The Costs and Benefits of Reducing Risk from Natural Hazards to Residential Structures in Developing Countries

Stefan Hochrainer-Stigler
International Institute of Applied Systems Analysis (IIASA)

Howard Kunreuther
The Wharton School
University of Pennsylvania

Joanne Linnerooth-Bayer
International Institute of Applied Systems Analysis (IIASA)

Reinhard Mechler
International Institute of Applied Systems Analysis (IIASA)

Erwann Michel-Kerjan
The Wharton School
University of Pennsylvania

Robert Muir-Wood
Risk Management Solutions

Nicola Ranger
London School of Economics

Pantea Vaziri
Risk Management Solutions

Michael Young
Risk Management Solutions

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

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Authors

Hochrainer-Stigler, S., Kunreuther, H., Linnerooth-Bayer, J., Mechler, R., Michel-Kerjan, E., Muir-Wood, R., Ranger, N, Vaziri, P., and Young M.

Abstract:

This paper examines the benefits and costs of improving or retrofitting residential structures in highly exposed low- and middle-income developing countries such that they are less vulnerable to hazards during their lifetime. Since it is misleading to assess the benefits of prevention using deterministic models, the challenges for cost benefit analyses are to express avoided losses in probabilistic terms, evaluate and assess risk, monetize direct and indirect benefits and include dynamic drivers such as changing population, land use and climate. In detail, we examine structures exposed to three different hazards in four countries, including hurricane risk in St. Lucia, flood risk in Jakarta, earthquake risk in Istanbul and flood risk within the Rohini River basin in Uttar Pradesh (India). The purpose in undertaking these analyses is to shed light on the benefits and costs over time, recognizing the bounds of the analysis, and to demonstrate a systematic probabilistic approach for evaluating alternative risk reducing measures.

Introduction

Retrospective analyses show large benefits from disaster risk reduction (DRR) in many developed and developing country contexts. Examining investments in 4,000 disaster risk reduction programs, including retrofitting buildings against seismic risk and structural flood defence measures, the U.S. Federal Emergency Management Agency (FEMA) found an average benefit-cost ratio of four suggesting that DRR can be highly effective in reducing future disaster losses (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 ratios (Mechler 2005).

In spite of potentially high returns, there is limited investment in loss reduction measures by those residing in hazard-prone areas. In the US, several studies show that only about 10 percent of earthquake- and flood-prone households have undertaken cost-effective DRR measures. Kunreuther et al. (in press) attribute this inaction to a myopic focus on short-time horizons - the upfront costs of the investment in DRR loom large relative to the perceived expected benefits from the measures. Policy makers are also reluctant to commit significant funds to risk reduction, which may also be explained by short time horizons, and additionally by the absence of concrete information on net economic and social benefits and limited budgetary resources. The consequence is that politicians face increasing pressure to provide assistance after a disaster (Benson and Clay 2004; Cavallo and Noy 2010).

This is especially true for development and donor organizations. According to some estimates, bilateral and multilateral donors currently allocate 98 percent of their disaster management funds for relief and reconstruction and only two percent to reduce the loss exposure and vulnerability (Mechler 2005). To redress this imbalance the 2005 United Nations World Conference on Disaster Reduction and the resulting Hyogo Framework for Action (United Nations 2005) emphasize the need for pro-active disaster investment and planning, which has resulted in increased attention to pre-disaster risk reduction. (Kreimer and Arnold 2000; Mechler 2004; Gurenko 2004; Linnerooth-Bayer et al. 2005; Hochrainer 2006).

Disaster risk reduction has also emerged on the climate change adaptation agenda (IPCC, 2007) Increasing losses from natural disasters can be mainly attributed to socio-economic developments (Munich Re 2005; Swiss Re 2008); yet, the International Panel on Climate Change (IPCC) has predicted that weather variability will increase and that overall extreme event impacts are 'very likely' to change (Solomon et al. 2007). There is even mounting evidence of a current "climate signal" with the IPCC reporting observations of widespread changes in temperature, wind patterns and aspects of extreme weather, including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (Carter et al. 2007). Recognizing the need for adaptation measures, the United Nations Framework Convention on Climate Change (UNFCCC) and the Bali Action Plan have placed emphasis on reducing and transferring risks due to extreme weather (IPCC 2007).

In this paper we apply probabilistic cost-benefit analyses (CBA) to evaluate selected DRR measures that reduce losses to structures in hazard-prone areas in low- and middle-income developing countries. There is a substantial literature on the use of CBA and

other appraisal methods to pro-actively evaluate risk-reduction investments, but there are few applications in developing countries (Benson and Twigg 2004; Penning-Rowsell et al. 1996; Smyth et al. 2004; Benson et al. 2007; Dixit et al. 2009; Moench et al. 2009; Mechler 2009). Since it is misleading to assess the benefits of prevention using deterministic models, the challenges for cost-benefit analyses are to express avoided losses in probabilistic terms, evaluate and assess risk, monetize direct and indirect benefits and include dynamic drivers such as changing population, land use and climate.

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. In detail, we examine structures exposed to three different hazards in four countries:

- **Hurricane** (wind only) risk in **St. Lucia** (Caribbean Island State)
- **Flood** risk in **Jakarta** (Indonesia)
- **Earthquake** risk in **Istanbul** (Turkey)
- **Flood** risk within the **Rohini River basin in Uttar Pradesh** (India)

The structures and risks chosen for this study are typical for many low-, middle- and high-income persons residing throughout Asia and the Caribbean. For this reason the results have relevance beyond the single choice of household. In order to simplify the analysis, we have disregarded several elements which can play an important role in the decision to adopt risk reduction measures: risk aversion, multiple hazards and indirect losses. Our purpose in undertaking these analyses is to shed light on the benefits and costs over time, recognizing the bounds of the analysis, and also to demonstrate a systematic probabilistic approach for evaluating alternative risk reducing measures. The models can be extended (given that relevant data are available) to incorporate risk aversion, multiple hazards, indirect losses and other aspects of the problem.

The paper is organized as follows: Following a brief discussion of our methodology in section 2, we show the results of the benefit-cost calculations for selected DRR measures across the four cases in section 3. In section 4 we discuss the relevance of the case studies to policies at the national and international scales, examine the opportunities of expanding the scale and scope of our analysis and provide a foundation for undertaking future research on the role that DRR can play in conjunction with other policy tools, notably insurance. Section 5 presents more details of the challenges and limitations of utilizing CBA analysis. Section 6 summarizes the main results and suggests a future research agenda.

Methodology

As described below, each of the case studies follows a similar format with respect to evaluating the costs and benefits of structural DRR measures.

Exceedance Probability Curve

The basic probabilistic measure for assessing the catastrophe exposure of a house or portfolio of assets is the *exceedance probability (EP) curve*. An EP curve indicates the

probability *p* that *at least* $X is lost in a given year. An EP curve is one output of a catastrophe model, involving four main modules depicted in Figure 1.

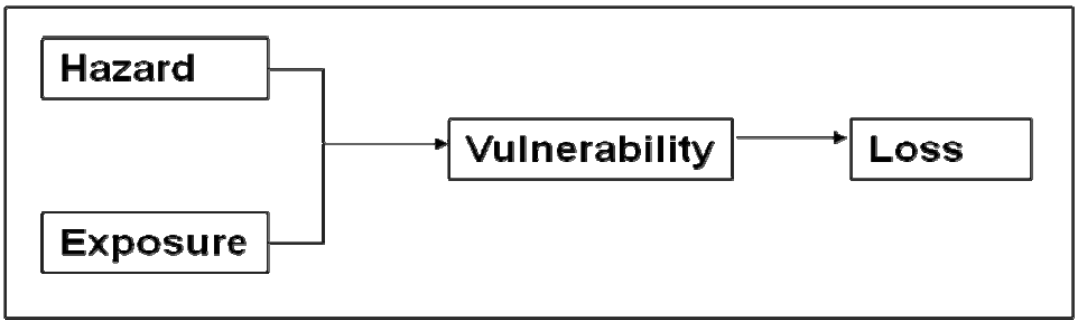

FIGURE 1: EP estimation methodology. Source: Grossi and Kunreuther (2005)

- A *hazard module* characterizes the hazard in a probabilistic manner. Often, the full suite of events which can impact the exposure at risk is described – by magnitude and associated annual probability, among other characteristics.
- A*n exposure mod*ule describes a single structure or collection of structures that m*ay be da*maged.
- A *vulnerability* module estimates the damage to the exposure at risk given the magnitude of the hazard. Vulnerability is typically characterized as a mean estimate of damage (e.g. percentage of house destroyed) and associated uncertainty given a hazard level.
- A financial *loss* module estimates losses to the various stakeholders that must manage the risk (e.g., homeowner, insurer, reinsurer).

