A Framework for Reducing Vulnerability to Natural Disasters: Ex Ante and Ex Post Considerations

Howard Kunreuther
The Wharton School
University of Pennsylvania

Erwann Michel-Kerjan
The Wharton School
University of Pennsylvania

November 2008

Working Paper # 2008-11-01

Risk Management and Decision Processes Center
The Wharton School, University of Pennsylvania
3730 Walnut Street, Jon Huntsman Hall, Suite 500
Philadelphia, PA, 19104
USA
Phone: 215-898-4589
Fax: 215-573-2130
http://opim.wharton.upenn.edu/risk/

CITATION AND REPRODUCTION

THE WHARTON RISK MANAGEMENT AND DECISION PROCESSES CENTER

Established in 1984, the Wharton Risk Management and Decision Processes Center develops and promotes effective corporate and public policies for low-probability events with potentially catastrophic consequences through the integration of risk assessment, and risk perception with risk management strategies. Natural disasters, technological hazards, and national and international security issues (e.g., terrorism risk insurance markets, protection of critical infrastructure, global security) are among the extreme events that are the focus of the Center's research.

The Risk Center's neutrality allows it to undertake large-scale projects in conjunction with other researchers and organizations in the public and private sectors. Building on the disciplines of economics, decision sciences, finance, insurance, marketing and psychology, the Center supports and undertakes field and experimental studies of risk and uncertainty to better understand how individuals and organizations make choices under conditions of risk and uncertainty. Risk Center research also investigates the effectiveness of strategies such as risk communication, information sharing, incentive systems, insurance, regulation and public-private collaborations at a national and international scale. From these findings, the Wharton Risk Center's research team – over 50 faculty, fellows and doctoral students – is able to design new approaches to enable individuals and organizations to make better decisions regarding risk under various regulatory and market conditions.

The Center is also concerned with training leading decision makers. It actively engages multiple viewpoints, including top-level representatives from industry, government, international organizations, interest groups and academics through its research and policy publications, and through sponsored seminars, roundtables and forums.

More information is available at http://opim.wharton.upenn.edu/risk.

A Framework for Reducing Vulnerability to Natural Disasters: Ex Ante and Ex Post Considerations*

Howard C. Kunreuther and Erwann O. Michel-Kerjan
Wharton Risk Management and Decision Processes Center
The Wharton School, University of Pennsylvania
Philadelphia, PA 19104

REVISED VERSION

Final version - November 20, 2008

***This paper is being prepared as a background paper for the joint World Bank – UN Assessment on Disaster Risk Reduction. Helpful comments were received by Apurva Sanghi, Ricardo Zapata, Fred Krimgold, and Alejandro Fuentes.**

[THIS PAGE BLANK]

Table of Contents

Introduction and Executive Summary

Despite increasing concern about natural disasters among the international community and a somewhat decreasing trend in number of victims, extreme events continue to kill legions of people all over the world. In southeast Asia, the tsunami in December 2004 killed more than 280,000 people residing in coastal areas. When Cyclone Nargis, which made landfall in Myanmar in May 2008, killed an estimated 140,000 people, it was the deadliest natural disaster in the recorded history of the country. The same month, the Great Sichuan Earthquake in China is estimated to have killed nearly 70,000 people. Five million others became homeless. Other estimates put this number as high as 11 million.

But even in a developed country like the United States, which has extensive experience with natural catastrophes and resources to adequately prepare, the 2004 and 2005 hurricane seasons have demonstrated the lack of adequate loss reduction measures and emergency preparedness capacity to deal with large-scale natural disasters. Hurricane Katrina, which hit Louisiana and Mississippi at the end of August 2005, killed 1,300 people and forced 1.5 million people to evacuate the affected area - a historic record for the country. Economic damages are estimated in the range of US$150 to US$200 billion. After two relatively quiet hurricane seasons in 2006 and 2007 in the U.S., a series of hurricanes made landfall in 2008, causing billions of dollars in direct economic losses along the Caribbean Basin and in the US. Hurricane Ike, which produced severe damage to Galveston and Houston, Texas in September 2008 ($11 billion of which was insured), ranked in the top five most devastating natural disaster in U.S. history, after Hurricane Katrina and Hurricane Andrew which hit southeast Florida in August 1992 and Hurricanes Ivan and Wilma in 2004 and 2005.[1]

What happens in the US is not necessarily equivalent to what happens globally. As in previous years, hydro-meteorological disasters in 2007 were the major source of casualties, particularly in the form of hydrological disasters. The latter affected over 177 million people and killed more than 8,859 others. Although the human impacts were essentially concentrated in Asia, all the regions experienced some major hydro-meteorological events. Meteorological disasters were on the increase in 2007 compared to 2006. Tropical cyclones were the major contributor to this increase, their occurrence increased by 28% compared to the 2000-2006 average and they accounted for 61% of meteorological disaster occurrence[2].

---

[1] Sources: Insurance Information Institute.

[2] Source: CRED, various years.

These recent extreme events, which have been occurring at an accelerating pace, signal that we have entered a new era of large-scale catastrophes. They also highlight the importance of developing a coherent risk reduction and adaptation strategy to avoid future catastrophic human and economic losses. This report analyzes how to systematically link efforts undertaken prior to a disaster (i.e. *ex ante* measures such as risk assessment, investment in cost-effective risk reduction measures and the purchase of financial protection) with actions taken after a disaster has occurred (i.e. *ex post* measures such as rescuing those at risk, financial aid from government and international donors, and reconstruction activity.

This report is divided into three parts. **Part A** focuses on the new scale of destruction from natural disasters that has occurred since the early 1990s as measured by economic losses, insured losses, percentage of GDP, and number of fatalities. Although the absolute magnitude of the economic losses is greatest in the developed countries, their impact is more devastating and enduring in emerging countries. We discuss the main drivers of this new era: the significant increase in population and property value in high-risk areas coupled with more intense weather-related catastrophes that is possibly due to climate change. Part A also discusses the importance of growing interdependencies between nations and markets. In a highly interconnected world, natural disasters in low- and middle-income countries are of concern for developed countries as well, since more and more of their activities are either outsourced to suppliers located there.

Disasters continue to have devastating consequences even though the effectiveness of protective measures against natural hazards is now well understood. To address this challenge, one needs to better understand why these measures have not been adopted, so one will be in a position to develop innovative strategies for reducing future losses from potentially catastrophic disasters. **Part B** first develops a normative model of protective decision making where individuals are assumed to have full information and make tradeoffs that satisfy a set of axioms characterizing rational choice. We look specifically at self-insurance versus market insurance as well as the decision to invest in self protection. We then move to a descriptive analysis to explain why many people do not necessarily purchase insurance when it is attractively priced or only invest in cost-effective risk reduction measures after a disaster occurs, when it is too late. The behavioral biases we study here include budgeting heuristics, misperception of probability, affective forecasting errors, underweighting the future, myopic behavior, learning failures, social norms, interdependencies as well as the Samaritan and politician dilemma. Part B concludes by offering some guidelines for improving individual decision making and public policy, including: (1) properly assessing risks and characterizing uncertainties surrounding these estimates; (2) understanding behavioral biases and heuristics utilized by decision makers such as those described above; and (3) designing risk management strategies based on risk assessments *and* the recognition of these behavioral biases and heuristics used by decision makers in deciding what protective measures they will undertake.

Part C proposes concrete solutions to overcome the behavior characterized in Part B. We first discuss the role of risk transfer mechanisms whereby those in hazard-prone areas are protected against potentially large losses from disasters by undertaking ex ante measures to reduce the ex post financial consequences. We focus on insurance as a risk transfer mechanisms to highlight this point. In theory, insurance is an effective policy tool for developing a sustainable disaster management strategy. It rewards investments in cost-effective mitigation with lower premiums and provides claims payments to policyholders should a disaster occur. We recommend two guiding principles that convey the need to balance efficiency and equity issues in any disaster management program: *Principle 1 – Premiums Reflecting Risk*: If insurance is to be part of the risk-financing solution, then premiums should reflect the risk based on quantitative assessments; *Principle 2 – Dealing with Equity and Affordability Issues*: Any special treatment given to those residing in hazard-prone areas (e.g. low-income residents) should come from general public funding and <u>not</u> through artificially low insurance premiums.

We also recognize that insurance is currently not available in many developing countries. We thus focus on other risk reducing mechanisms that could reduce future losses from disasters. These include assuring that proper building codes and land-use regulations are implemented in hazard prone areas coupled with mitigation grants to reduce both economic losses and fatalities/injuries from future natural disasters. We also suggest ways that new forms of insurance such as all-hazards coverage, a policy that currently exists in some European countries. Given the lack of interest in individuals investing in protective measures, one should consider requiring that property owners purchase insurance. This may present special challenges in developing countries where regulations and standards are often not well-enforced. Even though Turkey passed a law following two severe earthquakes in the country in 1999 requiring all property owners to purchase earthquake insurance, only 21 percent of residential structures in the country have coverage today.

We also propose offering long-term contracts such as loans for mitigation, multi-year property insurance to provide stability to residents and overcome behavioral biases such as myopia and misperceptions of risk. If these long-term contracts are structures in an appropriate way they can be financially attractive to those residing in hazard-prone areas For example, by combining long-term insurance policies with long-term mitigation loans, property owners would find it financially attractive to invests in cost-effective loss reduction measures: the insurance premium reductions will be greater than the annual loan payments. Taxpayers would benefit because the reduced losses will mean lower government and international financial assistance following a disaster. The World Bank could take the lead in developing such long-term contracts in partnership with governmental and private institutions. Part C concludes by discussing two recent cases of innovative thinking in emerging economies: the establishment of a catastrophe insurance pool in Turkey against losses from future earthquakes and the creation of weather derivatives in Ethiopia to provide financial protection to local farmers should an extreme drought occur in the country.

Part A

New Era of Catastrophes

A-1. Economic and Human Impacts of Disasters

Over the past 15 years there has been a significant increase in the number of fatalities, injuries and property damage from natural disasters. Unless a better link is established between pre-disaster preparedness/risk-financing solutions and post-disaster intervention and risk reducing measures undertaken in advance of a catastrophic event we are likely to witness even more severe large-scale natural disasters in many parts of the world in the coming years.

Although this report focuses on natural hazards, it is useful to understand similarities and differences with other extreme events. To highlight this point Table 1 contrasts these events with terrorism on dimensions associated with estimating and managing the risk. Although there is uncertainty associated with estimating the risks from natural disasters, experts are more confident in determining the likelihood and consequences of an earthquake, flood or other natural event than a terrorist attack, it is easier to manage the natural hazard risk than that of terrorism because information can be more easily shared and there are more well-defined mitigation measures that can be adopted.

TABLE 1. NATURAL HAZARDS VERSUS TERRORISM RISKS

		Natural Hazards	Terrorism Risks
Estimating the Risk	**Historical Data**	*Some historical data:* Record of several extreme events already occurred.	*Very limited historical data*: 9/11 events were the first terrorist attacks worldwide with such a huge concentration of victims and insured damages.
	Risk of Occurrence	*Risk reasonably well-specified:* Well-developed models for estimating risks based on historical data and experts' estimates.	*Considerable ambiguity of risk*: Terrorists can purposefully adapt their strategy (target, weapons, time) depending on their information on vulnerabilities; dynamic uncertainty.
	Geographic Risk	*Specific areas at risk:* Some geographical areas are well known for being at risk (e.g., Istanbul, Turkey for earthquakes; islands of Bangladesh for tropical cyclones	*All areas at risk:* Some cities may be considered riskier than others (e.g .,urban areas) but terrorists may attack anywhere, any time.
	Catastrophe Modeling	Developed in late 1980s and early 1990s.	The first models were developed in 2002.
Managing the Risk	**Information**	*Information sharing:* New scientific knowledge on natural hazards can be shared with all the stakeholders.	*Asymmetry of information:* Governments keep secret new information on terrorism for obvious national security reasons.
	Event Type	*Natural event:* To date no one can influence at a specific time the occurrence of a specific extreme natural event (e.g., an earthquake).	*Resulting event:* Governments can influence terrorism (e.g., foreign policy; international cooperation; national security measures).
	Preparedness and Prevention	Those at risk can invest in well-known mitigation measures.	Weapons and configurations are numerous. Negative externalities of self-protection effort; Those at risk may have difficulty in choosing measures to reduce consequences of an attack; Federal agencies may be in a better position to develop more efficient global mitigation programs.

Returning to natural hazards, catastrophes tend to inflict higher absolute economic and insured losses in developed countries than they do in the developing world.[3] However, when, measured as a percentage of Gross Domestic Product (GDP), catastrophes have typically inflicted higher proportional losses in lower-income countries. Relative to developing countries, the number of fatalities is disproportionately lower in the developed world where warning systems are more sophisticated and effective.

Nature of Insured Losses

Insurance protection against losses from natural disasters has been widespread in developed countries but less prevalent in the developing world. Between 1970 and the mid-1980s insured losses due to natural disasters in the world were in the range of US$3 to 4 billion a year.[4] In fact, until Hurricane Hugo hit the Charleston, South Carolina area in 1989, there was not a single disaster that cost insurers more than US$1 billion.[5] In the early 1990s, the scale of insured losses from major natural disasters changed radically. The occurrence of Hurricane Andrew in 1992 cost the insurance industry $15.5 billion (US$23.7 billion in 2007 prices) and caused nine small insurance companies to become insolvent. Several large insurers were also severely impacted by the disaster. For example, the Florida branch of State Farm Fire and Casualty (the largest homeowner insurer in the U.S.) suffered a US$4 billion loss and only survived because it was rescued by its parent company in Illinois. The Florida branch of Allstate, the other major player in the state at the time, paid about US$1.9 billion in claims. This loss exceeded by $500 million total profits that Allstate earned from all types of insurance they marketed in Florida during the 53 years the firm had been in business in the state.

Hurricane Andrew was a wake-up call for the insurance industry. Companies recognized that they were not well-equipped to estimate the potential loss distribution from disasters and began to utilize catastrophic models to estimate the likelihood and consequences from specific hazards that might cause damage in specific locations (Grossi and Kunreuther, 2005). Since that time, insurers have improved how they underwrite catastrophe risks: no insurance company declared insolvency as a result of the September 11, 2001 terrorist attacks and only one insurer

[3] Throughout the report we use the World Bank gross annual income per capita classification to define low-income countries (US$875 or less), middle-income countries (USD876-10,725) and high-income countries (US$10,726 or more).

[4] Unless noted all figures presented in this section are in current dollars.

[5] Hurricane Hugo cost insurers over $4 billion in 1989 prices (or $7.6 billion in 2007 prices).

became insolvent after the series of hurricanes that devastated Florida in 2004 (U.S. Government Accountability Office, 2005).

Extreme events have continued to inflict major insured losses from natural disasters. A new record was reached in 2004 with global insured losses of US$49 billion (Swiss Re, 2005). This upward trend continued in 2005 with total insured losses from natural catastrophes of US$87 billion in 2005.[6] Hurricane Katrina alone cost insurers and reinsurers US$46.3 billion,

Losses due to natural catastrophes and man-made disasters were far below the long-term trend in 2006. Of the US$48 billion in catastrophe-related economic losses worldwide, US$16 billion was covered by insurance (US$11 billion for natural disasters; US$5 billion for man-made). Insured losses were lower than 2006 in only two years (1988 and 1997) during the period 1987-2006. According to Munich Re, there were 950 natural catastrophes in 2007, the most since 1974 that inflicted nearly US$27 billion in insured losses. With Tropical Storms Fay and Hanna, and Hurricanes Gustav and Ike[7] occurring in the North Atlantic in 2008 coupled with earthquakes in China, Japan and Indonesia and typhoons and floods in other parts of the world, insured losses for the current year are likely to be considerably higher than in 2006 and 2007.

Figure 1 depicts the evolution of worldwide insured losses due to catastrophes between 1970 and 2007 (in 2007 indexed prices). The increased losses during the past 19 years (1989-2007) compared with previous 19 years (1970-1988) are clearly displayed. Table 2 characterizes the 20 most costly catastrophes for the insurance sector over the past 35 years (in 2007 dollars). Note that 18 of the 20 most costly events occurred during the past 17 years. Furthermore, except for the terrorist attacks on September 11, 2001, all of these events were natural disasters.

---

[6] This figure excludes US$17 billion in flood insurance claims paid by the U.S. National Flood Insurance Program

[7] If preliminary estimates of damage from Hurricane Ike at $25 billion are borne out it would be the third-costliest hurricane in U.S. history.

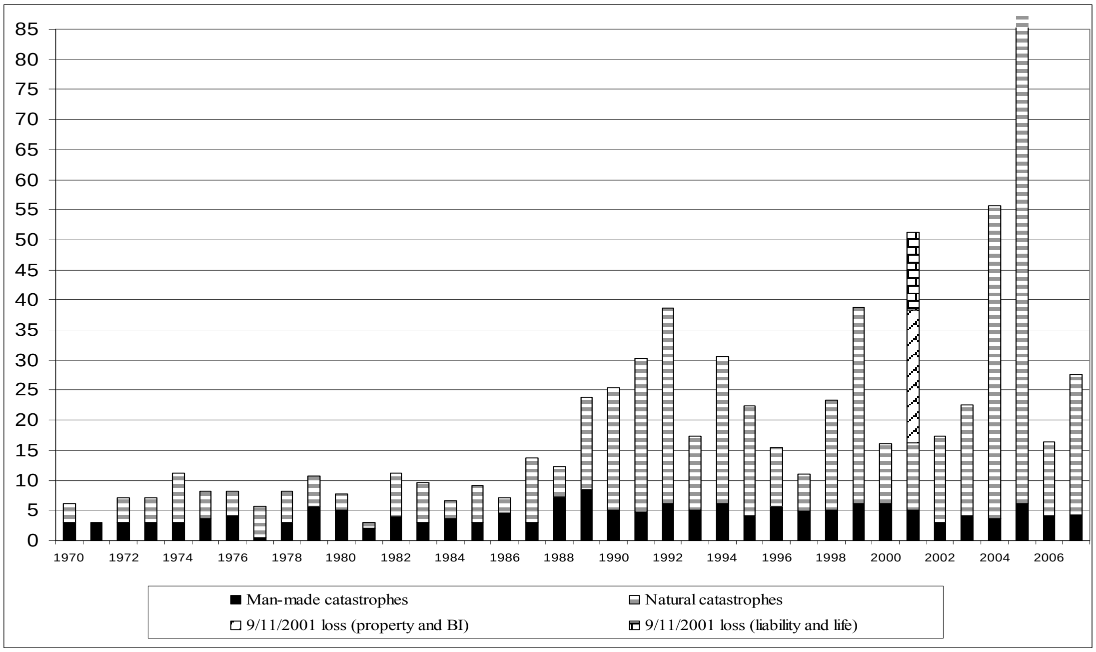


FIGURE 1. WORLDWIDE EVOLUTION OF CATASTROPHE INSURED LOSSES, 1970-2007

(9/11: All lines, including property and business interruption (BI); in U.S. $ billon indexed to 2007)

Source: Wharton Risk Center with data from Swiss Re and Insurance Information Institute

TABLE 2. THE 20 MOST COSTLY INSURED IN THE WORLD, 1970-2007 (INDEXED TO 2007 PRICES)

U.S.$ Billion (indexed to 2007)	Event	Victims (Dead or missing)	Year	Area of Primary Damage
46.3	Hurricane Katrina	1,836	2005	USA, Gulf of Mexico, et al.
35.5	9/11 Attacks	3,025	2001	USA
23.7	Hurricane Andrew	43	1992	USA, Bahamas
19.6	Northridge Earthquake	61	1994	USA
14.1	Hurricane Ivan	124	2004	USA, Caribbean, et al.
13.3	Hurricane Wilma	35	2005	USA, Gulf of Mexico, et al.
10.7	Hurricane Rita	34	2005	USA, Gulf of Mexico, et al.
8.8	Hurricane Charley	24	2004	USA, Caribbean, et al.
8.6	Typhoon Mireille	51	1991	Japan
7.6	Hurricane Hugo	71	1989	Puerto Rico, USA, et al.
7.4	Winterstorm Daria	95	1990	France, UK, et al.
7.2	Winterstorm Lothar	110	1999	France, Switzerland, et al.
6.1	Winterstorm Kyrill	54	2007	Germany, UK, NL, France
5.7	Storms and floods	22	1987	France, UK, et al.
5.6	Hurricane Frances	38	2004	USA, Bahamas
5.0	Winterstorm Vivian	64	1990	Western/Central Europe
5.0	Typhoon Bart	26	1999	Japan
4.5	Hurricane Georges	600	1998	USA, Caribbean
4.2	Tropical Storm Alison	41	2001	USA
4.2	Hurricane Jeanne	3,034	2004	USA, Caribbean, et al.

Sources: Wharton Risk Center with data from Swiss Re and Insurance Information Institute

Insured versus Economic Impact

One measure of the economic impact of natural disasters on those suffering damage is the ratio of total losses to insured losses (L/I). When there is a limited insurance market, as is the case in most low- and middle-income countries, the value of L/I will normally be very high. For example, in 1996 major floods in China inflicted about US$24 billion in economic losses, less than US$500 million of which was covered by insurance so that the L/I ratio was greater than 50. Two years later, other floods in China cost about US$30 billion in direct economic loss, but only US$1 billion was covered by insurance so that the L/I ratio was 30.

