challenge paper

NATURAL DISASTERS

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Policy Options for Reducing Losses from Natural Disasters: Allocating $75 billion

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Comments welcome

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Erwann Michel-Kerjan teaches Environmental Sustainability and Value Creation at the Wharton School and is Managing Director of the Wharton Risk Management and Decision Processes Center, which for nearly three decades has been at the forefront of research into catastrophe risks. Dr. Michel-Kerjan is Chairman of the *OECD Secretary-General Board on Financial Management of Catastrophes*, which advises its thirty-four member countries and the G20 on these issues. Named a Young Global Leader (YGL) by the World Economic Forum (Davos), an honor bestowed to recognize and acknowledge the most extraordinary leaders of the world under the age of 40, Michel-Kerjan served on the World Economic Forum's Global Agenda Council on *Leadership and Innovation for Reducing Risks from Natural Disasters* (2009-2010) and he co-led the Global Risks component of the G20 YGL Paris Initiative under the High Patronage of President Sarkozy in 2011. He has worked extensively with top decision makers in the public and private sectors on how better manage and finance extreme events (terrorism, natural disasters). Michel-Kerjan is the author of over 50 publications and several acclaimed books, including, most recently, *The Irrational Economist* (PublicAffairs, with P. Slovic) and *At War with the Weather* (MIT Press, with H. Kunreuther) which received the Kulp-Wright award for the most influential book on risk management. He is a regular contributor in the media and has given over 100 public speeches. He has studied at Polytechnique in France, McGill and Harvard.

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SECTION 1. INTRODUCTION

Thirty years ago, large-scale natural disasters were considered to be low-probability, high-consequence events. Between 1970 and the mid-1980s, annual insured losses from natural disasters worldwide (including forest fires) were only in the $3 billion to $4 billion range. The insured losses from Hurricane Hugo, which made landfall in Charleston, South Carolina, on September 22, 1989, was the first natural disaster in the United States to inflict more than $1 billion of insured losses. Times have changed.

Economic and insured losses from great natural catastrophes such as earthquakes, hurricanes and floods have increased significantly in recent years. According to Munich Re (2011), economic losses from natural catastrophes increased from $528 billion (1981-1990), $1,197 billion (1991-2000) to $1,213 billion over the period 2001-2010. During the past ten years, the losses were principally due to hurricanes and resulting storm surge occurring in 2004, 2005, and 2008. Figure 1 depicts the evolution of the direct economic losses and the insured portion from great natural disasters over the period 1970-2011.[2] Given the massive economic losses from the March 2011 earthquake and resulting tsunami in Japan, the year 2011 was the most costly year on record for disasters globally: $370 billion (Swiss Re, 2011).

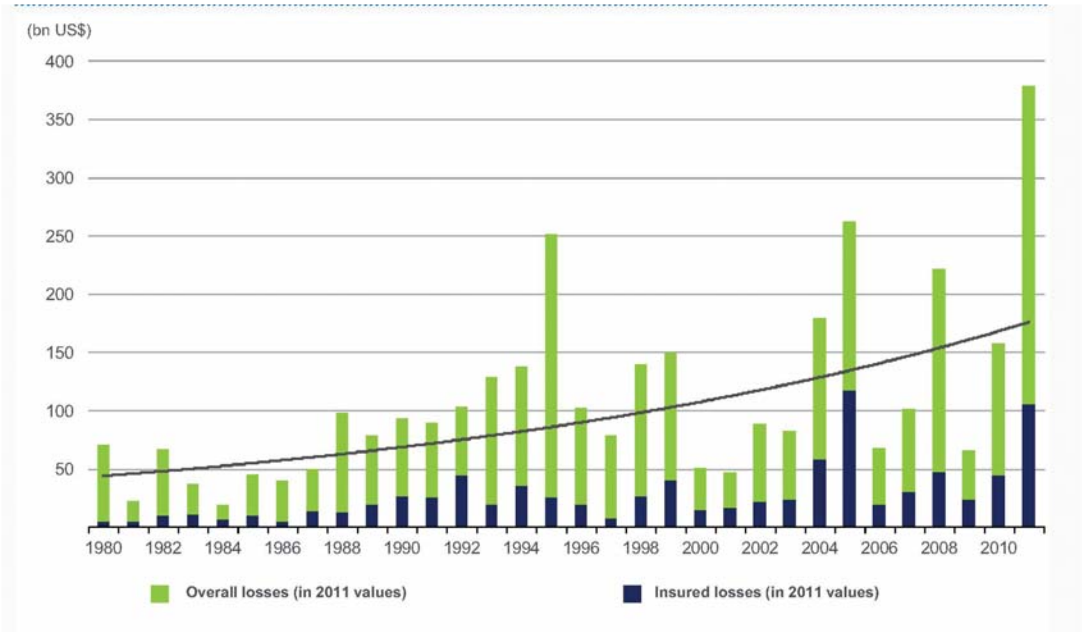

FIGURE 1. NATURAL CATASTROPHES WORLDWIDE 1980-2011.
OVERALL AND INSURED LOSSES WITH TREND ($ BILLION)
Sources: Munich Re Geo Risks Research

[2] Catastrophes are classified as "great" if the ability of the region to help itself is overtaxed, making inter-regional or international assistance necessary. This is normally the case when thousands of people are killed, hundreds of thousands made homeless or when a country suffers substantial economic losses.

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. In 2010, China suffered its most devastating flood in a decade, which cost about US$50 billion in direct economic losses, with US$1 billion covered by insurance so the L/I ratio was 50 (Michel-Kerjan and Kunreuther, 2011).

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 United States, the L/I ratio has been much lower (ranging from 2 to 4) due to higher insurance coverage. In the cases of Hurricane Andrew (in 1992 prices), the Northridge earthquake (1994 prices) and Hurricane Katrina (2005 prices) the L/I ratios were about 1.5 (26/17), 2.8 (44/15.5) and 3 (150/45), respectively.

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 a similar event occurring in a developing country. In the United States where the GDP is nearly US$15 trillion, even a US$250 billion loss due to a series of major disasters 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. 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 as shown in Table 1.

Table 1. Examples of Disasters and Damages as Percentage of GDP

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	Oceana	278	248%
2004	Hurricane (Ivan)	Grenada	Caribbean	889	203%
1990	Cyclone (Ofa)	Samoa	Oceana	200	178%
1985	Cyclone (Eric and Nigel)	Vanuatu	Oceana	173	143%

Sources: World Bank (2008)

Larger countries also often have a greater geographical spread of their economic assets relative to the spatial impact of disasters, and can therefore avoid more direct losses while minimizing indirect and downstream losses. Smaller countries like island nations can also face increased disaster risks by not only having a smaller economy, but by also having a larger proportion of their total land exposed to hazard (UNDP, 2004).

Using annual GDP to measure the relative economic impact of a disaster does not necessarily reveal the impact of a disaster to the affected region, however; property damage, business interruption, real estate prices and tax revenue could be very severe locally but not be large enough to have an impact on the GDP.[3] The long-term effects of disasters on a country's GDP can also vary based on the state of development of the country, the size of the event, and the overall economic vulnerability of the country. Potentially negative long-term economic effects after a disaster include the increase of the public deficit and the worsening of the trade balance (demand for imports increase and exports decrease). For example, after Hurricane Mitch in 1998, Honduras experienced total direct and indirect losses that were 80 percent of its GDP, (Mechler, 2003).

Fatalities

Natural disasters in developing countries also have often a devastating human impact. The Bhola cyclone in the Ganges Delta in 1970 killed an estimated 500,000 in East Pakistan (now Bangladesh) and is classified as one of the deadliest natural disasters in history. In recent years, the 2004 tsunami in Southeast Asia killed between 225,000 and 275,000; the earthquake in Haiti in 2010 killed approximately 230,000 (CBC News, 2010). The historical floods in Pakistan in the summer of 2010 killed 2,000 and affected 20 million people. It is a challenge to think about how to address a large-scale crisis where one-fifth of the entire country's land is underwater and 20 million are displaced for weeks (Michel-Kerjan and Slovic, 2010). These fatalities have a long-term impact on the development potential for a country. A population weakened by a natural disaster can often lack the organizational capacity to maintain social assets, making communities more vulnerable. In addition to the loss of social assets, losses in sanitation, education, health, housing, etc., can further cripple an already affected nation (UNISDR/World Bank, 2011).

[3] 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 loss of residents will be permanent.

Reasons for Concern

The main drivers of the aforementioned increasing losses from natural disasters are two socio-economic factors which directly influence the level of economic damage: *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 as the population reaches 8.3 billion people. A direct consequence of this trend is the increasing number of so-called mega-cities with population above 10 million. In 1950, New York City was the only such mega-city. In 1990, there were 12 such cities. By 2015, there are estimated to be 26, including Tokyo (29 million), Shanghai (18 million), New York (17.6 million), and Los Angeles (14.2 million) (Crossett, et. al., 2004).

With respect to the developing world, Istanbul, a city 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 13 million by the end of 2010. This makes the Istanbul metropolitan area the third largest one in Europe after London and Moscow. In India, about 48 percent of the land is prone to cyclones, 68 percent to droughts and more than 40 million hectares (nearly 1/8th of India) are prone to floods (Government of India, 2004). Ten of the most deadly disasters since 1970 occurred in this country. Furthermore, several large cities in India subject to natural disasters are very densely populated. Mumbai (20 million people) has a population density of over 20,000 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 16.7 million in 2011. Its population density is very high as well.[4]

Many urban centers in India and other countries have large informal settlements and slums, with a population that is now over 1 billion people. The poor building standards and land use strategies, overcrowding, and location in often significantly hazard-prone locations (for example, low lying areas or riverbanks) leads to a compounding of disaster risk for these populations (Wilton Park Conference, 2010).

This trend toward much higher populations in disaster-prone locations does not seem to be reversing. Quite the opposite: in the next 10-15 years there will be an additional billion people on planet Earth, after one billion had already been added in the previous decade. Most of those people will be in developing countries, a large portion of whom will live in urban zones located in hazard-prone areas. So we expect disasters to

[4] 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 square kilometer.

become more devastating in the next coming ten years, unless we become more proactive at building resilient communities.

Disasters in Low-Income Countries: Vicious Cycle Creates Poverty Traps

As discussed above, disasters are known to have enduring negative effects on less-developed countries because of the magnitude of the damage relative to their gross domestic product (GDP) (Gurenko, 2004; Linnerooth-Bayer et al., 2005; UNISDR/World Bank, 2011). The macro-economic status in developing countries has also been shown to be an important factor in how they respond to disasters (Hallegate and Dumas, 2009; Hallegate and Ghil, 2008). One other major challenge of disasters in developing countries is that they not only destroy physical infrastructure on a large scale, but also affect a disproportionally high number of individuals, compared to OECD countries. Finally, many developing countries do not undertakeappropriate risk reduction measures nor do they purchase adequate insurance to protect themselves against the economic consequences of future catastrophes.

When one combines all these elements that characterize the situation in a number of low-income countries, one can see a vicious cycle emerge. When disasters occur there, the countries themselves may have a difficult time achieving sustainable economic development if those disasters repetitively destroy crops, infrastructure and services. Any previous development gains can also be wiped out. As a result, the reconstruction process will be slow and during that time financial and human capital are allocated to rebuilding the country, rather than being used for development. Another disaster is likely to occur before the region has had the time to fully recover from the previous one. And so on and so forth—repeated disasters have pushed these countries into poverty traps.

More frequent and relatively localized disasters thus take a toll on the development potential of a country. The frequency of these events can deplete sustainable coping mechanisms and favor the adoption of unsustainable coping mechanisms, which can increase the vulnerability of the environment and livelihoods of the population. If the economy is also relatively lacking in diversification, a disaster can have an increased economic impact (UNDP, 2004). This raises the question as to the appropriate private and public sector strategies to encourage individuals and communities in these countries to undertake measures that improve human well-being and social equity (UNEP, 2010).

A key challenge facing developing countries as well as many nations in the developed world is constructing buildings that can withstand the impacts of severe natural disasters such as earthquakes, floods and tropical cyclones/hurricanes. Many countries do not have building codes in place today. For hazard-prone areas where there are codes on the books, the empirical evidence suggests that they often are not enforced. When the next disaster hits these areas, the property damage can be severe and there are likely to be many fatalities due to individuals trapped inside these buildings.

To address this problem we will undertake a benefit-cost analysis (BCA) of allocating $75 billion to designing and constructing schools in developing countries that can withstand damage from severe earthquakes and to residential structures in areas that are subject to severe flooding and tropical cyclones. The two companion discussion papers on natural hazards will suggest complementary strategies for reducing the economic and human impacts of disasters: early warning systems (by Stephane Hallegatte) and macroeconomic policies (by Ilan Noy).

The next section of the paper proposes a framework for undertaking a BCA of alternative hazard reduction measures that highlights the importance of linking risk assessment and risk perception with risk management strategies. **Section 3** details a methodology for undertaking a BCA of alternative disaster risk management strategies. In **Section 4** we introduce four proposals for significantly reducing damage and human deaths from earthquakes, floods and cyclones/hurricanes/storm, and calculate the benefit generated by spending $75 billion on these proposals. We vary the discount rate (d) (3% and 5%) and Value of Life (VoL) ($40,000/$200,000/$1.5 million/$6 million) to show how the B/C ratios change and their impact on expected benefits for a given cost.

> ***Proposal I*** **retrofits schools in seismically active countries in the developing world so they are earthquake resistant.** It would cost approximately $300 billion to retrofit all the schools in the 35 most exposed countries we studied, saving the lives of 250,000 individuals over the next 50 years. With a VoL of $40,000, only several countries exhibit a benefit-cost ratio (BCR) greater than 1. As the the VoL increases, the BCR exceeds 1 for an increasing number of countries. More specifically for a discount rate of 3% and a VoL= $1.5 milion, thirteen countries have a BCR higher than 1 and the entire $75 billion could be spent on retrofitting schools in the twelve countries with the highest BCR, saving more than 135,000 lives over the next 50 years.

> ***Proposal II*** **examines two measures for reducing losses from severe flooding: (a) constructing a one-meter high wall to protect homes in communities subject to flooding; (b) elevating each of these houses.** We find that it would cost nearly $940 billion to undertake the community-based disaster risk reduction measure of building walls around the affected communities and $5.2 trillion to elevate all houses exposed to floods in the 34 most exposed countries. Undertaking either of these measures will save 61,000 lives over the next 50 years. If one invested $75 billion in building one-meter high walls surrounding communities, the estimated benefits would be $4.5 trillion with an average BCR= 60. Elevating homes would yield estimated benefits of $1.1 trillion and an average BCR= 14.5 for {d=.03 VoL=$40,000}.

Proposal III **improves roof protection of homes to reduce losses in areas subject to cyclones, storms and hurricanes.** We estimated that it would cost $951 billion to undertake this loss reduction measure in the 34 countries most exposed to severe wind damage; all of them exhibit a BCR > 1. Doing so could save 65,700 lives over the next 50 years. If investment were limited to $75 billion in countries with the highest BC ratio, then the expected benefit will be $168 billion for {d=.03 VoL=$40,000}.

Proposal IV **introduces early warning systems in advance of the onset of floods, tropical cyclones and storm-related disasters to improve emergency actions and save lives.** We discuss several benefit-cost analyses that have been published in the literature and show significant BCRs.

Section 5 discusses the practical challenges in implementing these programs, drawing on recent empirical studies in behavioral economics and disaster management. **Section 6** proposes innovations for addressing these issues. We conclude the paper by summarizing the key points of our analysis and suggesting directions for future research on ways to cost-effectively fund programs for reducing losses from future disasters.