Based on these modules a typical EP curve can be constructed as depicted in Figure 2, where the likelihood that losses will exceed L_i is given by p_i, i.e. the x-axis shows the magnitude of the loss in US dollars and the y-axis depicts the annual probability that losses will exceed this level (see for example Grossi and Kunreuther (2005) and Hochrainer (2006) for details on constructing EP curves in the context of catastrophe models). The area under the EP curve is the average annual loss (AAL). Structural DRR measures typically decrease the vulnerability of the building and therefore reduce the expected loss. Graphically, DRR shifts the EP curve to the left and therefore reduces the AAL value (Figure 2).

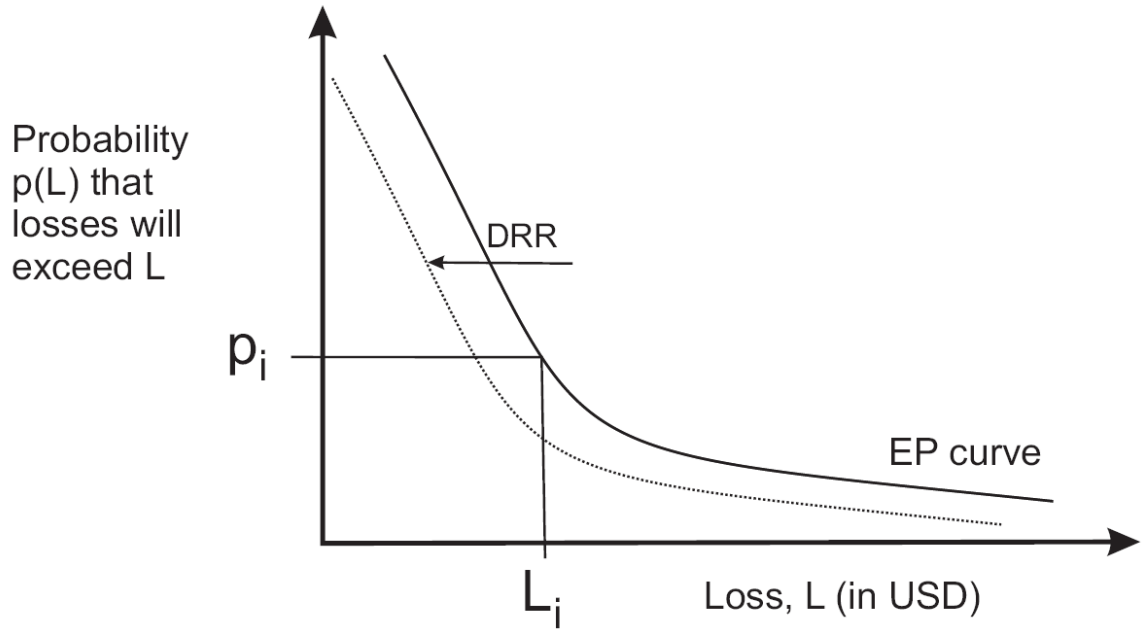

FIGURE 2: EXAMPLE OF AN EXCEEDANCE PROBABILITY CURVE AND DRR EFFECT

Cost-Benefit Analysis (CBA) for Specific DRR Measures

For each case study we select measures for reducing losses from the disaster in question. 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. Cost estimates of each DRR measure are derived from various sources. Combining these estimates, we compute a *benefit-cost ratio* (B/C ratio). The most attractive DRR measure from an economic standpoint is the one with the highest B/C ratio assuming there are no budget constraints with respect to the cost of the investment. Using the B/C ratio 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. This point is further illustrated in section 4.1 where recommendations of the four case studies are summarized.

Sensitivity Analyses

In addition to the probabilistic benefits and costs of improving structures to withstand these hazards, we show how changes in the discount rate and time horizon over which the expected benefits are examined impact on the analysis. We estimate the sensitivity of the B/C ratio to variations in the discount rates (0-15%) as well as the selected time horizon for the life of the structure (1, 5, 10, 25 years).

Limitations

It is important to note that the assumptions underlying this analysis are conservative in a number of ways. Firstly, taking account of lost lives and climate change would likely

increase the benefits of the selected mitigation measures. These effects are only taken into account in the Istanbul and Rohini River Basin case studies, respectively. Secondly, not considered in this paper are the costs of household assets, loss of livelihoods and broader indirect losses from disasters; taking into account these effects would tend to increase the benefits of risk reduction.

Finally, the cost-benefit analyses in this paper are expected value analyses. This means that they assume zero risk aversion; if the householder were more risk averse then this too would increase the economic benefit of risk reduction investment. The analyses also do not consider uncertainties in risk estimation. The implications of these issues will be discussed in detail in section 5.

Four Case Studies

As summarized in Table 1, the cases focus on a representative house or houses in four developing country locations: St. Lucia, Jakarta, Istanbul and the Rohini River Basin in India. The analyses are representative across a wide range of income levels, including very poor, middle-income and high-income structures. Three hazards are considered: hurricane, flood and earthquake.

For each case we examine specific DRR measures that can be undertaken for a representative house or houses. Making use of the methodology described above, we determine under what conditions the discounted expected benefits with respect to reducing losses exceed the cost of the measure. In the case of Istanbul, we examine the benefits of seismic DRR measures in light of the probabilistic reduction in both physical damages and fatalities. In the Rohini River Basin case we include possible impact of climate change into the flood-risk analysis.

TABLE 1: SUMMARY TABLE OF THE FOUR CASE STUDIES

	Hazard	*Value of representative house USD*	*Additional elements accounted for*
St. Lucia, Caribbean	Hurricane wind	100,000	-
Jakarta, Indonesia	Flood	19,200	-
Istanbul, Turkey	Earthquake	250,000	Lives at risk
Rohini River Basin, India	Flood	150-1500	Climate change

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 the hazard 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 rising 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 surge 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 wood outer walls such as plywood and wood/timber walls (Kairi 2007). Two representative houses, one wood frame and the other masonry, are selected for study. It is assumed that the replacement value of the houses is 100,000 USD. These representative houses are located in the higher and lower risk cities of Canaries and Patience.

EP curve and selected DRR measures

In the absence of DRR measures, the EP curves for the representative residential buildings in the two cities are shown in Figure 3. These curves show wood frame housing is more vulnerable than masonry and there is a significant difference in expected loss between minimum and maximum hazard areas, e.g. AAL for wood frame structures is 4070 USD in the Canaries (max hazard area) but only 830 USD in Patience (min hazard area).

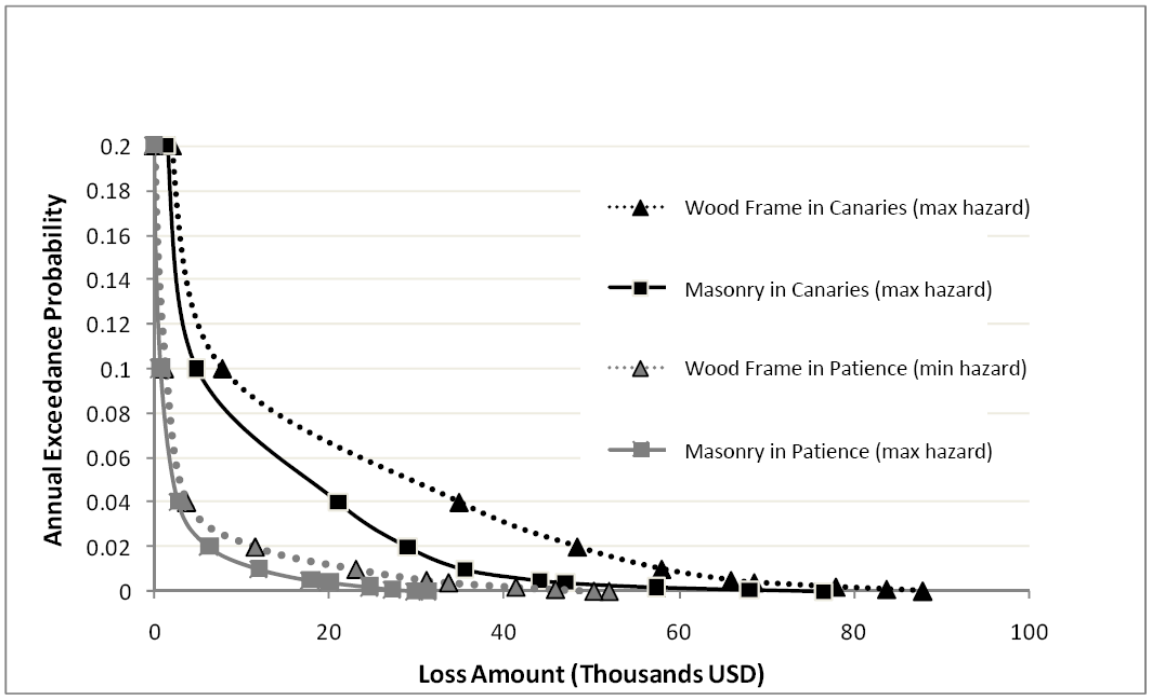

FIGURE 3: EP CURVES WITH NO DRR - HURRICANE RISK IN ST. LUCIA

Three DRR measures were examined for reducing hurricane risk to the representative wood frame and masonry houses. The DRR costs for the houses have been developed based on a RMS' survey of DRR costs for contractors in Florida in 2009 and from roofing costs reports on Hurricane Ivan damage in 2004 (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 USD.