Even in developed countries, such as Japan, the L/I ratio from a disaster can be high. The large-scale earthquake that devastated Kobe, Japan in 1995 cost US$110 billion (L), only US$3 billion of which was covered by insurance resulting in an L/I=36.7. In the U.S. the L/I ratio has been much lower due to higher insurance coverage ranging from 2 to 4. In the cases of Hurricane Andrew (in 1992 prices), the Northridge earthquake (1994 prices) and Hurricane Katrina (2005 prices) the L/I ratio was about 1.5 (26/17), 2.8 (44/15.5) and 3 (150/45), respectively.

Figure 2 compares economic and insured losses for "great natural disasters"[8] from 1980-2007. Economic losses follow the same increasing trend described earlier for insured losses. A comparison of these economic losses over time reveals a huge increase: US$53.6 billion (1950-59), US$93.3 billion (1960-69), US$161.7 billion (1970-79), US$262.9 billion (1980-89) and US$778.3 billion (1990-99). From 2000-2007 insured losses were US$420.6 billion but this figure is likely to be considerable higher by the end of 2008 due to the disasters that have already occurred during this year. It should be noted that precise loss analyses and reports are compiled by governments and other public sector organizations only after significant natural catastrophes. Definitions differ as to what characterizes a catastrophe or not. For example, natural disasters inflicting insured losses above US$38.7 million or total losses above US$77.5 million are considered a major catastrophe by Swiss Re (we use this threshold in figure 1) which explains the differences between figures 1 and 2. For example, when Munich Re estimated insured loss from natural disasters at about $42 billion in 2004, Swiss Re's estimate was over $52 billion.

[8] A "great nature disaster is defined by Munich Re as one that causes over a thousand of fatalities and losses of over US$500 million.

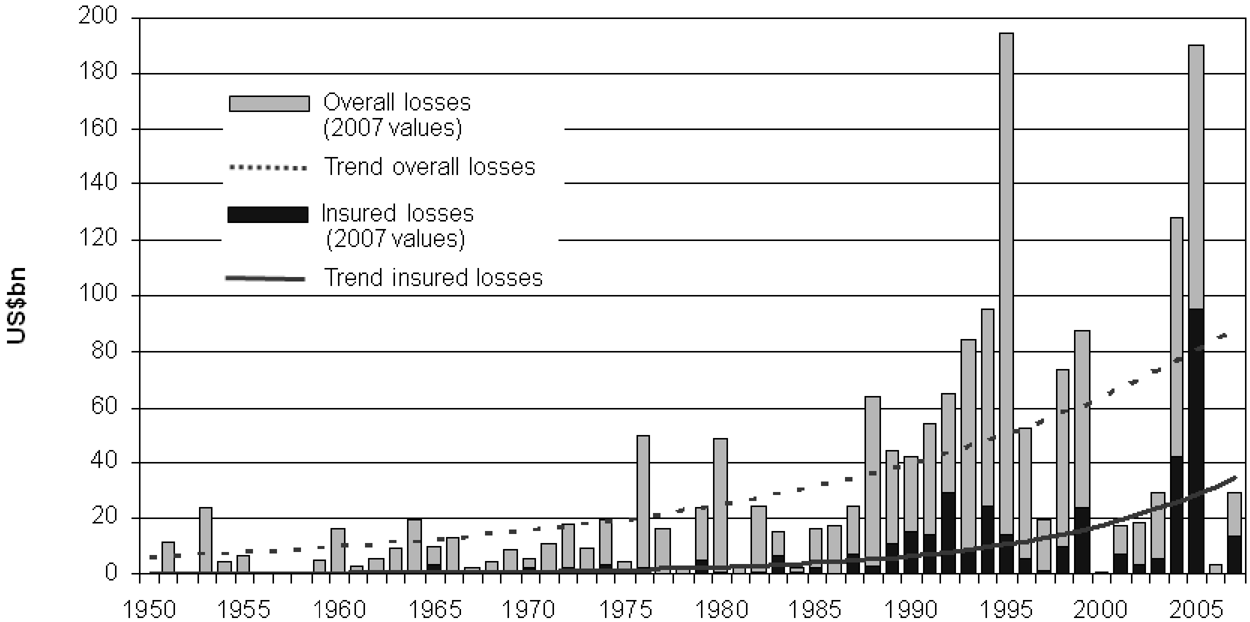


FIGURE 2. EVOLUTION OF "GREAT NATURAL CATASTROPHES" WORLDWIDE, 1950-2007 ECONOMIC VERSUS INSURED IMPACT

Sources: Data from Munich Re, 2008 Geo Risks Research – in U.S. $ billon indexed to 2007

Furthermore, in low- and middle-income countries it is not always clear whether measures of loss assessment have been conducted in a systematic and rigorous manner, even though the quality of reporting has risen perceptibly in many countries since the 1990s. According to Munich Re, which has been collecting such data for several decades, the percentage of natural catastrophes with very good reporting of economic losses has significantly increased over the past 25 years from 10 percent in 1980 to above 30 percent in 2005 (Munich Re, 2006). Still the proportion of catastrophes for which total cost is not necessarily well reported remains quite high.

Impact on Gross Domestic Product (GDP)

At a more aggregate level, one can estimate the economic impact of disasters by determining the losses in relation to the country's annual GDP. A major flood in the United States or a large European country will have much less of an impact on GDP than if a similar event occurred in a developing country. At one extreme, natural disasters have had a long-enduring impact on small islands, with economic losses from major natural disasters representing several times the annual GDP compared to losses in developed countries where damage is a very small percentage of annual GDP (See Table 3).

TABLE 3. EXAMPLES OF THE IMPACT OF DISASTERS ON ECONOMIES OF DIFFERENT SIZES

Year	Natural disaster	Country	Region	Damage (US$ million)	Damage (% of GDP)
Large Economies					
2005	Hurricane (Katrina)	USA	North America	125,000	1.1%
1995	Earthquake	Japan	East Asia	100,000	3.2%
1998	Flood	China	East Asia	30,000	0.7%
2004	Earthquake	Japan	East Asia	28,000	0.8%
1992	Hurricane (Andrew)	USA	North America	26,500	0.4%
Small Island Economies					
1988	Hurricane (Gilbert)	St. Lucia	Caribbean	1,000	365%
1991	Cyclone (Val and Wasa)	Samoa	Oceania	278	248%
2004	Hurricane (Ivan)	Grenada	Caribbean	889	203%
1990	Cyclone (Ofa)	Samoa	Oceania	200	178%
1985	Cyclone (Eric and Nigel)	Vanuatu	Oceania	173	143%

Sources: Cummins and Mahul (2008)

Using annual GDP to measure the relative economic impact of a disaster does not reveal the costs of a disaster to the affected region, however. In the United States where the GDP is nearly US$15 trillion, even a US$250 billion loss due to a series of major hurricanes and/or earthquakes will have an impact on GDP that is less than 2 percent. In Myanmar a 2 percent GDP loss would mean approximately a US$1.8 billion loss. The use of GDP might be somewhat misleading, however. Indeed, while a disaster can have a limited impact on GDP, if one measures a disaster in the context of the affected regions, the economic impact in terms of property damage, business interruption, real estate prices and tax revenue could be very severe.[9]

[9] Three years after Hurricane Katrina struck New Orleans, the population was estimated to be 325,000, two-thirds of the size that it was before the disaster in 2005. It is very likely that this lost of residents will be permanent. As highlighted in a recent article in *The Economist*, "about a third of the 50 districts that flooded have yet to regain 50 percent of their households."

Number of Fatalities

If one uses the magnitude of insured losses in ranking disasters, catastrophic cyclones, earthquake and floods in poor and emerging economies would not even be noted since insurance does not exist or plays a minor role in covering losses in these countries. For example, the tsunami that devastated South Asia in December 2004 cost the insurance industry about US$5 billion (mostly due to tourist activities in the region) but the disaster killed over 220,000 people. More generally, the most severe natural disasters from the point of view of lives lost have occurred in poor countries. As shown in Table 4, of the top 40 most devastating disasters ranked by number of victims, only four occurred in OECD countries, namely the heat wave in France, Italy and Germany in 2003, the Izmit earthquake in Turkey in 1999, the Kobe earthquake in Japan in 1995 and the heat wave/drought in France in 1976.

Using number of fatalities as an indicator of the losses from natural disasters, we find that during the period 1970-2007, the average annual number of fatalities was 55,000. Aggregating over the entire period, earthquakes killed nearly 860,000 people, storms and floods 535,000 and heat waves about 40,000 people worldwide. Moreover, despite growing awareness, natural disasters have continued to kill a significant number of individuals.[10]

[10] While beyond the scope of this report, there is a critical need for improving protection and alert systems as well forced evacuations to reduce the number of fatalities.

TABLE 4. THE 40 MOST DEVASTATING DISASTERS RANKED BY NUMBER OF VICTIMS - 1970-2007

Victims	Date	Nature of the disaster	Area(s)
300,000	14.11.1970	Storm and flood catastrophe	Bangladesh
255,000	28.07.1976	Earthquake (M 7.5)	China
220,000	26.12.2004	Earthquake (Mw 9), tsunami in Indian Ocean	Indonesia, Thailand et al
138,000	29.04.1991	Tropical cyclone Gorky	Bangladesh
73,300	08.10.2005	Earthquake (Mw 7.6); aftershocks, landslides	Pakistan, India, Afghanistan
66,000	31.05.1970	Earthquake (M 7.7); landslides	Peru
40,000	21.06.1990	Earthquake (M 7.7); landslides	Iran
35,000	01.06.2003	Heat wave and drought in Europe	France, Italy, Germany
26,271	26.12.2003	Earthquake (M 6.5) destroys 85% of Bam	Iran
25,000	07.12.1988	Earthquake (M 6.9)	Armenia, ex-USSR
25,000	16.09.1978	Earthquake (M 7.7) in Tabas	Iran
23,000	13.11.1985	Volcanic eruption on Nevado del Ruiz	Colombia
22,084	04.02.1976	Earthquake (M 7.5)	Guatemala
19,737	26.01.2001	Earthquake (Mw 7.6) in Gujarat	India, Pakistan, Nepal
19,118	17.08.1999	Earthquake (M, 7) in Izmit	Turkey
15,000	11.08.1979	Macchu dam burst in Morvi	India
15,000	01.09.1978	Floods following monsoon rains	India, Bangladesh
15,000	29.10.1999	Cyclone 05B devastates Orissa state	India, Bangladesh
11,069	25.05.1985	Tropical cyclone in Bay of Bengal	Bangladesh
10,800	31.10.1971	Floods in Bay of Bengal and Orissa state	India
10,000	12.12.1999	Floods, mudflows and landslides	Venezuela, Colombia
10,000	20.11.1977	Tropical cyclone in Andrah Pradesh	India, Bay of Bengal
9,500	19.09.1985	Earthquake (M 8.1)	Mexico
9,475	30.09.1993	Earthquake (M 6.4) in Maharashtra	India
9,000	22.10.1998	Hurricane Mitch in Central America	Honduras, Nicaragua
6,425	17.01.1995	Great Hanshin earthquake (M 7.2) in Kobe	Japan
6,304	05.11.1991	Typhoons Thelma and Uring	Philippines
6,000	02.12.1984	Accident in chemical plant in Bhopal	India
6,000	01.06.1976	Heat wave, drought	France
5,778	27.05.2006	Earthquake (M, 6.3); Bantul almost completely destroyed	Indonesia
5,422	26.06.1976	Earthquake (M 7.1)	Papua New Guinea
5,374	10.04.1972	Earthquake (M 6.9) in Fars	Iran
5,300	28.12.1974	Earthquake (M 6.3)	Pakistan
5,112	15.11.2001	Floods and landslides caused by heavy rain	Brazil
5,000	05.03.1987	Earthquake; oil pipeline damaged	Ecuador
5,000	23.12.1972	Earthquake (M 6.3) in Managua	Nicaragua
5,000	30.06.1976	Earthquake in West Irian	Indonesia
4,500	10.10.1980	Earthquake in EI Asnam	Algeria
4,375	21.12.1987	Ferry Dona Paz collides with oil tanker Victor	Philippines
4,234	15.11.2007	Cyclone Sidr in Gulf of Bengal; floods	Bangladesh, India
1,482,178		Total	

Sources: Data from Swiss Re

A-2. Principal Causes of Natural Disaster Losses

Increasing urbanization and value at risk

The two socio-economic factors which directly influence the level of economic losses due to natural disasters are *degree of urbanization* and *value at risk*. In 1950 about 30 percent of the world's population – 2.5 billion people – lived in cities. In 2000, about 50 percent of the world's population (6 billion) lived in cities. Projections by the United Nations show that by 2025, this figure will have increased up to 60 percent to a population of 8.3 billion people. A direct consequence of this trend is the increasing number of so-called mega-cities with populations above 10 million. In 1950, New York City was the only such a mega-city. In 1990, there were 12 such cities. By 2015, there are estimated to be 26, including the following: Tokyo (29 million inhabitants), Shanghai (18 million), New York (17.6 million), and Los Angeles (14.2 million inhabitants) (Crossett, et. al., 2004).

With respect to the developing world, a city such as Istanbul that is subject to losses from earthquakes has significantly increased in population over the past 60 years from less than 1 million in 1950 to more than 11 million by the end of 2007. In India, about 48 percent of the country is prone to cyclones, 68 percent to droughts and more than 40 million hectares or nearly 1/8th of India are prone to floods.[11] Table 4 shows that 10 of the most deadly disasters since 1970 occurred in this country. Furthermore, several large cities in India which are subject to natural disasters are very densely populated. Mumbai has a population density of 22,770 inhabitants per square kilometer. More than 3,300 people were killed in the monsoons in the summer of 2007; the overall loss is estimated at US$750 million. Delhi, which is also prone to major floods, has seen its population increase from 2 million in 1950 to over 16 million at the end of 2007. Its population density is 26,200 inhabitants per square kilometer.[12]

To more fully understand the implications of growing urbanization one can calculate the total direct economic cost of specific disasters that occurred decades ago and see how much a similar catastrophe would cost today. A recent study by Pielke et al. (2008) normalizes to the year 2005 mainland U.S. hurricane damage during the period 1900–2005 by adjusting for inflation, population and wealth. Table 5 provides estimates for the top 20 most costly hurricanes assuming they had occurred in 2005. The authors propose two ways to normalize these losses,

---

[11] Government of India, Ministry of Home Affairs (2004), Disaster management of India, New Delhi.

[12] In the U.S., New York City has the highest density population of all American cities with, 10,500; Los Angeles is three times less densely populated. As a reference point, the density population of the city of New Orleans is only 1,000 inhabitants per kilometer-square.

each of which gives a cost estimate. In Table 5 we provide the range of costs using these two estimates, the year when the hurricane originally occurred, the states that were the most seriously affected and the hurricane category on the Saffir-Simpson scale. The data reveals that the 1926 hurricane that hit Miami would have been almost twice as costly as Hurricane Katrina had it occurred in 2005 given the growth of the city. The Galveston hurricane of 1900 would have had total direct economic costs similar to Hurricane Katrina if it occurred in 2005. This means that independently of any possible change in weather patterns, we are very likely to see even more devastating disasters in the coming years because of the ongoing growth in population and property values in hazard-prone areas.

In summary, increased urbanization, inflation, and property value in hazard-prone areas will have a major impact on the level of economic and insured losses due to natural catastrophes. In low- and middle income-countries, many large cities have very high population density in comparison of most cities in North America and Europe. This can be an extremely challenging situation to assure timely evacuation and rescue to reduce the number of potential fatalities.

Quantifying each of these factors at a local level (rather than at a gross national level) requires more accurate measurement over time for specific locations at risk. The World Bank might consider taking a leading role in developing a more granular data collection system on a global basis by extending their currently work in Central America, where they are developing an open-source Central American Probabilistic Risk Assessment (CAPRA). Without this type of information one is forced to use global economic measures that may not be a good proxy for changes in specific regions.

TABLE 5. TOP 20 HURRICANE SCENARIOS IN THE U.S. (1900-2005) RANKED USING 2005 INFLATION, POPULATION, AND WEALTH NORMALIZATION

Rank	Hurricane	Year	Category	Cost range (US$ billion) in 2005
1	Miami (Southeast FL/MS/AL)	1926	4	140-157
2	Katrina (LA, MS)	2005	3	81
3	North Texas (Galveston)	1900	4	72-78
4	North Texas (Galveston)	1915	4	57-62
5	Andrew (Southeast FL and LA)	1992	5-3	54-60
6	New England (CT,MA,NY,RI)	1938	3	37-39
7	Southwest Florida	1944	3	35-39
8	Lake Okeechobee (Southeast	1928	4	32-34
9	Donna (FL-NC,NY)	1960	4-3	29-32
10	Camille (MS/Southeast LA/VA)	1969	5	21-24
11	Betsy (Southeast FL and LA)	1965	3	21-23
12	Wilma	2005	3	21
13	Agnes (FL/CT/NY)	1972	1	17-18
14	Diane (NC)	1955	1	17
15	4 (Southeast FL/LA/AL/MS)	1947	4-3	15-17
16	Hazel (SC/NC)	1954	4	16-23
17	Charley(Southwest FL)	2004	4	16
18	Carol (CT,NY,RI)	1954	3	15-16
19	Hugo (SC)	1989	4	15-16
20	Ivan (Northwest FL/AL)	2004	3	15

Sources: Data from Pielke et al. (2008)

Impact of Climate Change[13] / Environmental Degradation

One also needs to consider the impacts of disasters on environmental degradation should be given equal treatment. Landslides and floods as well as the severity of the impact of storm surges is aggravated by the lack of forest cover, the degradation of ecosystems, particularly river basins and coastal wetlands. An example of the type of research that has been undertaken on these issues is discussed below in the context of Hurricane Katrina under the subsection on *Issues of Interdependencies* (see p. 25).

[13] The material in this subsection is taken from Kunreuther and Michel-Kerjan (2009).

Is a change in climate likely to affect the number and severity of future weather-related catastrophes? One of the expected effects of global warming will be an increase in storm/hurricane/typhoon intensity. This has been predicted by theory and modeling, and substantiated by empirical data on climate change. Higher ocean temperatures lead to an exponentially higher evaporation rate in the atmosphere which increases the intensity of cyclones and precipitation. Emanuel (2005) introduces an index of potential destructiveness of hurricanes based on the total dissipation power over the lifetime of the storm. He shows a large increase in power dissipation over the past 30 years and concludes that this increase may be due to the fact that storms have become more intense, on average, and/or have survived longer at high intensity. His study also shows that the annual average storm peak wind speed over the North Atlantic and eastern and western North Pacific has increased by 50 percent over the past 30 years.

A paper by Webster et al. (2005) published a few weeks after Emanuel's paper, indicates that the number of Category 4 and 5 hurricanes worldwide has nearly doubled over the past 35 years.[14] The Webster, et al. (2005) study concludes that "global data indicate a 30-year trend toward more frequent and intense hurricanes." This significant increase in observed tropical cyclone intensities, linked to warming sea surface temperatures that may be associated with global warming, has been shown in another study published recently (Hoyos et al., 2006).

But this is not to say that there is consensus by scientists on the relationship between hurricane activity and global warming.[15] In a perspective article published in *Science*, Landsea et al. (2006) point out that subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones. This conclusion is reinforced in a recent summary of articles on global climate change by Patrick Michaels, past president of the American Association of State Climatologists, who notes that all studies of hurricane activity that claim a link between human causation and the recent spate of hurricanes must also account for the equally active period around the middle of the 20th century. Studies using data from 1970 onward begin at a cool point in the hemisphere's temperature

---

[14] Category 4 hurricanes have sustained winds from 131 to 155 miles per hour; Category 5 systems, such as Hurricane Katrina at its peak over the Gulf of Mexico, have sustained winds of 156 mph or more.

[15] See for instance the exchange between Pielke R., Jr., C.W. Landsea and K. Emanuel (2005) and Chan, J. (2006), and Webster P.J., J.A. Curry, J. Liu, G.J. Holland (2006).

history, and hence may draw erroneous conclusions regarding global climate change and hurricane activity (Michaels, 2006).

The current debate in the scientific community regarding changes in the frequency and intensity of hurricanes and their relationship to global climate change is likely to be with us for a long time to come. The results to date do raise issues for the insurance industry to the extent that an increase in the number of major hurricanes over a shorter period of time is likely to translate into a greater number hitting the coasts, with a greater likelihood of damage to a much larger number of residences and commercial buildings today than in the 1950s.[16] Moreover, recent work by the International Panel on Climate Change (IPCC) clearly indicates that one of the impacts of a change in climate will be an increase in weather-extremes. We are likely to witness not only more intense storms, but also more intense heat-waves and drought, and more intense flooding episodes as well. The impacts are predicted to be more important in many low- and middle income countries (Africa, South America, Asia) than in the developed world (IPCC, 2007).