SECTION 2. FRAMEWORK FOR ANALYSIS

This section develops a framework for evaluating the costs and benefits of alternative programs and policies for reducing future damage and fatalities from natural disasters and facilitating the recovery process. Engineering and the natural sciences provide data on the nature of the risks associated with disasters of different magnitudes and the uncertainties surrounding them (*Risk Assessment*). Geography, organizational theory, psychology, sociology, and other social sciences provide insights into how individuals, groups, organizations, and nations perceive risks and make decisions (*Risk Perception and Choice*). Economics and policy analysis examine various strategies for reducing future losses as well as dealing with recovery problems (*Risk Management*).

Risk Assessment

The science of estimating the chances of specific extreme events occurring and their potential consequences originates in the field of property insurance and the science of natural hazards. In the 1800s, residential insurers managed their risk by “mapping” the structures that they covered, pinning tacks onto a wall map to display the degree of physical concentration of exposure. Now, Geographic Information Systems (GIS) software and other digital products address this issue with far more extensive data and sophisticated technologies (Kozlowski and Mathewson, 1995).

Four basic elements for assessing risk – hazard, inventory, vulnerability, and loss – are depicted in Figure 2. The first element focuses on the risk of a *hazard*. For example, an earthquake hazard is characterized by its likely epicenter location and magnitude, along with other significant parameters. A hurricane is distinguished by its projected path and wind speed. The hazard can also be usefully characterized as a range of potential scenarios. For example, what is the likelihood that a hurricane of magnitudes 3, 4 or 5 on the Saffir-Simpson scale could cause damage if it struck the Miami, Florida area in 2012?

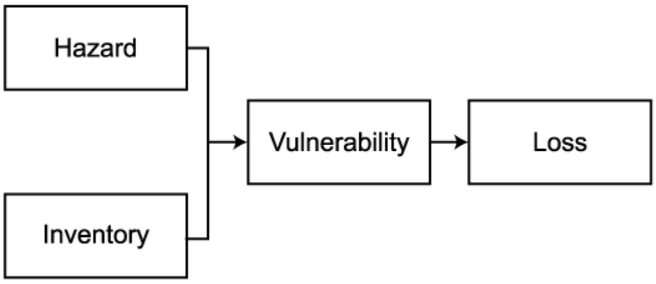

FIGURE 2. ELEMENTS OF THE RISK ASSESSMENT PROCESS MODEL

The risk assessment process model's second element identifies the *inventory* of properties, humans, and the physical environment at risk. To inventory structures, for instance, would require evaluation of their location, physical dimensions, and construction quality. Taken together, the hazard and inventory elements enable calculation of the model's third element, the damage *vulnerability* of the structures or people at risk. And from the measure of vulnerability, the human and property *loss*, the fourth element, can be evaluated.

In working with catastrophes in this model, it is also useful to distinguish between *direct* and *indirect* losses. Direct losses include injuries, fatalities, financial losses, and the cost to repair or replace a structure, restore a service, or rescue a company. Indirect losses include future foregone income, slower growth, and other longer-term consequences of evacuation costs, disrupted schooling, and company bankruptcies.

Risk Perception and Choice

While risk assessment focuses on objective losses such as financial costs, *risk perception* is concerned with the psychological and emotional factors associated with risk. Research has demonstrated that the perception of risk has an enormous impact on behavior, regardless of the objective conditions.

In a set of path-breaking studies begun in the 1970s, decision scientists and psychologists such as University of Oregon's Paul Slovic, Carnegie Mellon University's Baruch Fischhoff, and others began studying people's concerns about various types of risks. They found that people viewed hazards with which they had little personal knowledge and experience as highly risky and especially dreaded their possible occurrence. In the case of unfamiliar technologies with catastrophic potential such as nuclear power, people perceived the risks as much higher than the experts (Slovic, 2000).

Research also found that people often perceive the world of low-probability and high-consequence events quite differently from experts, and that this impacts on their decision-making process and choice behavior. In recent years, however, the scientific and engineering communities have devoted attention to the psychological factors that impact on how individuals make decisions with respect to risks from natural and technological hazards. Rather than simply urging policy makers and organizational leaders to take actions on the basis of their traditional risk assessment models, experts are increasingly incorporating salient human emotions such as fear and anxiety into the models.

Researchers have discovered that people are generally not well prepared to interpret low probabilities when reaching decisions about unlikely events. In fact, evidence suggests that people may not even want data on the likelihood of a disastrous event when the information is available to them. If people do not think probabilistically, how then do they make their choices in the face of risk? Extensive research on decision making now confirms that individuals' risk perceptions are affected by judgmental biases and the use of simplified decision rules (Kahneman et al., 1982). We will discuss the way decision makers process information and make choices in Section 5.

Risk Management Strategies

In developing effective risk management strategies for reducing losses from natural disasters, leaders of public agencies and private and non-profit organizations will want to appreciate the findings of risk assessment studies and the factors that influence risk perception and choice. A coherent strategy should build on the following elements:

Mitigation Measures: A key challenge is to encourage those at risk from natural hazards to invest in cost-effective loss reduction measures, which is called *mitigation* in the disaster literature.[5] Property owners can invest in measures that will reduce losses from future disasters (for example, elevating their residence or business so it is less prone to flood damage; making their property more earthquake-resistant). Mitigation can also be undertaken by the public sector through investments in structural measures such as sea walls, dams and levees that protect communities and regions from damage from disasters such as floods, cyclones or hurricanes.

The core of our analysis will focus on determining the potential benefit of investing in protective actions in low-income and developing countries. But as we will show in Section 5, there are several factors that discourage decision-makers from investing in these measures. In addition to undertaking a BCA, one needs to understand the role of

[5] Note that in the climate change literature "mitigation" refers to reducing greenhouse gas emissions and "adaptation" to what can be done to avoid or limit to consequences of a changing climate.

incentive mechanisms and public policies in fostering the adoption of specific loss reduction measures. In this regard well-enforced regulations and standards can play a key role in encouraging those at risk to undertake mitigation measures. A well-enforced building code will encourage property owners and developers to make sure that the structure is well designed against disasters. For these regulations to be effective there is a need for third-party inspections to ensure that the property meets the code and sufficiently high penalties for those who do not adhere to the standard.

Insurance: Insurance can encourage the adoption of mitigation measures by offering premium reductions to reflect the reduced losses that would result from these investments. Should a disaster occur, insurance could facilitate the recovery process through claim payments to cover some of the resulting damages and losses. For insurance to play this dual role and address distributional issues, we propose the following two guiding principles:

Principle 1: Premiums should reflect risk. Insurance premiums should be based on risk in order to provide signals to individuals about the hazards they face and to encourage them to engage in cost-effective mitigation measures that reduce their vulnerability to catastrophes. Risk-based premiums should also reflect the cost of capital that insurers must integrate into their pricing in order to assure adequate return to their investors.

Principle 2: Equity and affordability issues should be addressed. Any special treatment given to homeowners currently residing in hazard-prone areas (e.g., low-income uninsured or inadequately insured homeowners) should be funded through general public funding and not through insurance premium subsidies. (In the case of low-income countries, international donors such as European Commission, USAID and the World Bank could also provide such vouchers). This principle reflects a concern for some residents in high-hazard areas who will be faced with large premium increases if insurers adhere to principle 1. Newly acquired property will be charged premiums reflecting risk.

Early warning systems: As we discuss in more detail later in the paper, investment in early warning systems can be extremely important in reducing human harm and damage from disasters. Advance knowledge of an oncoming hurricane, tsunami or tornado, enables residents to leave the threatened area. The large number of lives taken by the 2004 tsunami because of inadequate warning system was a wake-up call for the international community in that regard. The potential savings in loss of life and serious injury from a well-publicized and timely warning can be significant. An advance warning can also enable homeowners and businesses to take steps to reduce damage to their property and contents. For example, valuable contents could be moved to higher floors to avoid destruction from flooding or storm surge from hurricanes. Residents could sand bag levees to reduce the likelihood that these protective structures would be breached.

Pre-Disaster Assistance: One also needs to consider the costs and benefits of programs to aid those who cannot afford to undertake mitigation measures or purchase insurance at premiums reflecting risk. This type of assistance can be in the form of low-interest loans for investing in loss-reduction measures or grants such as vouchers to purchase disaster insurance. If these programs are effective then the damage and losses from natural disasters will be considerably reduced over time so that less post-disaster assistance will be required.

The aforementioned elements constitute the prongs of a more comprehensive strategy for disaster risk reduction and recovery. Mitigation programs are unlikely to be successful without a well-designed insurance program. Early warning systems can be combined with mitigation programs and pre-disaster assistance programs.

SECTION 3. A METHODOLOGICAL APPROACH TO EVALUATE THE ECONOMIC COSTS AND BENEFITS OF DISASTER RISK REDUCTION MEASURES

Anecdotal evidence and retrospective analyses show large benefits to disaster risk reduction in many developed and developing country contexts. Examining investments in 4,000 mitigation programs, including retrofitting buildings against seismic risk and structural flood defense measures, the US Federal Emergency Management Agency (FEMA) found an average **benefit-cost ratio (BCR)=4** (MMC, 2005). In developing countries, a review of 21 studies on investments as diverse as planting mango forests to protect against tsunamis, and relocating schools out of high-hazard areas demonstrated, with few exceptions, equally high benefit-cost (B-C) ratios (Mechler, 2005).

Despite high returns, relatively few people engage in disaster prevention measures. In the U.S. several studies show that only about 10 percent of earthquake- and flood-prone households have adopted loss-reduction measures (hereafter referred to as mitigation measures). Kunreuther, Meyer and Michel-Kerjan (in press) attribute this lack of interest to myopia: the upfront costs of the investment in mitigation loom large relative to its perceived benefits over time.

In the absence of concrete information on net economic and social benefits, and faced with limited budgetary resources, many policy makers are also reluctant to commit significant funds for risk reduction. However, when a disaster occurs they then are pressured into providing funds to assist victims and aid the recovery process (Benson and Twigg, 2004; Michel-Kerjan and Volkman Wise, 2011). This may be especially true for development and donor organizations. According to some estimates, bilateral and multilateral donors currently allocate 98 percent of their disaster management funds to relief and reconstruction and only 2 percent to pro-active disaster risk management (Mechler, 2005). Recently, individuals, governments, and the donor community have encouraged pre-disaster, pro-active disaster investment and planning to redress this balance and reduce overall costs of disaster management (Gurenko, 2004; Kreimer and Arnold, 2000; Linnerooth-Bayer, et al., 2005; UNISDR/World Bank, 2011).

More complete knowledge about the cost and benefits of disaster risk reduction measures to be implemented *before* a disaster hits is thus critical. In this section we will focus on three types of natural hazards – earthquakes, hurricanes and floods – and use a BCA methodology to evaluate several physical risk reduction measures to decrease the probability and consequences of untoward events. There is a substantial literature on the use of BCA to evaluate risk-reduction investments, but surprisingly few applications in developing countries (Benson and Twigg, 2004; Benson et al., 2007; Dixit et al., 2009; Mechler, 2009; Moench et al., 2009; Penning-Rowsell et al., 1996; Smyth et al., 2004).

Building on ongoing research programs by the Wharton Risk Management Center, Risk Management Solutions and IIASA, we examine the benefits and costs of improving or retrofitting residential structures in highly exposed developing countries such that they are less vulnerable to hazards during their lifetime[6].

In order to provide a diversified portfolio, we selected three locations in three different parts of the world: the Caribbean Islands, Indonesia and Turkey. We also selected three different types of natural disasters: hurricanes, floods, and earthquakes. The structures and risks chosen for this study are typical for many low-, and middle-income persons residing throughout these parts of the world.

The methodology developed here could be applied to any location and any type of hazard, provided that good quality data are available. After undertaking these three individual cases and selecting the most cost-effective measures, we will scale up the investment in those disaster risk reduction measures across different countries and focusing on where the BCR is the most attractive.

Methodology

The basic measure for assessing the catastrophe exposure of a house, city or any portfolio of assets is called the *exceedance probability (EP) curve*. An EP curve is basically the mathematical tool used to summarize, for a given location/infrastructure/hazard, all the possible events that can happen and the probability associated with them. More precisely, the EP curve indicates the probability p that *at least* \$X (or lives) is lost in a given year for a given location and type of risk. A typical EP curve can be constructed as depicted in Figure 3, where the likelihood that losses will exceed L_i is given by p_i, that is, the x-axis shows the magnitude of the loss in U.S. dollars, and the y-axis depicts the annual probability that losses will exceed this level. (See for example, Grossi and Kunreuther (2005) for details on constructing EP curves in the context of catastrophe models).

[6] The analysis and results in this section are based on Michel-Kerjan et al. (2012).

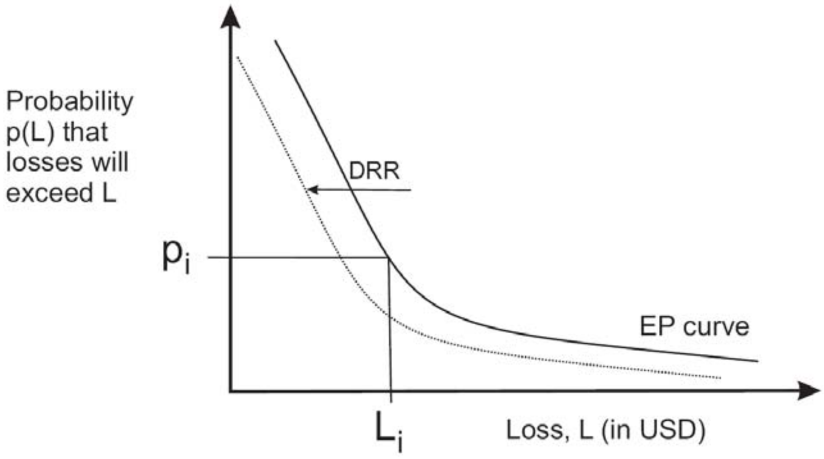

FIGURE 3. EXAMPLE OF AN EP CURVE AND DISASTER RISK REDUCTION EFFECT

One of the advantages of using such a tool is that the area under the EP curve is the average annual loss (AAL). As the term implies, the AAL means that over a long period of time this location should expect to lose this amount, on average, every year. Of course, in some years no disasters occur, while in other years there can be massive losses. Hence the concept of averaging the expected yearly losses over a long period of time.)[7]

Structural disaster risk reduction (DRR) measures typically decrease the vulnerability of the building and therefore reduce the expected loss. Should effective DRRs be implemented in buildings and infrastructure in the area under study, this would shift the EP curve to the left in Figure 3 and reduce the AAL value. Note that the tail of the curve (the right part of it) would also be diminished, thus reducing the likelihood of suffering catastrophic losses.

For each of our three case studies we select measures for reducing losses from each type of disaster. We then construct EP curves for a representative house or houses with and without the DRR measure in place. Benefits are quantified through reductions in the AAL after measures have been applied to a structure and discounted over the relevant time horizon (e.g., 5, 10, 20 years). Cost estimates of each DRR measure are derived from various sources. Combining these estimates, we compute a *benefit-cost ratio* (B/C ratio).[8] The most attractive DRR measure from an economic standpoint is the one with the highest BCR, assuming there are no budget constraints with respect to the cost of the investment. Typically, for a specific disaster risk reduction project in given location, the analysis will be extended to integrate budget constraints and willingness to pay.

[7] Assuming everything else being equal; the addition of new construction and population in that location would require one to calculate this curve again.

[8] Using the BCR as the metric captures the concept of the complex interactions of three main components that affect the final decision: vulnerability of the building, the hazard level of the area, and the cost of the measure discussed.

From each case study we will select the disaster-reduction measure that offers the highest BCR and use it in Section 4 when we scale up our analysis to other countries.