- **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 USD.
- **Measure 3: *Roof Upgrade and Opening Protection:*** Options 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 USD.

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 and 12% (which are typical low and high values used for evaluating development projects, see Mechler 2004) and an expected life of the structure of 10 and 25 years.

TABLE 2: SUMMARY OF SELECTED B/C RATIOS (NUMBERS ABOVE 1 IN BOLD)

DRR measure	Time horizon (years)	Masonry				Wood Frame			
		Canaries (Max Hazard)		Patience (Min Hazard)		Canaries (Max Hazard)		Patience (Min Hazard)	
		Discount rate		Discount rate		Discount rate		Discount rate	
		5%	12%	5%	12%	5%	12%	5%	12%
1. Roof upgrade	10	0.75	0.55	0.16	0.11	0.95	0.69	0.22	0.16
	25	**1.37**	0.76	0.29	0.16	**1.73**	0.96	0.41	0.23
2. Opening protection	10	0.62	0.46	0.09	0.07	**1.48**	**1.08**	0.25	0.18
	25	**1.14**	0.63	0.17	0.09	**2.70**	**1.51**	0.46	0.26
3. Combined	10	0.59	0.44	0.11	0.08	0.99	0.72	0.20	0.14
	25	**1.09**	0.60	0.20	0.11	**1.80**	1.00	0.36	0.20

The results show that strengthening the resistance of windows and doors (opening protection - measure 2) yields a positive net return for both wood and masonry structures that have an expected lifetime of 10-25 years. The highest B/C ratio occurs in the maximum hazard location (Canaries) and on the more vulnerable structure (wood) with the opening protection measure. As expected, the lowest B/C ratio occurs in the minimum hazard location (Patience) with the less vulnerable masonry structure, with the opening protection measure.

To illustrate the sensitivity of our results to the selected discount rate, in Figure 4 we show how the B/C ratio for strengthening the resistance of windows and doors for a wood frame house in Canaries varies over a range of rates (0 to 0.15 on the x-axis) and across different assumed lifetimes of the structure (1, 5, 10, and 25 years shown as separate trend lines).

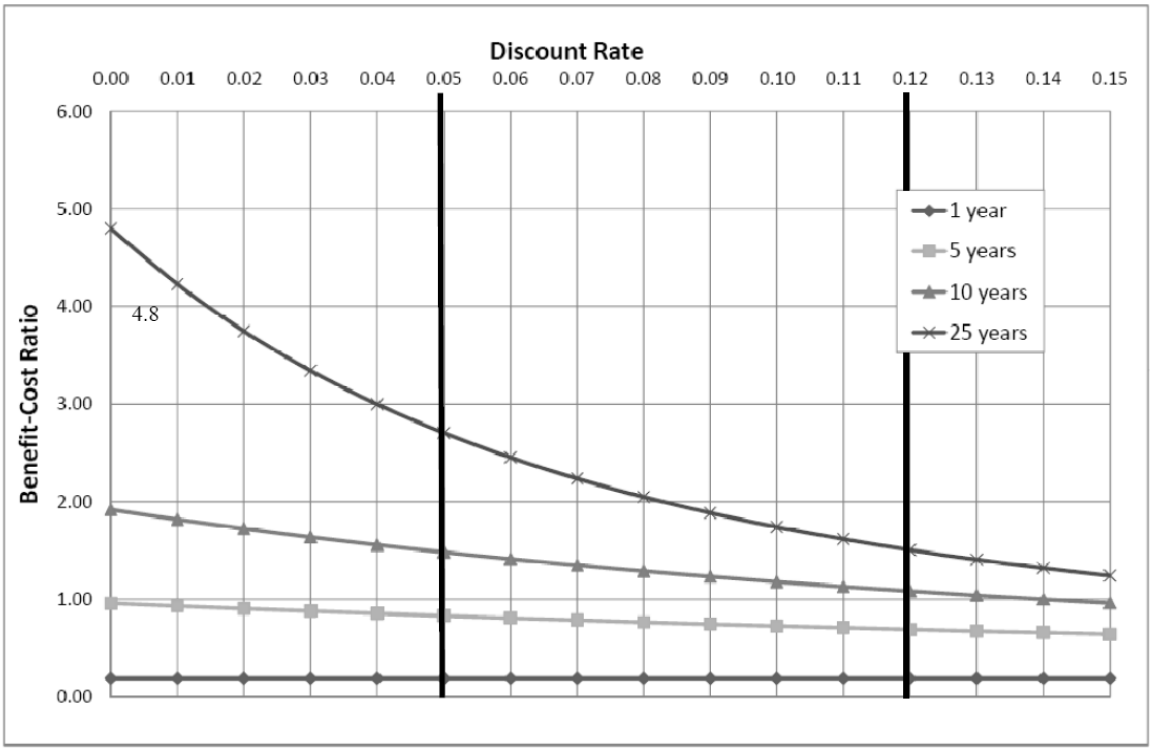

FIGURE 4. Canaries: B/C rations for different discount rates and time horizons for protecting a wood frame structure by improving window and door protection

For a zero discount rate over a 25 year time horizon (point on upper curve), the expected B/C ratio is approximately 4.8. In other words, if this DRR measure was put in place in such a house this year, the expected benefit resulting from it over a period of 25 years would be 4.8 times the cost of this measure today. The main factor driving this high ratio is the relatively inexpensive cost of protecting the openings of the house ($6,720) on a sample house worth $100,000. The present value of the expected average annual loss (AAL) reduction in this case is $32,219 (for the 25 year time horizon.) Generally speaking, once the time horizon is extended to 10 or more years, DRR becomes cost-effective for the opening protection measures applied to a wood frame house in the high-risk city of Canaries. It is also important to note that for a poorer household, if the replacement cost of the house were lower than the economic benefits of the same DRR investment would also be lower and therefore, may not be cost-effective. This simple logic is unlikely to hold in practice, however. For example, the property of a low-income family may be less well constructed and so less costly to strengthen, making the benefit-to-cost ratio far larger.

Case Study II: Flood Risk in Jakarta (Indonesia)

Jakarta is the capital of Indonesia with around 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 area 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. We focus our study on residential properties in East

Jakarta, which make up about 60% of the city's structures (Hendrayanto 2008). Images from Google Earth suggest that the vast majority of the buildings not located in the commercial centre are two- or three-story masonry residential homes typically occupied by persons of high and medium wealth. The buildings are built tightly in blocks.

We selected two representative housing types: a high-value two-story home constructed with brick walls, concrete floor and clay roof (referred to as Masonry) and a middle-income two-three story home constructed with mixed wall, concrete floor and asbestos roof (referred to as Mixed Wall). We do not include low-income housing in this study as risk management could involve complete rebuild or relocation. The replacement value of the representative building is assumed to be 19,200 USD (based on estimates from Silver 2007).

EP curve and selected DRR measures

Given very limited flood hazard data for Jakarta, we base our analysis 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 curves also allows us to test the sensitivity of findings to the hazard approximation.