Issues of Interdependencies

There is another important element to take into account in the development of a disaster management strategy that links *ex ante* and *ex post* considerations. With the increasing globalization of economic and social activities, the world has now become so interdependent that actions taken today can affect others thousands of miles away tomorrow. Conventional wisdom holds that one country or one organization has the capacity and expertise to manage future large-scale global risks alone. However, in an increasingly global interdependent world, this may not be possible. In particular, if one considers the indirect impacts of disasters, such as supply chain disruptions or lack of available resources supplied to other parts of the world, then there can be global ripple effects. This view of a disaster differs from that of Albala-Bertrand (2006) who focused on direct damage and argued that a localized disaster is unlikely to affect the macro economy in any significant way. Interdependent risks may amplify the consequences of natural disasters and should be taken into account when developing strategies for risk reduction, preparedness and recovery. Box 1 provides a set of illustrative set of examples of interdependencies.

[16] For more discussion on this issue see Mills, E. (2005), and Höppe, P. and R. Pielke (eds.) (2006).

BOX 1: ILLUSTRATIVE EXAMPLES OF INTERDEPENDENCIES

This box provides examples of the nature of interdependencies and the types of private-public partnerships that might be considered in dealing with them.

Reducing the risk of power failures[17]

Consider a utility that is part of is part of an integrated system, (i.e. the power grid) and wants to determine whether to invest in additional capacity or security measures (e.g., trimming vegetation near distribution lines) to reduce the chance of a power failure. In any highly interdependent system, such as the power grid, there is a systemic tendency to under-invest in reliability. A consequence of the interdependency is that a part of the cost of a failure, perhaps a large part, is passed on to competitors and their customers. In the case of the August 2003, power failures in the northeastern U.S. and Canada, the costs of a failure at an Ohio utility, were passed on to other utilities and customers over the northeastern US and southeastern Canada. There are two routes to a solution. One, the property rights approach, is to hold a utility responsible for the full costs of a service failure, wherever it occurs. The second, the regulatory approach, is to mandate minimum reliability standards with monitoring and serious penalties for non-compliance. By forcing each utility to bear the full costs of its shortcomings, the first route provides a clear incentive to avoid failures. The second seeks to prevent them through regulatory action.

Supply-chain management[18]

The effects of supply-chain disruptions (whether due to natural disasters, terrorists, or other unexpected events) on the profitability of supply-chain participants are now recognized as being potentially catastrophic. Shipping delays and other supply-chain disruptions during the 1990s showed that companies experiencing such disruptions underperformed their peers significantly in stock performance, as well as in operating performance (as reflected in costs, sales, and profits). Coping with the management challenges of such disruptions and weak links in the supply chain is, however, a difficult matter, as the interdependencies require cooperative activity and monitoring across the supply chain in ways that are not captured in the traditional metrics of price, time/responsiveness, and product quality. For example, firms who are protecting themselves against disruptions due to the avian flu may find that their own measures may be of little use unless accompanied by protections on the part of their suppliers, the suppliers' suppliers, etc. Another example of interdependency in the supply chain is protecting food or agricultural products against physical contamination (bacteria, toxins, etc.) such as protecting milk from botulinum toxin, and protecting cattle from foot-and-mouth disease. In these cases, the product could be distributed widely and poison thousands. Another example is the Taiwan earthquake of September 1999 which sent shock waves through the global semiconductor market

Vaccination against diseases[19]

If people face the possibility of catching an infectious disease and have the option of a vaccine, how many will choose to be vaccinated? Intuition suggests that not all will. If most people are vaccinated, there is little incentive for the unvaccinated individuals to join them, if they can only catch the disease from another human. In this case, if everyone else is vaccinated, then it is optimal for the last

[17] See Feinstein (2006) for more details on this scenario
[18] See Heal et al., (2006) for more details on this scenario
[19] See Heal and Kunreuther, (2005) for more details on this scenario

person not to be vaccinated, since she faces no risk and can free-ride on the herd immunity of the community. Likewise, if no one is vaccinated, everyone has a strong incentive to be vaccinated if there is a risk of exposure. In this case, no one being vaccinated is an equilibrium solution only if the cost of vaccination is extremely high. This seems to suggest that there should be an interior solution with some but not all of the population being vaccinated. Who, and how many, should be vaccinated? Can one identify individuals who are more susceptible to the disease and/or are more likely to spread it to others who are prime candidates for protection if there is a limited supply of the vaccine?

Environmental treaties[20]

Suppose that countries are asked to sign a treaty to reduce some environmental risk, such as global warming or atmospheric pollution. There is a net cost to any one country for adopting the treaty, but potential benefits to the planet if enough countries take this action. What incentive is there for any one country to adopt the treaty if it knows that a number of other countries will not join? How can one convince countries with leverage to sign the treaty to induce others to follow suit? There are equity-efficiency tradeoffs that may have to be addressed here. For example, one can envision that it might be economically more efficient for only a subset of countries to take preventive actions by being part of a treaty, but more equitable and politically saleable for all countries to sign the treaty.

Interdependent critical infrastructures[21]

In the wake of an accelerating rhythm of major disasters, the private and public sector share an interest in making social and economic systems less vulnerable to disasters. There is a growing interest in protecting critical infrastructure that assure the social and economic continuity of a nation (transportation, water distribution, telecommunication, electricity, emergency services, finance sector, etc.). One of these challenges is the existence of interdependent operations between multiple infrastructures in different sectors. For example, financial systems and emergency services are highly dependent on telecommunication operations, which are highly dependent on electricity. When the interdependencies cut across sectors, the nature of the risks are often not well understood so that they pose special policy challenges.

Reducing the Risk of Wildfire[22]

Suppose you have built a home in one of the areas outside of an area that is designated as a red or high hazard zone with respect to wildfires. You are aware of the potential for fire and decide to install a tile or metal roof to reduce the chances that a fire will damage or destroy your house. Unfortunately, your next door neighbor, who has not thought about the possibility of fire because it "won't happen to me" installs a shake roof made of cedar. This roof is pleasing to the eye and less expensive than either a tile or metal roof. However, in a dry desert climate, the roof is like a match stick that could be ignited by a spark and cause the house to burn. Such a disaster will not be confined to your neighbor's house but will very likely to spread to yours and others even though you have a tile or metal roof.

[20] See Barrett (2003) for more details on this scenario
[21] See Auerswald et al. (2006) for more details on this scenario
[22] See Spyratos, V, P. Bourgeron, and M. Ghil, (2007) for more details on this scenario.

A challenge for public policy is to find a way for the government to provide incentives for the residents and businesses to invest adequately in protection so as to avoid large-scale public assistance following a disaster. One aspect of interdependency is the grants and loans provided from organizations such as the World Bank to assist countries that have suffered losses from disasters. The major tsunami in Asia in December 2004 triggered aid from all over the world, not only from the national governments. International organizations were mobilized to devote special financial relief to the victims; there are obvious opportunity costs here since those funds could not be used elsewhere. To the extent that residents of these countries invest in protection in advance of the disaster there will be less need for this type of relief. We will provide a normative framework to analyze this issue in Part B of the report. Recent major catastrophes, such as Hurricane Katrina, also have revealed failure in government preparedness prior to a disaster (e.g. poorly constructed levees and flood control project and other infrastructure), which negatively impacted on property losses and the operation of firms in the private sector. (e.g. business interruption losses) (Michel-Kerjan, 2008a).

There is an additional challenge related to global risks: interdependencies exist not only across regions and industries but also across *time*. A catastrophic event such as Hurricane Katrina or Great Sichuan earthquake can cause business interruption risk that can impact on the economic viability of the area as well as have negative impacts on other parts of the world.

People tend to look for local causes to explain events. There is generally little discussion of the numerous actions taken years before that have little apparent connection to a disaster but can increase risk levels or damages significantly.

Kousky and Zeckhauser (2006) introduce the concept of *JARring* actions: those actions that Jeopardize Assets that are Remote to characterize this form of interdependency. JARring actions impose a particular type of negative externality – one in which the cost is imposed on people who are spatially or temporally distant. Unless there is a system in place that allows victims to hold the responsible parties accountable, internalizing such externalities will be a challenge. An illustrative example the authors highlight is associated with Hurricane Katrina where major storm surge caused wetland losses. Hurricane Andrew in 1992 foreshadowed this impact. As noted in, a coastal restoration plan for Louisiana, a decrease in storm surge was measured as Hurricane Andrew made its way through Louisiana's coastal marshes. The reduction amounted to a decrease of 3.1 inches in storm surge per linear mile of marsh (and open water) in one site, giving total reductions in storm surge of 6 feet. One must add here that while Louisiana contains about 40 percent of the country's wetlands it also have witnessed 80 percent of the country's wetland loss; since 1900 over 1 million acres have vanished. (Kousky and Zeckhauser 2006). According to the authors, it is estimated that another 513 square miles (a little over 328,000 acres) of land will be lost by 2050. The rate of wetland loss has dropped from a high of about 40 square miles per year in the 1960s to 24 square miles per year today. Thus, an area of wetlands close to the size of Manhattan is lost annually off the Louisiana coast, or about one football field of wetlands every 38 minutes.

There is also a positive side of globalization and disaster management in the context of increased interdependencies. More top decision makers realize that catastrophe financing issues are complex and a single organization cannot solve these problems alone. Innovative partnerships become a key to addressing these challenges. Furthermore, if an increasing number of companies in the developed world depend on suppliers and outsourced activities in emerging economies, then major natural disasters in these poor countries become a global issue that demands attention.

Conclusion of Part A

Increasing population, population density and greater property value at risks constitute a key element of future large-scale disasters. Other elements likely to have an important impact on future weather-related disasters are the possibility of catastrophe climate change leading to more intense storms, hurricanes and typhoons, more important flooding episodes as well as droughts and heat waves in many parts of the world, as well as environmental degradation that diminishes the capacity to sustain the impact of these extreme events. We already know that poor countries are likely to suffer the most from these changes in climate (Stern, 2006; IPCC, 2007). Unless proper risk reduction measures are in place and people and business have adequate level of financial support, we are likely to witness even more severe catastrophes in the near future. In that sense it is critical to better appreciate the link between steps taken prior to a disaster (*ex ante* actions) and those required after a catastrophe occurs (*ex post* measures)

It is also important to focus on a more *global* and *spatial view* by characterizing the types of interdependencies over space and time. Disasters can be caused by actions or inactions years before the event and when they strike in either the developed or developing world they can have ripple effects on markets and countries far away. The importance of understanding how individuals and businesses decide on whether to invest in risk reducing measures assumes even greater importance when one introduces the negative externalities due to interdependencies from an increased globalized world. Part B of this report, to which we now turn, focuses on issues of protection and risk reduction.

PART B

FROM A NORMATIVE MODEL TO A BEHAVIORAL MODEL OF PROTECTIVE DECISIONS

The effectiveness of protective measures against natural hazards is now well understood. We know how to design better homes, businesses and critical infrastructure against all types of natural hazards. We know how to develop proper warning systems that can save thousands of lives.[23] We also know how to construct financial instruments (e.g. insurance systems) to provide adequate economic protection to people and firms against the economic losses from natural disasters. Given that disasters continue to have devastating human and economic consequences all over the world, we need to better understand why these measures have not been properly adopted, so one will be in a position to develop innovative strategies for reducing future losses from potentially catastrophic disasters.

Part B begins by developing a normative model of protective decision making where individuals are assumed to have full information and make tradeoffs that satisfy a set of axioms characterizing rational choice. We then move to a behavioral analysis to explain why many people do not necessarily purchase insurance when it is attractively priced or invest in cost-effective risk reduction measures until after a disaster occurs, when it is too late.

B-1. Normative Model of Protective Decisions

In a normative model of choice under uncertainty, individuals are assumed to behave as rational decision-makers who maximize their expected utility. In the context of natural hazards, they decide prior to a disaster the types of protective measures in which to invest and how much should be expended on these actions. In a seminal paper, Ehrlich and Becker (1972) develop a normative model of individual choice that focuses on three types of protective measures:

- *Self Insurance*: Believing you have enough personal resources to cope with the consequences of a disaster to finance the recovery process should one suffer a loss
- *Market Insurance:* Purchasing coverage from an insurer to reduce the financial consequences following a loss
- *Self Protection:* Investing in risk reduction measures in advance of a disaster
- *Coping: There may* be situations where the individual decides not to take any s*pecial ac*tions in preparing for a disaster. In some cases the individual may consider the potential

[23] And because of the Internet, this knowledge is now available at low cost to those residing in developing countries, even though Internet penetration is still very low in many of those countries.

consequences of a disaster and believe that he and his family will be able to cope with the consequences without having to take any special steps *ex ante,*. In other cases, one which believe to be the predominant ones, individ*uals cope* with future disasters by behaving as if it will not happen to me. Treating the probability of a future disaster as zero enables the person to avoid having to think about investing in mitigation, purchasing insurance or even self-insure. We believe that this systematic bias is a principal reason why so many residents of hazard-prone areas are unprepared for a catastrophic event. In what follows we first determine whether an individual wants to invest in insurance and then consider the decision on whether one wants to consider self-protection when insurance is not available.[24]

Self-Insurance versus Market-Insurance

To motivate the analysis, consider the Lowlands, a hypothetical family living in Wenchuan County of the Sichuan province of China. Their house was partially destroyed by the devastating earthquake on May 12, 2008 and they are in the process of rebuilding the property and are considering whether or not they should purchase some earthquake insurance coverage *(I)* for next year, and if so how much coverage they should purchase. To keep the analysis simple, and without loss of generality, we assume only two states of nature—earthquake or no earthquake, with annual probabilities p and $1-p$, respectively. If another earthquake occurs, the damage to the Lowlands' house will be the equivalent of L dollars. The Lowlands are assumed to have accurate information on the likelihood and consequences of an earthquake occurring next year and be averse to risk.

As in the United States and several European countries, according to Chinese central government income tax laws, any uninsured loss from a natural disaster can be written off on the family's federal income taxes at the marginal tax rate t based on the Lowlands' current income. $D(I,L)$ is the amount of disaster assistance the family will receive from local and central governments or from international donors to replace the damaged property should they have I dollars of insurance coverage and L dollars of losses.[25] The cost of insurance per dollar coverage is z which covers future losses and administrative costs of marketing a policy and settling claims.

---

[24] The normative analysis could include the joint decision of insurance purchase (market or self insurance) and investment in mitigation (self protection) as in Ehrlich and Becker (1972). We have opted not to do this as it does not provide any additional insight into differences between normative and behavioral models of choice.

[25] The amount of disaster assistance is assumed to have no impact on the uninsured losses that a person can write off for tax purposes. According to the Chinese Ministry of Finance, the government disaster relief fund for quake-

We assume that there are no moral hazard problems so that the Lowland family will not take advantage of purchasing insurance by either being more careless or putting objects in harm's way.[26] Furthermore we assume that the insurer has the same information about risk as the Lowland family, so that there are no adverse selection problems.[27] If the Lowland family has wealth *W,* the optimal amount of insurance I_{opt} will be determined by maximizing the Lowlands' expected utility E[U(I)]:

$$E[U(I)] = pU_0(W - L + I(1 - z) + t(L - I) + D(I, L)) + (1 - p)U_1(W - zI) \qquad (1)$$

where $0 \le I \le L$, U_0 and U_1 represent their utility of wealth in the disaster and non disaster states, respectively. More specifically I_{opt} is first determined by setting $dE[U(I)]/dI = 0$ under the assumption that the amount of insurance that one can purchase is unconstrained and is given by the following result:

$$\frac{(1 - p)z}{p[1 - z - t + \left(\frac{\partial D(I, L)}{\partial I}\right)_{I_{opt}}]} = \frac{\left(\frac{\partial U_0[W - L + I(1 - z) + t(L - I) + D(I, L)]}{\partial I}\right)_{I_{opt}}}{\left(\frac{\partial U_1(W - zI)}{\partial I}\right)_{I_{opt}}} \qquad (2)$$

The left-hand side (LHS) of equation (2) is a contingency price ratio reflecting the tradeoff between the marginal benefit of not having insurance (the numerator) and the marginal benefit of having coverage (the denominator). The right-hand side (RHS) of (2) is the ratio of the marginal utility of an individual in the disaster state to the marginal utility in the non-disaster state. If the Lowlands are expected utility maximizers they will be more likely to buy more insurance for a given value of *W* as *L* increases and/or as the premium *z* decreases relative to *p*. Insurance coverage will be less attractive when the Lowlands expect significant disaster relief as

---

stricken areas in the aftermath of the May 2008 earthquake had reached 53.761 billion yuan (7.73 billion U.S. dollars), 50 percent of which came from central government for post-disaster reconstruction).

[26] Moral hazard refers to careless behavior caused by the presence of insurance that may increase claim payments.

[27] In the insurance context, the term adverse selection describes a situation where, as a result of private information, the insured are more likely to suffer a loss than the uninsured. But if the insurer is unable to distinguish between good and bad risks, it will price an average price that will be perceived too high by good risks. As a result, good risks prefer not to be covered; at the extreme adverse selection leads to the total failure of the market.

a function of their uninsured losses and magnitude of her loss (L) and a higher tax write-off for uninsured losses (t).

One can now determine the amount of insurance I^* an individual should purchase given that $0 \leq I \leq L$. Whenever the value of I_{opt} determined by (2) is between 0 and L, then this is the actual amount of insurance a homeowner should purchase. Should (2) yield a value of $I_{opt} > L$, which could be the case if the insurance premium is subsidized so that a person would want to buy more than full coverage, then $I^* = L$. If (2) indicates that $I_{opt} < 0$, then the individual will not purchase any coverage and $I^* = 0$.

Investing in Self Protection Measures

Suppose now that the Lowlands have an opportunity to reduce the future losses from a future earthquake by bracing the structure to its foundation with additional cripple walls at an upfront cost of c. Should an earthquake occur then the losses will be reduced to $L' < L$. The mitigation measure yields risk-reduction benefits over the life of the house so in this sense it differs from an insurance policy which provides financial benefits only for a single year. Given an annual discount rate d and an estimated life of their home of T years, the Lowlands expected utility [E(U(B)] from investing in mitigation is given by

$$E[(U(B)] = \sum_{t=1}^{T} p\,[U(W-L') - U(W-L)]/(1+d)^t \qquad (3)$$

The decision rule facing the Lowlands is very straightforward

If $E[(U(B)] > c$ Invest in self-protection

If $E[U(B)] < c$ Do Not invest in self-protection

Self-protection will be more attractive as the life of the house (T) increases, the discount rate (d) decreases, the reduction in loss from self-protection ($L-L'$) increases and c decreases.

Interdependencies and the Coordination Challenge

Up to this point we have assumed that the risk an individual faces could be influenced only by her own actions. In reality, the vulnerability of one individual, one firm and/or country often depends not only on her/its own choice of protection investments, but also on the actions of other agents. This concept of *interdependent security* implies that failures of a weak link in a connected system could have devastating impacts on all parts of it, and that as a result there may be suboptimal investment in the individual components (Kunreuther and Heal, 2003; Heal and Kunreuther, 2006).

Consider the problem facing two villages located next to each other near a river that exchange goods for their respective production activities. Both villages might want to increase their population and economic base by using land closest to the river, which requires destroying trees and other natural vegetation. In undertaking such development they might increase the risk of flooding for both villages, since replacing soil and vegetation with concrete increases the runoff from rain and storms. In addition, there is no natural barrier anymore to restrain excess water. To reduce the likelihood of future flooding, each village could construct a flood control measure to control this additional flow of water from their new economic developments.

Coping with the management challenges of such floods is, however, a very difficult matter, as the interdependencies involved require cooperative activity and monitoring across these two villages in ways that are not captured in the traditional risk assessment and risk management approach where each village is assumed to make its own decision and there are no negative externalities associated with their actions.

To highlight the need for coordination in this context, consider the two-village example above where *Village 1* (V_1) is with assets A_1 and *Village* 2 (V_2) with assets A_2. Each village could invest in measures to protect its citizens, infrastructure and businesses against damage from flood that will occur at either one village or the other. The cost of a protective measures for village i is c_i , $i=1,2$. To keep the analysis simple, assume that if both villages undertake this action, the chances of experiencing a loss from this event is zero.

If V_1 does not invest in proper mitigation measures to protect itself and V_2 does, then there is a probability p_1 that V_1 will experience a loss L_{11} and will create a loss to V_2 of L_{12}. For example, L_{12} represents the lost profits to V_2 if V_1 experiences damage from an flood so that it has reduced its export activity with V_2. Similarly, if V_2 does not invest in protection but V_1 does, then it has a probability p_2 of experiencing a loss from flooding of L_{22}, that will also create problems for V_1 , who has lost profits from flooding of L_{21}.

If neither village invests in protection, then there is the possibility that either of the villages will experience a loss with probabilities p_i $i=1,2$ and have a negative impact on the other village. For simplicity, we assume throughout that the damages that result from multiple protection failures are no more severe than those resulting from a single failure. In other words, damages are non-additive.[28] The key issue is actually whether or not there is a failure, not how many failures there are. The loss matrix for the different outcomes under the assumption that each village wants to minimize its expected cost is depicted in Table 6.