Case Study I: Hurricane Risk in St. Lucia (Caribbean Island State)

St. Lucia is a small Caribbean island highly prone to hurricane risks. The frequency and magnitude of hurricanes are above what is usual in the region. While a large portion of the population is classified as below the poverty level, there is a growing middle class. The coastline of St. Lucia generally has a sharp topography and although there are locations that can experience significant flooding, experts agree that storm does not create a significant loss potential. Hence, this analysis focuses on wind damage to housing structures only.

Over 70 percent of residential buildings are constructed using concrete blocks (i.e., masonry structures) or have wooden outer walls such as plywood and wood/timber walls (Kairi, 2007). It is assumed that the replacement value of the houses is $100,000. These representative houses are located in the higher- and lower-risk cities of Canaries and Patience, respectively.

Methodology: For our analysis in Section 4 we will focus on masonry homes. In the absence of DRR measures, the EP curves for a representative residential structure in the two cities are shown in Figure 4.

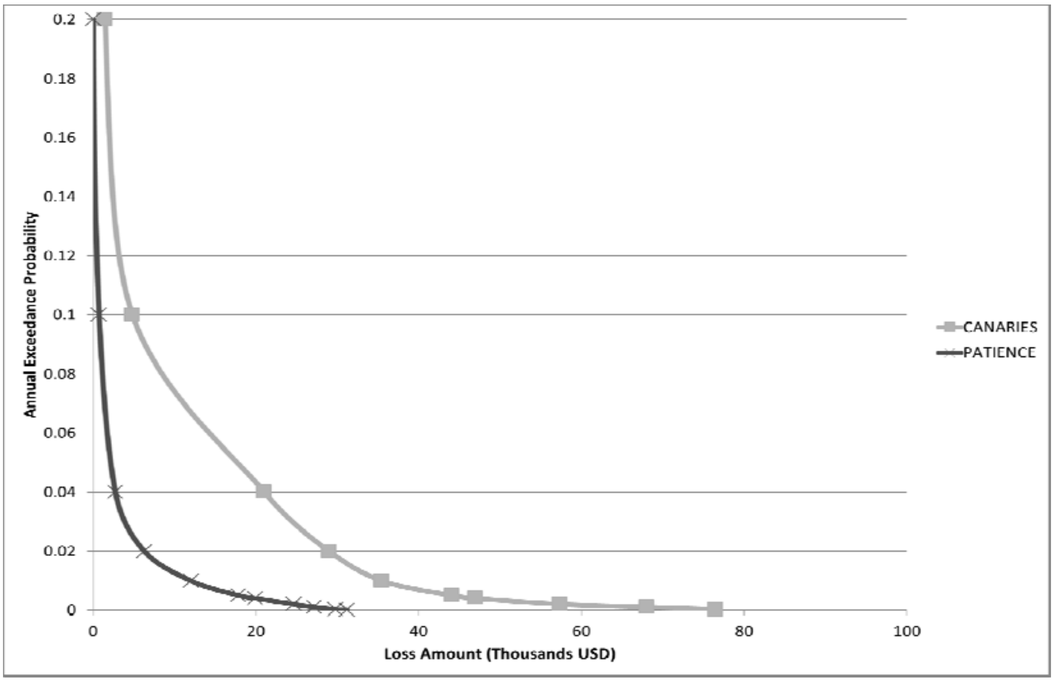

FIGURE 4. EP CURVES WITH NO DRR - HURRICANE RISK IN ST. LUCIA

Three DRR measures were examined for reducing hurricane risk to the representative masonry homes in Canary and Patience. The DRR costs for the homes have been developed based on an RMS survey of DRR costs and from roofing costs reports (Louis, 2004).

- Measure 1: *Roof Upgrade.* This includes the replacement of the roof material with thicker sheeting and tighter screw spacing as well the use of roof anchors. The total cost of this measure is estimated to be $9,200.
- Measure 2: *Opening Protection.* This includes strengthening the resistance of windows and doors against wind and heavy pressure. The total costs are estimated to be $6,720.
- Measure 3: *Roof Upgrade and Opening Protection.* Measures 1 and 2 can be combined to provide a more comprehensive level of protection for the structure. The cost for both is estimated at $15,920.

Benefit-cost calculations: Table 2 shows the results of the benefit-cost calculations for the three measures. Not surprisingly, the results are highly sensitive to the choice of the discount rate, the assumed length of life of the residential structure and the hazard level. The results in Table 2 are based on discount rates of 5 percent and 12 percent[9] and an expected life of the structure of 10 and 25 years.

Table 2. Summary of Selected B/C Ratios (Amounts greater than 1 in bold)

DRR measure	Time horizon (years)	Masonry			
		Canaries (Max Hazard)		Patience (Min Hazard)	
		Discount rate		Discount rate	
		5%	12%	5%	12%
1. Roof upgrade	10	0.75	0.55	0.16	0.11
	25	**1.37**	0.76	0.29	0.16
2. Opening protection	10	0.62	0.46	0.09	0.07
	25	**1.14**	0.63	0.17	0.09
3. Combined	10	0.59	0.44	0.11	0.08
	25	**1.09**	0.60	0.20	0.11

The highest B/C ratio occurs in the maximum hazard location (Canaries) for the roof upgrade measure as highlighted by the shaded area. **We will thus use this roof upgrade measure (replacement of the roof material with thicker sheeting and tighter screw spacing as well the use of roof anchors) in our global analysis in Section 4.**

[9] These are typical low and high annual discount rates used for evaluating development projects. For more details see Mechler (2004).

Case Study II: Flood Risk in Jakarta (Indonesia)

Jakarta is the capital of Indonesia with about 8.5 million inhabitants. Severe flooding is frequent and closely linked to extreme rainfall events. This case study focuses on the region around the Ciliwung River in central east Jakarta, a densely populated and economically important part of the city where flooding occurs most frequently. Jakarta has a wide variety of buildings, from very modern skyscrapers to informal settlements erected on wooden stilts.

Mitigation of Individual Homes

We focus our study of individual homes on residential properties in East Jakarta, which make up about 60 percent of the city's structures. Images from Google Earth suggest that most buildings outside of the commercial center are two- or three-story masonry residential homes typically occupied by persons of high and medium wealth.

We selected a representative housing type: a high-value home constructed with brick walls, concrete floor and clay roof (referred to as *masonry*) and a middle-income home constructed with mixed wall, concrete floor and asbestos roof (referred to as *mixed wall*). The replacement value of the representative house is assumed to be $19,200 (based on estimates from Silver, 2007).

Methodology. Given very limited flood hazard data for Jakarta, we base our EP estimation on approximate flood extent maps and limited depth estimates for two past floods in January/February 2002 and February 2007 (Dartmouth Flood Observatory, 2008). Our hazard analysis also uses a 30-year monthly rainfall time series, observed at the Jakarta Observatory (NOAA global database) within the catchment of the Ciliwung and an elevation map based on data from the NASA Shuttle Radar Topography Mission. Based on these inputs, two probabilistic flood depth curves are generated, representing a higher ('max hazard') and lower ('min hazard') hazard location. Using two EP curves we can test the sensitivity of findings to the hazard approximation. Figure 5 depicts these EP curves for masonry and mixed wall structures.

Two individual DRR measures are selected for reducing flood risks to the masonry and mixed wall dwellings. The cost estimates are based on FEMA, adapted to account for labor cost differences in the U.S. (Davis, 2002; Teicholz, 1998):

- Measure 1: Improve flood resilience and resistance of the property. Approximate cost is $3,100 for the typical home.
- Measure 2: Elevate the property by 1 meter. Costs are estimated to be $9,345 in total.

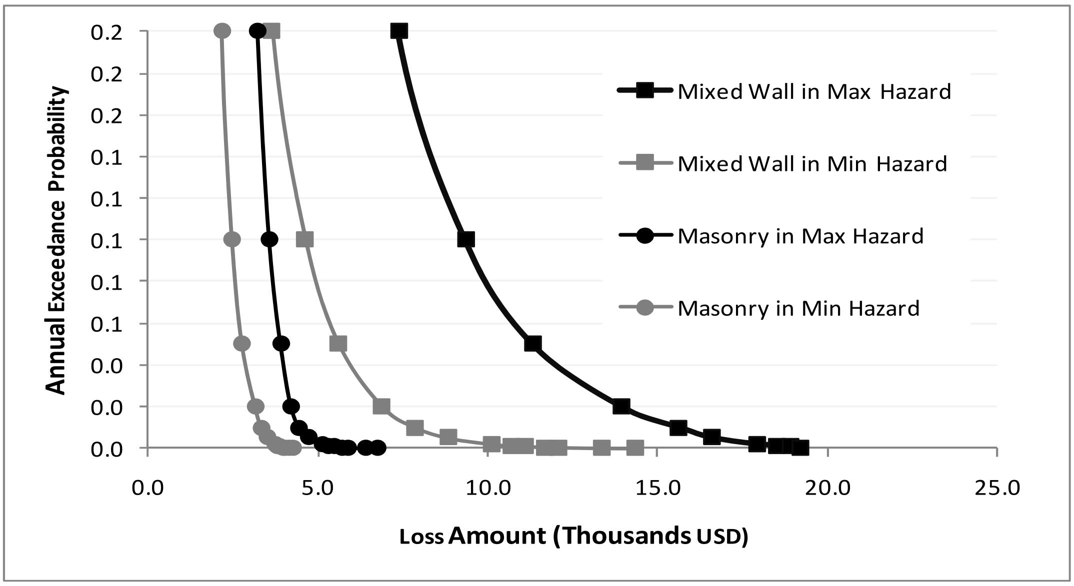

FIGURE 5. FLOOD RISK IN JAKARTA - EP CURVES FOR TWO BASE LINE STRUCTURES IN TWO DIFFERENT HAZARD LOCATIONS WITH NO DRR

Cost-benefit calculations. Using data on expected average annual loss (AAL) and estimates of AAL reductions resulting from the application of each aforementioned measure, Table 3 shows the results of the cost-benefit calculations for the two options. As in the case of St. Lucia, the results are highly sensitive to the choice of the discount rate, the assumed length of life of the residential structure and the hazard level. We show the results for discount rates of 5 and 12 percent and for an expected lifetime of the structures of 10 and 25 years.

Table 3. Flood Risk in Jakarta - Summary of Selected B/C Ratios (Amounts greater than 1 in bold)

DRR Measure	Time Horizon (years)	Masonry				Mixed Wall			
		Min Hazard		Max Hazard		Min Hazard		Max Hazard	
		Discount Rate		Discount Rate		Discount Rate		Discount Rate	
		5%	12%	5%	12%	5%	12%	5%	12%
Improve flood resilience	10	0.49	0.36	0.63	0.46	0.10	0.07	0.11	0.08
	25	0.90	0.50	**1.16**	0.64	0.18	0.10	0.21	0.11
1 m elevation	10	0.83	0.61	**1.18**	0.86	**2.06**	**1.51**	**3.69**	**2.70**
	25	**1.51**	0.84	**2.15**	**1.20**	**3.77**	**2.10**	**6.73**	**3.75**

The BCRs are substantially higher for **mixed-wall structures** than for masonry structures. Elevating these homes by 1 meter is a cost-effective way of reducing future flood damage (BCR>1); improving flood resilience is not (BCR<1). **Our global analysis in Section 4 will thus focus on elevating mixed-wall houses by 1 meter to reduce damage from flooding in countries subject to this disaster (individual flood protection).**

Protecting Jakarta with a Sea Wall

Building a wall around a community is typically the work of government that undertakes large-scale protection projects. According to U.S. data from New Orleans, such a project could is estimated to cost around $2 billion. The number of permanent residences in Jakarta is about 1,152,000 (Silver, 2007); so the cost of this mitigation measure per household is approximated at $1,736.

Assume that a wall is constructed to protect the 1.2 million permanent residences in Jakarta, we find that the construction of a 1 meter wall would lead to the highest BCR (48.6) relative to higher walls as shown in Figure 6. We calculate that the benefit for the representative house over 25 years would be $84,338 (Wharton-IIASA-RMS, 2009). **We will also use this community-based flood protection measure in our global analysis in Section 4.**

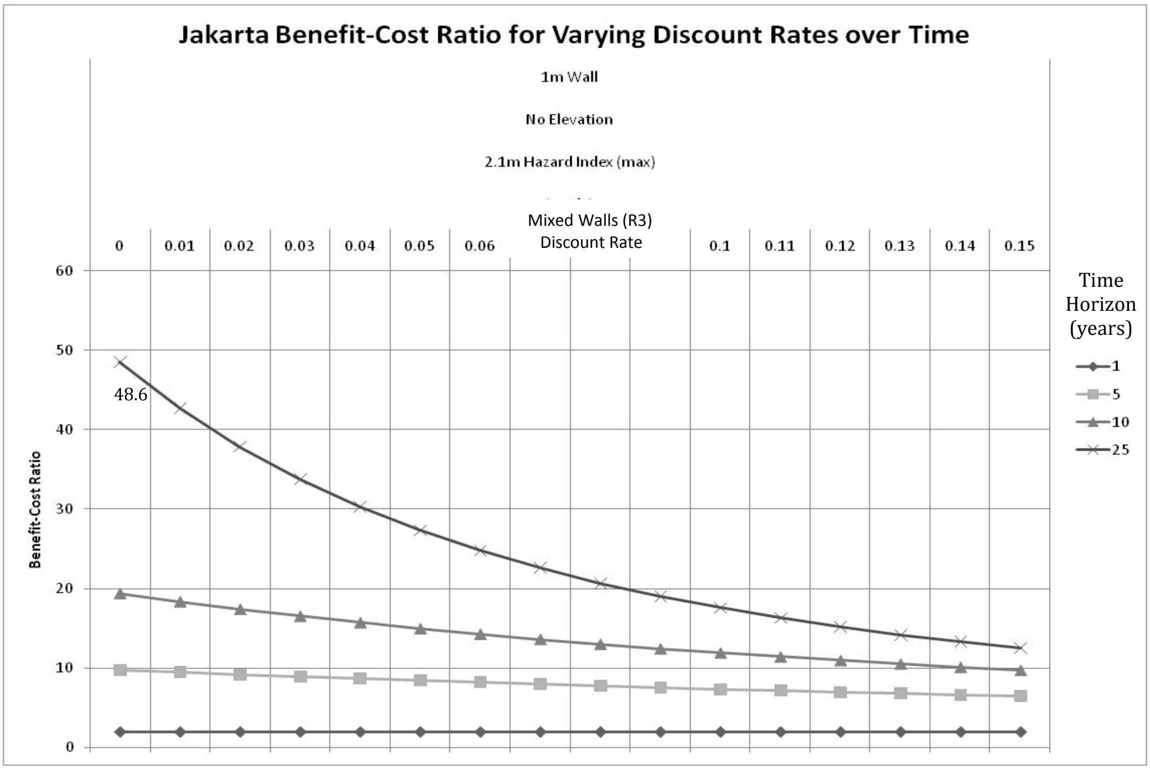

FIGURE 6: B/C RATIO FOR COLLECTIVE FLOOD MITIGATION MEASURE (1 Meter Wall) FOR DIFFERENT DISCOUNT RATES AND TIME HORIZONS

Case Study III: Earthquake Risk in Istanbul (Turkey)

Istanbul, which has a population of around 11 million people and accounts for about 40 percent of the GDP of Turkey, is at high risk to earthquake. (For a comprehensive background on Istanbul's seismic risk, see Smyth et al., 2004.) The World Housing

Encyclopedia report on Turkey (Gulkan et al., 2002) indicates that approximately 80 percent of Turkey's urban households live in mid-rise apartment blocks constructed of reinforced concrete with masonry infill. The representative structure selected in this study is a five-story reinforced concrete building with unreinforced masonry infills (similar to the structure analyzed by Smyth et al., 2004) with a replacement value assumed to be $250,000.