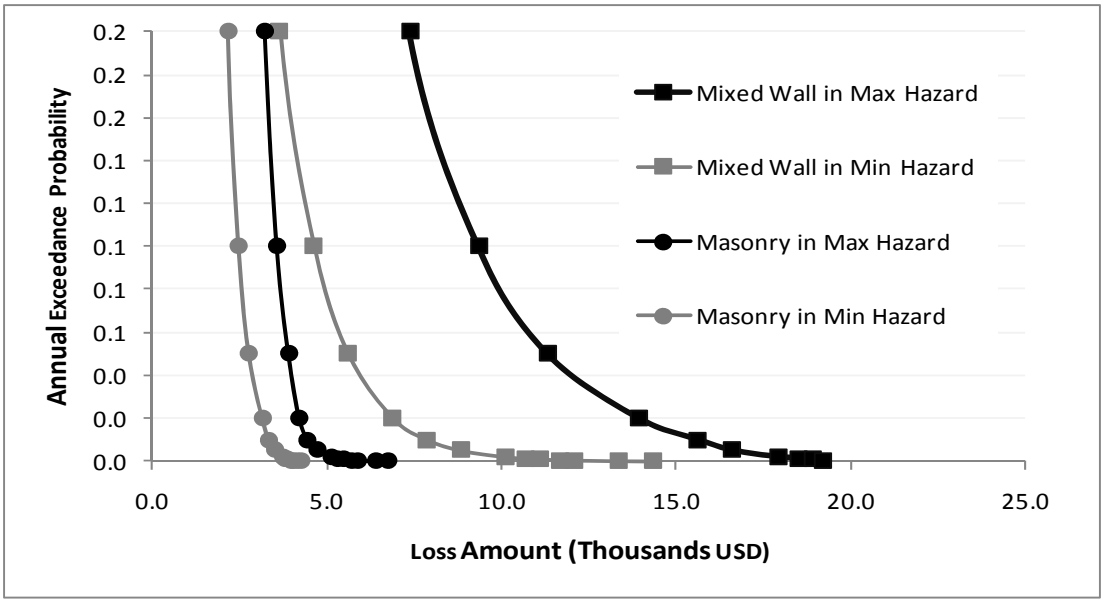

FIGURE 5: FLOOD RISK IN JAKARTA - EP CURVES FOR TWO BASE LINE STRUCTURES IN TWO DIFFERENT HAZARD LOCATIONS WITH NO DRR

Two 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 US (Teicholz 1998; Davis 2002):

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

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% 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 (NUMBERS ABOVE 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%
1. 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
2. 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 results show B/C ratios that are substantially higher among mixed wall structures than among masonry structures, due to a greater hazard level. Elevating the property by 1 m also has mostly favorable results, with B/C ratios ranging from 0.61 to 6.73.

While this paper considers household-level structural measures, we note that for flood risk management in urban areas (unlike for windstorm or earthquake) the most cost-effective structural measures tend to be community-level protection, for example, flood defenses or improved drainage systems. These measures effectively reduce risks but also distribute the costs of protection across a group of properties. These measures are typically implemented by the public sector, property developers or community groups. Household-level protection can be beneficial where such options are not available.

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, Erdik 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.

On average such 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.

EP curve and selected DRR measures

As shown in Table 4, we assume that there are 3 study buildings characterized by a ground floor with a soft story, possessing short columns or both. Soft story means that the ground-floor space – a window, garage door – is situated where a wall might otherwise be. Soft story structures, possessing large ground floor openings, are collapse hazards in strong ground shaking. A short column is a column in a reinforced concrete buildings where the partial height infill walls are used to provide natural lighting and ventilation and thus, creating a column shorter than the other columns within the structure. Short column failure occurs when the column is subject to high shear stresses and unable to resist these stresses.

Moreover, the flexibility of the frame can be increased by adding partial or full shear walls (here referred to as structural upgrade) as described in Smyth et al. (2004). In the absence of shear walls, risks to soft story buildings can be reduced through the use of a steel moment frame in the open floor. We assume that the addition of shear walls will automatically retrofit the effect of soft story and therefore there is no additional cost for soft story DRR. The short column effect can be mitigated either through adding masonry inserts at both sides of the column (Guevara and García 2005) or separation of the infill wall from the surrounding frame.

In Table 4, Type 1 and Type 3 buildings are about 4% and 14% 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
Type 3	Yes	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).

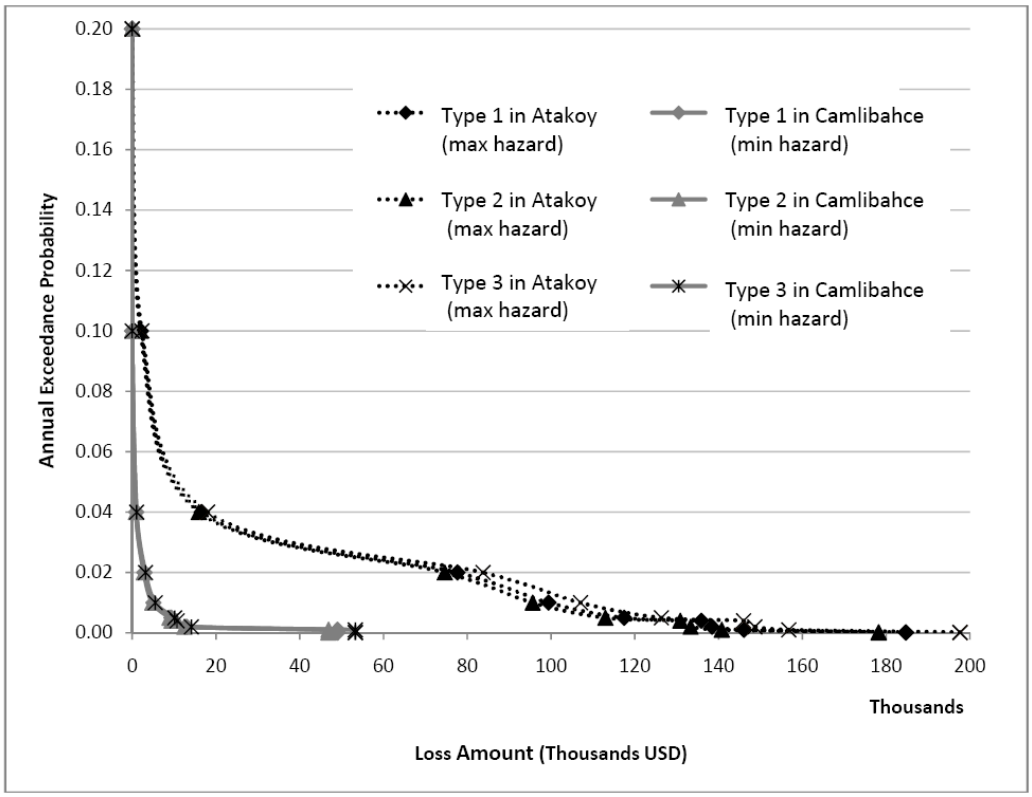

FIGURE 6: EARTHQUAKE RISK IN ISTANBUL - EP CURVES WITH <u>NO DRR</u>

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) are added. Short columns are mitigated if applicable.
- Measure 3: Full shear walls (FSW) are added. Short columns (SC) are mitigated if applicable.

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

TABLE 5. COSTS OF ALTERNATIVE DRR MEASURES FOR EACH BASELINE TYPE

DRR Option	Costs (USD) for Type 1	Costs (USD) for Type 2	Costs (USD) 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 6 with selected discount rates (5 and 12%) and time horizons (10-25 years).

TABLE 6: EARTHQUAKE RISK IN ISTANBUL: SUMMARY OF SELECTED B/C RATIOS

DRR Measure	Time Horizon (years)	Type1				Type2				Type3			
		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 B/C ratio below one 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

3.1.1. The value of reducing mortality risk

Cost-benefit analyses of projects/investments that save at-risk lives generally make use of a value of statistical life (VSL) to estimate the benefits or costs (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. Applying a VSL to CBA, however, can be controversial since it is ethically difficult to put a price tag on a

life. For this reason we do not make use of a point value, but undertake a sensitivity analysis using a range of statistical life value estimates.

As an upper bound of the VSL, we take the highest practical estimate in the United States, USD 6 million, which is commonly used by the US 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 VSL (in this case, for Turkey) according to the country's per capita income relative to the US. This method yields a Turkish VSL approximately equal to USD 750,000. We use these figures as the lower and upper range of the VSL for the Istanbul case.

In Table 7 we show how the B/C estimates 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. As can be seen, the B/C ratios when VSL is not incorporated in the analysis (ranging from 0.09 to 0.21 depending on the discount rate and time horizon of the building) increase significantly if the value of reducing mortality risk is included. Even for the lowest VSL (USD 750,000) the DRR measure is attractive assuming a discount rate of 5% and a time horizon of 25 years. With the maximum VSL (USD 6 million) the B/C ratios ranges from 3.5 to 8.1) as a function of the discount rates and time horizons that we consider in our analyses.

TABLE 7: EARTHQUAKE RISK IN ISTANBUL: B/C RATIOS TAKING INTO ACCOUNT THE VALUE OF LIFE FOR BASELINE TYPE 1 AND MEASURE 1 (NUMBERS ABOVE 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
VSL= USD 750,000	10	0.7	0.5
	25	**1.3**	0.7
VSL= USD 6 million	10	**4.5**	**3.5**
	25	**8.1**	**4.9**

These findings confirm the result by Smyth et al. (2004) that only by including the value of lives saved (at $400,000 each) do earthquake strengthening measures for apartment buildings and schools in Turkey pass the benefit-cost test.