Table 6: Expected Costs Associated with Investing and Not Investing in Protection

		Village 2 **(V_2)**	
		S	N
Village 1 **(V_1)**	S	$A_1-c_1,\quad A_2-c_2$	$A_1- c_1 - p_2 L_{21},\quad A_2- p_2 L_{22}$
	N	$A_1-p_1 L_{11},\quad A_2-c_2 - p_1 L_{12}$	$A_1-[p_1 L_{11} + (1-p_1) p_2 L_{21}],$ $A_2- [p_2 L_{22} + (1-p_2) p_1 L_{12}]$

In this two-agent game there can be two Nash equilibria ***(S,S)*** or ***(N,N).*** For both villages to decide to invest in protection may require them to coordinate their actions. They would have to agree that it would be in each of their best interests as well as society's to incur these upfront costs to avoid the potential consequences of a disaster to their villages. Without such coordination there may be economic incentives for each of the villages not to incur this extra cost of investing in flood protection. Why? Because even after protecting itself, each village knows that it can suffer an additional loss if the other village does not follow suit. The possibility of experiencing this negative externality may make it more profitable for each village to **not** incur these costs of protection and expend these resources in other ways. As one expands the number of villages to an entire province or state, the likelihood of incurring losses from others due to interdependencies in the system increases, and the importance of coordination becomes even greater (see Appendix 1).

In some cases a change of strategy by one agent or a small set of agents can shift the equilibrium radically. We refer to this change as tipping in the sense of Schelling (1978), Katz and Shapiro (1994), Watts (1999) (in the context of general networks) and more recently Gladwell (2000). For example, there may be a Nash equilibrium at which no village invests in protection. Yet if one village changes strategy and invests, then other villages may follow suit.

[28] We recognize that there are lots of scenarios of natural disasters that could inflict additive damage or where the presence of several protection barriers makes a system more unlikely to suffer a loss. The model characterized in Table 6 can be modified to incorporate these situations.

Heal and Kunreuther (2007) indicate that tipping of equilibria are natural consequences of mutual reinforcement. If there are several equilibria, one of which Pareto dominates, then they show that the inefficient equilibria can be tipped to the efficient one, a result of interest in the context of coordination problems.

Tipping requires an initial mover or group of movers who begin the process. Sometimes it may be in their interest to do so. In other cases agents may need an incentive from outside the game(a subsidy or a penalty) to change strategy and tip the equilibrium. This is the case for many of the interdependency examples discussed in Box 1. Regulators can use the existence of a tipping set as a way of coordinating on a socially preferable equilibrium. They only have to persuade the members of the tipping set to change, rather than persuading everyone.

What are the policy and strategy implications of these tipping behavior results on critical coalitions in the context of large-scale global risks? Clearly one is that an equilibrium with no investment in self-protection may be converted to one with full investment by persuading a subset of the agents to change their policies. Leadership, either through trade associations and/or through influential firms, or international organizations that take the lead, may convince others of the need to adopt adequate mitigation measures. A trade association can play a coordinating role by stipulating that any member must follow certain rules and regulations and has the right of refusal if they are asked to do business with an agent that is not a member of the association and/or has not subscribed to the ruling. Even without such a formal mechanism, if a few villages or organizations voluntarily take actions, they could convince others to follow suit and induce tipping in the spirit of Schelling (1978).

B-2. Behavioral Models of Protective Decisions[29]

The normative framework developed above is a useful benchmark but is also based on the following assumptions: risk is perfectly known and there is no uncertainty surrounding estimates of the probability and the loss; the Lowlands determine what actions to undertake by maximizing their expected utility based on a utility function which they are able to construct. Individuals have full information on the insurance premium, the types of mitigation measures available and the costs of each one as well as the expected benefits to them of undertaking these investments. Individuals convert future benefits into the present by using an exponential discount rate *d*. Investment in insurance and self-protection does not compete with other expenditures a

[29] The material in this section is based on Kunreuther, Meyer and Michel-Kerjan (2009).

family might incur (e.g., food, clothes, education of the children). Finally, in the case of interdependent risks, each agent has accurate information on the likelihood of being contaminated or negatively impact by others.

In this subsection, we focus specifically on some of these assumptions by developing a descriptive model of choice using the concept of goals and plans as guiding forces. We then provide empirical evidence characterizing the decision processes of individuals, managers and public sector officials with respect to investing in protective measures prior to a disaster.

Goals and Plans in Decision Making[30]

The concept that goals and context have a strong influence on decision making can be traced to Aristotle's Ethics (circa 350 B.C.E.). There, he highlighted the importance of multiple goods as a basis for making choices and stated that the way in which different goals fit together should vary with the occasion. This concept is consistent with a theory of choice where preferences are constructed based on context (Slovic, 1995) and a decision maker focuses on goals rather than on maximizing happiness or utility.

A plan to purchase a particular amount of fire and theft insurance (on a home, say, or on the contents of a rented apartment) may be designed to satisfy the following seven goals (and perhaps others) simultaneously: (i) reducing the chances of a catastrophic financial loss, (ii) reducing anxiety about risks of fire and theft, (iii) avoiding regret and/or providing consolation in case a loss occurs, (iv) satisfying requirements stated by a bank or by a landlord, (v) presenting the appearance of prudence to others who will learn about the insurance purchase, (vi) maintaining ones relationship with an insurance agent, and (vii) avoiding highly burdensome insurance premium payments.

The relative importance of these goals obviously varies with the decision maker, but may also be affected temporarily by contextual variables. When reflecting on paying monthly bills, an insurance purchaser may think chiefly about the goals of satisfying the requirements of the bank that holds the mortgage loan (goal iv above), at the lowest possible insurance premium (goal vii). When that same person reflects on her valuable works of art, she may think chiefly about reducing anxiety (goal ii) and avoiding regret (goal iii).

The plan/goal representation appears to capture the insurance decision making process, as illustrated by the following example. People often purchase flood insurance (Plan 1) rather than

[30] This section draws heavily on Krantz and Kunreuther (2007).

not purchasing it (Plan 2) after suffering damage in a flood, but then many cancel their policies when several consecutive years pass with no flood. (Kunreuther, Sanderson & Vetschera, 1985). A simple explanation is that avoiding anxiety and feeling justified are both important goals. Following flood damage, anxiety is high, and reducing it is a salient goal; it is also easy to justify buying the insurance, since a flood has just occurred.

Thus, Plan 1 is selected, based strongly on feeling justified and avoiding anxiety. After several years, many people may find that the prospect of a flood no longer troubles their "peace of mind" so anxiety avoidance now has low value. Meanwhile, insured individuals do not feel justified in continuing to pay premiums and not collecting on their policy. The differential weighting of these two goals (relative to protection of a valuable asset) can lead to deciding not to purchase it (Plan 2) (i.e. cancel their existing policy).

Note that this theory predicts that a decision maker who puts heavy weight on the goals of avoiding catastrophic loss and avoiding vast regret will likely continue to purchase flood insurance year after year if the cost is modest. A decision advisor, confronting such a view, might well ask the individual about the role played by feeling that insurance which has never paid anything is unjustified, about the importance of having a good justification for purchasing insurance, and about whether protection against catastrophic losses might justify paying the premium.

Table 7 depicts aspects of the plan/goal model in an abstract form. Here, the i^{th} plan yields a decision weight w_{ij} (cell entries) for the j^{th} goal, G_j. This notation does not, however, explicitly show the contingencies leading to each goal. Each G_j is assigned a value $v_j = v(G_j)$. Plans have decision weights for each goal; $w_{ij} = w(G_j \mid \text{plan } i)$. Plan i is evaluated in terms of the v_j and w_{ij}.

TABLE 7: GENERAL PLAN/GOAL STRUCTURE FOR DECISION MAKING

MATRIX ENTRIES ARE DECISION WEIGHTS FOR DIFFERENT GOALS, CONDITIONAL ON EVENTS

Possible plans	Active Goals			
	G_1	G_2	…	G_n
plan 1	w_{11}	w_{12}	…	w_{1n}
plan 2	w_{21}	w_{22}	…	w_{2n}
…	…			
plan m	w_{m1}	w_{m2}	…	w_{mn}

Informal Processes Used to Make Choices

To examine how individuals actually deal with catastrophic risks, consider again the Lowland family who are unsure whether they want purchase insurance and/or invest in earthquake reduction measure (e.g. retrofitting). Below, we review the range of informal processes that are used to make choices regarding investing in mitigation measures (self-protection), many of which also apply to insurance decisions. Table 8 summarizes the principal decision biases and heuristics that will be discussed in more detail below.

TABLE 8. DECISION BIASES - CATASTROPHE RISK PROTECTION AND INSURANCE PURCHASE

	Mitigation (Self Protection)	Insurance
Budgeting Heuristics	X	X
Misperceptions of probability	X	X
Affective forecasting errors	X	X
Underweighting the future	X	
Myopic behavior	X	
Learning failures	X	X
Social norms and interdependencies	X	X
Samaritan dilemma	X	X
Politician dilemma	X	

Budgeting Heuristics

The simplest explanation as to why individuals fail to mitigate or purchase insurance in the face of transparent risks is affordability. If the Lowland family focuses on the upfront cost of quake-proofing their house or the insurance premium to cover their potential loss, and they have limited disposable income after purchasing necessities, they may decide not to even think about undertaking either of these protective measures.

In focus group interviews to determine factors influencing decisions on whether to buy flood or earthquake coverage, one uninsured worker responded to the question "How does one decide how much to pay for insurance?" as follows:

> A blue-collar worker doesn't just run up there with $200 [the insurance premium] and buy a policy. The world knows that 90 percent of us live from payday to payday….He can't come up with that much cash all of a sudden and turn around and meet all his other obligations." (Kunreuther et al 1978, p. 113)

The budget constraint for investing in protective measures may extend to higher income individuals if they set up separate mental accounts for different expenditures (Thaler, 1999). Under such a heuristic, a homeowner who is uncertain about the cost-effectiveness of mitigation might simply compare the price to that which is typically paid for comparable home improvements. Hence, a $2,000 investment may be seen as reasonable affordable by those who frame it as a large improvement similar to installing a new roof, but unaffordable to those who frame it as a repair similar to fixing a leaky faucet.

Making mitigation decisions in this manner does not conform to guidelines implied by the expected utility model and there is evidence from controlled laboratory experiments that it may not be uncommon. For example, in a study that asked individuals why they were willing to pay only a fixed amount for a dead bolt lock when the lease for the apartment was extended from 1 to 5 years, one respondent said, "$20 is all the dollars I have in the short-run to spend on a lock. If I had more, I would spend more—-maybe up to $50." (Kunreuther, Onculer and Slovic (1998) p. 284). Similarly, we suspect that some residents in coastal zones are discouraged from buying and installing storm shutters because the cost exceeds that of the window itself rather than evaluating the benefits of the storm shutters with respect to protecting the contents inside the house that will be a major loss if there is no shutter and the window breaks.

Misperceptions of Probability

Another factor that could impact on investment decisions in mitigation and/or the purchase of adequate insurance coverage is the failure to consider the likelihood of the event occurring in a systematic manner. Magat, Viscusi and Huber (1987) and Camerer and Kunreuther (1989), for example, provide considerable empirical evidence that individuals do not seek out information on probabilities in making their decisions. Huber, Wider and Huber (1997) showed that only 22 percent of subjects sought out probability information when evaluating risk managerial decisions. When consumers are asked to justify their decisions on purchasing warranties for products that may need repair (a form of insurance) they rarely use probability as a rationale for purchasing this protection. (Hogarth and Kunreuther, 1995).

This evidence that individuals do not find statistical probability to be a useful construct in making risky decisions does not, of course, imply that decisions are not based on subjective beliefs about relative risk. To the contrary, when asked, individuals have no problem expressing beliefs about the relative riskiness of hazards (e.g., Lerner et al. 2003). But these beliefs are not well-calibrated. When directly asked to express an opinion about the odds of being personally affected by different hazards, people consistently respond with numbers that, perhaps surprisingly, are far *too high* relative to actuarial base rates. For example, in a recent study of risk perception, Lerner et al. (2003) found that when people were asked to provide an estimate of the probability that they will be the victim of a violent crime over the coming year, the mean estimate was 43 percent – an estimate that was far too high compared to actuarial base rates, and comparable to that which they expressed when asked to estimate the odds of getting the flu (47 percent). If these estimates actually reflected heightened fears about being exposed to hazards, it would strongly argue against the idea that people fail to mitigate simply because they assume that they will be immune. But these results may be speaking more to individuals' lack of familiarity with statistical constructs than real evidence that people are pessimistic.

On the other hand, there is also evidence that people tend to ignore risks whose subjective odds are seen as falling below some threshold. In a laboratory experiment on purchasing insurance, many individuals bid zero for coverage, apparently viewing the probability of a loss as sufficiently small that they were not interested in protecting themselves against it (McClelland et al. 1993).[31] If the Lowland family in China exhibits similar threshold-based behavior, they would not have any interest in investing in a loss mitigation measure nor to purchase financial protection no matter how large the savings would be.

Prior to the Bhopal chemical accident in India in 1984, firms in the industry estimated the chances of such an accident as sufficiently low that it was not on their radar screen. Similarly, even experts in risk disregard some hazards. For instance, after the first terrorist attack against the World Trade Center in 1993, terrorism risk continued to be included as an unnamed peril in commercial insurance policies so insurers were liable for losses from a terrorist attack without ever receiving a penny for this coverage. Because insurers had not integrated the threat into their portfolio management, the September 11, 2001 attacks obligated nearly 150 insurers and reinsurers from all over the world that covered firms in the World Trade Center to pay over $35 billion in claims.

---

[31] Others were willing to pay considerably more than the expected loss suggesting that these individuals were fearful of suffering a loss as documented by Lerner et al. (2003) for other risks.

There is an additional element to consider here. Some public sector investments in infrastructure such as levees and dams can give residents a false sense of security with respect to the likelihood that they will suffer future damage from natural disasters. The geographer Gilbert White pointed out many years ago that when these projects were constructed, many individuals believed that they would be fully protected against future disasters, leading to increased development of the flood plains just behind levees, and larger losses from a future disaster than otherwise would have been the case. This behavior and its resulting consequences has been termed as the *levee effect.*

Affective Forecasting Errors

There are extensive bodies of work showing that individuals tend to be both poor forecasters of future affective states (e.g., Wilson and Gilbert, 2003), and focus on different features of alternatives when they are viewed in the distant future versus today (e.g., Trope and Liberman 2003). Probably the most relevant heuristic with respect to insurance and mitigation decisions is the tendency for affective forecasts to be subject to what Loewenstein, O'Donoghue, and Rabin (2003) term the *projection bias*—a tendency to anchor beliefs about how we will feel in the future on what is being felt in the present.

As a result, there will be a natural tendency to underestimate the value that one would attach to having protection prior to a disaster occurring. After major catastrophes, a common theme heard from survivors trapped in the floods or whose house has been destroyed by an earthquake or a storm is, "Had I known it would be this bad, I would have left." Comments such as these were heard in September 2008 from Galveston residents who refused to evacuate prior to Hurricane Ike. The reality, of course, was that in high-risk areas inhabitants knew that there was a risk; Hurricane Katrina was quite illustrative of this too: the storm was preceded by warnings of the most dire sort, that Katrina was "the big one" that New Orleans' residents had been warned to fear for years (Brinkley 2006). But it is one thing to imagine being in a flood, quite another to actually be in one. Judgments of the severity of the experienced were unavoidably biased downward by the relative tranquility of life before the storm.

Finally, the tendency to value costs and benefits differently depending on temporal perspective is another mechanism that could result in procrastination. Trope and Liberman

(2003) offer a wide array of evidence showing that when making choices for the distant future we tend to focus on the abstract benefits of options, whereas when making immediate choices we tend to focus on concrete costs. It would not be uncommon to hear politicians pledge their deep commitment to building safer societies at election-time (when costs loom small relative to abstract benefits), but then back away from this pledge when the time comes to actually make the investment—when the costs loom larger.

Underweighting the Future

The empirical evidence on how individuals make inter-temporal judgments is not encouraging. Although decisions often follow the directional advice of normative theory (such as by valuing temporally distant events less than immediate ones), they frequently depart from those prescribed by rational theories of inter-temporal choice. Moreover, they depart in a way that collectively discourages far-sighted investments in mitigation.

To see this, consider the investment problem faced by the Lowlands. For simplicity, suppose that that the family knows that they will be living in their new home in Wenchuan County for T years, that each year there is a probability p_t of a major earthquake in year t, and that should such an event occur the mitigation measures will reduce losses by an amount B. In this case, the decision to mitigate could be made by observing whether the upfront cost (C) of mitigation is less than the discounted stream of benefits; i.e., if

$$u(C) < \sum_{t=1}^{T} p_t u(B) \beta^t \qquad (4)$$

where β is the family (consumer)'s discount rate, and $u(x)$ is the family's utility associated with the benefit *(B)* or cost *(C)*.

While simple in its structure, implicit in (4) are a series of rather strong assumptions about how the Lowlands will value costs and benefits over time. Specifically:

1) all future benefits are evaluated vis-à-vis a constant rate of discounting;
2) individuals can estimate future probabilities of earthquake in year t accurately
3) the utility function is time-invariant.

There is ample evidence that violations of these assumptions will be common. In particular, homeowners are likely to overweight short-term cash expenditures, have distorted beliefs about probabilities, and value common outcomes differently over time. The implications of these biases for mitigation decisions will be reviewed in turn.

Specifically related to the underweighting of the future, a fundamental feature of human cognition is that we are influenced more by cues that are concrete and immediate than those that are abstract and delayed. To some extent, of course, rational inter-temporal choice theory prescribes that we *should* give less weight to distant future outcomes, and this prescription is captured by the constant discount rate β in (4). there is extensive experimental evidence showing, however, that human temporal discounting tends to be *hyperbolic*, where temporally distant events are disproportionately discounted relative to immediate ones. As an example, people are willing to pay more to have the timing of the receipt of a cash prize accelerated from tomorrow to today than from two days from now to tomorrow (Loewenstein and Prelec 1992). The implication of hyperbolic discounting for mitigation decisions is that we are asking residents to invest a tangible fixed sum now to achieve a benefit later that we instinctively undervalue—and one that we, paradoxically, hope never to see at all.

The effect of placing too much weight on immediate considerations is that the upfront costs of mitigation will loom disproportionately large relative to the delayed expected benefits in losses over time. A homeowner might recognize the need for mitigation, and see it as a worthwhile investment when it is framed as something to be undertaken a few years from now when both upfront costs and delayed benefits are equally discounted. However, when the time arrives to actually make the investment, a homeowner subject to hyperbolic discounting might well be reluctant to make the decision to invest today in cost risk-reduction measures.

This tendency to shy away from undertaking investments that abstractly seem worthwhile is exacerbated if individuals have the ability to *postpone* investments—something that would almost always be the case with respect to mitigation whether one focuses on high-, middle- or low-income individuals. A case in point is the relative lack of preparedness demonstrated by the city of New Orleans and FEMA in advance of Hurricane Katrina in 2005 in the United States. In this case, the consequences of failing to invest in mitigation—such as developing a workable evacuation plan—could not have been more salient or more temporally proximate; just two months prior to the storm the city engaged in a full-scale simulation that graphically demonstrated what would happen should a hurricane of Katrina's strength hit the city, and the city was moving into the heart of an active hurricane season (Brinkley 2006). Yet, little was done to remedy known flaws in their preparedness plans. The explanation, we suggest, lies in the fact that the investments could be postponed; the natural instincts that policy makers have to not mitigate because of an aversion for short-term costs became easier to rationalize when it was simply a matter of delaying rather than permanently aborting investments (see also the *Politician's Dilemma* discussed below). Emergency planners and the New Orleans Mayor's office were fully aware of the risks the city faced, and publicly announced their intention to invest the resources needed to mitigate them. But these measures were never enacted for the simple reason that the expenditures were always politically more attractive when presented as part of next year's budget than this year's.

To see this effect more formally, imagine that the Lowlands view the future benefits of mitigation not in terms of a constant discounting schedule, but rather by the hyperbolic discounting function:

$$f(t) = \begin{cases} 1/k \;\; for \;\; t = 0 \\ \beta^t \;\; for \;\; t > 0 \end{cases} \tag{5}$$

where $0<k<1$ is a constant that reflects the degree to which immediate costs and benefits are given disproportionately more weight than delayed ones (Laibson 1997; Meyer, Zhao, and Han 2007). Expression (5) has an intriguing implication. Suppose that it is January 2010 ($t=0$) and the Lowlands are considering whether it is worthwhile to invest in a mitigation project for their new house that would start in June 2010 ($t=1$). As long as costs remain temporally distant, the value of the project will be assessed via the rational inter-temporal discounting model in (4); that is, the expected net value of the mitigation project, $V(I|January)$, is:

$$V(I \mid January)) = [\sum_{t=1}^{T} p_t k \beta^t u(B)] - \beta u(C) \tag{6}$$

Suppose the Lowlands conclude that the project is minimally worthwhile, that is, $V(I|January)=\varepsilon$, where ε is a small positive valuation. Hyperbolic discounting carries a curious implication for how the Lowlands will value the risk-reduction project come July; when the prospect of the expenditure *C* is immediate. In June, the project will look decidedly less attractive, since it value will now be:

$$V(I \mid June) = [\sum_{t=1}^{T} p_t u(B) k \beta^t] - u(C)/k \qquad (7)$$

Hence, if $(1/k-\beta)C>\varepsilon$, it will no longer seem worthwhile to invest.