In the benefit-cost analysis described below we highlight two points that play an important role in our analysis of retrofitting schools against earthquake damage in several countries described in Section 4:

1. If one considers only the physical damage to the building, then the BCRs will be considerably less than 1 and the measure will be deemed economically unattractive
2. When one adds the reduction in fatalities from retrofitting the structure, then this measure is likely to yield BCRs greater than 1 for the values of a life (VoLs) that are considered to be reasonable ones for Turkey.

We reach similar conclusions in our analysis of retrofitting schools in countries subject to seismic risk. A key issue that we discuss in Section 4 is the appropriate VoL to utilize in evaluating alternative measures.

Turning now to Turkey, on average, a typical building in the area has ten units per building and five people per unit. In the aftermath of the 1999 Kocaeli earthquake in Turkey, most buildings of this type collapsed because the columns lacked adequate transverse steel reinforcement to resist lateral loads. Many buildings were also designed with an open ground floor to accommodate other uses, such as parking, and the soft story conditions exacerbated the failures (RMS, 2001). Another phenomenon that contributed to the breaking of the columns and possible collapse of the buildings is a gap between the columns and the infill wall, which reduces the effective height of the column (known as *short column)* (Guevara and García, 2005). Two case study sites, Camlibahce and Atakoy, were selected representing high and low hazard locations, respectively.

Methodology. As shown in Table 4, we assume that the initial non-mitigated building can be of three types depending on whether it is characterized by soft story, short columns or both. *Soft story* means that the ground-floor space – a window, garage door – is situated where a wall might otherwise be. *Short column* refers to reinforced concrete buildings where the partial height infill walls are used to provide natural lightening and ventilation (if the infill walls in the frame in a structure are made shorter than the column length and they are connected to the column, i.e. there is not enough gap between the columns and the infill wall, the effective height of the column is reduced). Type 1 and Type 3 buildings are about 4 percent and 14 percent more vulnerable than Type 2, respectively.

Table 4. Type of Structures For Case Study – Unmitigated Attributes

Type	Have Soft Story (SS)?	Have Short Column (SC)?	Need Structural Upgrade?
Type 1	Yes	No	Yes
Type 2	No	Yes	Yes

Figure 6 illustrates the EP curves for the different building types given they are located in Camlibahce (min hazard) as well as Atakoy (max hazard).

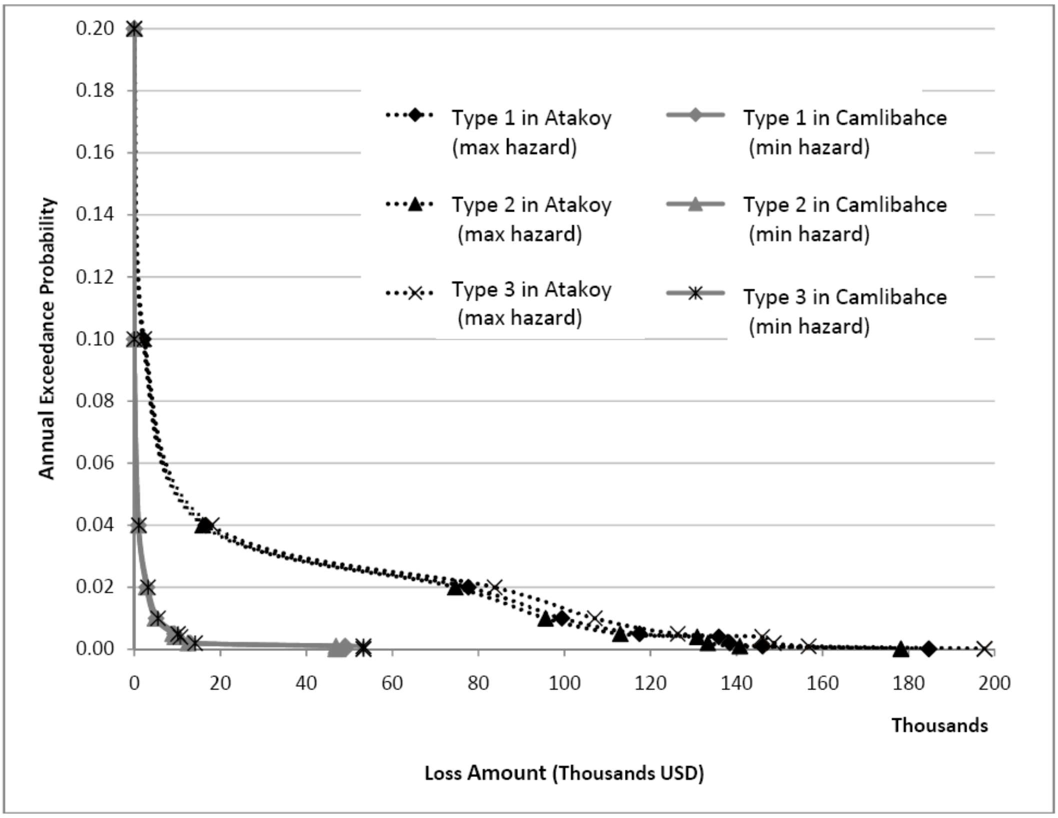

FIGURE 7. EARTHQUAKE RISK IN ISTANBUL - EP CURVES WITH NO DRR

Three DRR measures for reducing seismic risk to a representative five-story reinforced concrete building are thus analyzed:

- Measure 1: Retrofit short column (SC), and/or soft story (SS) but no shear walls added.
- Measure 2: Partial shear walls (PSW) added. Short columns are mitigated if applicable.
- Measure 3: Full shear walls (FSW) added. Short columns (SC) mitigated if applicable.

Table 5 shows the combined cost of different applicable DRR measures for each building type based on Burnett (2004), Erdik (2003) and Smyth et al. (2004).

Table 5. Costs of Alternative DRR Measures for Each Baseline Type

DRR Option	Costs ($) for Type 1	Costs ($) for Type 2	Costs ($) for Type 3
1. Mitigating SC/Mitigating SS	25,000	40,000	65,000
2. Mitigating SC/Adding PSW	80,000	120,000	120,000
3. Mitigating SC/Adding FSW	135,000	175,000	175,000

SS=Soft Story; SC=Short Column; PSW=Partial Shear Wall; FSW=Full Shear Wall

Cost-benefit calculations. Table 6 summarizes the CB ratios for the DRR measures shown in Table 5 with selected discount rates (5 percent and 12 percent) and time horizons (10-25 years).

Table 6. Earthquake Risk in Istanbul: Summary of Selected B/C Ratios

DRR Measure	Time Horizon (years)	Type 1				Type 2				Type 3			
		Camlibahce Min Hazard		Atakoy Max Hazard		Camlibahce Min Hazard		Atakoy Max Hazard		Camlibahce Min Hazard		Atakoy Max Hazard	
		Discount Rate		Discount Rate		Discount Rate		Discount Rate		Discount Rate		Discount Rate	
		5%	12%	5%	12%	5%	12%	5%	12%	5%	12%	5%	12%
Mitigating SC/ Mitigating SS	10	0.12	0.09	0.01	0.01	0.05	0.04	0.00	0.00	0.08	0.06	0.01	0.00
	25	0.22	0.12	0.02	0.01	0.09	0.05	0.01	0.00	0.14	0.08	0.01	0.01
Mitigating SC/ Adding PSW	10	0.12	0.09	0.01	0.01	0.05	0.04	0.00	0.00	0.07	0.05	0.00	0.00
	25	0.22	0.12	0.01	0.01	0.09	0.05	0.01	0.00	0.12	0.07	0.01	0.00
Mitigating SC/ Adding FSW	10	0.06	0.05	0.00	0.00	0.03	0.02	0.00	0.00	0.06	0.04	0.00	0.00
	25	0.11	0.06	0.01	0.00	0.06	0.03	0.00	0.00	0.11	0.06	0.01	0.00

SS=Soft Story; SC=Short Column; PSW=Partial Shear Wall; FSW=Full Shear Wall

All measures considered have a BCR < 1 regardless of the hazard level. They range from 0 to 0.22, indicating that from a financial standpoint alone, these measures are not recommended. However, the picture changes when one takes into account the value of reducing risk to human life as shown in the next subsection

Reducing mortality risk: Our previous analyses focused only on the direct economic benefits generated by making a construction more disaster resilient. In reality, there are of course many other benefits beyond the reduction in AAL associated with damage reduction to a given building. The most important additional benefit is the lives one can save by making houses more resistant to catastrophes.

Cost-benefit analyses of projects/investments that save at-risk lives generally make use of a value of statistical life (VoL) to estimate the benefits or costs—that is, they attempt to associate a monetary value to each life so it is possible to undertake economic comparison (Viscusi, 1993). If a disaster risk DRR project reduces the probability that an individual dies, conditional on the disaster event occurring, the project will save a number of *statistical lives* equal to the sum of reductions in the risk of death over the exposed population. We are aware that applying a VoL to CBA, however, can be controversial since it is ethically difficult to put a price tag on a life.[10] For this reason we do not make use of a point value, but undertake sensitivity analyses using a range of statistical life value estimates.

As an upper bound of the VoL, we take the highest estimate in the United States, $6 million, a figure that is commonly used by the U.S. Environmental Protection Agency (Cropper and Sahin, 2008). As a lower range, we make use of a method suggested by Cropper and Sahin (2008), which scales the VoL (in this case, for Turkey) according to the country's per capita income relative to the U.S. This method yields a Turkish VoL approximately equal to $750,000. We use these figures as the lower and upper range of the VoL for the Istanbul case. We extend the range of VoLs in our global analysis to include $40,000 and $200,000 suggested by the Copenhagen Consensus team.

In Table 7 we show how the BCRs change if we include the value of reducing mortality risk in the Istanbul analysis. We take as an example the case of seismic retrofit using steel metal frames for a Type 1 constructed house in a low-risk area. The BCRs when VoL is not incorporated in the analysis range from 0.09 to 0.21 depending on the discount rate and time horizon of the building. When lives saved are included in the analysis the DRR measure is attractive assuming a discount rate of 5 percent and a time horizon of 25 years.

Table 7. Earthquake Risk in Istanbul: B/C Ratios Taking into Account the Value of Life for Baseline Type 1 and Measure 1 (Amounts greater than 1 in bold)

Analysis	Time Horizon (Years)	Camlibahce Min Hazard	
		Discount Rate	
		5%	12%
Value of statistical life **not** included	10	0.12	0.09
	25	0.22	0.12
VoL= $750,000	10	0.7	0.5
	25	**1.3**	0.7
VoL= $6 million	10	**4.5**	**3.5**
	25	**8.1**	**4.9**

[10] At the core of the debate on attributing a monetary value to life is whether a life saved in a rich country should be valued differently than a life saved in a poor country; if so, why and how significant the difference should be? If not, what is the value of these lives? Likewise, should the life of a teenager be valued differently than the life of an elderly person, why, etc.?

These findings confirm the result by Smyth et al. (2004) that only by including the value of lives saved do earthquake-strengthening measures for apartment buildings and schools in Turkey pass the benefit-cost test. Our results also show that an international development organization or a donor that would base its decision not to provide support for the studied disaster risk reduction program based on the sole results of the CBA for construction would probably be misled--- the program would have potentially saved many lives and reduced the economic loss in the city after a massive earthquake, which taken together would have by far offset the cost of the DRR.

SECTION 4. FOUR PROPOSALS TO REDUCE ECONOMIC AND HUMAN LOSSES FROM DISASTERS GLOBALLY

This section generalizes the benefit-cost analyses (BCA) undertaken in the previous section for one single building to a large number of buildings in countries around the world, following the guidelines provided by the Copenhagen Consensus 2012.

That is, we will do analyses with an annual discount rate (d) of 3 and 5 percent and value of life (VoL) of $40,000 and $200,000 (equivalent to a disability-adjusted life year (DALY) of $1,000 and $5,000 respectively). In addition we estimate the expected benefits of saving lives by including VoL=$1.5 million and VoL= $6 million, values typically used in other studies, as detailed in a comprehensive survey by Kip Viscusi and Joseph Aldy (2003).[11]

We focus on three hazards –earthquakes, floods and hurricanes/storms/cyclones and for each hazard on 30 to 34 countries that are the most exposed to each type of disaster. Our four proposals are as follows:

- We begin with a detailed analysis of the cost-effectiveness of constructing schools that are earthquake-proof to reduce the damage and the number of fatalities to children, teachers and other staff who are in the school at the time of the *earthquake* (***Proposal I***).
- We then examine the cost-effectiveness of investing in a structural measure (community wall) and designing better residential structures (elevating homes) in areas subject to *floods* (***Proposal II***).
- We will then undertake an analysis of disaster-reduction measures for *hurricanes and cyclones* by strengthening the resistance of windows and doors against wind and heavy pressure from these storms (***Proposal III***).
- We will then examine the merits of an early warning system (***Proposal IV***).

[11] In their paper Viscusi and Aldy point out that the value of a statistical life (VoL) for U.S. labor market studies lies within a range of $4 million to $9 million. In developing countries the VoL presented in the Viscusi/Aldy survey varies from $750,000 in South Korea to $4.1 million in India. (See Table 4, pp. 27-28).

Proposal I: Designing Schools to Withstand Damage from Earthquakes

Nature of the Problem: The damage and number of fatalities from schools impacted by earthquake is highlighted by recent seismic disasters. On October 31 and November 1, 2002, two magnitude Mw 5.7 earthquakes struck the rural Molise region in southeastern Italy killing 30 people, 27 of whom were children trapped in the collapse of an elementary school (Maffei and Bazzurro, 2004). Had the earthquake been more severe, the damage to schools in the area and the number of fatalities is likely to have been much more severe. The magnitude 6.4 earthquake that hit the Bingol area in eastern Turkey in May 2003 caused 4 of the 27 schools in the area to collapse or experience heavy damage and 9 others to suffer moderate damage. Eighty-four fatalities occurred when a dormitory block collapsed in a boarding school in Celtiksuyu (Ellul and D'Ayala, 2003). In China, after the Sichuan earthquake, more than 7,000 classrooms collapsed. In the provinces of Sichuan and Gansu, more than 12,000 and 6,500 schools were affected, respectively (Reliefweb, 2009).

In the Mw 7.0 earthquake of Haiti in 2010, more than 97 percent of the schools in Port-au-Prince were destroyed. Half of the public schools and the three main universities in the country suffered severe damages (Fierro and Perry, 2010). In a country where 35 percent of the population is under 15 years of age, the death toll of children constituted a large portion of the 250,000 who died directly or indirectly from the earthquake. Moreover, a study by the Children's Hospital of Los Angeles and the University of Southern California estimated that the number of children injured was 110,000, or roughly half the total number of injuries (Agence France-Press, 2010).

Determining Seismic Risk of Schools: We were not able to perform BCA on retrofitting schools in every country that faces a seismic risk, so we utilized data from several sources using the following six-step process:

- ***Step 1: Expected Reduction in Damage from Retrofitting Schools in Latin America.*** A detailed study analyzed the benefits and costs of retrofitting schools against earthquakes in 14 countries in Latin America, *Seismic Risk Assessment of Schools in the Andean Region in South America and Central America* (henceforth **SRAS**). The study was undertaken by a consortium of experts from Columbia, Spain and Mexico (ERN, 2010) and was included in the World Bank/United Nations *Global Assessment Report on Disaster Risk Reduction 2011*. The study compared the average annual property loss to the buildings and contents with and without retrofitting by undertaking a probabilistic seismic hazard analysis similar to the one undertaken for apartment buildings in Turkey described in the previous section. Exceedance probability (EP) curves with and without retrofitting are constructed using a structural typology representative of the building stock of schools in each of the countries ranging from adobe to reinforced masonry and concrete structures. Current average annual loss (AAL) from earthquakes for the entire portfolio of schools in the country was compared with the reduced AAL if these buildings had been retrofitted as detailed in Table 8.