Case Study IV: Flood Risk within the Rohini River Basin in Uttar Pradesh

The Rohini River originates in Nepal and flows through the Indian state of Uttar Pradesh with a catchment area in India of about 870 square km. Because of the flat terrain, even small deviations from the natural flow of water can cause large-scale and long-term flooding. The Rohini is especially flood prone during the four monsoon months from June to September. Flood losses are recurrent and compounded by losses from droughts, earthquakes and other hazards.

The river basin is densely populated and characterized by a high level of poverty. Households largely derive their livelihoods from subsistence farming, and the monetary "income" values (average annual income is about USD 712) are based on cash crops and monetizing caloric intakes derived from consuming crops. Many people in this area live in *kacha* houses that are constructed mainly of mud and are highly vulnerable to flooding or *pukka* houses constructed mainly of brick and are less vulnerable. The representative structures selected for this study are a mud and brick house with a replacement value of USD 150 and USD 1,500, respectively. The average mud house is built to last about 5-10 years and the average brick house is built to last 25 years or more. These numbers are based on survey studies in that region (see Hochrainer et al. 2010).

EP curve and selected DRR measures

Our analysis is based on historical flood data and on a survey of losses from floods (Hochrainer et al. 2009). For determining vulnerability and exposure of mud and brick housing we make use of data on housing losses from past floods, namely major floods occurring in 1998 and 2007. We calculate flood frequency and severity with flood models that utilize common statistical analysis, rainfall-runoff assessment (the ARNO model, see Todini 1996) and flood inundation by HEC-RAS (Hydrologic Engineering Center – River Analysis System). The approach is based on historical data and does not take account of population movements and land-use change. Based on the approach described in section 2 the EP curves for mud and brick houses are shown in Figure 7.

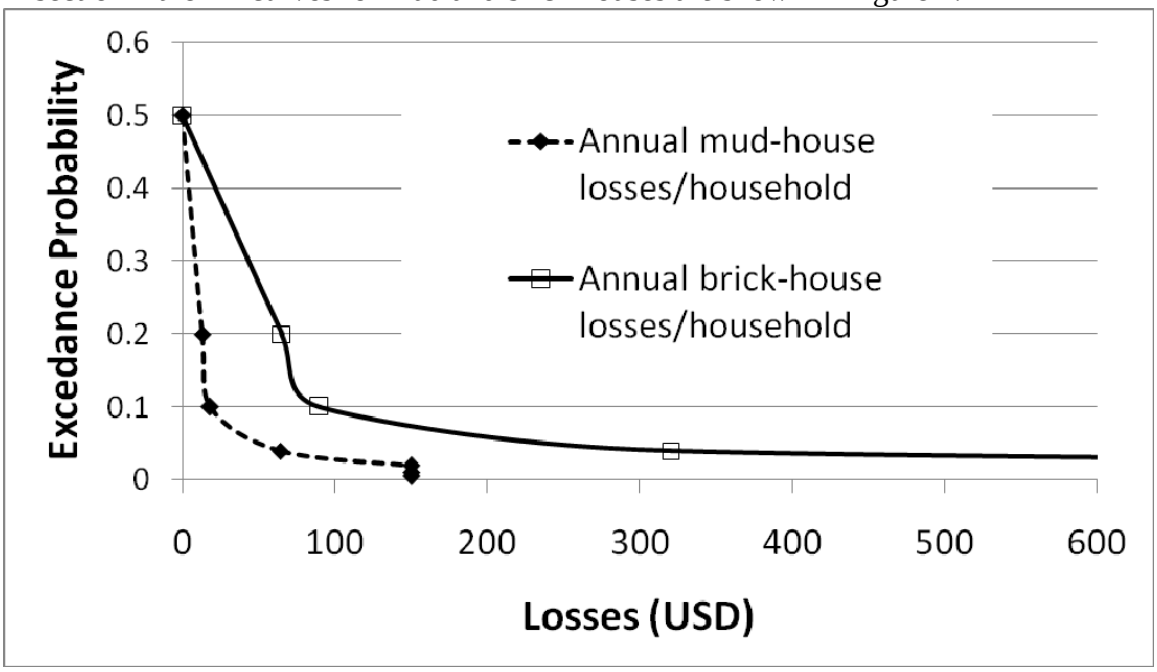

FIGURE 7: FLOOD RISK WITHIN THE ROHINI RIVER BASIN IN INDIA - LOSS EXCEEDANCE FUNCTION FOR BRICK AND MUD CONSTRUCTED HOUSES

We examine six different DRR measures (and timing of the measures) to reduce flood damage to mud and brick dwellings. DRR costs are calculated based on survey studies and estimation of labour force costs (see Moench et al. 2009).

- **Measure 1 (replacement in year 1)**: Demolish a mud house and replace it with a mud house built on a raised plinth. If the house is relatively new, the additional cost for the DRR benefit is the cost of building a new mud house (USD 150[1]) and the cost of the raised plinth (USD 25). The additional cost for the flood proofing is thus USD 175 (demolition costs not included);
- **Measure 2 (replacement in year 1)**: Demolish a mud house and replace it with a brick house built on a raised plinth. If the house is relatively new, the additional cost for the DRR benefit is the cost of building a brick house (USD 1500) and the cost of the raised plinth (USD 25). The additional cost for this flood-proofing measure is thus USD 1525;
- **Measure 3 (replacement in year 1)**: Demolish a brick house and replace it with a brick house built on a raised plinth. If the house is relatively new, the additional cost for the DRR benefit is the cost of building a brick house (USD 1500) and the cost of the raised plinth (USD 25). The additional cost for this flood-proofing measure is USD 1525.
- **Measure 4 (replacement at end of lifetime)**: Replace retired mud house with a mud house on a raised plinth. The additional cost of this measure is approximately USD 25 for the labor involved in raising the plinth.
- **Measure 5 (replacement at end of lifetime)**: Replace retired mud house with a brick house on a raised plinth. The additional cost of this measure is the difference in costs between constructing the brick and mud house (USD 1350) plus the labor involved in raising the plinth (USD 25) The additional cost for the flood-proofing measure is USD 1375;
- **Measure 6 (replacement at end of lifetime)**: Replace retired brick house with a brick house on a raised plinth. The additional cost of this measure is the labor involved in raising the plinth (USD 25).

Cost benefit calculations

Table 8 shows the C/B ratios of the DRR measures for selected discount rates and time horizons.

[1] Alternatively, Kumar (2003a, 2003b) estimates the typical mud house to cost USD 350.

TABLE 8: India- SUMMARY TABLE OF SELECTED B/C RATIOS (NUMBERS ABOVE 1 IN BOLD)

DRR Measure	Time Horizon (Years)	Mud		Brick		Retired Mud		Retired Brick	
		Discount Rate		Discount Rate		Discount Rate		Discount Rate	
		5%	12%	5%	12%	5%	12%	5%	12%
Replace with a Mud building raised on a plinth	10	0.36	0.31	n/a	n/a	**2.83**	**2.42**	n/a	n/a
	25	**1.42**	0.8	n/a	n/a	**9.94**	**5.6**	n/a	n/a
Replace with a Brick building raised on a plinth	10	0.05	0.04	0.04	0.04	0.06	0.05	**2.8**	**2.4**
	25	0.23	0.13	0.18	0.1	0.21	0.12	**11**	**6.22**

The results show that in all but one case it is not advisable from a benefit-cost perspective to demolish homes and rebuild them on a plinth. The exception is a mud house if a low discount rate of 5 percent is adopted. DRR measures applied to retired mud and brick housing (M4 and M6) are highly cost-effective. This is not surprising given the low additional cost of building a new mud or brick house on a raised plinth.

With a discount rate of 12 percent (commonly used) only two measures appear to have high economic returns: building new mud or brick homes on a plinth. It does not pay to build a new house in brick instead of mud if the only benefit is reducing flood losses.

Including climate change

We extend this case by including climate change in the CBA. Specifically, we estimate the loss exceedance (EP) curves assuming that the conditions today (exposure and vulnerability) still exist in 2030, but with a changed climate. The purpose of this exercise is to show a methodology for estimating how climate change will increase risks, all other factors held constant. We recognize that exposure and vulnerability would be different from today in 2030 even in the absence of climate change. A more comprehensive analysis, at least for decisions spanning this long time horizon, would need to incorporate other changes affecting flood risks.

Given the difficulty in assessing probabilities of future climate impacts, we rely on storylines or scenarios. The cost-benefit estimates can be evaluated with regard to their sensitivity to these scenarios. Following this approach, we base our analysis on two storylines from the Intergovernmental Panel on Climate Change (IPCC 2000), the so-called A2 and B1 storylines. These storylines trace different assumptions on human behavior and the reaction of the physical climate system to construct global temperature changes and variability. The A2 and B1 storylines are generally considered the worst- and best-case scenarios, respectively, and therefore qualitatively represent the range of climate outcomes.