So will the Lowlands abandon their interest in mitigation? Paradoxically, we suggest no; if the builder gives them the option to restart the project the *following* January, it will once again seem worthwhile, since its valuation would be given by the standard model in (6). Hence, the Lowlands would be trapped in an endless cycle of procrastination; when viewed from a temporal distance the investment will always seem worthwhile, but when it comes time to undertaking the work the prospect of a slight delay always seems more attractive.

Other psychological mechanisms could also produce perpetual postponements of investments in mitigation. The most salient is the observed tendency for individuals to defer ambiguous choices. The less certain one is about a correct course of positive action, the more likely one is to choose inaction (Tversky and Shafir, 1992). This ambiguity would seem particularly acute in the context of mitigation decisions against low-probability/high impact events where the question of whether it is optimal to mitigate is often unknowable for a single household, and there is infinite flexibility in *when* one can undertake the investment. Finally, when viewed locally, the risk of a short delay in the start of mitigation is typically negligible. While seismologists are reasonably certain that there will be a major earthquake in Istanbul, Turkey in the next 25 years, odds are strongly against it happening tomorrow morning.[32] As such, residents who postpone the decision from day-to-day will rarely be punished for their inaction.

[32] As of 2006, insurance penetration for quake coverage was only 30 percent in the city of Istanbul (Gurenko et al., 2006).

Myopic Behavior

The concept of hyperbolic discounting discussed above is distinct from *myopic behavior* or the tendency to consider consequences over a time horizon that is too short relative to relevant value of *T.* For example, if the Lowlands wanted to recover the costs of their mitigation measure in two or three years they would underestimate the expected benefits of mitigation by using this truncated time period rather than the expected life of the house as depicted in equation (2) which might by T=20 or 30 years.

While we are not aware of work that has examined empirically whether individuals exhibit such myopic behavior, the fact that the vast majority (72 percent) of U.S. homeowners prefer 30-year fixed (as opposed to adjustable) mortgages has been taken by some economists as evidence that homeowners, if anything, *over*estimate the length of time they will likely live in their homes (Campbell, 2006). In any case, it is paradoxical, then, that homeowners would display acute concern for minimizing long-term risk when securing mortgages, but display little comparable concern when making decisions about investing in mitigating potential damage to their home. Whether this applies also to low- and middle-income countries is an open question for future research.

Learning Failures

The above discussion makes a clear argument that individuals are likely to under invest in protective measures by focusing too much on upfront costs in relation to expected benefits and/or underestimate the likelihood that the disaster will happen to them. Once the consequences of under-mitigation are observed in the aftermath of a major disaster, intuition suggests that there would be a natural tendency to correct the biases that led to the initial error. Indeed, there is some evidence that mitigation errors are naturally correcting; early Mayans learned (no doubt by experience) that it was safer to build cities inland than on the hurricane-prone coasts of the Yucatan, the loss of 6,000 lives in Galveston in 1900 taught the city that it needed a seawall to protect against future storms, and it took the disaster of Katrina for New Orleans to finally put in place a comprehensive evacuation plan (Brinkley, 2006).

The problem, however, is *not* that we do not learn, but rather that we do not seem to learn *enough* from the experiences of disaster. As an illustration, when Hurricane Wilma hit south Florida in October of 2005 thousands residents failed to take such simple preparatory measures as securing bottled water and filling their cars up with gas—oversights that greatly added to the challenges of recovery. What was surprising about this lack of preparation was that the region had ample warning of the storm's approach (the impact was forecast up to four days in advance), and it came at the end of the most destructive hurricane season on record, one where the news media were constantly filled with graphic illustrations of the destructive power of such storms (such as the flooding in New Orleans). Other familiar examples exist as well—such as the tendency to re-settle in flood plains after major floods, and become increasingly lax in earthquake preparedness as the time since the last quake lengthens.

What explains the seeming lack of learning by residents? The reason, we suggest, is that we instinctively learn to protect ourselves against hazards by relying on the same trial-and error heuristics that have proven successful in other walks of life: heuristics that encourage us to repeat those behaviors that yield positive rewards and avoid those behaviors that yield negative outcomes. But while reinforcement learning is a highly efficient way to learn to perform such repeated tasks as walking, speaking, and playing tennis, it is particularly ill-suited for learning how best to respond to low-probability, high-consequence hazards. The reason is simple: most protective behaviors will be negatively reinforced far more often than they will be positively reinforced[33].

As an example, when Hurricane Wilma approached south Florida in 2005, the vivid news depictions of suffering Katrina survivors were counterbalanced by a different, and more salient source of information: residents' recollections of the seven false-alarms that the area had received during the previous two years. For many, the hurricane warnings posted for Wilma triggered memories of rushing to secure supplies of water and gas before a storm, only later to find out that their efforts were unnecessary. For everyone else, it was memories of how gambling paid off; their decisions *not* to prepare for all the *previous* storms had turned out to be the right ones (in hindsight). These elements are likely to be reinforced in poor and middle income countries where both population and local government have to consider upfront investment in long-term risk-reduction measures as competing proposals than more urgent needs.

[33] A good example of reinforcement learning is in Cuba which replays footage from past hurricanes on national TV to "remind" viewers about the damages that they could incur.

A second major impediment to learning is the inherent ambiguity of feedback about what constitutes optimal mitigation. In the course of disasters, one can rarely observe the counterfactuals critical to learning: what damage would have occurred had certain mitigation steps been taken (or not taken) and what would it have taken to ensure these protections measures were in place when the disaster hit.

As noted by Meyer (2006), one consequence of this feedback property is that it supports the persistence of superstitious beliefs about mitigation strategies. A good example is the old adage that one should open windows in advance of a storms or typhoons so as to equalize pressure everywhere in the house. It took structural engineers years to discover that open windows were more likely to be the *cause* of building failures than the cure (entering wind exerts upward pressure on roofs); yet the myth is still widely held. The reason, of course, is that it is impossible to infer from observing a destroyed house whether it would still be standing had the windows been closed—or indeed whether they were open or closed to begin with.

Social Norms and Interdependencies

Let us return again to the dilemma faced by the Lowland family in China, who is considering investing in protection measures for its new house that was destroyed by the May 2008 earthquake. Decisions made by their neighbors also carry information value—or at least are likely to be perceived as such. As in an information cascade (Sunstein 2006), if a large number of neighbors have already decided to reinforce the structure of their house and purchase insurance, the Lowlands might plausibly conclude that that these investments must be cost effective. Of course, such inferences could be wildly mistaken if their neighbors' decisions were also based on imitation; much like a fad, one might observe communities collectively adopting mitigation measures that have little actuarial or engineering basis.

To illustrate such effects, the Wharton Risk Center recently conducted a laboratory study of social network effects in earthquake mitigation. In the study, participants were told that they would be living in an area prone to periodic earthquakes, and that they could purchase structural improvements in their homes that potentially mitigated the effects of quakes should one arise. The task was to make these decisions as efficiently as possible in the following sense: at the end of the simulation they would be paid an amount that was tied to the difference between their home value and interest earning, minus the cost of mitigation plus damage repairs. Throughout the simulation they could observe the investment decisions being made by others in their virtual community, as well as damage they suffered from quakes. The key source of uncertainty in the simulation was whether the mitigation was cost effective or not; half of the participants were placed in a world where mitigation was not cost effective (hence the optimal investment was 0 percent), and the other half were placed in a world where it was long-term effective (hence the optimal investment was 100 percent). Our interest was in observing whether communities could discover the optimal level of mitigation over repeated plays of the game.

The basic result was that they could not; consistent with the findings on learning discussed above, there was little evidence of either community naturally discovering the optimal level of mitigation (the investment level in both worlds averaged 40 percent). There was, however, a social norm effect: the major driver of individual decisions about how much to invest was the average level of investment made by neighbors. Would learning have been enhanced had the communities been populated with a few opinion leaders who had knowledge of mitigation's true effectiveness? To investigate this, we ran a new set of studies where, prior to the simulation, one player in each community was privately informed of the true effectiveness of mitigation. Other players knew that one among them had this information, but that person's identity was not revealed—but could likely be inferred by observing players' investment behavior. For example, a player who is told that investments are ineffective would, presumably, invest 0 percent from the start. Did this "knowledge seeding" help communities learn? It did but—quite surprisingly—only in the case where investments were ineffective. In these communities, players seemed to immediately recognize the informed player (who was not investing), and after two rounds of the game almost all investments in mitigation had vanished, as it should have.

In contrast, in communities where mitigation was effective, rather than investments increasing over time, they *decreased.* For many of the reasons described earlier in this section, players who were told that mitigation was effective did not play the optimal strategy of investing 100 percent at the start—they procrastinated. The other players, seeing no one with a high level of investment, then mistakenly concluded that they must be in a world where mitigation was ineffective, hence invested only a small amount themselves. Then, bizarrely, the informed players—who should have been opinion leaders—became followers, reducing their own investments. After multiple plays of the game, few players were making any investments at all, even though it was optimal for them to do so in the long-run. (Meyer 2008).

Of course, one might hope that in real-world settings, opinion leadership and tipping strategies might be more effective. Evidence along these lines has been presented by Schelling (1978) and popularized by Gladwell (2000). Heal and Kunreuther (2005) provide a game theoretic treatment of the impact of interdependency on the decision to invest in protective measures and suggest ways to coordinate actions of those at risk, ranging from subsidization or taxation to induce tipping or cascading to rules and regulations, such as well-enforced building codes (see Appendix 1).

The Samaritan's Dilemma

One of the arguments that has been advanced as to why individuals do not adopt protective measures or purchase adequate insurance coverage prior to a disaster is that they assume liberal aid from the government or the international community will be forthcoming anyway, should they suffer losses from an earthquake, hurricane or flood. A graphic example comes from the Alaska earthquake of 1964, when the federal government provided low-interest loans to aid the recovery and retired debts from existing mortgages for those who were uninsured. It was not uncommon to hear the few homeowners who did purchase earthquake insurance bemoan their decision because they discovered they would have been better off financially had they not purchased this coverage. (Dacy and Kunreuther, 1968).

More recently, only one month after the tsunami in Asia in December 2004 that killed over 250,000 people, the International Federation of Red Cross and Red Crescent Societies announced that the $1.2 billion pledged worldwide in the 30 days since the tsunami was sufficient to meet the costs of the entire Red Cross tsunami relief program. Two months after the Sichuan Earthquake in May 2008, the Chinese government disaster relief fund reached 59.1 billion yuan (US$8.44 billion) and domestic and foreign donations has increased to 57.6 billion yuan in cash and goods.

This post-disaster assistance is viewed as legitimate in the aftermath of a catastrophe. No one is suggesting that governments and the international community should not help the victims.

But it must also be recognized that this response can create a type of Samaritan's dilemma: providing assistance *ex post* (after hardship) reduces the economic incentive to invest in protective measures *ex ante* (before hardship occurs) (Buchanan, 1975). If the Lowland family expects to receive government assistance after a loss, it will have less reason to invest in mitigation measures and purchase insurance prior to an earthquake. Translating this on a large scale, the increased losses from future catastrophes increases the government's incentive to provide liberal assistance to victims with the media amplifying the need for relief.

The empirical evidence on the role of disaster relief suggests, however, that individuals or communities have *not* based their decisions on whether or not to invest in mitigation measures by focusing on the expectation of future disaster relief. Kunreuther et al. (1978) found that most homeowners in earthquake- and hurricane-prone areas did not expect to receive aid from the federal government following a disaster. Burby et al. (1991) found that local governments that received disaster relief undertook more efforts to reduce losses from future disasters than those that did not.

The Politician's Dilemma

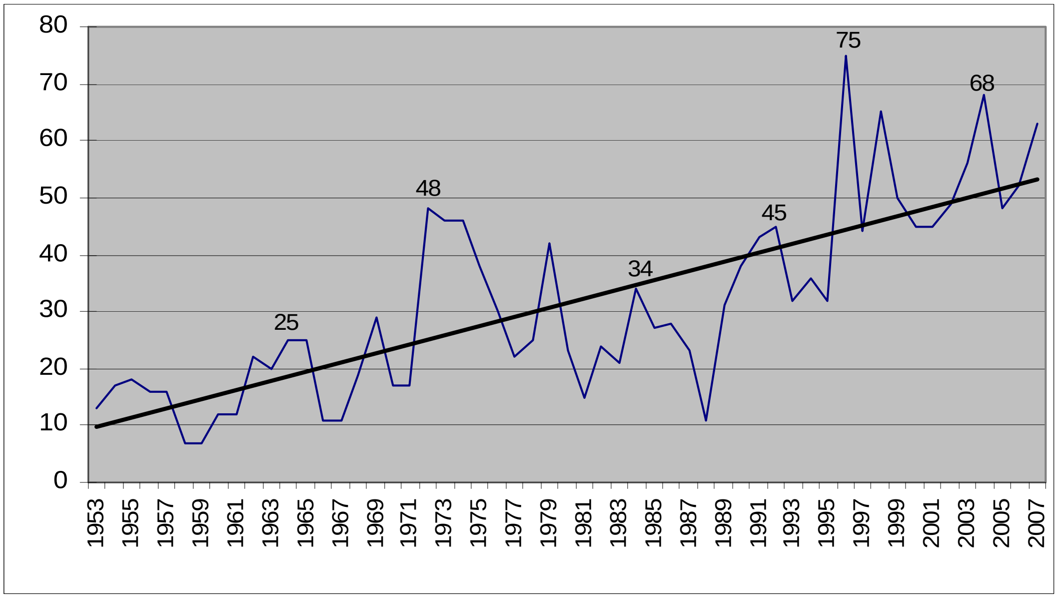
The fact that politicians can benefit from their generous actions following a disaster raises basic questions as to the capacity of elected representatives at the local, state and federal levels to induce people to adopt protection measures before the next disaster. The difficulty in enforcing these mitigation measures has been characterized as the *politician's dilemma* (Michel-Kerjan, 2008a).

Imagine an elected representative at the city or state level. Should s/he push for residents and businesses in his/her constituency to invest in cost-effective mitigation measures to prevent or limit the occurrence of a disaster? From a long-term perspective, the answer should be *yes*. But given short-term re-election considerations, the representative is likely to vote for measures that allocate taxpayers' money elsewhere where they yield more political capital. Little consideration is given to supporting mitigation measures prior to a disaster (*ex ante)* because elected officials believe that their constituencies are not concerned about these events. There is likely to be a groundswell of support for generous assistance to victims from the public sector after a disaster (*ex post)* to aid their recovery.

While one would need to study disaster assistance systems in a large range of countries to provide a robust empirical analysis of how politics and disasters coalesce (see Raschky and Schwindt, 2008), evidence from the U.S. is quite enlightening in this regard. Under the current U.S. system of disaster assistance, the Governor of the state(s) can request that the President declare a "major disaster" and offer special assistance if the damage is severe enough. Although the President does not determine the amount of aid (the House and Senate do), he is responsible for a crucial step in the process. This obviously raises the question of what are the key drivers of such a decision and whether some states are more likely to benefit from such situation than others, and if so, when does this occur? A look at the number of U.S. presidential disaster declarations over the past 55 years clearly reveals an upward trend (as depicted in Figure 3). Overall, the number of Presidential disaster declarations has dramatically increased over the past 50 years: there had been 162 over the period 1955-1965, 282 over 1966-1975, increasing to 319 over the period 1986-1995 and 545 for 1996-2005 (Michel-Kerjan, 2008). On average, one can consider that the average annual number of declarations has increased by 10 every decade since the 1950s.

As Figure 3 also shows many (although not all) of the peak years correspond to presidential election years. This is consistent with recent research that has shown that election years are a very active time for disaster assistance (all other things being equal). Four salient examples are the Alaska earthquake in 1964 (a Presidential election year), Tropical Storm Agnes and the Rapid City Floods in June 1972, Hurricane Andrew in September 1992 and the four hurricanes in 2004. Following the Alaska earthquake of 1964, Congress passed special legislation whereby homeowners or businesses suffering damage from the earthquake were give funds not only to repair damage structures but to retire old debts such as outstanding mortgages. Thus, instead of continuing to pay conventional 7 or 8 percent rates on these outstanding claims, the borrower could retire them at a subsidized 3 percent. After Tropical Storm Agnes and the Rapid City floods, Congress effectively converted the disaster loan programs into primarily a grant program where the first $5,000 of each loan was forgiven and the annual interest rate on the remaining portion was 1 percent. (Kunreuther 1973).

FIGURE 3. DISASTER PRESIDENTIAL DECLARATIONS PER YEAR (PEAK-VALUES ON THE GRAPH CORRESPOND TO SOME PRESIDENTIAL ELECTION YEARS)



Sources: Authors' calculation with data for the U.S. Department of Homeland Security

One way to address this dilemma is to work directly with these political parties to ensure good risk management practices are viewed as a core value and by holding elected officials legally responsible for negligence if they did not address the natural hazards that their community is exposed to. Admittedly it may be difficult to take such a case to court following a severe disaster, but the knowledge by elected officials that they may be legally responsible for some of the damage following a disaster by failure to take action during their term of office, may lead them to pay attention.

One silver lining to myopic politically-driven behavior is that following a natural disaster when residents and the media focus on the magnitude of the losses, politicians will respond by favoring stronger building codes and other loss reduction measures. One notable example is the Long Beach Earthquake of April 10, 1933 (magnitude 6.3 on the Richter scale) in which 70 schools were destroyed and another 120 schools suffered major structural damage. The public outcry led to the passage of the Field Act on April 10, 1933, requiring that the building designs be based on high level standards adopted by the stat. The quality of construction was to be enforced through independent plan review and independent inspection. Finally, the design professionals, independent inspector and the contractor had to verify under penalty of perjury that the building was constructed according to the approved plans. (See http://www.excellence.dgs.ca.gov/StudentSafety/S7_7-1.htm for more details).

Following Hurricane Andrew in 1992, Florida reevaluated its building code standards and their enforcement. In 1995, coastal areas of Florida began to use and enforce high high-wind design provisions for residential housing. Toward the end of the 1990s, the state began the process of developing and enforcing a statewide building code. The Florida Building Code (FBC) 2001 edition was, adopted in mid-2002, was accompanied by an extensive education and training program that included a requirement that all licensed engineers, architects, and contractors take a course on the new building code. Hurricane Charley in 2004 demonstrated the impact of the new building code. One insurance company provided the Institute for Business & and Home Safety (IBHS) data on 5,636 policies in Charlotte County at the time that this hurricane made landfall on August 13, 2004. Homes built under the new wind-resistant standards that were enforced in 1996 had a claim frequency that was 60 percent *less* than those that were built prior to 1996. (Kunreuther and Michel-Kerjan 2009).

Conclusion of Part B.

Using a simplified normative model such as expected utility enables one to better appreciate the trade-off rational individuals face between different strategies: they can purchase insurance to protect their assets or decide to self-insure themselves. They can also invest in mitigation measures (self-protection) that can reduce the probability and/or the consequences of future disasters. At one extreme they can decide to nothing and if a disaster occurs hope that they will receive public disaster assistance to aid the recovery process.

Recent disasters have provided empirical evidence that a large number of people do nothing in advance of a disaster or under invest in insurance and/or mitigation because they use budgeting heuristics, misperceive the risk, underweight the future and/or are myopic, fail to learn from past experience and are influenced by social norms and interdependencies. This behavior is reinforced by the Samaritan's dilemma and the politician's dilemma. Following a major disaster, many victims suffer severe losses because they had not mitigated their homes and have not purchased flood insurance *ex ante* to cover the resulting damage. As a result, there is an unprecedented level of disaster assistance for aiding these victims.

If we as a society are to commit ourselves to reducing future losses from natural disasters and limit government and international assistance after the event, then we have to recognize these behavioral realities and integrate them into any future disaster management strategy. Some guidelines for improving individual decision making and public policy would include the following points:

- Properly assessing risks and characterizing uncertainties surrounding these estimates
- Understanding behavioral biases and heuristics utilized by decision makers such as those described above
- Designing risk management strategies based on risk assessments *and* the recognition of these behavioral biases and heuristics used by decision makers in deciding what protective measures they will undertake

Using these guidelines, Part C proposes some innovative strategies for reducing future losses and aiding the recovery process in a more equitable and efficient manner than under current programs and policies.

Part C

Designing Innovative Strategies for Dealing with a New Era of Catastrophes

C-1. Developing a Sustainable Disaster Management Strategy

Part B has documented the lack of interest by those in hazard-prone areas in voluntarily purchasing disaster insurance and investing in cost-effective risk-reducing measures prior to a catastrophe and the inefficiency of governmental assistance as a form of insurance following a major disaster. Given the reluctance of individuals to adopt these protective measures there may be a need for strategies that involve public-private partnerships.

We believe that any disaster management strategy should be based on a set of principles to address both efficiency and equity concerns with respect to improving social welfare over the status quo. We briefly discuss two of these principles when using insurance as a risk transfer mechanism. Insurance plays a major role in protecting residents and business against losses from natural disasters in the developed world. It has also demonstrated sustained growth in many developing countries (e.g. Peru, India, El Salvador). To highlight this point, India liberalized its insurance market in 2000 which then grew at a rate of 15 percent per year, far surpassing the average growth rate for the world's insurance markets during the same time period. (USAid, 2006).