Table 8. Effectiveness of Retrofitting Schools in Latin America

Country	AAL					
	Current		Retrofitted			
	Million $US	(‰)	Millions $US	(‰)	% AAL Reduction	Retrofitting Costs (Millions $US)
ARG	$7	0.2	$3	0.1	57%	$9,623
BOL	$6	7.0	$3	2.9	50%	$991
CHL	$49	6.4	$15	1.9	69%	$2,750
COL	$31	2.7	$20	1.8	35%	$5,022
CRI	$32	16.4	$18	9.1	44%	$742
ECU	$33	21.2	$29	18.7	12%	$947
SLV	$12	24.4	$6	11.8	50%	$263
GTM	$10	15.1	$5	8.0	50%	$501
HON	$2	4.6	$0	1.5	100%	$349
MEX	$75	0.8	$34	0.4	55%	$32,354
NIC	$5	20.8	$3	9.8	40%	$353
PAN	$10	6.4	$5	3.3	50%	$445
PER	$296	33.3	$160	18.0	46%	$4,094
VEN	$22	0.8	$13	0.5	41%	$5,978
				Average	**50%**	

Sources: ERN (2010)

From this table it is possible to identify three categories of countries based on the ratio of the AAL to the value of the current portfolio of schools in the country (i.e. Column 3 and Column 5 of Table 8). The lowest values of the AAL (less than 0.1%; one per thousand) are found in Argentina, Venezuela and Mexico. In general, these results reflect a lower concentration of buildings in zones of relative high seismic hazard (in the case of Argentina) as well as the composition of the schools portfolio by structural typologies of relative low vulnerability such as reinforced concrete and reinforced masonry. The highest values of the AAL (greater than 10%) are estimated for Peru, Ecuador, El Salvador, Nicaragua, Costa Rica and Guatemala. These results reflect the composition of the school portfolio by structural typologies of relative high vulnerability such as unreinforced masonry and adobe, located in zones of relative high seismic hazard. In the case of Chile, the seismic hazard is relative high meanwhile the school portfolio is composed by structural typologies of relative low vulnerability such as reinforced concrete and reinforced masonry (ERN, 2010).

With this analysis it is possible to estimate the expected average annual reduction in property damage from retrofitting schools in country i, [$E(AARPD_i)$], where i is one of the 14 countries in the SRAS study. It varies from a low 12 percent in Equator to a high virtually 100 percent in Honduras. We calculate that the average AAL reduction obtained by retrofitting schools across the 14 countries is 50 percent. We will then use this number when extrapolating our analysis to other countries.

- ***Step 2: Expected Costs of Retrofitting Schools in Latin America.*** The SRAS study also provided data on the costs of retrofitting schools to withstand earthquake damage (shown in last column of Table 8). These dollar values were obtained by obtaining data on the costs of retrofitting schools of different construction in Bogota, Columbia and Quito, Ecuador and estimating the number of square meters (m^2) of the relevant type schools. These data enabled the SRAS study to estimate the retrofitting costs in US$/$m^2$ for different construction materials. By combining these data with the distribution of building stock in each country using the structural typology one could obtain the costs of retrofitting all schools in each of the fourteen Latin American countries in the study. Let the expected upfront cost of retrofitting all schools in country i be $E(C_i)$.

- ***Step 3: Expected Number of Fatalities due to Earthquakes.*** To estimate this figure for each country in our analysis, we first approximate the number of schools in each country. To do this we use available data on children from 0 to 14 years. We then determine the population of this cohort in 2010 for each country in the world that has a significant seismic risk.[12] We then specify the degree of seismic risk for each country in our sample using the classification from the *Global Assessment Report on Disaster Risk Reduction (*UNISDR 2009). In this study, the United Nations classified all countries according to a mortality risk index from the least prone to earthquakes (Class 1) to those facing the most severe earthquakes (Class 9) [See Table 9].

Table 9. Average Annual Number Killed per Million as a Function of Seismic Risk Class

Class	Relative Risk (killed per million per year)	Midpoint of Relative Risk
9	100-300	200
8	30-100	65
7	10-100	55
6	3-10	6.5
5	1-3	2
4	.3-1	.65
3	.1-.3	.2
2	0.03 - .1	.065
1	>0 - 0.03	.015

Source: Global Assessment Report on Disaster Risk Reduction (UNISDR, 2009).

[12] See http://data.worldbank.org/indicator/SP.POP.0014.TO.ZS for the specific data we used for each country.

We focused our study on 35 countries with an index of Class 5 or higher and eliminated Japan and the United States (Class 6) and Taiwan (Class 7) given their high-income status.[13] Note that all the fourteen countries from Latin America we discussed above are in that list. The UNISDR study also provides a range for the number of lives lost per million, as shown in Table 9 under the column *Relative Risk* (defined as the number of people killed per million per year) and the midpoint of the range. Multiplying the midpoint of the range for country i's seismic risk classification by the number of million people in that country, the resulting figure $E(AAF_i)$ is the average annual number of fatalities (AAF) due to earthquakes in country i.

- ***Step 4: Expected Average Annual Reduction in Fatalities from Retrofitting Schools.*** To estimate this figure, $E(AARF_i)$ for country i, we assume that children, teachers and staff are in school 8 hours a day (one-third of a day) and that there is one adult in the building per 5 children. This means that a school of 1,000 children has 1.2 (1,000)=1,200 individuals in it. The enrollment rate is estimated to be 70 percent of the eligible population of school age children based on UNICEF data provided in the Country Profiles.[14] We assumed that retrofitting a school will save the lives of 40 percent of those in the building at the time of the earthquake from what would have occurred if the school had not met the building code standards – the same assumption used in examining the reduction in fatalities in Turkey from reinforcing an apartment building[15] (Smyth et al., 2004). Based on these assumptions, $E(AARF_i)=(1.2)\bullet 1/3\bullet(.70)(.40)\, E(AAF_i)$ where $E(AAF_i)$ is obtained in Step 3 for each country i.

- ***Step 5: Expected Benefit/Cost Ratio for 14 Latin American Countries.*** In addition to annual benefits provided by lowering physical exposure one can also integrate the number of lives saved by retrofitting the schools. In order to generate an overall BCR (physical and human benefits) one needs to attribute a value for each statistical life (VoL) saved by retrofitting schools. We estimate schools to last for T=50 years and utilize a discount rate of d=0.03 and 0.05 for converting the expected annual benefits of retrofitting in year t > 1 to the present. The expected benefits of retrofitting a structure in country i from the SRAS study for specific values of VoL and d is given by:

$$E(B_i) = \sum_{t=1}^{T=50} \frac{\{VoL \bullet E(AARF_i) + E(AARPD_i)\}}{(1+d)^t} \quad (1)$$

[13] The list for earthquakes is composed of the following countries in alphabetical order: Afghanistan; Albania; Algeria; Argentina; Armenia; Bolivia; Chile; China; Colombia; Costa Rica; Democratic Republic of Congo; Ecuador; El Salvador; Guatemala; Honduras; India; Indonesia; Iran; Kyrgyzstan; Mexico; Myanmar; Nepal; Nicaragua; Pakistan; Panama; Peru; Philippines; Romania; Solomon Islands; Sudan; Tajikistan; Turkey; Uganda; Uzbekistan and Venezuela.

[14] ata on eligible population of school age children can be found at www.childinfo.org (UNICEF data).

[15] A higher protection rate would generate a much higher B/C ratio. We do not undertake sensitivity analysis on that parameter though in this paper.

The benefit-cost ratio for retrofitting schools in country i (BCR_i) is given by

$$BCR_i = E(B_i)/E(C_i) \text{ where } E(C_i) \text{ is obtained from Step 2}$$

Step 6: Determining the expected benefits and costs of other countries. To extrapolate from the expected cost of retrofitting schools in the Latin American countries examined in the SRAS report to other parts of the world that have seismic risks, we needed to normalize the benefits and costs. More specifically we needed to estimate the expected benefits and costs from a retrofitting a school. Recognizing this figure can vary across countries, we assumed that the average number of children per school in any country was 2,000[16]. The expected retrofitting cost per school $[E(SC_i)]$ and retrofitting benefit per school $[E(SB_i)]$ for country i, $i = 1 \ldots 14$ are respectively given by:

$$E(SC_i) = E(C_i)/2{,}000 \qquad (2)$$

$$E(SB_i) = E(B_i)/2{,}000 \qquad (3)$$

To extrapolate the costs and benefits of retrofitting schools in the 14 countries in the SRAS study to other parts of the world, we focus on countries that had mortality index risks in the Class 5-9 range based on the UN's *Global Assessment Report on Disaster Risk Reduction.*[17] We also assumed that there is a constant relationship between GDP per capita and both the costs and benefits of school retrofitting in each country. Using the data from the SRAS study from equations (2) and (3) for each of the 14 countries we estimated the relationship using ordinary least squares with its intercept at the origin (i.e., the constant term suppressed) to obtain the following regression equation:[18]

$$E(SC_i) = \beta_1 . GDP_i$$

Ideally one would want to consider the nature and enforcement of building codes in each country outside of Latin America with a seismic risk. To the best of our knowledge, such detailed data does not exist on an international scale. We thus assume that the expected benefits for each country *i* $[E(SB_i)]$ in other parts of the world is 50 percent of the AAL reduction across the 14 Latin American countries (i.e. Ave ΔAAL_{14LA})[19] normalized by the country's GPD (i.e. GDP_i) in relation to the Average GDP of the 14 Latin American countries (i.e. Ave GDP_{14LA}). The $E(SB_i)$ is given by the following equation:

$$E(SB_i) = 50\% * (\text{Ave } \Delta AAL_{14LA}) * GDP_i / \text{Ave } GDP_{14LA}$$

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[16] The number of children in a school will obviously vary from one type of school to another and from one country to another; 2,000 is the average number of children per school from the different project discussed in the SRAS analysis undertaken in several Latin American countries.

[17] The report can be found on http://www.preventionweb.net/english/hyogo/gar/report/index.php?id=9413

[18] An OLS regression with both GDP and RiskClass as explanatory variables leads to a negative coefficient for RiskClass which triggers cost that would be negative for some of these countries so we only use the GDP variable. We find that $\beta_1 = 6.75$ $\beta_2 = 0.86$ and $\beta_3 = 0.002$.

[19] Table 8 (Col. 4) shows that this average percent AAL reduction was estimated to be 50 percent.

The above two equations enabled us to estimate the costs and benefits of retrofitting the schools in 21 other countries that have a relatively high seismic risk. We then followed the analysis outlined in Steps 1 to 5 to determine benefit/cost ratios for each country given different VoLs and annual discount rates.

Findings for Proposal I:

Countries are ranked in descending order based on the B/C ratio determined by the above analysis for different discount rates (d) and value of life (VoL). For each (d, VoL) pair we then calculate the cumulative retrofiting cost and expected benefit (i.e. reduction in physical damage and cumulative number of lives saved across countries multiplied by VoL and properly discounted over time). Our analysis reveals several findings.

- **It would cost about $300 billion to retrofit all the schools in the 35 most exposed countries.** Several highly populated countries would require a large investment to retrofit all schools, for instance, $32 billion in Mexico, $65 billion in India, and more than $100 billion in China.
- **Retrofiting the schools in all 35 countries studied here would save the lives of 250,000 individuals over the next 50 years.**

Several of our country-specific findings are highly dependent on the above assumptions made. As the the VoL increases, the BCR exceeds 1 for an increasing number of countries. As shown in Table 10 for {d=.03 VoL= $1.5 million} the BCR>1 for 13 countries and the $75 billion is exhausted with Ecuador, most of the funding going to retrofit schools in India (which has nearly 1.2 billion people).

Table 10. Key Results of the Analysis with 3 Percent Discount Rate and $1.5 million VoL

Country	Final B/C Ratio	Cumulative Retrofitting Cost (Million $US)	Cumulative Benefits	Cumulative Lives Saved
Solomon Islands	6.45	$36	$235	72
Afghanistan	5.11	$698	$3,617	4,382
Myanmar	4.65	$1,570	$7,675	9,548
Guatemala	3.50	$2,071	$9,428	11,652
Armenia	2.87	$2,222	$9,863	11,835
El Salvador	2.35	$2,485	$10,481	12,435
Albania	2.31	$2,740	$11,070	12,648
Congo	2.02	$3,220	$12,037	13,880
Uzbekistan	1.66	$4,504	$14,174	16,416
Peru	1.37	$8,598	$19,781	19,147
India	1.36	$73,923	$108,797	134,207
Ecuador	1.26	**$74,870**	$109,986	135,614
Indonesia	1.09	$89,756	$126,175	156,256

From Table 10 we find that it would cost only $36 million to retrofit schools in the Solomon Islands. This expenditure would generate a benefit that is more than six times the estimated cost. The costs of retrofiting schools in Afghanistan and Myanmar would be $698 million and $1,570 million, and generate high B/C ratios of 5.11 and 4.65 respectively. By instituting these measures in the two countries, more than 9,500 lives would be saved over the next 50 years, an average of 200 lives per year.

The Appendix shows the results of our analysis for all 35 countries, varying the discount rate (3 and 5%) and the VoL ($40,000, $200,000 and $6 million). For low VoL only a handful of countries have a BCR>1. When the VoL is $6 million, we find that the $75 billion can best by allocated to retrofiting schools in Afghanistan, Myanmar, Guatemala, Solomon Islands, Congo, El Salvador, Uzbekistan, Armenia, India, Ecuador and part of Indonesia. When d=5% the expected benefits decreases as does the BCR since the retrofitting costs do not change.

Proposal II: Elevating Residential Structures and Designing a Community Wall to Reduce Losses from Floods

We undertook a similar BC analysis for the 34 countries most exposed to flood risk around the world.[20] We analyze the effectiveness of elevating residential structures by one meter and building a community wall around communities. Those are the two most effective measures revealed by our analysis of Jakarta in Section 3, which we use here in order to scale up the analysis to a large number of countries.

We illustrate the methodology here with respect to elevating a residential home. A similar methodology was used for building a community wall around exposed communities in the 34 countries.

- ***Step 1: Extrapolating the expected reduction in damage from elevating residential homes exposed to flood in Jakarta, Indonesia to other countries.***

The Indonesia study in Section 3 provided the average annual property loss to mixed-wall houses before and after they were elevated by 1 meter. It is possible to utilize this analysis to extrapolate the average annual reduction in property damage (AARPD) from undertaking this measure in country i, $E(AARPD_i)$, where i is one of the countries that have a mortality risk index of class 5 or above from the *Global Assessment Report on Disaster Risk Reduction* (UNISDR 2009)). The AAL extrapolation from Indonesia to another country i assumes that homes are elevated by 1 meter. If a country has a risk class greater than 5 then the reduction in AAL per house that is assumed to be 10 percent

[20] This list of 34 countries for floods is (in alphabetical order): Afghanistan, Algeria, Argentina, Armenia, Bangladesh, Bhutan, Cambodia, Central African Republic, Chad, China, Colombia, Côte d'Ivoire, Democratic People's Republic of Korea, Democratic Republic of Congo, Egypt, Georgia, India, Indonesia, Iran, Iraq, Kazakhstan, Lao People's Democratic Republic, Myanmar, Nepal, Nigeria, Pakistan, Russian Federation, Somalia, Sudan, Syrian Arab Republic, Thailand, Turkmenistan, Uzbekistan and Viet Nam.

higher for each risk class (i.e., a country of class 7 will have an AAL reduction percentage equals to 120 percent what it is in Indonesia).

The AAL reduction for that house in country 1 will be:

$$\text{AAL Reduction}_{\text{Indonesia}} * (1 + [\text{RiskClass}_i - \text{RiskClass}_{\text{Indonesia}}] * 10\%)$$

By assuming an average of five individuals living in a house, the number of homes in the country is equal to one-fifth of the country's population. We also assume that 50% of the houses in these highly exposed countries are exposed to flood hazard.