To estimate the baseline case precipitation (without climate change) we make use of data from the nearest station to the Rohini Basin, the Bhairawa Airport, which is located in neighboring Nepal and which records rainfall amounts for each dekad, i.e. 10 day periods (there are 36 dekads per year). We consider the 30-year period (1976-2006), and

from this pattern, we simulate daily precipitation for the future until 2030 by taking into account the results of the IPCC A2 down-scaled scenario (Optiz-Stapleton et al. 2008). Figure 8 shows the simulation results for the A2 scenario (worst case scenario) (results of the B1 scenario are not discussed here). This figure shows mean rainfall for each dekad for the current climate regime based on historical precipitation patterns as recorded at the weather station and for 2030 with climate change.

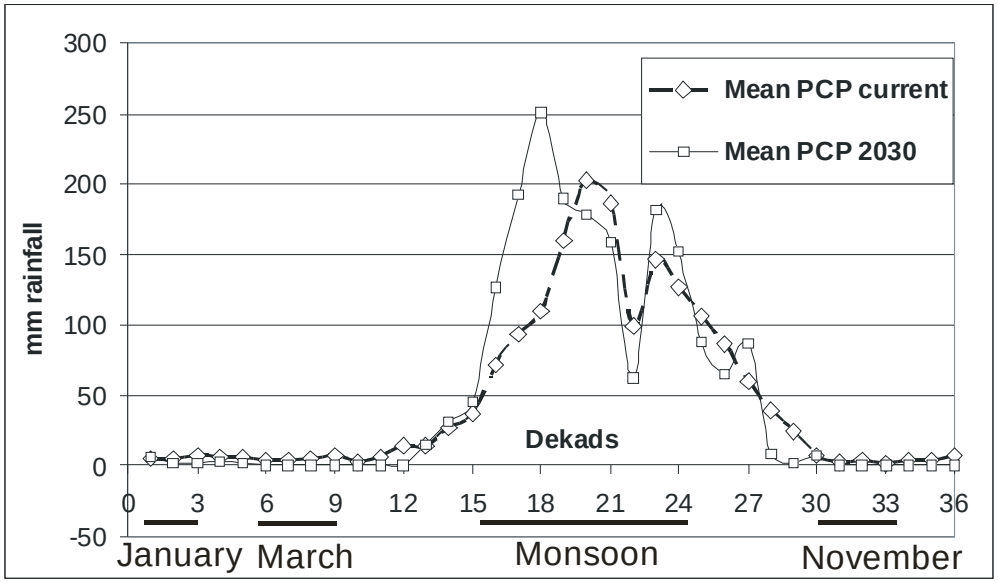

FIGURE 8: MEAN PRECIPITATION OF DEKADS BASED ON PAST DATA AND CLIMATE CHANGE PROJECTIONS FOR THE YEAR 2030

The estimated rainfall parameters for 2030 serve as the basis for Monte Carlo simulations as input to the flood model. We make use of the ARNO model, and flood inundated areas for the various return periods are calculated based on the HEC-RAS model (Hydrologic Engineering Center – River Analysis System), where water flows from the ARNO model are used as an input parameter. Figure 9 shows the new EP curves for the IPCC A2 and B1 climate scenarios for 2030 (all other factors held constant), and compares them with the current situation.

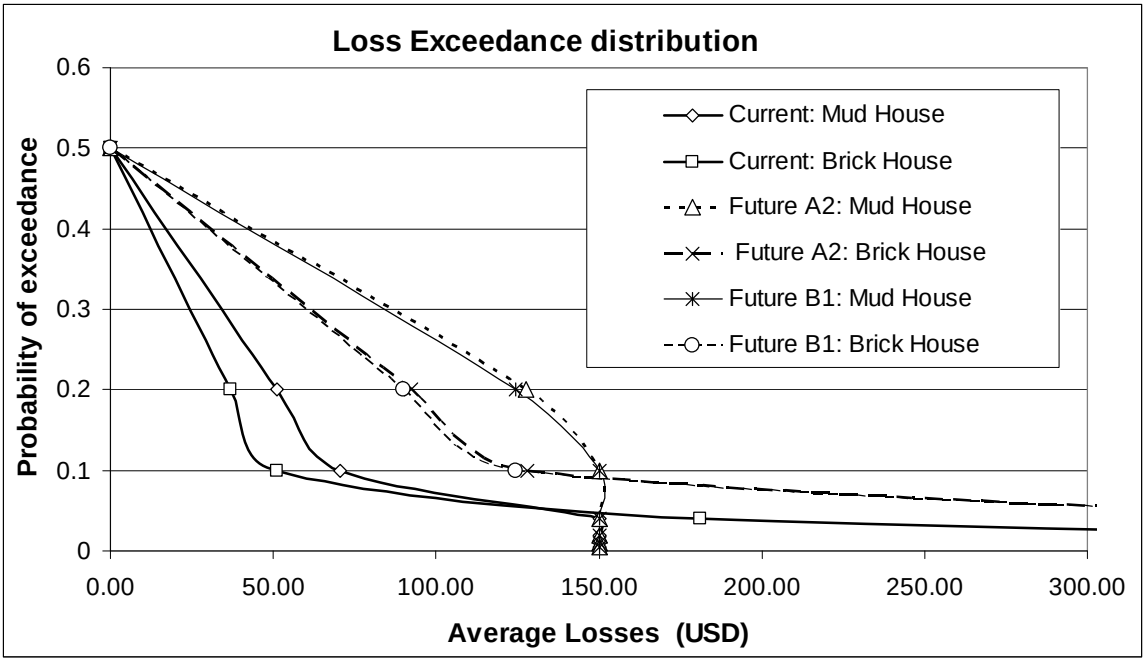

FIGURE 9: LOSS EXCEEDANCE PROBABILITIES TAKING ACCOUNT OF CLIMATE CHANGE AT 2030

Climate change (according to this analysis) results in a significant increase in flood risk in the Rohini Basin as early as 2030. Note that there is little difference in the worst- (A2) and best-case (B1) climate scenarios in this 20 year time span. This analysis examines climate change in 2030, which has little effect on current decisions on housing expected to last only 25 years. Nonetheless, we show how climate change would affect the B/C calculations if we fast forwarded our analysis to 2030. Again, we focus on model projections for the A2 scenario, i.e. we estimate rainfall (gamma type) distributions based on the A2 scenario projections and use them for simulation of future extreme events. The climate-change adjusted benefit cost ratios for different discount rates are shown in Table 9.

TABLE 9: SUMMARY OF B/C RATIOS CURRENT AND FUTURE (NUMBERS ABOVE 1 IN BOLD)

DRR Measure	Scenario	Mud		Brick		Retired Mud		Retired Brick	
		Discount Rate		Discount Rate		Discount Rate		Discount Rate	
		5%	12%	5%	12%	5%	12%	5%	12%
Replace with a Mud building raised on a plinth	Current	**1.42**	**1.8**	n/a	n/a	0.94	**5.6**	n/a	n/a
	A2	**2.9**	**1.7**	n/a	n/a	**20**	**11**	n/a	n/a
Replace with a Brick building raised on a plinth	Current	0.23	0.13	0.18	0.1	0.21	0.12	**11**	**6.2**
	A2	0.4	0.3	0.4	0.3	0.4	0.22	**25**	**13**

How does climate change (if the A2 climate conditions of 2030 existed today) affect the CBA analyses? With a discount rate of 12 percent only two measures passed the B/C test

in the analysis not taking account of climate change: building new mud and brick homes on a plinth (M4 and M5). These measures become more attractive with climate change. Moreover, an additional measure meets the B/C test: demolishing a new mud home and replacing it on a plinth. It continues not to pay (economically) to replace mud homes with brick homes if the only benefit is reducing the economic losses from flood risks, although this result would likely change if fatalities and injuries were included in the analysis.

Summary of results and policy implications

Summary of Results

In Table 10 we show those DRR measures with the highest benefit-cost ratios across the four case studies.

TABLE 10: SUMMARY OF BEST B/C RATIOS AND DRR MEASURES

	Region	*St. Lucia, Caribbean*	*Jakarta, Indonesia*	*Istanbul, Turkey*	*Rohini River Basin, India*
	Hazard	*Hurricane*	*Flood*	*Earthquake*	*Flood*
Best DRR Measure Characteristics	**DRR Measure**	*Opening Protection*	*1m Elevation of Building*	*DRR of SC(1) and SS(1) (if applicable)*	*Replace with a brick building raised on a plinth*
	Construction Type	*Wood frame*	*Mixed wall*	*Type 1 structure*	*Retired brick*
	Regional Hazard Level	*Max*	*Max*	*Max*	*Max*
	Building Value (USD)	*100,000*	*19,200*	*250,000*	*1,500*
	DRR Cost (USD)	*6,720 (Least cost)*	*9345 (Medium cost)*	*25000 (Least cost)*	*25(3) (Least cost)*
	AAL Reduction (USD)	*1,290*	*4,460*	*54,779(2)*	*20*
	B/C ratio (10 year, 5% discount rate)	*1.48*	*3.69*	*0.12*	*2.8*
	B/C ratio (25 year, 5% discount rate)	*2.70*	*6.73*	*0.22*	*11*
	B/C ratio (10 year, 12% discount rate)	*1.08*	*2.70*	*0.09*	*2.4*
	B/C ratio (25 year, 12% discount rate)	*1.51*	*3.75*	*0.12*	*6.22*

(1) SC=Short Column; SS=Soft Story; (2) Including Value of life=750,000 USD; (3) Incremental cost associated with raising the building at time of the construction.

