effects.
Polar	* Natural systems in polar regions are highly vulnerable to climate change and current ecosystems have low adaptive capacity; technologically developed communities are likely to adapt readily to climate change, but some indigenous communities, in which traditional lifestyles are followed, have little capacity and few options for adaptation. * Climate change in polar regions is expected to be among the largest and most rapid of any region on the Earth, and will cause major physical, ecological, sociological, and economic impacts, especially in the Arctic, Antarctic Peninsula, and Southern Ocean (*high confidence*). * Changes in climate that have already taken place are manifested in the decrease in extent and thickness of Arctic sea ice, permafrost thawing, coastal erosion, changes in ice sheets and ice shelves, and altered distribution and abundance of species in polar regions (*high confidence*). * Some polar ecosystems may adapt through eventual replacement by migration of species and changing species composition, and possibly by eventual increases in overall productivity; ice edge systems that provide habitat for some species would be threatened (*medium confidence*). * Polar regions contain important drivers of climate change. Once triggered, they may continue for centuries, long after greenhouse gas concentrations are stabilized, and cause irreversible impacts on ice sheets, global ocean circulation, and sea-level rise (*medium confidence*).

IPCC Assessment of Regional Impact of Climate Change (concluded)

Region	Expected Impacts of Climate Change[a]
Small Island States	* Adaptive capacity of human systems is generally low in small island states, and vulnerability high; small island states are likely to be among the countries most seriously impacted by climate change. * The projected sea-level rise of 5 mm. per year for the next 100 years would cause enhanced coastal erosion, loss of land and property, dislocation of people, increased risk from storm surges, reduced resilience of coastal ecosystems, saltwater intrusion into freshwater resources, and high resource costs to respond to and adapt to these changes (*high confidence*). * Islands with very limited water supplies are highly vulnerable to the impacts of climate change on the water balance (*high confidence*). * Coral reefs would be negatively affected by bleaching and by reduced calcification rates due to higher carbon dioxide levels (*medium confidence*); mangrove, sea grass beds, other coastal ecosystems and the associated biodiversity would be adversely affected by rising temperatures and accelerated sea-level rise (*medium confidence*). * Declines in coastal ecosystems would negatively impact reef fish and threaten reef fisheries, those who earn their livelihoods from reef fisheries, and those who rely on the fisheries as a significant food source (*medium confidence*). * Limited arable land arid soil salinization makes agriculture of small island states, both for domestic food production arid cash crop exports, highly vulnerable to climate change (*high confidence*). * Tourism, an important source of income and foreign exchange for many islands, would face severe disruption from climate change and sea-level rise (*high confidence*).

II. Megacities at Risk

Cities with 10 Million or More Inhabitants
2000 and 2015

City–2000	Population (in millions)	City–2015	Population (in millions)
Tokyo 1/	26.4	Tokyo 1/	26.4
Mexico City	18.1	Bombay 1/	26.1
Bombay 1/	18.1	Lagos 1/	23.2
São Paulo	17.8	Dhaka 1/	21.1
Shanghai	17.0	São Paulo	20.4
New York 1/	16.6	Karachi	19.2
Lagos 1/	13.4	Mexico City	19.2
Los Angeles 1/	13.1	Shanghai 1/	19.1
Calcutta 1/	12.9	New York 1/	17.4
Buenos Aires 1/	12.6	Jakarta 1/	17.3
Dhaka 1/	12.3	Calcutta	17.3
Karachi 1/	11.8	Delhi	16.8
Delhi	11.7	Metro Manila 1/	14.8
Jakarta 1/	11.0	Los Angeles 1/	14.1
Osaka 1/	11.0	Buenos Aires 1/	14.1
Metro Manila 1/	10.9	Cairo 1/	13.8
Beijing	10.8	Istanbul 1/	12.5
Rio de Janeiro 1/	10.6	Beijing	12.3
Cairo 1/	10.6	Rio de Janeiro 1/	11.9
		Osaka 1/	11.0
		Tianjin 1/	10.7
		Hyderabad	10.5
		Bangkok 1/	10.1

Source: United Nations Population Division, March 2000.

1/ Cities located in coastal areas.

III. Precautionary Saving and Insurance in the Face of Disaster Risks

This appendix uses a simple model of consumer optimization to explore optimal provisioning and insurance in the face of disaster risk. To focus on the issues at hand, this is structured so as to ensure that in the absence of disaster risk savings would be zero.

Consider a consumer who lives for two periods, and has preferences $U(C_1)+U(C_2)$ defined over consumption in each. Lump sum income Y is the same in each period, but with some probability p a loss of Δ will be experienced in period 2. Knowing this, the individual decides in period 1 on the level of savings S (on which an interest rate of zero is paid—ensuring, given the other assumptions, that there will indeed be no savings if Δ=0) and on the number of units of insurance, n, to purchase. While insurance decisions are taken in the first period, payment is made in the second. Each unit of insurance costs q, and pays Q if disaster occurs. Thus consumption in period 1 is:

$$C_1 = Y - S \tag{1}$$

while in period 2 it is:

$$C_2^B = Y + S - \Delta + nQ \tag{2}$$

in the "bad" state in which disaster occurs, and

$$C_2^G = Y + S - nq \tag{3}$$

in the good state in which it does not.

The individual's problem is thus to:

$$\max_{S,n} \; U(Y-S) + pU(Y+S-\Delta+nQ) + (1-p)U(Y+S-nq), \tag{4}$$

the necessary conditions for which are:

$$\text{S:} \qquad -U'(C_1) + E[U(C_2)] = 0 \tag{5}$$

$$\text{n:} \qquad -(1-p)qU(C_2^G) + pQU'(C_2^B) = 0. \tag{6}$$

Take first the benchmark case in which actuarially fair insurance is available, so that:

$$pQ = (1-p)q. \tag{7}$$

Using this in (7), it is immediate that in this case $C_2^G = C_2^B$, so that full insurance is purchased ($nQ = \Delta - nq$). Since (5) then implies that $C_1 = C_2$, it also follows that $S = nq/2$:

enough is saved to purchase half of the insurance that will be bought in period 2, the other half coming from second period income.

More generally, (5)-(6) can be solved for S and n as functions of p, Δ, and, the load factor $\pi \equiv ((1-p)q/Q)-1$.

One convenient special case is that of the constant absolute risk aversion utility function,

$$U(C) = \kappa_1 - \kappa_2 e^{-\alpha C}, \text{ with } \alpha > 0. \tag{8}$$

In this case, assuming that insurance cannot be purchased, (5) can has an explicit closed form solution, with optimal saving given by:

$$S^* = \frac{\ln[1 + p(e^{\alpha\Delta} - 1)]}{2\alpha} \tag{9}$$

Illustrative calculations of (9) suggest that optimal savings, relative to expected disaster cost):

- Increase with the degree of risk aversion α and the level of the disaster cost itself—both as one would expect; and;
- Perhaps surprisingly, decrease with the probability of disaster.

Using the approximation $\ln(1+x) \approx x$ in (9) gives the particularly simple rule of thumb:

$$S^* = \left(\frac{1}{2}\right) p\Delta \tag{10}$$

meaning that it is optimal save an amount equal to about half the expected loss. This has a simple intuition. Consumption in period 1 is Y-S; expected consumption in period 2 (given the absence of insurance) is Y+S-$p\Delta$. Smoothing expected consumption thus requires that $S=p\Delta/2$.

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