The expected benefit of elevating homes in country i $E(SB_i)$ is given by:

$$E(SB_i) = \Delta AAL_{\text{Indonesia}} * (1 + [\text{RiskClass}_i - \text{RiskClass}_{\text{Indonesia}}] * 10\%) * GDP_i / GDP_{\text{Indonesia}}) * (\text{Population}_i /5) * 0.50$$

- ***Step 2: Extrapolating the cost of elevating a home exposed to flood in Jakarta, Indonesia by one meter to other countries.***

The estimated cost of elevating a house in Indonesia was estimated to be $9,345 as shown in the previous section. Let the expected upfront cost of retrofitting all homes in country i be $E(SC_i)$ be scaled down appropriately by the ratio of the $GDP_i / GDP_{\text{Indonesia}}$ multiplied by the estimated number of homes exposed to flooding in country i:

$$E(SC_i) = \$9{,}345 * (GDP_i / GDP_{\text{Indonesia}}) * (\text{Population}_i / 5) * 0.5$$

- ***Step 3: Expected number of fatalities due to flooding.*** To estimate this figure for each country in our analysis that has a flood risk, we first approximate the number of exposed individuals in each country. To do this we determine the exposed population in 2010 for all countries that have a significant flood risk.[21] (We then specify the degree of flood risk for each country in our sample using the classification from the *Global Assessment Report on Disaster Risk Reduction* (UNISDR 2009). In this study, the United Nations classified all countries from the least prone to flooding (Class 1) to those facing the most severe floods (Class 9). We focused on countries in the mortality risk index risk Class 5 or higher. Multiplying the midpoint of the range for country i's flood risk classification by the number of million people in that country (see Table 9)[22], the resulting figure $E(AAF_i)$ is the we obtained the average annual number of fatalities (AAF) due to flooding in country i.

[21] See http://data.worldbank.org/indicator/SP.POP.0014.TO.ZS for the specific data we used for each country. Individual countries risk profiles from www.preventionweb.net

[22] The risk mortality rate table does not change across hazards; the list of countries of different class for different hazards does. For that reasons we don't repeat here in our flood analysis the relative mortality table used for earthquake since it is similar for flood.

- ***Step 4: Expected average annual reduction in fatalities from elevating a house exposed to flood.*** To estimate this figure, $E(AARF_i)$ for country i, we assume that the number of yearly fatalities from flooding will be reduced by 50%. The annual fatality figure is determined by multiplying the average fatalities per million per year by the exposed population per million of the country (total population * % exposed / 1 million). Based on these assumptions:

$E(AARF_i) = 0.5 * E(AAF_i)$ * (total population * % exposed / 1 million)

where $E(AAF_i)$ is obtained in Step 3 for each country i.

- ***Step 5: Expected Benefit/Cost Ratio for Countries prone to flood risk.*** Using the same values of life, discount rates, and time horizons as in the Earthquake study, the benefit cost ratio per country can be determined.

Here, the benefit-cost ratio for elevating homes in country i (BCR_i) is given by

$BCR_i = E(SB_i)/E(SC_i)$ where $E(SB_i)$ and $E(SC_i)$ are obtained from Step 2

A similar analysis is done for our second mitigation measure: building a one-meter high community wall that will protect all the houses from flood (up do a certain height). Similarly we used the AAL reduction obtained in our Indonesia study and extrapolated to the other countries under study here.

Findings for Proposal II

- **It would cost $5.2 trillion to elevate by one meter all houses exposed to flood in those 34 countries** and **nearly $940 billion to undertake the structural disaster risk reduction measure of building walls around the affected communities in all 34 countries**.
- **Undertaking one of those measures in all 34 countries will save 61,000 lives over the next 50 years** (compared to 250,000 for retrofitting schools agains earthquake damage)
- Because the reduction in flood damage is so high when collective or individual measures are in place and because fewer lives are saved from such measurss than from retroffiting schools against earthquakes, varying the VoL factor does not change the BCRs very much.

Given that the resources available are only $75 billion, Table 11 summarizes where the funds would be best spent for the two measures we consider here. We show the list of countries where the two disaster-reduction measures yield the highest BCR. We find that the cumulative benefit for the community wall will be $4.5 trillion (average BCR=60 across these countries). Elevating homes will yield a benefit of $1.1 trillion (average BCR=14.5).

Note that we find a BCR significantly higher than from retrofitting schools for earthquakes as discussed in previous proposal. Furthermore the community-based disaster protection leads to a much higher BCR than the individual measure. In the case of {d= 3% VoL= $40,000}, the BCR for elevating houses by one meter ranges between **11.9** (Russian Federation) and **15.6** (Cambodia). The community wall raises the BCR for the Russian Federation to 50 and for Cambodia to **65.**

Table 11. Proposal II (flood protection) - Discount rate of 3%; VoL: $40,000

Measure	Investment	Cumulative Benefit	Lives Saved	Average BCR	Countries which will benefit the most
Community-Wall	$75 billion	$4.5 trillion	19,894	60.1	Cambodia; Laos; Bhutan; Somalia; Central African Republic; Afghanistan; Myanmar; Bangladesh; Korea; Chad; Sudan; Viet Nam; India (partially)
Elevating houses	$75 billion	$1.1 trillion	7,195	14.5	Cambodia; Laos; Bhutan; Somalia; Central African Republic; Afghanistan; Myanmar; Bangladesh (partially)

Proposal III: Designing Residential Structure to Reducing Wind Losses from Cyclones, Hurricanes and Storms

Our analysis for hurricanes/storm/cylones follows a similar process than the one just described for flood.

Expected reduction in damage from improving roof protection of a masonry house in St. Vincent and the Grenadines and extrapolating to other countries. Here we turn to the study cited in the previous section of the paper for hurricane risk in St. Lucia. It provided the average annual property loss to masonry houses with and without the **roof upgrade measure** (i.e. replacement of the roof material with thicker sheeting and tighter screw spacing as well the use of roof anchors).

Due to its small size, St. Lucia was not on the list of countries with a cyclone risk in the *Global Assessment Report on Disaster Risk Reduction*. We assumed that the same figures determined from the St. Lucia analysis in the World Bank Report would hold true for the nearby Caribbean islands of St. Vincent and the Grenadines, both of which were on the list of country of class 5 and above for wind-related disaster,[23] and have relatively

[23] The list of countries for cyclones/hurricanes/storms is (in alphabetical order): Antigua and Barbuda, Australia, Bahamas, Bangladesh, Belize, China, Cuba, Dominican Republic, Fiji, Haiti, India, Jamaica, Japan, Lao People's Democratic Republic, Madagascar, Mauritius, Mexico, Micronesia (Federated States

similar geography, population and GDP to St. Lucia.[24] Note that there are 34 most exposed countries but many of them are different than the 34 countries we analyzed for the flood risk. As we focus only on masonry structures for our BCA, we computed the average percentage of masonry households from the 2010 World Population and Housing Census Programme of the United Nations for Vanuatu, the Philippines, Mauritius, India, St. Lucia, Belize, and Jamaica, -- **47.6%** -- and rounded this figure to 50% in our analysis.

Every country prone to cyclones/storms/hurricanes in our analysis is assumed to have one-half of their homes built with masonry construction and that half of them are exposed to wind damage. As we did for the analysis of elevating homes against flood we assume that the risk reduction measure is more effective in a country of higher class exposure than St Vincent and the Grenadines (class 5) by 10% for each risk class above 5 (i.e. 10% more effective in a country of class 6, 20% for class 7, 30% for class 8, etc).

The cost of protecting all masonry homes against wind damage in a country i is given by[25]:

$$E(SC_i) = \text{Mitigation Cost}_{\text{St. Lucia}} * (GDP_i / GDP_{\text{St. Lucia}}) * (\text{Population}_i / 5) * 50\% * 50\%$$

We follow the same process as before to calculate the expected number of fatalities due to wind-related damage from cyclones.

Findings for roof protection against wind-related damage

- **It would cost $ 951 billion to undertake this disaster risk reduction measures in all 34 countries, each of which has a BCR>1[26].**
- **Undertaking this measurewill save 65,700 lives over the next 50 years**

Because cyclones tend to kill large number of people in developing countries, our results are significantly affected by the VoL figure as shown in Table 12 in which we compare the total benefit of investing $75 billion in countries with the highest BCR and consider four different VoLs. We find the highest BCR for Bangladesh (BCR ranging from 2.9 with VoL of $40,000 up to 18.6 with a VoL of $6 million).

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of), Mozambique, Myanmar, Netherlands Antilles, New Caledonia, Nicaragua, Northern Mariana Islands, Palau, Philippines, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Samoa, Solomon Islands, Tonga, Vanuatu, Viet Nam and Zimbabwe.

[24] St Lucia population is 170,000; St Vincent's population is 120,000. St Lucia's GDP per capita is $5,600; St Vincent's is $5,300.

[25] The first 50 percent in the equation comes from our assumption that half of the population is exposed to major wind damage; the second 50 percent comes from our assumption that half of these houses are masonry types, on which we focus here.

[26] Note that two-thirds3 of that amount would go for Japan, Australia and China, which we kept in the list.

Table 12. Proposal III (Wind protection against hurricanes, cyclones and storms) – 3% discount rate

VoL	Investment	Benefit	BCR	Lives Saved
$6 million	$75bn	$354bn	Average: 4.7 Min/Max: 2/18.6	60,761
$1.5 million	$75bn	$214bn	Average: 2.8 Min/Max: 2/6.7	60,761
$200,000	$75bn	$173bn	Average: 2.3 Min/Max 2/3.3	60,761
$40,000	$75bn	$168bn	Average: 2.2 Min/Max: 2/2.9	60,761

Summary of Findings for Reducing Damage from Earthquakes, Floods, Cyclones Hurricanes and Storms

Our findings with respect to investing in disaster risk reduction measures to protect building and individuals against earthquakes, flood and wind-related damage from cyclones, hurricanes, and storms can be summarized as follows:

- The most cost-effective measure for reducing future losses would be to invest $75 billion into building flood walls around communities. The cumulative expected benefits would be $4.5 trillon (BCR = 60). (See Table 11).
- If one is concerned with saving lives then one will want to retrofit schools against earthquake damage. Based on the $40,000 and $200,000 VoL figures designated by the Copenhagen Consensus, the proposed risk-reducing measures for retrofitting schools are cost-effective for relatively few countries. On the other hand, if we consider VoL=$1.5 million or VoL=$6 million, then retrofitting schools becomes attractive for 13 and 20 countries, respectively, when the annual discount rate (d) is 3 percent.
- For the case of cyclones, hurricanes and storms have BCRs> 1 for all 34 countries for VoL=$40,000 or $200,000.
- Given the scale of the analyses we undertook (more than 30 countries around the world for each of the three hazards assessed), we had to make very simplifying assumptions. In reality, one would want to gather information about the hazard, type of exposure, return period of different events, type of buildings one consider, their vulnerability to that hazard, etc.

Proposal IV: Saving More Lives by Investing in Effective Early Warning Systems

Proposals I-III focus on reducing damage and saving lives by implementing building codes in countries facing earthquakes, floods and cyclones. As a complement to these measures, Proposal IV examines early warning systems (EWS) for reducing fatalities from severe weather events. For example, in the U.S., mortality fell by 45 percent and injuries by 40 percent in 15,000 tornadoes from 1986 to 1999 thanks to more timely warnings that allowed for people to take shelter. In a companion paper, Stephane Hallegate (2012) discusses the effectiveness of this proposal in more detail and derives benefit-cost ratios to highlight its importance. Our main purpose here is to indicate the role that EWS can play as part of a comprehensive disaster risk reduction program. It is unlikely that the investment cost for EWS would be more than several billion dollars so that it can easily complement Proposals I-III.

In order to be effective, early warning systems must be multifaceted. Early warning systems must monitor the risk as it evolves, disseminate that information, and respond to the event. For example, an effective early warning system for floods should be able to estimate the risk of flooding in different areas based on historical and topographical data, monitor rainfall levels, predict short-term flooding occurrences based on those levels, alert at-risk communities and the government if necessary, and assist in flood mitigation methods such as sandbagging or shelter construction. Early warning systems can communicate their message in many different ways including television, radio, loud speaker, text message, etc. Currently, early warning systems exist for floods, heat waves, hurricanes, tornadoes, droughts, etc. in many forms on both a localized and more regional/global scale.

Early warning systems can provide a multitude of benefits including reducing loss of life and injuries and reducing property damage. These systems reduce loss of life and injuries by giving citizens time to flee and prepare against an impending disaster, whether this is getting to a shelter, higher ground, etc. Property loss can be avoided depending on the system's disaster lead times. If a lead time of several days or weeks can be given, communities can prepare by securing property, engaging in loss mitigation measures of crops, and relocating certain property. For example, with a larger lead time on a cyclone, a fisherman could remove his nets and traps, avoiding their destruction. These benefits can be especially evident in low-income countries where disasters can often cripple an unprepared country. Note also that while many other prevention techniques can often marginalize the impoverished by, for example, making them relocate to make way for infrastructure improvements, early warning systems serve all members of the population equally.

A main challenge that these systems face is balancing the advantages of longer lead times (allowing more property and infrastructure to be protected) with greater accuracy and fewer false alarms (which increase the costs associated with these systems). The benefits relative to the costs of early warning systems also vary depending on the frequency and severity of the event, and the predictability with reasonable lead times and accuracy. By coupling these systems with investments in critical infrastructure and environmental buffers, early warning systems form the third leg of an effective disaster prevention program. However, determining how much to invest in these early warning systems, as well as which systems to invest in, has proven challenging. By utilizing a similar CBA approach as used in previous sections of the chapter, examination of different systems and their effectiveness can be conducted. Since early warning systems can reduce human casualties, traditional CBA analysis sometimes has to be modified to take into account the value of these lives (as we did in our analysis of earthquake risks in Istanbul). Table 11, from a study by Subbiah, Bildan, and Narasimhan (2008), summarizes several case studies that utilized CBA to assess the potential effectiveness of different early warning systems.

Table 13. Cost-Benefit Analysis of Several Early Warning System Projects

Bangladesh **Sidr Cyclone case study**	Enhancement of computing resources – i.e. advanced computing equipment, latest numerical weather prediction (NWP) models, trained human resources – in addition to existing level of services in the Bangladesh Meteorological Department, would help increase lead time and accuracy of forecast information. With additional investment for building capacity for translating, interpreting and communicating probabilistic forecast information, the case study demonstrates that *for **every $1 invested, a return of $40 in benefits over a ten-year period may be realized**.*
Sri Lanka **May 2003 floods case study**	Existing NWP models, coupled with use of model outputs from regional and global centers, could help anticipate events such as the extreme floods of May 2003. Cost-benefit analysis reveals that *for every $1 invested, there is a return of only $0.93 in benefits, i.e., the costs outweighs the benefits*, since the significantly damaging flooding is not very frequent. In such a case, it makes great sense for such countries to join a collective regional system, due to economies of scale, as demonstrated in the case study on the Regional Integrated Multi-Hazard Early Warning System (RIMES).
Vietnam **2001-2007 hydro-meteorological hazards case study**	Increased lead time as well as accuracy due to incorporation of the advanced Weather Research Forecasting (WRF) model run at much higher resolutions could help reduce losses and avoidable damages. Due to increased accuracy in predicting landfall point, as well as associated parameters such as wind speed and rainfall, it would be possible to reduce avoidable responses – such as evacuation across hundreds of kilometers along the coast, as well as disruption of fishing and other marine activities. ***The case study shows that every $1 invested in this EWS will realize a return of $10.4 in benefits***
Indonesia **Seasonal forecasting case study**	Seasonal climate forecasting model has already been replicated in over 50 districts by the Indonesian government (and is being replicated in other districts). The case study shows that the indicative value of each seasonal forecast is $1.5 million (currently in 50 districts), and potentially $7.5 million (for 250 districts) per season. The actual one-time investment to produce this forecast is not more than $ 0.25 million, with a marginal recurring cost of $0.05 million per year.