The results underline the importance of examining the hazard, exposure and vulnerability, as well as the costs of the DRR measure, for prioritizing investments. The results are sometimes counter intuitive. For example, in the Jakarta case it is not the lowest cost measure that exhibits the highest B/C ratio, and in the Istanbul case it is not the most vulnerable building which exhibits the highest ratio. The India case shows the advantages of incorporating DRR measures at the time of construction as well as (in this case) the importance of including climate change in the analysis. Finally, the Istanbul case illustrates the sensitivity of the results to including a value of life. The challenges for a more comprehensive analysis are examined in section 5.

Policy Implications

What do these results mean for local and national governments, international donors and other policy makers? Since our studies cover DRR measures that can be undertaken by private households, we first examine what these results imply for those residing in hazard prone areas and whether they can be expected to make socially beneficial decisions on mitigating risks to their homes and lives on their own. Then we turn to the implications for public sector interventions.

Implications for individual households: Integrating behavioral factors

It should be emphasized that positive B/C ratios are a necessary but not sufficient condition to justify investments in DRR measures. Because individual households may have limitations on financial resources, they should examine the full range of options for prioritizing their expenditures. It is possible, and in some cases likely, that other investments will have higher expected returns. Another consideration is the expectation households may have that their governments will provide post-disaster assistance to repair damage to their homes. If this is the case, they will have even a lower financial incentive to invest in DRR measures. At least three conditions, thus, must be satisfied to justify an individual or household investing in a DRR measure: (1) the B/C ratio of the measure is sufficiently high that the household prioritizes this investment, (2) the household has sufficient funds to undertake the investment, and (3) the household does not anticipate substantial ‘free’ post-disaster assistance.

Even given these conditions, research undertaken in the U.S. and other developed countries shows that property owners residing in hazard-prone areas often do not invest in loss reduction measures that exhibit high returns. There is extensive evidence that individuals are myopic in the sense that they have short time horizons when planning for the future, especially if they do not expect to benefit, themselves, from the investment (Kunreuther and Michel-Kerjan 2009).The upfront costs of DRR loom disproportionately high relative to the delayed expected benefits over time. Studies have shown that individuals with low incomes in the developing world are especially myopic given that they often face extremely pressing and immediate problems (Kunreuther, Meyer and Michel-Kerjan, forthcoming).

These behavioural issues cannot be fully overcome by providing individuals more information on the probabilistic risks they are facing. For instance, even with extensive public awareness campaigns in earthquake-prone California, there has been little change in risk perception (Kunreuther 2006). Moreover, in one study, researchers found that only 22 percent of the subjects sought out probability information when evaluating several

risky managerial decisions (Huber et al. 1997). Since most people have a hard time gauging how concerned to feel about a 1 in 100,000 probability of a catastrophic event without some comparison points (Kunreuther et al. 2001), they need a context in which to evaluate the likelihood of an event occurring. Finally, there is evidence that individuals tend to ignore risks with perceived likelihoods falling below some threshold of concern. Many property owners residing in hazard-prone communities have a tendency to dismiss the risk as negligible until after a disaster occurs.

***Implications for public policy**:*

Encouraging individual investment

Before discussing what measures public policy makers might take to encourage appropriate high-return DRR measures, it is important to recognize that government decision makers and to some extent international donor organizations may suffer from the same decision biases that influence individual decisions. Policy makers, faced with myopic voters, appear reluctant to allocate public resources to reducing disaster risks—Not-In-My-Term-Of-Office (NIMTOF) behaviour. Governmental agencies, and especially those anticipating post-disaster international assistance, often do not invest adequately in infrastructure or enforce regulations designed to reduce the likelihood and consequences of catastrophic accidents and disasters. It is often only after the event occurs that the affected parties take action.

Recognizing these political hurdles it is nonetheless instructive to consider how policy measures might overcome the constraints facing investments by individual households in cost-effective structural DRR measures. As a start, governments could set and enforce more stringent building codes. For example, the Indian government might consider requiring new mud homes to be built on a plinth to protect against flood risk and to be reinforced to protect against earthquake risk. Our analysis showed that these measures exhibit high benefit-cost ratios. Governments and donor organizations might also consider offering assistance to households who agree to undertake appropriate DRR measures. This could be in the form of technical assistance or even direct subsidies, which could be justified on grounds that subsidies would reduce even higher post-disaster assistance to households that had not taken preventive measures.

Insurance for reducing risks

Recently, insurance mechanisms have been given attention as a policy tool for encouraging households and businesses in low- and middle-income countries to adopt DRR measures (Linnerooth-Bayer et al. in press). Insurance is generally not viewed as a measure to prevent loss of life and property, but this view overlooks the long-term preventive benefits of insurance. By enabling recovery, insurance can significantly reduce long-term indirect losses – even human losses – which do not show up in the disaster statistics. Moreover, well-designed insurance programs provide incentives for physical interventions and lifestyle changes that reduce disaster risks.

Several examples illustrate this point. In Turkey, apartment owners who take part in the Turkish Catastrophe Insurance Pool, and choose to disaster-proof their properties, pay a lower insurance premium; in Mongolia, herders who take part in a recent index based micro insurance program will face increasing premiums as climate change worsens weather conditions giving them an added incentive to change livelihoods if animal

husbandry becomes unproductive; in Thailand, designers of an index-based flood insurance system anticipate that middle-class property owners will relocate out of the high-risk areas. Although the potential for behavioural changes induced by insurance are well documented, there is little empirical evidence to support these claims, and for this reason more attention needs to be given to the role of insurance in promoting loss-reducing behaviour.

Poorly-designed insurance contracts, on the other hand, can discourage investments in loss prevention or even encourage negligent behaviour, commonly referred to as "moral hazard." A major advantage of index-based insurance schemes is their avoidance of moral hazard. Mongolian farmers can only gain by taking measures to protect their herds against adverse winter weather, since insurance claims are based on average livestock loss in designated regions. While index-based insurance discourages moral hazard (taking risks that are not socially beneficial), paradoxically it can encourage risks that are socially beneficial. In Malawi, for example, farmers participating in a recently piloted index based micro insurance program have the needed security to plant riskier but higher yield crop varieties with a higher expected return – ultimately reducing vulnerability to weather shocks.

A novel idea proposed for the US context is to combine multi-year property insurance contracts with loans for mitigating risks, both of which are tied to the property not the individual (Kunreuther and Michel-Kerjan 2010; Jaffee et al. in press). If the payment on the loan is less than the premium reduction received if the DRR measure is adopted, the investing household would receive an immediate gain. By overcoming the problem of myopia, multi-year contracts thus will provide economic incentives for homeowners to invest in DRR, whereas current annual insurance policies (even if they are risk-based) are unlikely to do so. An example of how this idea might be extended to micro-insurance contracts in a developing country, and the principles governing this innovation, are discussed in Box 1.

Box 1: Multi-year micro-insurance

Consider the following simple example where insurance premiums reflect the risks of future disasters. A middle-income family in India could invest $150 to strengthen the roof of its house so as to reduce the damage by $3,000 from a future cyclone with an annual probability of 1 in 100. An insurer would be willing to reduce the annual charge by $30 ($1/100 \times \$3{,}000$) to reflect the lower expected losses that would occur if a cyclone hit the area in which the family is residing. If the house was expected to last for ten or more years, the net present value of the expected benefit of investing in this measure would exceed the up-front cost at an annual discount rate as high as 15 percent.

Principle 1: *Even in low- and middle income countries, (micro)-insurance can be a useful policy tool for encouraging adoption of DRR measures, especially for the wealthier middle class, if premiums reflect risk.*

Under current annual insurance contracts, many property owners would be reluctant to incur the $150 expenditure, because they would get only $30 back next year and are likely to consider only the benefits over the next two or three years when making their decisions. If they underweight the future, the expected discounted benefits would likely

be less than the $150 up-front costs. In addition, budget constraints could discourage them from investing in the DRR measure.