Even in countries an early stage of development (e.g., Bolivia, Egypt, Mongolia) one can expect insurance to play a growing role in economic development. In fact, several studies provide solid econometric support for the premise that economies that experience more growth do so in part because they have access to efficient and effective insurance products. For instance, in a large, multiple-country study, Webb, Grace and Skipper (2002) found that both banking and life insurance penetration were robustly indicative of increased productivity (as measured by increase in growth rate of real GDP per capita) in 55 countries over the period from 1980 to 1996. Arena (2006) tests whether there is a causal relationship between insurance market activity (life and non-life insurance) and economic growth. Using a panel data for 56 countries and for the 1976-2004 period, he also finds robust evidence of a causal relationship between insurance market activity and economic growth.[34]

We also recognize that the development of a sustainable insurance infrastructure might not be feasible in the near future for other poor economies. For these countries we discuss innovative risk transfer mechanisms where one first pools a large number of individual risks to reach a critical mass of assets that needs to be protected against losses from disasters. This has been achieved with success in recent years with the development of index-based insurance products at a country-wide level. In the case of low income countries, other risk transfer mechanisms are also important to consider and we briefly discuss some of them as well.

Part C concludes by proposing innovative strategies for addressing the linkages between *ex ante* and *ex post* behavior prior to a disaster by combining risk transfer mechanisms with other policy tools such as well-enforced building codes and long-term mitigation loans.

Guiding Principles

Two principles, which appear to conflict with each other, can be used as the basis for developing a sustainable disaster management strategy that couples insurance with mitigation measures (self protection) for reducing future disaster losses and aiding the recovery process:

> *Principle 1 – Premiums Reflecting Risk*: If insurance is to be part of the risk-financing solution, then premiums should reflect the risk based on quantitative assessments.

This first principle is important because risk-based premiums would provide a clear signal of relative damage to those currently residing in areas subject to natural disasters and those who are considering moving into these regions. Risk-based premiums also enable insurers to provide discounts to homeowners and businesses who invest in cost-effective loss-reduction mitigation measures. If the premiums are not risk-based, insurers have no economic incentive to offer these discounts. In fact, they prefer not to offer coverage to these property owners because it is a losing proposition in the long-run. In developing countries, an insurance market is more likely to develop over time if premiums are allowed to reflect risk because foreign insurers will be more willing to market policies there.

> *Principle 2 – Dealing with Equity and Affordability Issues*: Any special treatment given to those residing in hazard-prone areas (e.g. low income residents) should come from general public funding and <u>not</u> through artificially low insurance premiums.

This second principle reflects a concern for residents in high-hazard areas who will be faced with large premium increases if insurers adhere to Principle 1. Today, for instance, in many Gulf Coast states in the U.S. subject to hurricane damage, insurance premiums are highly subsidized due to rate regulations imposed by state insurance commissioners. If insurers are permitted to reflect risk-based rates in the premiums they charge, homeowners residing in hurricane-prone areas will pay considerably more for coverage than they do today.

To deal with the affordability issue, some type of insurance vouchers could be provided by the public sector (e.g. state or federal government) to low-income residents and others who may deserve special treatment. The system could work in a manner similar to the food stamp program in the United States where a family is given vouchers to purchase food as a function of their annual income and size of their family. Under this proposed system, a homeowner in a hazard-prone area would pay an insurance premium that reflects risk and then be reimbursed by the state in which they reside for a portion of the increased cost of insurance over last year's policy. The amount of reimbursement would be determined by their income and the insurance premium that they are charged. Insurers could then reward individuals for undertaking risk reduction measures through premium reductions. In low income countries, these vouchers might have to be provided by international organizations such as the World Bank.

Insurance as a Cornerstone for a Sustainable Disaster Management Strategy

In theory private or social insurance is an effective policy tool for developing a sustainable disaster management strategy because it can reward investments in cost-effective mitigation with lower premiums and provides claims payments to policyholders should a disaster occur. In recent years, however, insurance has not played this role because they feel that few people would voluntarily adopt these measures based on the small annual premium reductions for taking these actions compared to the up-front cost. If individuals have short time horizons, they would have little interest in investing $1,500 in return for a reduction in annual premiums of, say, $100.

For insurance to play a positive role in encouraging homeowners to adopt mitigation measures, it is also necessary that premiums reflect risk (*our first principle above*) so that insurers will want to provide price reductions for those who adopt these risk reduction measures. As an example, imagine that a risk-based premium for insuring a property in Mumbai, India should be priced at $100 but that insurers are constrained by regulators to charge only $75. Even if a homeowner invested in mitigation measures that reduced the risk-based price to $80, the insurer would still be constrained to charge no more than $75 for this coverage. It would rather not offer this homeowner a policy (where it will lose money) even if this mitigation measure were adopted since in the long-run the insurer would lose money on this coverage.

Role of Building Codes, Land-Use Regulations and Warnings

An insurance-based solution with premiums reflecting risk should be coupled with actions by the local or national governments to establish building codes and land use regulations in order to reduce the risk and vulnerability to future disasters. Well-enforced building codes may play an important role in encouraging the private sector to become proactive with respect to fostering cost-effective mitigation measures. Building codes require property owners to meet standards on new structures. Often such codes are necessary, particularly when property owners are not inclined to adopt mitigation measures on their own because of their misperception of the expected benefits resulting from adopting the measure or their inclination to underestimate the probability of a disaster occurring.

Cohen and Noll (1981) provide an additional rationale for building codes. A collapsed structure may create negative externalities in the form of economic dislocations and other social costs that are beyond the owners' financial loss. For example, a poorly designed structure that collapses in a hurricane may cause damage to other buildings that are well designed and still standing in the storm. Knowing this, an insurer may offer a smaller premium discount than it would otherwise have given to a homeowner investing in loss reduction measures.

One of the main challenges of building codes, however, is to make sure they are well-enforced. Indeed, in many countries the local government does not have the necessary workforce to audit all houses to make sure they complain with the most recent building codes. It has been estimated that one-third of the damages from Hurricane Andrew in 1992 could have been avoided had building codes been enforced. In Turkey there was general agreement that much of the damage to buildings from the 1999 earthquake was due to the lack of enforcement of building codes. This might be even more challenging in low-income countries.

Land use regulations play a similar role to building codes but they are often difficult to enforce politically. In fact, there are incentives for elected officials to encourage economic development in hazard-prone areas in order to expand their tax base. A salient example of this behavior is the development of Florida as a tourism and retirement paradise. The population of

Florida was 2.8 million inhabitants in 1950, 6.8 million in 1970, 13 million in 1990, and is projected to be 19.3 million population in 2010 (a nearly 700 percent increase since 1950), thus increasing the vulnerability of this state to large scale damage from hurricanes. AIR Worldwide estimated that in 2004 there was more than $1.9 trillion of insured exposure (commercial and residential) located in the coastal areas of Florida. This represents almost 80 percent of the statewide insurance exposure. (Kunreuther and Michel-Kerjan, 2009). More generally, the increase in the exposed property values in risk-prone areas due to a combination of pure inflation, speculation and rise in standard of living increase the likelihood of significant increases in economic and insured losses from future natural disasters.

There is also a need for improved warning systems to reduce the number of injuries and fatalities due to natural disasters. More research is need to evaluate the expected benefits from more sophisticated technology to provide information to residents in hazard-prone area of oncoming disasters such as the tsunami in December 2004 that killed more than 280,000 people residing in coastal areas of southeast Asia and Cyclone Nargis, which made landfall in Myanmar in May 2008 and killed an estimated 140,000 people.

Mitigation Grants Another role that the public sector can play is allocating money to support mitigation efforts through government grants. This was the purpose of a multiyear study undertaken by the U.S. National Institute of Building Science and released in 2005 evaluated the effectiveness of these governmental grants by systematically assessing the future savings from hazard mitigation activities supported by the U.S. Federal Emergency Management Agency's grants from 1993–2003. The study quantified these savings for three types of hazards: wind, flood, and earthquake. Benefits were defined as losses avoided and included reduced direct property damage, reduced direct business interruption, reduced indirect business interruption (ripple effects), reduced environmental damage (to wetlands, parks, or historical structures), and reduced human losses (deaths, injuries, homelessness). Benefits also included the reduced cost of emergency responses, as well as reduced amount of federal funds being used for disaster assistance and recovery (including post-disaster tax revenue decreases because of tax breaks or interruption of activities).

These findings are interesting because they demonstrate a high benefit-to-cost ratio of mitigation grants. The study estimates that the benefits from FEMA mitigation grants represent

US$14 billion (in 2005 dollars) compared to US$3.5 billion for grants made by FEMA on the studied programs. In other words, a statistically representative sample of FEMA grants awarded between 1993 and 2003 can be used to show that on average **$1 spent on mitigating the risk of wind, flood, and earthquake in the United States saves an average of $4**. On the human side, it is estimated that these mitigation measures are likely to save over 200 lives and prevent almost 4,700 injuries over fifty years. There is a need for more detailed quantitative analyses characterizing the return on investment of cost-effective mitigation measures. The U.S. National Institute of Building Science's Multihazard Mitigation Council (MMC) indicates that federal grants are not only cost-effective, but that they often lead to the implementation of additional mitigation measures that are supported by other sources, especially in communities that have implemented specific mitigation programs in a systematic way.

For low-income countries additional funds may have to be provided by international organizations to support investments in loss reduction measures. One could imagine pilot programs in which the World Bank provided mitigation grants to countries with the assurance from the local government that these funds would be given to residents to make their structures less vulnerable to disasters. There could also be link between the catastrophe risk-financing programs the Bank is preparing with economic incentives for encouraging mitigation measures (see the discussion on the World Food Program pilot study for drought insurance in Ethiopia at the end of this section).

Requiring Comprehensive Disaster Insurance

One way to ensure that residents in hazard-prone areas are financially protected against the losses from natural disasters is to require them to purchase insurance against these events. Several countries have made the purchase of comprehensive insurance mandatory. In 1954, Spain formed a public corporation, the Consorcio de Compensacion de Seguros (CCS) that provides mandatory insurance for so-called "extraordinary risks." These include natural disasters and political and social events such as terrorism, riots and civil commotion. Such coverage is an add-on to property insurance policies that are marketed by the private sector. CCS pays claims only if the loss is not covered by private insurance, if low-income families did not buy insurance and/or the insurance company fails to pay because it becomes insolvent. The government collects the premiums and private insurers market the policies and handle claims settlements (Consorcio de Compensacion, 2008).

In France, a mandatory homeowners policy also covers number of different natural disasters along with terrorism. The "Cat Nat" system was developed in 1982 as a response to major flooding episode in 1981 in several regions of France and is a partnership between private insurers and the French government which provides reinsurance through a publicly owned reinsurer, the Caisse Centrale de Reassurance, for flood, earthquakes and droughts, and by an insurance pool with unlimited government guarantee for terrorism. There is no public reinsurance for storms (Michel-Kerjan and de Marcellis-Warin, 2006).

A mandated all-natural-hazards insurance program will very likely reduce the variance associated with nationwide insurers' losses relative to their surplus in any given year.[35] Consider an insurer marketing coverage to homeowners throughout a country like India which, as discussed early, is prone to all types of disasters. The insurer will collect premiums that reflect the earthquake risk in one region, hurricane risk in another, tornado damage in a third and flood risk in a fourth. Because of the mandate, insurers will not be concerned that buyers will drop coverage should it charge high premiums based on risk. Using the law of large numbers, this higher premium base and the diversification of risk across many hazards reduces the likelihood that such an insurer will suffer a loss that exceeds its surplus in any given year.

Such insurance may also be attractive to both insurers and policyholders in hurricane-prone areas because it avoids the costly process of having an adjuster determine whether the damage was caused by wind or water. This problem of separating wind damage from water damage has been a particularly challenging one following Hurricane Katrina in the United States. Across large portions of the coast, the only remains of buildings are foundations and steps where it will be difficult to reach a settlement due to the difficulty in determining the cause of damage. In these cases insurers may decide to pay the coverage limits rather than litigating about whether

[35] Insurers who offer coverage in one region of the country could have the variance of their losses increase by combining all-hazards in one policy. For example, a Florida insurance company providing protection against hurricane damage might find the variance in losses to be higher than it is today if both wind and water damage were covered under a homeowners policy. It would collect more premiums than before but may still want to purchase additional reinsurance than it currently does to cover the possibility of a very large loss resulting from a future hurricane.

the damage came from water or wind because of the high costs of taking the case to court. For a house still standing, this process is somewhat easier since one knows, for example, that roof destruction is likely to be caused by the wind, and water marks in the living room are signs of flooding (Towers Perrin, 2005).

Another reason for having an insurance policy that covers all perils, including natural hazards regardless of type, is that there will be no ambiguity by the homeowner as to whether or not she has coverage. The attractiveness of insurance that guarantees that the policyholder will have coverage against all losses from disasters independent of cause has also been demonstrated experimentally by Kahneman and Tversky (1979). They showed that 80 percent of their subjects preferred such coverage to what they termed probabilistic insurance where there was some chance that a loss was not covered. What matters to an individual is the knowledge that she will be covered if her property is damaged or destroyed, not the cause of the loss. How these policies are framed also matters. Are they characterized as an investment on which one might obtain a high return, are they presented as a way of pooling risk in the community, or are they sold simply as insurance? By combining all natural disasters into a single policy, it is more likely that a property owner will consider purchasing insurance because the likelihood of some loss is above her threshold level of concern and search becomes rational. If all natural hazards were included in a homeowners' policy, the risk might be large enough to get the consumer's attention (Kunreuther and Pauly, 2004). Such a policy has added benefits to the extent that individuals are unaware that they are unprotected against rising water or earthquake damage in their current homeowners' policy.

If the insurance is to be comprehensive, the price for such a broad coverage will be by definition higher than a policy that covers only one type of hazard. Some policyholders may believe that they are being charged for coverage they do not need. For instance, an individual living in an earthquake area that is not prone to hurricanes and floods might only want to purchase quake insurance. This concern should be solved by our first principle: if insurance is risk-based, these individuals will not be charged any premium for flood and hurricane coverage included in their comprehensive insurance policies. It would be important for the insurer to itemize each of the covered hazards and the portion of the premium that is used to cover future losses.

It might also be necessary to provide public sector involvement for assuring supply of protection against catastrophic losses for coverage that cannot be handled by the private reinsurance, insurance-linked securities or insurance pools. Insurance would obviate the need for disaster assistance for property damage. Following *Principle 2* the public sector should be prepared to provide subsidies for coverage to those to low income residents and others who deserve special treatment.

C-2. An Innovative Market-Based Solution: Long-Term Risk Financing Contracts[36]

To address the problem of volatility of insurance premiums and homeowners' failure to protect their property against disaster, we propose a new approach to providing homeowners' coverage: long-term insurance contracts (LTI) rather than the usual annual policies on residential property.

For a long-term insurance policy to be feasible, insurers would have to be able to charge a premium that reflects their best estimate of the risk over that time period (say, ten or twenty-five years) (*Principle 1*). The uncertainty surrounding these estimates could be reflected in the premium as a function of the length of the insurance contract in much the same way that the interest rate on fixed-rate mortgages varies between fifteen-, twenty-five-, and thirty-year loans. Insurance vouchers could be provided to homeowners who cannot afford coverage if premiums reflect risk (*Principle 2)*.

The obvious advantage of a long-term insurance contract from the point of view of policyholders is that it provides them with stability and an assurance that their property is protected for as long as they own it. This has been a major concern in hazard-prone areas where insurers have cancelled policies following severe disasters such as those that occurred during the 2005 hurricane season. With a long-term insurance policy in place, homeowners in hazard-prone areas would be protected following the next disaster, providing them with financial resources for recovery and reducing the need for liberal disaster assistance.

[36] This section is partially based on Jaffee, Kunreuther and Michel-Kerjan (2008).

Benchmark from the mortgage industry: The need for coordinating mechanisms

The mortgage market provides a useful benchmark for developing LTI. Although home loans today typically have maturities of twenty or thirty years in many OECD countries, until the Great Depression such long-term mortgages were rare. For instance, U.S. bank mortgages were commonly short-term (maturities 1 to 4 years) with the full principal due at maturity. House prices were naturally falling under the dire depression conditions, so in most cases the loan balance exceeded the house value, giving the borrower further incentive to default. In addition, a vicious circle ensued, as falling house prices begot more mortgage defaults and mortgage defaults begot greater declines in house prices. To curtail this process, the federal Home Owners Loan Corporation (HOLC) was created in 1933 to recycle the failing home mortgages (reminiscent of government programs now being proposed to deal with subprime mortgages); the HOLC also expanded the use of long-term, fixed payment, and fully amortizing mortgages in the U.S. The HOLC finished its business and was closed by 1935, a notable achievement. It was replaced by the Federal Housing Administration (FHA), established under the National Housing Act of 1934, to oversee a program of home mortgage insurance against default and it continued to promote the use of long-term mortgages (Aaron 1972).

Encouraging Adoption of Mitigation Measures

Long-term insurance provides economic incentives for homeowners to invest in mitigation, whereas current annual insurance policies (even if they are risk based) are unlikely to do so. To illustrate this point, consider the following simple example where insurance premiums reflect the actuarial risk. Suppose that the Lowland family in China could invest $1,500 to strengthen the roof of its house so as to reduce the damage by $30,000 from a future typhoon with an annual probability of 1 in 100. An insurer charging a risk-based premium would be willing to reduce the annual charge by $300 (1/100 × $30,000) to reflect the lower expected losses that would occur if a typhoon hit the area in which the policyholder was residing. If the house was expected to last for ten or more years, the net present value of the expected benefit of investing in this measure would exceed the up-front cost at an annual discount rate as high as 15 percent.

Under current annual insurance contracts, many property owners would be reluctant to incur the $1,500 expenditure, because they would get only $300 back next year and are likely to consider only the benefits over the next few years when making their decisions. If they underweight the future, the expected discounted benefits would likely be less than the $1,500 up-front costs. In addition, budget constraints could discourage them from investing in the mitigation measure. Other considerations would also play a role in a family's decision not to invest in these measures. The family may not be clear how long they will reside in the house or whether their insurer would reward them again when their policy is renewed, for example.

Suppose a twenty-year required insurance policy were tied to the property rather than to the individual. The homeowner could then take out a $1,500 home improvement loan at an annual interest rate of 10 percent, resulting in payments of $145 per year. If the insurance premium was reduced by $300, the savings to the homeowner each year would be $155. Alternatively, this loan could be incorporated as part of the mortgage at even a lower interest rate than 10 percent.

These mitigation loans would constitute a new financial product. A bank would have a financial incentive to provide this type of loan, since it is now better protected against a catastrophic loss to the property, and the insurer knows that its potential loss from a major disaster is reduced. Moreover, the general public will now be less likely to have large amounts of their tax dollars going for disaster relief—a win-win-win situation for all! (Kunreuther, 2006).

There is an additional benefit to insurers in having banks encourage individuals to invest in cost-effective mitigation measures. The cost of reinsurance, which protects insurers against catastrophic losses, should now decrease. If reinsurers know that they are less likely to make large payments to insurers because each piece of property in a region now has a lower chance of experiencing a large loss, then they will reduce their premiums to the insurer for the same reason that the insurer is reducing its premium to the property owner.

Suppose that an insurer had 1,000 identical insurance policies in a particular area and that each would expect to make claims payments of $40,000 following a hurricane if homeowners had not strengthened their roofs. The insurer's loss from such a disaster would be $40 million. Suppose also that the insurer would want to have $25 million in coverage from a reinsurer to protect its surplus. If the hypothetical hurricane has a 1 in 100 chance of hitting the region where these families reside, the expected loss to a reinsurer would be $250,000 and the premium charged to the insurer would reflect this. If the bank required that all 1,000 homes had their roofs mitigated to meet the local building code and each homeowner's loss were reduced to $10,000, then the insurer's total loss would be $10 million should all 1,000 homes be affected, and it would not require reinsurance. This savings would be passed on by the insurer to the homeowner in the form of a lower premium.

In addition to all these benefits, LTI would also reduce transaction costs from the consumer's and insurer's point of view. More specifically, an insurer who offers an LTI policy has reduced marketing costs since this is only incurred at the time the contract is offered rather than every year. Similarly, consumers with one-year policies whose contracts are canceled at the end of the year are able to avoid the search costs of looking for another policy by buying an LTI policy. The expected social welfare benefits to the consumer based on a long-term policy can be quite substantial.

Why Does a Market for Long-Term Insurance Not Exist Today?

To move forward in developing a market for LTI, it is important to consider some of the reasons why this market does not exist today. In his seminal work on uncertainty and welfare economics, Kenneth Arrow defined "the absence of marketability for an action which is identifiable, technologically possible and capable of influencing some individuals' welfare (…) as a failure of the existing market to provide a means whereby the services can be both offered and demanded upon the payment of a price." (Arrow, 1963). Here we shall discuss several factors which have contributed to the non-marketability of LTI for protecting homeowners' property against losses from fire, theft and large-scale natural disasters. We discuss elements which affect both the supply and demand sides.

Supply Side As pointed out earlier, insurance rates are frequently restricted to be artificially low in hazard-prone areas due to political pressure. The result is that the risks most subject to catastrophic losses also become the most unattractive for insurers to market. A second stumbling block, derived from premium regulation, is that insurers are unclear as to how much they will be allowed to charge in the future.