Sources: Subbiah, Bildan, and Narasimhan, 2008

Hallegate (2012) provides a back-of-the envelope calculation of how much it would cost to implement early warning systems in developing countries and concludes that it would require less than $1 billion a year and would have direct benefits with respect to disaster loss reductions of between 1 and 5.5 billion USD per year, and co-benefits of between 3 and 30 billion USD.

SECTION 5. THE LIMITS OF BCA: BEHAVIORAL ECONOMICS AND DISASTER MANAGEMENT

The BCAs in sections 3 and 4 enable one to better appreciate the possible return of several disaster reduction measures ***if*** such measures were implemented. In reality decision makers are likely to utilize simplified choice rules, focus on constraints as well as short-run benefits and costs rather than discounting the future exponentially over a 50 year period, as we have done, and may not even consider probabilities in their decision on whether or not to invest in the risk-reduction measure. This behavior needs to be taken into account when designing disaster management strategies that have a high probability of being implemented. These strategies include land use, enforcement of the most recent international building codes, early warning systems, economic incentives and disaster risk financing mechanisms (e.g. (micro)-insurance).

Below we highlight several factors that have been well-studied in the behavioral economics literature. (See Kunreuther, Meyer, and Michel-Kerjan, in press, for a review).

Budgeting Heuristics

The simplest explanation as to why homeowners may fail to invest in flood mitigation measures is affordability. If a family has limited disposable income after purchasing necessities, there would be little point in it undertaking a BCA as to whether to incur the upfront cost of the new protective measure. If the homeowner is focusing on only the next period (i.e., $T=1$), he may not be able to afford the cost of home improvements.

Budget constraints may extend to higher income individuals if they set up separate mental accounts for different expenditures (Thaler, 1999). Empirical evidence for this budgeting heuristic comes from a study where many renters indicated no change in their willingness to pay for a dead-bolt lock when the lease for the apartment was extended from 1 to 5 years. When asked why, one individual responded by saying:

> $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).

Safety-first Behavior

Individuals may utilize a simplified decision rule that determines whether to invest in protective measures only if the probability of the event (p) is above their threshold level of concern (p^*). If the decision makers perceives $p < p^*$, then they will not undertake any protection. If, on the other hand, $p > p^*$ then they will want to invest in protection.

Should there be an opportunity to determine how much to invest in mitigating the consequences of the event, then the decision maker may utilize a safety first rule by determining the optimal amount of protection so that $p \leqslant p^*$. This "safety first" rule initially proposed by Roy (1952) is utilized by insurers today in determining how much coverage to offer and what premium to charge against extreme events such as hurricane wind damage in hazard-prone areas (Kunreuther and Pauly, in press).

Under-weighting the Future

There is extensive experimental evidence, revealing that human temporal discounting tends to be hyperbolic: temporally distant events are disproportionately discounted relative to immediate ones. The implication of hyperbolic discounting for protective decisions is that homeowners might be asked to invest a tangible fixed sum now to achieve a benefit later that they instinctively undervalue. The effect of placing too much weight on immediate considerations is that the upfront costs of protection will loom disproportionately large relative to delayed expected benefits in losses over time.

An extreme form of hyperbolic discounting is when the decision maker considers the expected benefits from the protective measure only over the next year or two rather than over the life of the equipment. Elected officials are likely to view the decision by reflecting on how their specific decisions are likely to affect their chances of re-election. If the perceived expected benefits from the measure before they start campaigning again are less than the costs of protection, they will very likely oppose the expenditure. They will prefer to allocate funds where they can see an immediate return. The fact that protective measures only yield positive returns when a disaster occurs makes it even more difficult to justify these measures. This reluctance to incur upfront costs that do not yield immediate benefits highlights a NIMTOF (Not in My Term of Office) behavior.

Underestimation of Risk

Another factor that has been shown to suppress investments in protection is under-estimation of the likelihood of a hazard—formally, under-estimation of p in equation (1). There is evidence that people tend to simply ignore risks when the likelihood is small enough. In laboratory experiments on financially protecting themselves against a loss by purchasing insurance or a warranty, 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; Schade et al., 2011). Many homeowners residing in communities that are potential sites for nuclear waste facilities have a tendency to dismiss the risk as negligible (Oberholzer-Gee, 1998).

Even experts in risk disregard some hazards. After the first terrorist attack against the World Trade Center in 1993, terrorism risk continued to be included as an unnamed peril in most commercial insurance policies in the United States. Insurers were thus liable for losses from a terrorist attack without their ever receiving a penny for this coverage. (Kunreuther and Michel-Kerjan, 2004). Following the attacks of September 11, 2001, insurers and their reinsurers had to pay over $35 billion in claims due to losses from the terrorist attacks, at that time the most costly event in the history of insurance worldwide, now second only to Hurricane Katrina.

SECTION 6. PROPOSED INNOVATIONS

We now propose innovations that could enable countries to be better prepared for future disasters taking into account the behavior of key decision makers outlined in the previous section. Specifically, we will focus on how combining cost-effective risk reduction measures and risk financing instruments with economic incentives and well-enforced standards and regulations can significantly reduce future disaster losses. We also discuss several initiatives in several developing countries that provide examples of good practices.

(Micro-)Insurance and (Micro-)Loans

Insurance provides assurance of financial protection.[27] When coupled with loans for disaster risk reduction measures, these two financial products can play a key role in promoting individuals and businesses' investment. We first discuss a recent example of financial innovation: index-based insurance in Peru. We then propose that both insurance and loans be issued as *multi-year contracts* so they encourage communities and governments to think more long term. We will also explain how innovative risk transfer instruments can supplement insurance when losses are truly catastrophic.

Initiative in Peru to reduce losses associated with El Niño. In a new collaboration between GlobalAgRisk, with the support of the Bill and Melinda Gates Foundation, and the United Nations Development Programme, Peru has initiated a new insurance model to mitigate losses associated with natural events. However, unlike the initiatives in India or Malawi that use insurance to compensate for losses *after* an event has occurred, Peru has a program that provides payments *before* the event occurs.

This program is intended to reduce losses associated with El Niño, an event characterized by the warming of the tropical Pacific Ocean that brings devastating rainfall and flooding to Northern Peru normally occurring with a frequency of once in every fifteen years. This event destroys crops, and the risk associated with such a disaster limits available credit for farmers. Fortunately, this warming can be predicted months in advance by measuring changes in sea temperatures off of the coast of Northern Peru. The financial program that has been developed triggers a payment based on the amount the farmer has chosen to insure whenever an El Niño event is predicted, allowing for the insured to use the payment to mitigate against any losses that would normally occur without the insurance.

There are multiple contract options. To illustrate, purchasers of the insurance make a relatively small initial payment and receive a payout when sea temperatures are in excess of 24 degrees Celsius between November and December. The payout is a percentage of the total percentage insured and increases in a linear fashion as sea temperatures increase, with 100 percent of the sum insured being paid when the

[27] We recognize of course that insurance is only one financial tool; saving accounts and redistributive tax programs are other possible policy tools.

temperature reaches 27 degrees Celsius. This provides a cash infusion to the insured in January, before the serious flooding occurs in February through April. Currently, the insurance is available for purchase by banks and other businesses through La Positiva, a local insurer with the backing of PartnerRe, a global reinsurance company. For banks and large businesses, the insurance allows them to be more prepared for the inevitable increased default rate after the event to prevent insolvency and transfer the portfolio risks.

This program has led to a change in thinking regarding potential opportunities for "forecast index insurance." In terms of El Niño events, there are opportunities to expand coverage to parts of Africa, Asia/Pacific, and the Americas where it affects seasonal patterns of rainfall and temperature. However, concerns still remain as to how this initiative will address issues related to moral hazard and potential adverse selection, as there is little information about what form the payments are to be made in and little explicit regulation of how the insured will be monitored in the use of their payouts. Either way, this program offers a unique solution to disaster mitigation (Cavanaugh et al., 2010).

Multi-Year Insurance and Loan Programs for Communities and Governments

Insurance is typically sold as a one-year contract. With respect to investments that have a relatively long life such as disaster risk reduction systems, there is an opportunity to develop new instruments such as multi-year insurance coupled with multi-year loans to encourage these investments.

Multi-year insurance (MYI) programs have been proposed to overcome the tendency for individuals to cancel their insurance policies after several years. Even in the United States, where knowledge about flood risk is available to any resident who seeks this information and flood insurance is available at reasonable cost, many residents in hazard-prone areas purchase flood insurance and then cancel their coverage after several years (Michel-Kerjan and Kunreuther, 2011). An MYI contract would increase the likelihood that individuals are protected over time. They will thus be less exposed to severe disaster losses while at the same time benefiting from their investment in risk-reduction measures by paying lower insurance premiums each year. Long-term loans would further encourage investments in cost-effective mitigation by spreading the upfront costs over time. If insurance rates are actuarially-based, then the premium reduction from adopting a risk-reduction measure will be greater than the annual loan cost. Well-enforced building codes such as those examined in Sect. 4 could ensure that structures are designed to withstand damages from future disasters.

An MYI policy combined with multi-year loans may also encourage communities and national governments in low-income countries to invest in risk reducing measures such as irrigation systems for reducing the impacts of drought. Here is how the combined insurance-loan system would work:

- The community or government would purchase index-based insurance to protect itself against losses from a disaster. The policy would pay a fixed amount based on certain triggers (e.g., rainfall below a certain amount during a given time period).
- The MYI premium would be based on risk to be reviewed every five years so it can reflect structural changes such as climate may change. The revised premium would be based on a credible index regarding the structural change.
- Property owners or farmers would be covered for five consecutive years, making the chances of receiving a claim during this period more likely than if they focused on the annual probability of a disaster occurring.
- The multi-year loan would spread the upfront cost of the investment over a number of years. Local authorities, banks or institutions such as the World Bank could provide the loan.
- The amount of protection against a disaster (for example, drought) required by the community or government would be much lower if they invested in a risk reducing measure such as an irrigation system.
- The annual premium reduction of the MYI policy when one invested in a risk reducing measure (for example, an irrigation system) should be greater than the cost of the loan if the measure is a cost-effective one.

Multi-year insurance policies have been examined by very few pilot studies, with the Peruvian initiative discussed in the previous section being a notable exception. Since this initiative is so recent there has been little time to examine the effects of tying multiyear loans and insurance policies. With the program's planned expansion into multiyear loans for households, small businesses, and the public sector we hope to see an increase in demand, as well as, increases in investments in long term mitigation strategies including irrigation systems (Cavanaugh et al., 2010).

Alternative Risk Transfer Instruments for Covering Catastrophic Losses[28]

A multi-year insurance and loan program should be a win-win for all interested parties. The farmers would be safer and could generate higher revenue, which in turn will help economic growth and further investment in innovative technologies. There would be less need for the government and international charities to provide financial assistance and aid to victims of future disasters since the exposure will be reduced by physical investment in risk reduction measures and by financial protection through insurance.

Still, there is the possibility that a truly devastating disaster could adversely affect a large number of individuals simultaneously even if risk reduction measures are in place. To deal with a catastrophic loss, governments can use dedicated financial products to supplement traditional insurance and reinsurance products. The development of alternative risk transfer (ART) instruments grew out of a series of insurance capacity

[28] For a more detailed discussion on the application of ART instruments to developing countries, see Michel-Kerjan et al. (2011).

crises in the 1970s through the 1990s that led purchasers of traditional reinsurance coverage to seek more robust ways to buy protection. Although ART instruments comprise a wide range of products, we focus here on catastrophe bonds that transfer part of the risk exposure directly to investors in the financial markets.[29] This financial instrument has increased in volume in recent years and is likely to continue to grow as the world experiences more costly catastrophes in the coming years.

How do catastrophe bonds work? Catastrophe bonds ("cat bonds") can enable a country, a company or any organization to access funds from investors if a severe disaster produces large-scale damage. Consider a country, Proactive, which would like to cover part of its exposure against catastrophes. To do so, it creates a company, BigCat, whose only purpose is to finance the disaster costs of Proactive. Notably, BigCat is not a government-run company but an independent company. In that sense, BigCat is a single purpose insurer (also called a special-purpose vehicle, or SPV) for Proactive. When the insurance contract is signed, the sponsor (Proactive) pays premiums to BigCat. SPV BigCat raises the capital to support its insurance policy by issuing a bond to investors. Premiums collected from Proactive will be used to provide the investors with a high enough interest rate to compensate for a possible loss of their principal should a disaster occur. Figure 10 provides the structure of a typical government cat bond.

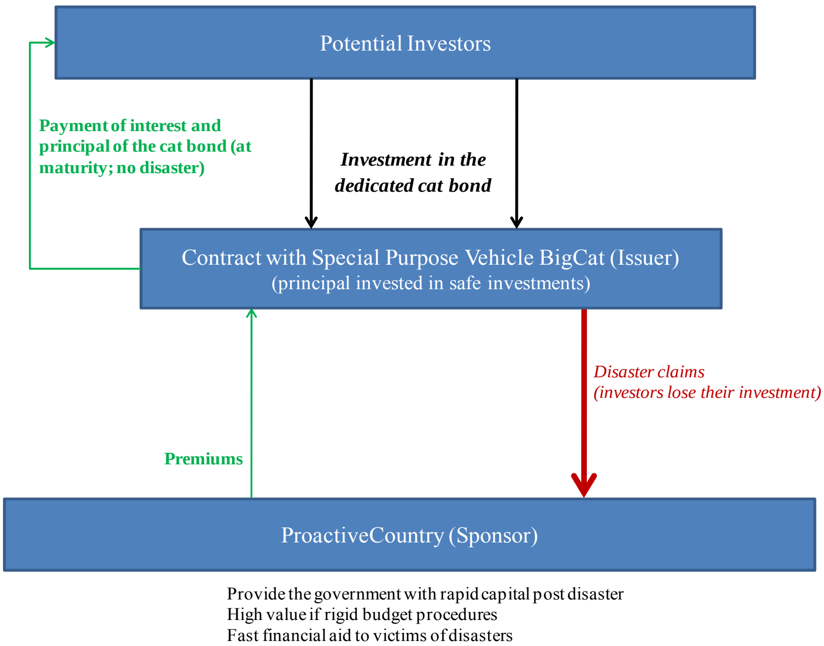

FIGURE 8. SIMPLIFIED STRUCTURE OF A GOVERNMENT CAT BOND

Source: Michel-Kerjan et al. (2011)

[29] See Anderson et al. (2000) and Cummins and Weiss (2009) for comprehensive journal articles, Barrieu and Albertini (2009) and Lane (2002) for edited volumes, and Michel-Kerjan (2010), OECD (2010), and WEF (2008) for a more general analysis.

How a government benefits from a cat bond. There are several widely used ways the payment of a cat bond can be triggered. First, all the stakeholders can agree at the execution of the contract on an external trigger for the insurance payment, independent of the actual level of losses the country has suffered, but easily verifiable, similar to the rainfall trigger on index-based insurance. This is called a *parametric* trigger. The data for this parameter can be collected at multiple reporting stations across a given geographical area. It is also possible to agree on a certain level of the actual economic losses incurred by Proactive from a disaster or series of disasters over the maturity of the cat bond. This is an *indemnity* trigger.[30] The main advantage of an indemnity trigger is that the payment received by Proactive will be much closer to its actual loss but it could create moral hazard problem by having the country overstate the loss it has incurred. Parametric cat bonds are more transparent and simpler to use and hence have been the preferred type in lesser developed countries.