Suppose a twenty-year required (micro)-insurance policy were tied to the property rather than to the individual. If the family were able to secure a $150 loan for 20 years at an annual interest rate of 10 percent, its annual payments would be $14.50. If the insurance premium was reduced by $30, the savings to the family each year would be $15.50.

***Principle 2**: Financial arrangements should tie cost-effective DRR measures to the property or land (or group of properties and pieces of land) rather than to the individuals.*

These DRR loans would constitute a new financial product. A financial institution such as the Grameen bank, would have a financial incentive to provide this type of loan, the insurer knows that its potential loss from a major disaster is reduced. Moreover, the general public will now be less likely to have large amounts of their tax dollars going for disaster relief—a win-win-win situation for all! (see Kunreuther and Michel-Kerjan 2010; Jaffee et al. in press).

***Principle 3**: Explicit linkages should be made to ex ante and ex post impacts of DRR measures.*

Investing in public goods for DRR

This research has focused exclusively on DRR measures that can be adopted by households and did not include measures that can be implemented only or most effectively at the community or national levels, such as early warning systems or school safety programs. The focus on a single structure or household is not appropriate for DRR measures that have a public good character and protect assets and lives at the community or national scales. Nor is the single household perspective convincing for governments or donors considering support for these one-household-based structural measures across a wide area. To be relevant for donors and other investors, it would be instructive to expand the scale and scope of the CBA undertaken in this study to provide a more realistic and complete assessment of the potential value of DRR for specific regions and covering both private and public-good investments.

Summary and Challenges

We have examined the benefits and costs of improving or retrofitting residential structures in highly exposed developing countries – St. Lucia, Indonesia, Turkey and India - such that they are less vulnerable to hurricane, flood and earthquake hazards during their lifetime. The structures and risks chosen for this study are typical for many low-, middle- and high-income persons residing throughout Asia and the Caribbean. The results indicate high returns on investments, including

- strengthening doors and windows of middle-income homes to protect them against hurricanes in St. Lucia;
- elevating high-income homes in Jakarta;
- strengthening apartment buildings to make them less vulnerable to earthquake risk in Istanbul; and
- building (and even replacing) brick homes on a plinth in Uttar Pradesh.

These results are robust in the sense that the underlying frame and assumptions of the analysis were conservative. The results also showed that many selected DRR measures were not cost effective, which might change, however, if the conservative assumptions were relaxed: In the Istanbul case, we demonstrated a methodology to take account of mortality risk, and in the Uttar Pradesh case we demonstrated a methodology to account for climate change. The analyses underline the importance of examining the hazard, exposure and vulnerability, as well as the costs of the DRR measure, for prioritizing investments.

The cases demonstrate many challenges in providing fully integrated benefit-cost estimates: valuing mortality/morbidity risk, taking account of climate change, risk aversion, multiple hazards and indirect losses, and giving a full account of the uncertainties in the analysis.

Valuing mortality/morbidity risk
Especially in the developing world, where reportedly over 95% of deaths from natural disasters occur, a challenge is to identify DRR measures that can cost effectively reduce mortality and morbidity risk (Cropper and Sahin 2008). If mortality and morbidity risk can be estimated it is important to ask how fatalities and injuries can be valued so as to be commensurate with other benefits and costs of the project. In the Istanbul case, we described and made use of a methodology for including mortality risk based on adjusted values of statistical life (VSL) from available empirical studies. We noted that applying a VSL is controversial, and for this reason we recommend not making use of a point value, but applying a sensitivity analysis to the results over a range of VSL estimates.

Taking account of time evolving risks, such as climate change
A CBA analysis that considers benefits accrued may be sensitive to changes in the baseline risk level over time. This is particularly relevant today where climate change is expected to adjust hazard levels. A methodology for including climate change in the benefit calculations was illustrated in the case of the Rohini river basin in India. This and other approaches, however, are still in their infancy and present an appreciable methodological challenge for future research. A key challenge here is how to represent uncertainty in the effect of climate change on hazard levels. To date it has not been possible to assign probabilities to climate scenarios. Moreover, climate change is not the only driver of adjustments in risk over time. We note that any increase in hazard intensity might in the future be outweighed by autonomous decreases in asset vulnerability or exposure (e.g. individuals moving away from high hazard regions). Other drivers of increasing risk are economic development and urbanisation (e.g. Nicholls et al. 2007). Jakarta is an interesting case in point as recent analyses showed that urbanisation itself has increased flood hazard significantly over the past few decades by reducing the effectiveness of natural and manmade drainage systems (Lloyd's of London, 2008). Loss estimates that do not incorporate such changes should be treated with caution.

Accounting for risk aversion
Risk-averse individuals are willing to pay more than their expected losses to avoid the risk of incurring very large losses at one time. This is particularly the case in the developing world, where absent reliable safety nets, a large loss can threaten livelihoods

and even lives. The case studies in this report, however, did not take risk aversion into account. Losses to housing structures were expressed in risk-neutral terms as mean damage ratios or expected losses. To take account of risk aversion, expected utility rather than expected value becomes the basis of the calculations, where expected utility might be expressed in terms of an equivalent monetary gain. In practice, it is not straightforward to determine a utility function, and to simplify, often a method is used that makes use of the mean and variance of the distributed losses, weighted by a risk aversion parameter.

Including multiple hazards

The India case illustrates the limitations of single-hazard analyses. If a mud house is demolished and built on a raised plinth, it could at the same time be reinforced with bamboo to strengthen it against earthquakes. This would be a relatively minor additional cost and might significantly increase the marginal benefits if both hazards were included synergistically in the analysis. The same might be the case in Jakarta if houses could be raised and strengthened in a way that reduces their vulnerability both flooding and windstorm damage.

Valuing indirect and non-monetary losses

Indirect disaster losses are seldom considered in cost-benefit analyses; yet, there is increasing evidence that indirect losses from disasters can be significant (see Cavallo and Noy 2010). In poor communities, the inability of households and businesses to fully recover can greatly exasperate poverty leading to what is referred to as disaster induced poverty traps (Barnett 2008). At the macro scale, recent research has attempted to quantify the indirect impacts of disasters in terms of loss in GDP, consumption, inflation, trade and investment (Burby 1991; Hochrainer 2006; Hochrainer 2009).

Accounting for uncertainty

Uncertainty imposes limitations on the accuracy of results from model approaches. While our approach accounted for *aleatory* uncertainty (the intrinsic randomness of the phenomenon which cannot be reduced as more data is available), it did not account for *primary* uncertainty, which refers to the uncertainty in the event generation model in the hazard module, nor *secondary* uncertainty, which refers to the uncertainty in the damage estimation in the vulnerability module. In addition, there is uncertainty related to how we specify and estimate uncertainty in the physical world, including: the underlying data (how accurate and sufficient is it?); the model structure (how accurately does the model describe the relevant physical, economic or social system?); or the numerical approximations (how appropriate are the numerical methods?). A challenge for future research is to systematically account uncertainty, for example, by specifying error bands around the loss exceedance curves, as well as including discussions of the selected framing, models and assumptions.

A future research agenda would ideally upscale current results as well as expand the scale of analyses from the single house cases reported here to DRR measures that reduce losses at the community and national scales across a range of slow- and sudden-onset hazards. This would necessarily require a scoping exercise to identify relevant DRR measures across a wide pallet of possibilities, and potentially involving risk financing mechanisms that can accompany risk DRR.

Notes:

Stefan Hochrainer-Stigler is research scholar at the International Institute of Applied Systems Analysis (IIASA): his e-mail address is hochrain@iiasa.ac.at. **Howard Kunreuther** is the James G. Dinan Professor; Professor of Decision Sciences and Public Policy at the Wharton School, and Co-Director of the Wharton Risk Management and Decision Processes Center. His email address is kunreuth@wharton.upenn.edu. **Joanne Linnerooth-Bayer** is leader of the Risk and Vulnerability program at IIASA: her e-mail address is bayer@iiasa.ac.at. **Reinhard Mechler** is leader of the Disaster, Adaptation and Development group at IIASA: his e-mail is mechler@iiasa.ac.at. **Erwann Michel-Kerjan** is Managing Director of the Risk Management and Decision Processes Center at the Wharton School. His email address is erwannmk@wharton.upenn.edu. **Robert Muir-Wood** is the Chief Research Officer at Risk Management Solutions (RMS): his e-mail address is Robert.Muir-Wood@rms.com. **Nicola Ranger** is with the Grantham Research Institute for Climate Change and the Environment at the London School of Economics: her email is n.ranger@lse.ac.uk. **Pantea Vaziri** is Catastrophe Risk Modeler at RMS: her e-mail address is Pantea.Vaziri@rms.com. **Michael Young** is Senior Director of the Mitigation and Regulatory Affairs group at RMS: his e-mail address is Michael.Young@rms.com.

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