Uncertainty regarding costs of capital and changes in risk over time may also deter insurers from providing long-term insurance. In principle, of course, insurers could add a component in their premium quotes to account for the costs created by these factors. The problem is that the insurance regulator presumed to be representing consumers interests, may not allow these costs to be embedded in the approved premiums. Furthermore, it is unclear what the voluntary demand for coverage will be, given the resulting premium. In a real sense, a new and less intrusive format for government regulation of insurance markets may be required if the private markets are to be successful in dealing with time-varying risks and capital. Impediments to risk spreading across insurance firms is another source of market failure.

A key benefit of organized insurance markets is, of course, the ability to spread risks across a large number of individuals and entities. To achieve this benefit, an organized market must be available for reinsurance or for capital market access based on insurance linked-securitization. The creation of such risk-spreading facilities, however, faces a fundamental coordination problem, since simultaneously there must arise both primary insurers who are willing to write policies, and reinsurers (or capital market investors) who are willing to provide reinsurance protection. Such coordination problems may be difficult for private markets to solve (Ibragimov, Jaffee, and Walden, 2008). However, if there is a welfare gain that can be achieved through coordination effort, then government entities should facilitate this effort (Baumol, 1952).

More specifically, government actions can enforce a coordinated equilibrium by requiring all insurers and reinsurers to participate in this market. One recent example of such intervention is the U.S. Terrorism Risk Insurance Act (TRIA) legislation of 2002. The development of a terrorism insurance market in the United States post September 11, 2001 can be attributed, at least in part, to the "make available" clause of the law which required all insurers to participate in the market.

One may ask why banks, which now provide long-term mortgages, have not played an active role in packaging insurance to cover the physical asset. Two factors contribute to the answer. First, until 1999, banks were prohibited from operating an insurance business. It was only with the passage of the 1999 Gramm-Leach-Bliley Act, which removed features of the Glass Steagall Act, that insurance activities were allowed. Even then, bank entry has been relatively slow as highlighted by the 2004 spin-off of the Travelers insurance division by

Citigroup just five years after they merged. Lenders may also feel they are protected by the first-loss position of the homeowner given the homeowner's equity in the dwelling. Lenders may also be able to transfer most of their exposure to capital market investors through securitization. However, regulatory responses to the subprime mortgage crisis may hamper the future securitization of high-risk instruments, with particularly negative consequences for insurance-linked securitization. Earthquake, wind damage, and flood risks may also be quite different in this regard. Homeowner's equity may protect lenders with respect to seismic risks, since most wood-frame homes are relatively resilient to earthquakes. This is not the case for hurricane and flood risks, where a house can be totally destroyed by these disasters. Indeed, most lenders do require homeowners to purchase insurance in such high-risk regions.

Demand Side Some homeowners may worry about the financial solvency of their insurer over a long period, particularly if they have the feeling they would be locked-in if they sign an LTI contract. Consumers might also fear being overcharged if insurers set premiums that reflect the uncertainty associated with long-term risks. Furthermore, those who have not suffered a loss for 10 years but have a 25-year LTI may feel that the premiums are unfairly priced. It is thus essential that the design of an LTI contract anticipates these concerns. The policy may also include specific features that allow contract terms to change over time.

Of course, there are many issues that have to be addressed if one is to develop long-term property insurance contracts:

- Could one offer adjustable rate insurance policies similar to these types of mortgage contracts?
- Could a property owner change his or her insurance policy over time in a manner similar to refinancing a mortgage?
- What role would the modeling companies and the scientific community studying climate science play in providing estimates for developing risk-based premiums, and for suggesting a rationale for changes over time as new information becomes available from the scientific community?
- What types of risk transfer instruments would emerge from the reinsurance market as well as from the capital markets to protect insurers against catastrophic losses?

- What role would the federal government play in providing such protection?
- Should property owners be required to purchase insurance or would this be at the discretion of the banks issuing a mortgage?

Although these issues will have to be resolved before such policies are marketed, we feel that the idea should be introduced as a way of dealing with the issue of myopia that often discourages individuals and firms from investing in cost-effective mitigation measures.

C-3. Recent Insurance-Based Innovations in Developing Countries

We provide brief descriptions of disaster management innovations that have been implemented recently in Turkey and in Ethiopia.

Insurance Pooling: The Turkish Catastrophe Insurance Pool (TCIP)

The vast majority of Turkey's urban population today lives in multi-storey apartment blocks constructed of reinforced concrete, Statistics on urban housing indicate that in the three largest cities (İstanbul, İzmir, Ankara) over 50 percent of the buildings are of reinforced concrete frame construction; over 75 percent of these are more than three stories tall. Recent earthquakes have demonstrated that this type of construction is more vulnerable to damage or collapse in an earthquake than the low-rise construction. In five urban earthquakes in Turkey during the past decade approximately 20,000 people have been killed, the vast majority of them through the collapse of high-rise buildings. Data from these recent earthquakes reveal that 70,000 buildings were damaged, and some 20,000 buildings destroyed. The cost of the damage to the destroyed buildings alone has been estimated at $20 billion.[37]

Concern with earthquakes in Turkey has drastically increased since two 1999 earthquakes that caused more than 18,000 deaths and produced severe damage to housing and reduced production capacity in northwest Turkey, including some recently developed parts of Istanbul. The severity of that disaster accounts for an increased perception of earthquake risk on

[37] Personal communication with Mr. Yucemen, Head, Department of Earthquake Studies, Middle East Technical University (Turkey) (September 11, 2008).

the part of the public and for an interest on their part and the government's in taking steps to mitigate future losses. The earthquake also highlighted the potential for severe future damage to Istanbul from future disasters as it is one of the world's largest and fastest growing cities. It has also pointed to widespread deficiencies in design and construction, which can be in part ascribed to the extremely high demand for new housing at affordable prices (U.S. Geological Survey 2000).

In Turkey, the State has a legal obligation to fund the costs of reconstructing buildings after an earthquake. Immediately after the two extremely destructive earthquakes in 1999 the Government of Turkey decided to enforce the earthquake insurance on a nationwide basis through the Turkish Catastrophe Insurance Pool (TCIP) at affordable premiums. Initially funded by the World Bank, TCIP was founded on August 2000 and the TCIP program became effective since then. With its 2.7 million policy count as of April 2008, Turkish Catastrophe Insurance Pool has a potential to become the largest earthquake insurance company in the world.

Even though this insurance is required, only 21 percent of residential structures in Turkey have coverage. Yucemen (2008) outlines a set of factors which have caused the insurance penetration rate to remain as low as it is today. They include several factors we discussed in Part B, namely:

- The low income level of many residents who perceive the earthquake insurance premium to be expensive without necessarily having accurate information on the cost.
- Limited awareness by the public of TCIP and the compulsory nature of earthquake insurance. There are also no legal penalties or fines if one does not purchase earthquake coverage.
- A lack of trust in TCIP with respect to the compensation of losses after an earthquake.
- Provision of post disaster aid to cover uninsured losses by homeowners. This creates a Samaritan's dilemma by destroying the homeowners' incentive to participate in the TCIP.

There is currently no linkage between insurance premiums and efforts by residents to reduce losses from future earthquakes by retrofitting their structures or investing in other mitigation measures. The rates are based only on construction type and seismic zone in which the structure is located. Features that affect the earthquake response of structures such as age, usage, features of the soil on which the buildings are located are taken into account when setting rates. (Personal communication with Semih Yucemen September 11, 2008).

Since there is a logical connection between the adoption of mitigation measures in advance of the next earthquake and the claims costs from insurance should a quake occur, Gulkan (2001) recommended that TCIP take the lead in developing guidelines for encouraging the adoption of mitigation measures for existing structures in Turkey because of the stake it has in maintaining its operability. It should be noted however, that it is not at all clear whether the TCIP in its present form can serve as an incentive mechanism for the adoption of relatively costly retrofitting schemes. As pointed out above, subscription to the TCIP is relatively weak. Given that maximum coverage is about $20,000 and the corresponding small premiums, no adjustment of this premium alone can serve as an incentive to upgrade one's property (Smyth et al. 2004).

In designing mitigation measures, one needs to consider ways of reducing the risk to new buildings as well as retrofitting existing structures. For the new buildings, adherence to the current Turkish earthquake code would limit future earthquake losses to acceptable levels. Further, the knowledge of the earthquake hazard and local ground conditions in many cities now enables areas of particularly high earthquake risk to be identified and avoided in future development. The challenge is to ensure enforcement and compliance with the code on the part of designers and builders and to enforce urban hazard zoning. In this regard, Yucemen (2008) has proposed that compliance with the Turkish Seismic Code be an important factor in determining earthquake insurance rates under TCIP.

Linking Ex Ante and Ex Post: A Pilot for Weather Derivatives in Ethiopia[38]

In recent years, there has been an effort to develop innovative solutions to provide some type of insurance in developing countries where coverage against natural disasters does not currently exists.[39] Under the leadership of the World Bank, the United Nations and other

[38] We appreciate the inputs and helpful comments from Ismael Le Mouel and Sabrina McCormack on this subsection of the report.

[39] See Cummins and Mahul (2008) for an analysis of the main reasons of this lack of insurance development.

international organizations, leading insurers and reinsurers have completed several deals that augur well for the future.

A successful example of risk financing solution involving multiple stakeholders and that had an impact on disaster preparedness was undertaken under the leadership of the World Food Program (WFP) in Ethiopia with the issuance of weather derivatives providing coverage to local farmers in the case of an extreme drought during the 2006 agricultural season. Even though Ethiopia is considered the fastest growing non-oil dependent African nation in 2007, it remains one of the poorest countries in the world.[40] Agriculture represents an important part of the local economy and formers are exposed to important risks of droughts. The objective of this pilot program was to develop an ex-ante disaster-management system to protect the livelihoods of Ethiopians vulnerable to severe and catastrophic weather risks as a first step in a process involving governments, donors and insurance and financial markets. (World Food Program, 2005).

Challenge: Collecting Objective Weather Data In 2004-2005, The World Food program partnered with the French insurer AXA to develop an index-based weather derivative instrument calibrated with rainfall data from weather stations across the country. To satisfy market concerns about the quality and integrity of data for risk transfer, capacity-building was needed for the National Meteorological Agency (NMA) to ensure that data were reported in real time. NMA in Ethiopia monitors more than 600 weather stations above the county, but only 44 of these stations are Class 1 stations, meaning stations recording pressure temperature, relative humidity, wind speed and direction, rainfall, evaporation and soil temperature every three hours from 06.00 to 18.00. These 44 stations had data missing, particularly because of extreme events such as civil war. Thus two companies specialised in modelling, EarthSat and Risk Management Solutions (RMS) were hired to clean data and replace values missing or erroneous. The quality of the final dataset, where two stations had been removed, was qualified as an excellent dataset by both of these companies when compared with similar datasets from industrialised countries.

[40] The International Monetary Fund estimates Ethiopian GDP per capita at USD$806 in 2007. Data available on www.imf.org (as of August 2008)

Definition of a Transparent Index

The Ethiopia Drought Index I was defined as follows:

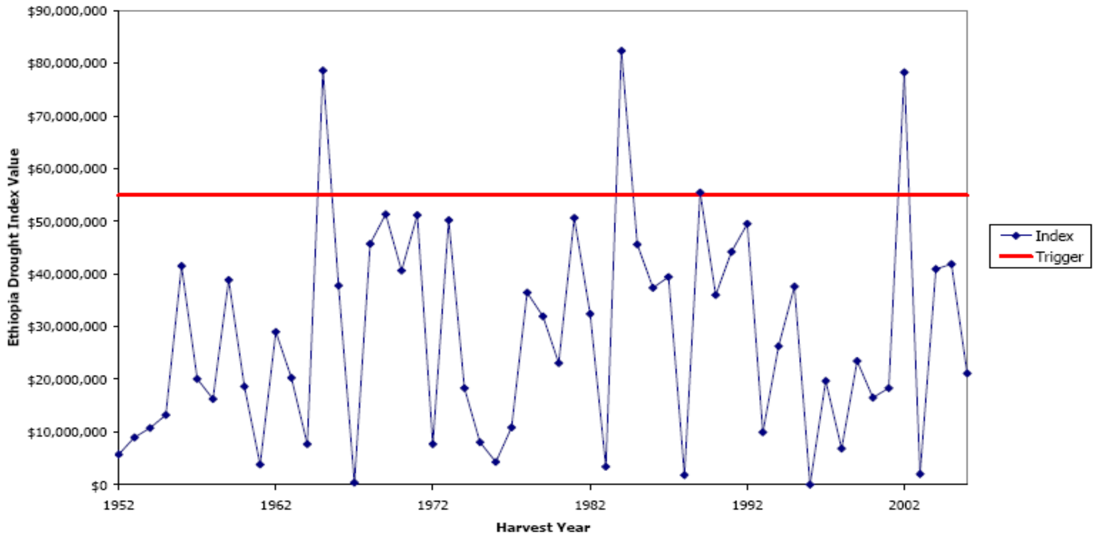
$$I = \sum_{i=1}^{26} \text{livelihood losses at the weather station } i$$
$$= \sum_{i=1}^{26} \sum_{j=1}^{\omega_i} L(i, j)$$

where $L(i, j)$ represents the livelihood losses in a *woreda* (administrative district) j at a weather station i, and ω_i is the number of *woredas* associated at the station i.

The drought index can be interpreted as an indicator of the value of total cereal production: years where agricultural income losses are high are years where staple crop production is low. Hence such years should correspond to years when cereal production is below average. The index was based on 62,000 households or 310,000 beneficiaries during the 2006 agricultural season from March to October 2006.

Based on historical data, the trigger level was fixed at the Ethiopia Drought Index (EDI) valuing US$55 million. If the Index value at the end of the contract (December 31, 2006) was above this threshold, WFP would receive a payout from AXA of US$ 0.35 for every US$1 the index is above the trigger level, up to a maximum of US$7.1 million.The average EDI of this population is US$28 million per year, with a maximum loss of US$80 million in 1984 (see figure 4 below) and a theoretical worst-case potential loss of US$154 million (World Food Program, 2007)

FIGURE 4. ETHIOPIA DROUGHT INDEX, 1952–2006



2006 Season in Ethiopia

It turns out that 2006 was a good year for crop production in Ethiopia. The EDI value at the end of October 2006 was well below the US$55 million trigger level and no payout came out of this innovative weather derivative contract.

The Ethiopia drought insurance pilot project is a powerful illustration that market mechanisms can be used to provide financial coverage even in low-income countries that are not seen as natural insurance markets. To do so, however, it is necessary to develop objective, timely and accurate risk indicators. Another lesson learned from this initiative lies in the link between *ex ante* and *ex post.* Indeed, the development and implementation of such a risk financing solution was also an incentive for the government to better develop its contingency plan, resulting in better preparation and earlier response to shocks. According to the world food program, "in drafting the implementation rulebook, the (Ethiopian) Government upgraded its contingency planning; the guarantee of predictable and reliable contingency funding catalyzed institutional interest and commitment."[41]

Swiss Re is now working with the Clinton Adaptation Development Program to extend the concept of weather-based insurance derivatives to nine other African countries (Ghana, Malawi, Nigeria, Rwanda, Senegal, Tanzania and Uganda). A trigger system is based on

[41] World Food Program (2007).

measurement of precipitation in several geographic areas. The Program began working in the Koraro village complex in northern Ethiopia in 2007. Payouts will be offered if drought levels reach certain levels as defined by researchers from Columbia University that are providing risk assessments and measurement systems. While these researchers provide the satellite data used to identify drought levels, the Millennium Villages provides the infrastructure for interacting with farmers and households in a uniform way. During the program's first year, drought levels did not reach levels that would result in disbursement to locals.

These two programs have been accompanied by another insurance program in Malawi that provides loans to farmers so that they can buy drought insurance and drought-resistant seed programs. It is administered by the World Bank in conjunction with the International Research Institute on Climate and Society at Columbia University (Hellmuth et al. 2007). The program was developed with the approval of the African Union and federal government of Malawi, but is administered through micro-credit lending agencies that provide support for individual farmers to buy seed. At the time of purchase, farmers are charged a fee for insurance from drought. This experiment is in the preliminary stages and has shown that farmers would like further such programs.

C-4. Other Risk Transfer Mechanisms

In developing countries, those lacking insurance, have traditionally made use of diverse financial strategies for coping with weather variability and extremes: savings or mutual arrangements with family and neighbors; loans from family, micro-credit institutions or money lenders, or in emergencies, selling or mortgaging assets and land if they cannot rely on government relief or international assistance. Governments of highly exposed countries have also relied on a range of financial approaches to meet their post-disaster liabilities: diverting funds from other budgeted programs, borrowing money domestically, or taking loans from international financial institutions. Conventional financial arrangements can fall short of meeting post-disaster capital needs, and the financial gap will likely worsen with more intense and frequent climate-related disasters. To close the gap, some governments are experimenting with capital market and hedging instruments (insurance related securities), like catastrophe bonds, risk swaps, and options, among others. Table 9 provides examples of non-insurance mechanisms for managing risks. We discuss each of these in turn. A more detailed discussion of these different risk transfer mechanisms appears in Linnerooth-Bayer (2009).

TABLE 9: EXAMPLES OF NON-INSURANCE MECHANISMS FOR MANAGING RISKS

	Micro-scale risk financing **Households/SMEs/ Farms**	***Meso-scale risk financing*** **Financial institutions, donor organizations, etc.**	***Macro-scale risk financing*** **Governments**
Informal risk sharing	Kinship and other mutual arrangements; remittances (*family and community solidarity)*		Diversions from other budgeted programs
Inter-temporal risk spreading	Micro-savings; micro-credit; fungible assets; food storage *(individual responsibility)*	Emergency liquidity funds	Reserve funds, regional pools, post-disaster credit; contingent credit
Collective loss sharing (solidarity)	Post-disaster government assistance; humanitarian aid (*national and international solidarity)*	Government guarantees/bail outs	Bi-lateral and multi-lateral assistance
Alternative risk-transfer		Catastrophe bonds	Catastrophe bonds; risk swaps, options, and loss warranties

Sources: Joanne Linnerooth-Bayer (2009).

CONCLUSION OF THE REPORT

The series of large-scale disasters that have occurred during the past 15 years throughout the world suggest that we have entered a new era of catastrophes. The increasing population and greater concentration of assets in high-risk areas coupled with the potential for even more weather extremes as a result of climate change signal even more devastating events in the coming years. With growing globalization of activities worldwide, the world is becoming more interdependent and the consequences of these disasters are likely to be felt far beyond where they initially hit. The need for implementing effective risk reduction measures and developing proper risk financing mechanisms are more important than ever before.

This report proposes a framework to achieve these objectives in two ways: linking *ex ante* considerations more systematically with *ex post* behavior and developing strategies for protection that incorporate our understanding of the simplified "rules of thumb" and biases people exhibit rather than relying on normative models of choice.

Linking *ex ante* and *ex post* is critical because it enables one to better appreciate the interdependencies between steps taken prior to a disaster and the reactions by the public sector following a catastrophic event. Furthermore the strategies require the involvement of all the key stakeholders who are affected by a disaster.

To develop strategies for managing disasters before they occur as well as after the event, it is necessary to undertake transparent quantitative risk assessments and understand how individuals perceive risks as discussed in Part B of this report. One can then develop ways of better communicating risk information as well as formulating economic incentives for encouraging the adoption of protective measures so as to reduce the need for government financing and international aid after a disaster.

In Part C we discuss a set of principles for developing catastrophe risk management strategies that involve insurance. We then propose strategies that we believe the World Bank and other international organizations could take the lead in designing and implementing in specific countries (e.g., multi-hazard insurance, long-term insurance policies, long-term mitigation loans). If some of these proposals are pilot-tested in some emerging economies, they may be viewed in sufficiently positive terms by the key stakeholders that they can be implemented at a more global level.

REFERENCES

Aaron, H. (1972), *Shelter and Subsidies: Who Benefits from Federal Housing Policies*, The Brookings Institution, Washington, D.C.

Albala-Bertrand, J. (2006) "The Unlikeliness of an Economic Catastrophe: Localization and Globalization" Working Paper No. 576 University of London October.

Arena, M., (2006), "Does insurance market activity promote economic growth? Country study for industrial and developing countries," Policy Research Working Paper Series 4098, The World Bank

Arrow, K. (1963), "Uncertainty and the Welfare Economics of Medical Care," *American Economic Review*, 53(5):941-973

Auerswald, P., L. Branscomb, T. LaPorte, and E. Michel-Kerjan, (2006), *Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability*. New York: Cambridge University Press.

Barrett, S. (2003), *Environment and Statecraft: the Strategy of Environmental Treaty-Making* Oxford University Press.

Baumol, W. (1952), *Welfare Economics and the Theory of the State*, Harvard University Press, Cambridge, MA.

Brinkley, D. (2006), *The Great Deluge: Hurricane Katrina, New Orleans, and the Mississippi Gulf Coast,* New York: Harper Collins

Buchanan, J. (1975), "The Samaritan's Dilemma," in Phelps, E. (ed.), *Altruism, Morality and Economic Theory,* New York: Russell Sage Foundation, 71-85.

Burby, R.J., B.A. Cigler, S.P. French, E.J. Kaiser, J. Kartez, D. Roenigk, D. Weist, and D. Whittington (1991), *Sharing Environmental Risks: How to Control Governments' Losses in Natural Disasters,* Boulder, CO: Westview

Camerer, C. and H. Kunreuther (1989), "Decision Processes for Low Probability Events: Policy Implications," *Journal of Policy Analysis and Management,* 8: 565-592.