Advantages of using a cat bond. There are several advantages of using a cat bond to provide protection against a catastrophic disaster. They are:

(1) *Multi-year coverage and price stability.* Insurance and reinsurance contracts are typically issued for one year and are subject to price increases particularly after a large-scale disaster.[31] Cat bonds offer an important element of stability for their users by guaranteeing a predefined price over several years. As of 2008, more than 170 cat bonds had been issued since 1996, and their average maturity has been three years with a few bonds being as long as five or ten years. Longer bonds reduce upfront costs by allowing fees to be amortized over a longer period of time (Michel-Kerjan and Morlaye, 2008).

(2) *Guaranteed expedited payment.* Another key advantage of a cat bond is that the money can flow to the government in just a few weeks. By design, the capital of the bond is commonly invested in risk-free assets, such as U.S. Treasury money market funds, so there is limited credit risk.[32]

(3) *Potentially easier to manage politically than a government reserve.* A typical financial policy tool for governments is to build up a reserve of money over time to be

[30] This form of cat bond trigger is more analogous to a traditional insurance policy with its loss settlement process. Other triggers are on *modeled losses* or *industry losses*. For *modeled losses*, instead of dealing with Proactive's actual losses, an exposure portfolio is constructed for use with catastrophe modeling software. When there is a disaster, the event parameters are run against the exposure database in the cat model. If the modeled losses are above a specified threshold, the bond is triggered. For *industry losses*, the cat bond is triggered when an entire industry loss from a certain peril for the insurance industry doing business in this country reaches a specified threshold.

[31] The Guy Carpenter Rate-on-Line index shows a 30 percent annual volatility over the past ten years. Premiums also differ markedly among perils that increase the concentration of risk to the reinsurers and perils which provide diversification. And it is not unusual to see reinsurance prices in a region increase by 20 to 50 percent after a major disaster. Catastrophe reinsurance prices in Florida increased by nearly 100 percent the year after Hurricane Katrina (Kunreuther and Michel-Kerjan, 2009, chapter 7).

[32] Note that some reinsurers now provide collateralized reinsurance treaties as well, but those are more expensive than traditional reinsurance treaties.

used in the case of a catastrophe. However, a catastrophe could occur in the very first years so that the fund simply does not have enough money to pay for the losses. If the country does not suffer major losses for a long period, attention fades and the reserves may be transferred to other programs particularly when budgets are tight.[33] It is difficult to have a long-term perspective on these issues for reasons discussed above (Michel-Kerjan and Slovic, 2010). Cat bonds overcome these challenges, since the catastrophe portion of the risk is transferred to financial investors who serve as third parties.

SECTION 7. CONCLUSION

During the past few years the world has experienced a series of truly devastating natural disasters that have taken many lives and triggered unprecedented economic losses. Hurricane Katrina in 2005 in the United States, the 2010 massive floods in Australia and the 2011 earthquake/tsunami in Japan have demonstrated that even the richest and most prepared countries in the world can experience large-scale damage and destruction. The situation is much worse in low-income countries since they often do not have the financial means to protect their population and economy against catastrophes, or do not consider it a priority. The earthquake in Haiti in 2010 illustrates the challenges of an unprepared and poor country.

Despite this upward trend, knowledge about exposure to natural disasters on an international scale is still rather limited. The recent development of probabilistic catastrophe models can be of significant help in this regard. This paper utilizes this methodology to undertake benefit-cost analyses (BCAs) for disaster-reduction measures by first focusing on a single building in the Caribbean (wind hazard from hurricanes), Indonesia (flood hazard) and Turkey (earthquake hazard).

Undertaking a similar benefit/cost analysis for the building portfolio of an entire country is a very time consuming and complex process. It requires a detailed knowledge of the hazard in different parts of the country (down to the local level) and the distribution and location of the entire building portfolio. This portfolio would comprise all residences, commercial and industrial construction, critical infrastructure, and all government buildings. Such detailed inventory is usually not available in low-income countries, so studies published in the literature have typically focused on one city or part of a community with respect to a specific hazard. A national risk assessment would require knowledge of the vulnerability of the entire portfolio of structures to all the hazards faced by the country. To undertake a BCA one would also need to determine for each loss reduction measures under study the cost of raw material and labor cost in different part of the country too.

[33] This was suggested in the United States for the Hurricane Relief Fund in Hawaii in 2009. Another example relates to the U.S. Pension Benefit Guaranty Corporation. In the 1990s there were interest groups lobbying the PBGC to reduce premiums because they were "too high," as evidenced by the fact that the PBGC was running a surplus.

For all those reasons, we have undertaken rather preliminary BCAs, building on limited studies that have been undertaken in different parts of the world to reduce losses from natural disasters. For three types of disasters — earthquakes, floods and cyclones/hurricanes/storms — we have focused on residences and schools in more than 30 countries each. We have determined the cost of different loss reduction measures and expected benefits in terms of physical damage reduction and number of lives saved. By design our BCAs are highly dependent on very simplifying assumptions we had to make. Furthermore, and as expected, the selection of different discount rates, time periods and values of life can have a significant impact on our findings.

Note, however, that our analysis has not taken into account several additional benefits from these disaster risk-reducing measures in the form of reduction of evacuation costs (from reducing housing damage), lowering the number of injured and possible subsequent health issues, continuity of education (from preserving schools) and relieving social stress to individuals and avoiding business interruption (Heinz Center, 2000).

We also discussed the importance of behavioral and economic barriers to implementing measures even though they can appear to be cost effective on paper. Moreover, in addition to risk assessments and cost-benefit analyses of specific loss reduction measures, one needs to design strong risk financing mechanisms for victims of disasters (individuals and firms) to get back on their feet more quickly after a catastrophe rather than relying on uncertain donor's money. Insurance and other alternative risk transfer instruments can play an important role here. In addition there is a need for innovations with short-term incentives (such as multi-year contracts) that could be more attractive to those living and working in exposed areas as well as to politicians who are concerned with re-election or staying in power. And could grasp the short-term benefits of such innovations.

Finally, the question of ***who should pay*** for these measures is an important issue. It is one we have not discussed in this paper. We have been asked to allocate $75 billion that has been hypothetically given to us from some unknown source. If we can convince a panel of our peers that these expenditures have value, we would then have to take our case to those who make decisions where there are scarce resources. We would then have to do the following:

- Convince international donors to start investing more systematically in disaster risk reduction rather than focusing almost exclusively on post-disaster assistance as they do today.
- Convince NGOs to put their time and energy into reflecting on ways to reduce future losses and fatalities rather than focusing solely on emergency relief.
- Convince more governments in developed countries and multinational corporations to provide some of their funding and technical expertise to assist low-income countries in undertaking these measures.

As our planet becomes more and more interdependent, a disaster in one part of the world can have ripple effects on many other countries. There may then be a recognition by the above stakeholders that is in their own best interest to take these steps now rather than procrastinating because the failure of poor countries can have impact on their future as well. If a few key decision makers, organizations and countries take the initiative this may lead others to follow suit, tipping the world in the right direction. As more people work on these questions, economies of scope and scale will likely develop, new technologies emerge, so the cost of reducing exposure to future disasters will significantly decrease too.

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Appendix

Analysis for Proposal I (retrofitting schools)

Countries are ranked from the highest BCR to the lowest.

Table A1. Discount rate of 3%; VoL: $40,000

Country	BCR	Cumulative Retrofitting Cost (U.S. $ Million)	Cumulative Total Benefits	Cumulative Number Of Lives Saved
Solomon Islands	4.97	$36	$181	72
Armenia	1.96	$188	$479	255
Albania	1.69	$443	$908	468
Peru	0.87	$4,537	$4,463	3,198
Kyrgyzstan	0.71	$4,724	$4,595	3,258
El Salvador	0.63	$4,987	$4,762	3,858
Costa Rica	0.50	$5,729	$5,130	4,215
Tajikistan	0.41	$6,000	$5,241	4,320
Romania	0.36	$7,906	$5,931	5,329
Guatemala	0.34	$8,407	$6,103	7,434
Chile	0.32	$11,157	$6,979	7,476
Panama	0.29	$11,602	$7,108	7,479
Afghanistan	0.22	$12,263	$7,251	11,789
Myanmar	0.20	$13,135	$7,428	16,955
Uzbekistan	0.18	$14,419	$7,660	19,491
Honduras	0.15	$14,768	$7,712	19,526
Nicaragua	0.15	$15,121	$7,764	19,533
Ecuador	0.14	$16,068	$7,895	20,939
Algeria	0.12	$19,321	$8,295	21,287
Nepal	0.11	$19,982	$8,368	21,408
Dr Congo	0.09	$20,462	$8,410	22,640
Sudan	0.09	$22,402	$8,576	22,794
Bolivia	0.08	$23,393	$8,654	22,807
Colombia	0.08	$28,415	$9,035	27,582
Iran	0.07	$38,874	$9,814	33,169
Uganda	0.07	$39,932	$9,889	33,362
Turkey	0.06	$54,239	$10,689	33,595
Indonesia	0.05	$69,125	$11,370	54,236
India	0.04	$134,450	$13,939	169,297
Venezuela	0.04	$140,428	$14,172	169,326
Philippines	0.04	$147,466	$14,422	170,648
Mexico	0.03	$179,820	$15,479	170,770
Pakistan	0.02	$188,633	$15,682	173,194
China	0.02	$289,951	$17,757	251,800
Argentina	0.01	$299,574	$17,860	251,812

Table A2. Discount rate of 3%; VoL: $200,000

Country	BCR	Cumulative retrofitting cost (US $ million)	Cumulative total benefits	Number of lives saved
Solomon Islands	5.13	$36	$187	72
Armenia	2.06	$188	$500	255
Albania	1.75	$443	$947	468
Peru	0.92	$4,537	$4,727	3,198
El Salvador	0.82	$4,800	$4,943	3,798
Afghanistan	0.75	$5,461	$5,441	8,108
Kyrgyzstan	0.73	$5,648	$5,578	8,168
Myanmar	0.69	$6,520	$6,180	13,334
Guatemala	0.69	$7,021	$6,526	15,438
Costa Rica	0.53	$7,763	$6,922	15,795
Tajikistan	0.44	$8,035	$7,042	15,900
Romania	0.41	$9,940	$7,816	16,909
Uzbekistan	0.34	$11,224	$8,256	19,446
Chile	0.32	$13,974	$9,136	19,488
Dr Congo	0.30	$14,454	$9,279	20,720
Panama	0.29	$14,899	$9,408	20,724
Ecuador	0.26	$15,846	$9,655	22,130
India	0.18	$81,170	$21,699	137,191
Indonesia	0.16	$96,057	$24,079	157,832
Honduras	0.16	$96,406	$24,134	157,867
Colombia	0.15	$101,428	$24,909	162,642
Nicaragua	0.15	$101,781	$24,961	162,649
Algeria	0.13	$105,034	$25,389	162,997
Nepal	0.13	$105,695	$25,472	163,118
Iran	0.12	$116,154	$26,711	168,705
Sudan	0.09	$118,094	$26,890	168,858
Uganda	0.09	$119,152	$26,981	169,051
China	0.08	$220,469	$35,528	247,657
Bolivia	0.08	$221,460	$35,607	247,671
Turkey	0.06	$235,767	$36,426	247,903
Philippines	0.05	$242,805	$36,785	249,225
Pakistan	0.05	$251,619	$37,187	251,649
Venezuela	0.04	$257,597	$37,422	251,679
Mexico	0.03	$289,951	$38,489	251,800
Argentina	0.01	$299,574	$38,593	251,812

Table A3. Discount rate of 5%; VoL: $200,000

Country	BCR	Cumulative Retrofitting Cost (U.S. $ Million)	Total Benefits	Cumulative Number of Lives Saved
Solomon Islands	3.64	$36	$133	72
Armenia	1.46	$188	$355	255
Albania	1.24	$443	$672	468
Peru	0.66	$4,537	$3,354	3198
El Salvador	0.58	$4,800	$3,507	3798
Afghanistan	0.53	$5,461	$3,861	8108
Kyrgyzstan	0.52	$5,648	$3,958	8168
Myanmar	0.49	$6,520	$4,385	13334
Guatemala	0.49	$7,021	$4,630	15438
Costa Rica	0.38	$7,763	$4,912	15795
Tajikistan	0.31	$8,035	$4,997	15900
Romania	0.29	$9,940	$5,545	16909
Uzbekistan	0.24	$11,224	$5,858	19446
Chile	0.23	$13,974	$6,482	19488
Dr Congo	0.21	$14,454	$6,584	20720
Panama	0.21	$14,899	$6,675	20724
Ecuador	0.19	$15,846	$6,851	22130
India	0.13	$81,170	$15,396	137191
Indonesia	0.11	$96,057	$17,085	157832
Honduras	0.11	$96,406	$17,124	157867
Colombia	0.11	$101,428	$17,673	162642
Nicaragua	0.10	$101,781	$17,710	162649
Algeria	0.09	$105,034	$18,014	162997
Nepal	0.09	$105,695	$18,073	163118
Iran	0.08	$116,154	$18,952	168705
Sudan	0.07	$118,094	$19,079	168858
Uganda	0.06	$119,152	$19,144	169051
China	0.06	$220,469	$25,208	247657
Bolivia	0.06	$221,460	$25,264	247671
Turkey	0.04	$235,767	$25,845	247903
Philippines	0.04	$242,805	$26,100	249225
Pakistan	0.03	$251,619	$26,385	251649
Venezuela	0.03	$257,597	$26,552	251679
Mexico	0.02	$289,951	$27,309	251800
Argentina	0.01	$299,574	$27,383	251812

Table A4. Discount rate of 3%; VoL: $6 million

Country	BCR	Cumulative Retrofitting Cost (U.S. $ Million)	Cumulative Total Benefits	Cumulative Number of Lives Saved
Afghanistan	20.20	$661	$13,362	4,310
Myanmar	18.37	$1,533	$29,382	9,476
Guatemala	13.22	$2,034	$36,008	11,580
Solomon Islands	11.02	$2,071	$36,410	11,652
Dr Congo	7.96	$2,551	$40,231	12,884
El Salvador	7.63	$2,814	$42,239	13,485
Uzbekistan	6.24	$4,098	$50,249	16,021
Armenia	5.67	$4,250	$51,108	16,204
India	5.44	$69,574	$406,567	131,264
Ecuador	4.69	$70,521	$411,013	132,671
Indonesia	4.30	$85,407	$475,002	153,312
Albania	4.25	$85,662	$476,083	153,525
Colombia	2.99	$90,684	$491,111	158,301
Peru	2.91	$94,778	$503,040	161,031
China	2.40	$196,096	$746,200	239,637
Romania	1.99	$198,001	$749,987	240,647
Costa Rica	1.97	$198,743	$751,449	241,004
Iran	1.71	$209,202	$769,364	246,591
Kyrgyzstan	1.69	$209,389	$769,680	246,651
Tajikistan	1.59	$209,660	$770,112	246,756
Pakistan	0.87	$218,474	$777,750	249,180
Nepal	0.67	$219,135	$778,192	249,300
Uganda	0.63	$220,193	$778,859	249,493
Philippines	0.61	$227,231	$783,164	250,815
Honduras	0.45	$227,580	$783,322	250,850
Algeria	0.45	$230,833	$784,788	251,198
Chile	0.37	$233,583	$785,793	251,240
Sudan	0.33	$235,523	$786,429	251,393
Panama	0.31	$235,968	$786,569	251,397
Nicaragua	0.21	$236,321	$786,643	251,404
Bolivia	0.12	$237,312	$786,761	251,417
Turkey	0.11	$251,619	$788,273	251,649
Venezuela	0.05	$257,597	$788,596	251,679
Mexico	0.04	$289,951	$790,026	251,800
Argentina	0.01	$299,574	$790,165	251,812