Campbell, J.Y. (2006), "Household Finance," working paper, Department of Economics, Harvard University.

Chan, J. (2006), Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment," *Science,* 311: 5768, 1713, March 24, 2006

Cohen, L. and R. Noll (1981), "The Economics of Building Codes to Resist Seismic Shocks." *Public Policy* (Winter): 1-29.

Consorcio de compensacion de Seguros (2008), "Natural Catastrophes Insurance Cover. A Diversity of Systems

Crossett, K.M., T.J. Culliton, P.C. Wiley, and T.R. Goodspeed (2004), "*Population Trends Along the Coastal United States: 1980-2008,*" National Oceanic and Atmospheric Administration, NOAA's National Ocean Service, Special Projects: Silver Spring, MD.

Cummins, J.D. and Mahul, O. (2008), *Catastrophe Risk Financing in Developing Countries* Washington, D.C.: The World Bank

Dacy, D. and H. Kunreuther (1968), *The Economics of Natural Disasters.* New York: The Free Press.

Ehrlich, I. and G. Becker (1972), "Market Insurance, Self-Insurance, and Self-Protection." *The Journal of Political Economy*, 80(4), pp. 623-648.

Emanuel, K. (2005), "Increasing destructiveness of tropical cyclones over the past 30 years." *Nature* 436(4): 686-688, August.

Feinstein, J. (2006), "Managing Reliability in Electric Power Companies" in *Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability*. P. Auerswald, L. Branscomb, T. LaPorte, and E. Michel-Kerjan, (eds.) New York: Cambridge University Press.

Gladwell, M. (2000), *The Tipping Point,* New York: Little Brown.

Grossi, P. and H. Kunreuther (eds.) (2005), *Catastrophe Modeling: A New Approach to Managing Risk*. New York: Springer

Government of India, Ministry of Home Affairs (2004), Disaster management of India, New Delhi

Gulkan, P. (2001), Rebuilding the Sea of Marmara Region: Recent Structural Revisions in Turkey to Mitigate Disasters, *A Wharton-World Bank Conference on Challenges in Managing Catastrophic Risks: Lessons for the US and Emerging Economies*, Washington, D.C.

Gurenko, E., Lester, R., Mahul, O., and Gonulal, S. O. (2006), Earthquake Insurance in Turkey. The World Bank

Heal, G., M. Kearns, P. Kleindorfer and H. Kunreuther (2006), "Interdependent Security in Interconnected Networks" (with), in *Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability*, P. Auerswald, L. Branscomb, T. LaPorte, and E. Michel-Kerjan, New York: Cambridge University Press, 2006.

Heal, G. and H. Kunreuther (2005), "The Vaccination Game", Wharton Risk Management and Decision Processes Center Working Paper.

Heal, G. and H. Kunreuther (2006), “You Can Only Die Once: Interdependent Security in an Uncertain World,” in H.W. Richardson, P. Gordon and J.E. Moore II, (eds.), *The Economic Impacts of Terrorist Attacks,* Cheltenham, UK: Edward Elgar

Heal, G. and H. Kunreuther (2007), “Modeling Interdependent Risks”, *Risk Analysis*, Vol. 27, No. 3, pp. 621-634.

Hellmuth, M.E., A. Moorhead, M.C. Thomson, and J. Williams (eds.) (2007), *Climate risk management in Africa: learning from practice.* International Research Institute for Climate and Society (IRI), Columbia University, New York, New York, USA.

Hogarth, R. and H. Kunreuther (1995), “Decision Making Under Ignorance: Arguing with Yourself,” *Journal of Risk and Uncertainty,* 10: 15-36.

Höppe, P. and R. Pielke (eds.) (2006), *Report of the Workshop on Climate Change and Disaster Losses*, May 25-26, Hohenkammer, Germany, October

Hoyos, C., P.A. Agudelo, P.J. Webster, and J.A. Curry (2006), “Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity,” *Science,* 312: 94-97, April 7, 2006.

Huber, O., R, Wider, and O. Huber (1997), “Active Information Search and Complete Information Presentation in Naturalistic Risky Decision Tasks,” *Acta Psychologica*, 95: 15-29.

Ibragimov, R., D.M. Jaffee, and J. Walden (2008), “Non-Diversification Traps in Markets for Catastrophic Risk (joint with Johan Walden and Rustam Ibragimov), forthcoming Review of Financial Studies.

IPCC (2007), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

Jaffee, D., H. Kunreuther, and E. Michel-Kerjan (2008), “Long Term Insurance (LTI) for Addressing Catastrophe Risk” NBER Working Paper # w14210

Kahneman, D. and A. Tversky (1979), “Prospect theory: An analysis of decision under risk,” *Econometrica,* 47(2): 263-291.

Katz, M. and C. Shapiro (1994), Systems competition and network effects. *Journal of Economic Perspectives*. 8: 93-115.

Kousky, C. and R. Zeckhauser (2006), "JARring Actions that Fuel the Floods" in Ronald J. Daniels, Donald F. Kettl, and Howard Kunreuther (eds.), *On Risk and Disaster: Lessons from Hurricane Katrina,* Philadelphia: University of Pennsylvania Press, *pp. 59-73.*

Krantz, D. and H. Kunreuther, (2007), “Goals and Plans in Decision Making,” *Judgment and Decision Making*, Vol. 2, No. 3, June 2007, pp. 137-168.

Kunreuther, H. (1973) *Recovery from Natural Disasters: Insurance or federal aid?* Washingon, D.C.: American Enterprise Institute.

Kunreuther, H. et al. (1978), *Disaster Insurance Protection: Public Policy Lessons,* New York: John Wiley & Sons.

Kunreuther, H. (2006), "Disaster Mitigation and Insurance: Learning from Katrina," *The Annals of the American Academy of Political and Social Science,* 604: 208-227.

Kunreuther, H. and G. Heal (2003), "Interdependent Security: The Case of Identical Agents", *Journal of Risk and Uncertainty*, *26*: 231-49

Kunreuther, H., R.J. Meyer and E. Michel-Kerjan (2009), "Strategies for Better Protection against Catastrophic Risks", in E. Shafir (ed), *Behavioral Foundations of Policy*, Princeton University Press.

Kunreuther, H., and E. Michel-Kerjan (2009), *At War with the Weather: Managing Large-Scale Risks in a New Era of Catastrophes.* MIT Press, (Forthcoming, 2009).

Kunreuther, H., A. Onculer, and P. Slovic (1998), "Time Insensitivity for Protective Measures," *Journal of Risk and Uncertainty*, 16: 279-299.

Kunreuther, H. and M. Pauly, (2004), "Neglecting Disaster: Why Don't People Insure Against Large Losses?" *Journal of Risk and Uncertainty, 28*:5-21, 2004

Kunreuther, H., W. Sanderson and R. Vetschera (1985), "A Behavioral Model of the Adoption of Protective Activities", *Journal of Economic Behavior and Organization*, March 1985.

Laibson, D.. (1997). Golden eggs and hyperbolic discounting. *Quarterly Journal of Economics*. 112, 443-477.

Landsea, C.W., B.A. Harper, K. Hoarau, J.A. Knaff (2006), "Can We Detect Trends in Extreme Tropical Cyclones?" *Science,* 313: 452-454, July 28, 2006.

Lerner, J., R. Gonzalez, D. Small, and B. Fischhoff (2003), "Effects of Fear and Anger on Perceived Risks of Terrorism: A National Field Experiment," *Psychological Science,* 14(2): 144-150.

Linnerooth-Bayer, J. (2009), in *United Nations Framework Convention On Climate Change (UNFCC) Technical Paper.*

Loewenstein, G. and D. Prelec (1992), Anomalies in intertemporal choice: Evidence and an interpretation. *Quarterly Journal of Economics.* 107 (2) 573-597.

Loewenstein, G., T. O'Donoghue, M. Rabin (2003), Projection bias in predicting future utility. *Quarterly Journal of Economics*. 118, 1209-1248

Magat, W., K.W. Viscusi, and J. Huber (1987), "Risk-dollar Tradeoffs, Risk Perceptions, and Consumer Behavior," in W. Viscusi and W. Magat (eds.), *Learning About Risk* (p. 83-97). Cambridge, MA: Harvard University Press

McClelland, G., W. Schulze and D. Coursey (1993), "Insurance for Low-Probability Hazards: A Bimodal Response to Unlikely Events," *Journal of Risk and Uncertainty,* 7: 95-116

Meyer, R. (2006), "Why we Under Prepare for Hazards", in On Risk and Disaster: Lessons from Hurricane Katrina, Ronald J. Daniels, Donald F. Kettl, and Howard Kunreuther (eds), University of Pennsylvania Press, pp. 153-174.

Meyer, R. (2008), "Lessons from the Earthquake Lab: An Experimental Analysis of Learning from Experience about Natural-Hazards" in *Emergency Management in Higher Education: Current Practices and Conversations: Papers From the 2007 FEMA Emergency Management Higher Education Conference*.

Meyer, R.J., S. Zhao and J.K. Han (2007), "Biases in Valuation and Usage of Innovative Product Features" Working paper, Department of Marketing, the Wharton School, University of Pennsylvania.

Michaels, P. (2006), "Is the Sky Really Falling? A Review of Recent Global Warming Scare Stories," *Policy Analysis*, 576, August 23, 2006, Washington, DC: The Cato Institute

Michel-Kerjan, E. (2008), "Disasters and Public Policy: Can Market Lessons Help Address Government Failures," *National Tax Association,* proceedings of the 99th National Tax Association Conference, Boston, MA

Michel-Kerjan, E. and N. de Marcellis-Warin (2006), "Public-Private Programs for Covering Extreme Events: The Impact of Information Distribution on Risk-Sharing," *Asia-Pacific Journal of Risk and Insurance,* 1(2): 21-49.

Mills, E. (2005), "Insurance in a Climate of Change" *Science* 308: 1040-44, August 12, 2005

Munich Re (2006), "Topics Geo- Annual Review: Natural Catastrophes 2005", *Knowledge series.*

Munich Re (2008), "Topics Geo- Annual Review: Natural Catastrophes 2007", *Knowledge series.*

Pielke R., Jr., C.W. Landsea and K. Emanuel (2005), *Nature*, 438, 22/29

Pielke, R. Jr, J. Gratz, C. Landsea, D. Collins, M. Saunders, and R. Musulin (2008), "Normalized Hurricane Damage in the United States: 1900–2005", *Natural Hazard Review*, February 2008.

Raschky, P.A. and M. Schwindt (2008), "Aid, Catastrophes and the Samaritan's Dilemma", Wharton Risk Center Working Paper # 2008-04-15

Schelling, T. (1978), *Micromotives and Macrobehavior,* New York: Norton

Slovic, P., (1995), The construction of preference. *Am. Psychol.* 50, pp. 364–371

Smyth, A. et al. (2004), "Probabilistic Benefit-Cost Analysis for Earthquake Damage Mitigation: Evaluating Measures for Apartment Houses in Turkey." *Earthquake Spectra* 20:171-203.

Spyratos, V., P. Bourgeron, and M. Ghil, (2007) "Development at the wildland–urban interface and the mitigation of forest-fire risk," The National Academy of Sciences of the USA

Stern Review (2006), *The Economics of Climate Change*, H.M. Treasury, December, and Intergovernmental Panel on Climate Change (2007), *Climate Change 2007*, January

Sunstein, Cass R. (2006), "Deliberating Groups vs. Prediction Markets (or Hayek's Challenge to Habermas) *Episteme: A Journal of Social Epistemology* 3,. 192-213.

Swiss Re (2005), Natural catastrophes and man-made disaster in 2004: more than 300,000 fatalities, record insured losses, 2005 SIGMA no. 1

Swiss Re (2006), "Natural catastrophes and man-made disasters in 2005", Sigma, #2, February 2006, Zurich

Thaler, R. (1999), "Mental Accounting Matters" *Journal of Behavioral Decision Making* 12:183-206

The Economist (2008), "After Katrina; half-empty streets", August 30th, p. 33.

Towers Perrin (2005), "Hurricane Katrina: Analysis of the Impact on the Insurance Industry." http://www.towersperrin.com/tillinghast/publications/reports/Hurricane_Katrina/katrina.pdf

Trope, Y. and N. Liberman (2003), Temporal construal. *Psychological Review*. 110 (3) 403-421.

Tversky, A. and E. Shafir (1992), "Choice under conflict: The dynamics of deferred decision," Psychological Science, 3, 6, 358-361.

USAid (2006), "Assessment On How Strengthening The Insurance Industry In Developing Countries Contributes To Economic Growth", February 15, 2006

U.S. Geological Survey (2000), "Implication for Earthquake Risk Reduction in the United States from the Kocaeli, Turkey, Earthquake of August 17, 1999", *USGS Circular 1193.*

U.S. Government Accountability Office (GAO) (2005), Catastrophe Risk, U.S. and European Approaches to Insure Natural Catastrophe and Terrorism Risks, Appendix III, GAO-05-199

Watts, Duncan J. (1999), *Small Worlds*. Princeton University Press.

Webb, I., M.F. Grace, and H.D. Skipper (2002), "The Effect of Banking and Insurance on the Growth of Capital and Output." Center for Risk Management and Insurance Working Paper.

Webster P.J., J.A. Curry, J. Liu, G.J. Holland (2006), Response to Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment," *Science,* 311, 1713c, 24 March, 2006

Webster, P., G.J. Holland, J. Curry and H.R. Chang (2005), **"**Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment," *Science,* 309: 1844-1846, September 16, 2005.

Wilson, T. and D.Gilbert. (2003), Affective forecasting. Mark Zanna, ed. *Advances in Experimental Social Psychology,* Vol. 35. New York: Elsevier, 345-411

World Food Program (2005), Projects for Executive Board Approval. Agenda item 8. Pilot Development Project. Ethiopia Drought Insurance", Executive Board, Second Regular Session, Rome, 7–11 November 2005

World Food Program (2007), Operational report. Agenda item 10. Final Report on the Ethiopia Drought Insurance Pilot Project", Executive Board, First Regular Session, Rome, 19–21 February 2007.

Yucemen, S. (2008), "Turkish Catastrophe Insurance Pool (TCIP): Contributions To Risk Awareness" Proceedings of the US Treasury-OECD International Conference on Financial Education, Washington, DC, May 6, 2008.

Appendix 1. Interdependent Risk and Tipping Behavior – Mathematical Approach[42]

It is possible to expand the simple model of interdependent risks to the case where n villages make decision in a global interdependent environment.

Consider A interdependent risk-neutral agents (in our example agents are villages) indexed by i. Each is characterized by parameters p_i, L_i, c_i and Y_i. Here p_i is the probability that agent $i's$ actions lead to a direct loss L_i. A direct loss can be avoided with certainty by investing in loss-prevention at a cost of c_i. Initial income before any losses are incurred or before expenditure on loss-prevention is Y_i. Each agent i has a discrete strategy, X_i, that takes as values either S or N representing investing and not investing respectively. If i incurs a direct loss, then this may also affect other agents' outcomes. We call the loss to them in this case "an indirect impact." More specifically, $q_i(K, X_i)$ is the expected indirect loss to agent i when it follows strategy X_i and the agents in the set $\{K\}$ are the only ones investing in loss-prevention.

When we use a letter to refer to a set, we will designate it $\{K\}$, except when it is an argument of a function, in which case we omit the brackets. A feature of the IDS problem described above is that an agent who has invested in prevention cannot cause an indirect impact on others, so if everyone other than *i* invests in prevention, then *i* cannot suffer indirect impacts. That is, if $\{K\} = \{1, 2, ..i-1, i+1, ..A\}$ then $q_i(K, X_i) = 0$ whether $X_i = S$ or N.

If agent i invests in prevention and agents in the set $\{K\}$ are also investing then the expected cost from this is $c_i + q_i(K, S)$ where the first term is the direct cost of investing in prevention and the second is the expected cost (or benefit if negative) of indirect impacts imposed by others who do not invest.

The expected cost of not investing is given by $p_i L + (1-\alpha p_i) q_i(K, N)$. Here, the first term is just the expected direct loss and the second is the expected indirect impact. In this second term, the parameter $\alpha \in [0,1]$ indicates the extent to which damages are non-additive. If $\alpha = 0$ then this second term is $p_i L_i + q_i(K, N)$, so that the total expected damage sustained by agent i in the case of non-investment is the sum of the direct and indirect effects.

If however $\alpha = 1$ then we have $p_i L + (1-p_i) q_i(K, N)$, which means that the indirect effects are conditional on the direct loss not occurring. In this case, the damages from harmful events are non-additive (i.e., you only die once).

[42] This model is based on Heal and Kunreuther (2007).

The agent is indifferent between investing and not investing when

$$c_i + q_i(K,S) = p_i L_i + (1-\alpha p_i) q_i(K,N)$$

or

$$c_i(K) = p_i L_i + (1-\alpha p_i) q_i(K,N) - q_i(K,S)$$

where $c_i(K)$ in the second equation is the cost of investment at which i is just indifferent between investing and not investing: if $c_i < c_i(K)$ then she will invest and vice versa.

The coordination problem associated with global supply chain security that we discussed above is a case where $q_i(K,N) = q_i(K,S)$ and $\alpha = 1$

so that

$$c_i(K) = p_i\left(L_i - q_i(K,N)\right)$$

It follows in this case that $c_i(K)$ increases in K : as more agents invest, the expected indirect loss falls and the cost threshold for investment rises, with $c_i(\varnothing) < c_i(A-i)$ where c_i *(A-i)* is defined as the critical cost when all agents other than i are investing. In this case the game is supermodular (see Milgrom and Roberts, 1994).

In that context, a Nash equilibrium is a set of strategies $X_1, \ldots. X_A$ such that (a) $X_i = S$ for all $i \in \{K\}$ (which may be empty), (b) if $X_i = S$ then $c_i(K) > c_i$ and (c) if $X_i = N$ then $c_i(K) < c_i$ and (d) if $c_i(k) = c_i$ then i is indifferent between S and N . It is possible to show that should the above four conditions hold, a Nash equilibrium in pure strategies exists. There may be equilibria where all agents invest in loss-prevention, those where none do, and asymmetric pure strategy equilibria where some invest and others do not. It is also possible that for some parameter values there is more than one equilibrium.

It is also possible to show that there are Nash equilibria at which all agents invest and also Nash equilibria at which none invest if and only if $c_i(\varnothing) < c_i < c_i(A-i) \forall i.$ Also, if both $(N,N,..,N)$ and $(S,S,...,S)$ are Nash equilibria, then $(S,S,,..,S)$ Pareto dominates $(N,N,...,N)$ (Heal and Kunreuther, 2007). If there are two equilibria, one with all not investing and the other with everyone investing in protection, then it is obviously interesting to know how we might tip the inefficient ($N,N.....N$) equilibrium to an efficient ($S,S,.....S$) equilibrium.

Let's now look into the possibility of tipping the non-investment equilibrium.

Tipping

Let $X_i = N \forall i$ be a Nash equilibrium. A critical coalition CC for this equilibrium is a set $\{M\}$ of agents such that if $X_i = S \forall i \in \{M\}$ then $c_j(M) \geq c_j \forall j \notin \{M\}$.

Let minimum critical coalition MCC be a critical coalition of which no subset is also a critical coalition and let a smallest critical coalition SCC be a minimum critical coalition with the property that no other critical coalition contains fewer members.

Define $\quad q_i^j(K,N) = q_i(K-j,N) - q_i(K,N) \geq 0$

This is the change in the expected indirect loss to agent i, who does not invest in loss-prevention, when agent j joins the set $\{K\}$ of agents who are already investing in loss-prevention. For the remainder of this section we make the following assumption:

$$\textit{Assumption A1}: q_i^j(K,N) \text{ is independent of } i : q_i^j(K,N) = q^j(K,N) \forall i$$

This implies that indirect effects are symmetrically distributed across agents. Also define $q_i^j(\varnothing,S) = q_i(\varnothing,S) - q_i(j,S)$ and $q_i^j(\varnothing,N) = q_i(\varnothing,N) - q_i(j,N)$ and make the additional assumption that:

$$\textit{Assumption A2}: q_i^j(\varnothing,S) = q_i^j(\varnothing,N) = q_i^j(\varnothing) = q^j(\varnothing)$$

This indicates that the indirect impact of a change of strategy by agent j on another agent does not depend on the other agent's strategy.

Finally, we shall need the following assumption:

$$\textit{Assumption A3}: \text{The ranking of agents by } q^j(K) \text{ is independent of } \{K\}$$

This says in intuitive terms that if agent k creates the largest negative externalities when agents in the set $\{K\}$ are investing in loss-prevention, then agent k creates more externalities than any other agent whatever the set investing in loss prevention.

Then it is possible to show the following. *Let $X_i = N \forall i$ be a Nash equilibrium. If a smallest critical coalition exists for this equilibrium then for some integer K it consist of the first K agents when agents are ranked in decreasing order of $q^j(\varnothing)$*[43].

[43] Note that these results on tipping apply only to the type of problems we introduce here, as these are the ones that have equilibria where all invest and where none invest, so that tipping from the latter to the former is of interest.