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Incentives for mitigation investment and more effective risk management: the need for public–private partnerships

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Abstract

A key question facing both well-developed industrial countries and emerging economies is how to reduce future disaster losses while still providing financial protection to victims from these events. This paper proposes a strategy for the use of cost-effective risk mitigation measures coupled with insurance and/or new capital market instruments to achieve these objectives. The mix of these measures will depend on the governance structure and the institutional arrangements in the particular country. There will always be a need for a combination of policy tools and the interaction among key interested parties from both the private and public sectors in developing a disaster management strategy. Two examples, one from US and the other from Honduras, illustrate differences between strategies that countries can adopt. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

This paper focuses on the type of incentives necessary to encourage the adoption of mitigation measures to reduce disaster losses. The word mitigation is treated synonymously with loss prevention. Most risk mitigation measures (RMMs) have the following characteristics. There is an up-front investment cost (C) incurred either by a property owner or by the government. The expected benefits (B) from the loss prevention measure are the reduction in losses weighted by the chance that a disaster will occur during some pre-specified length of time (T). The value of T is often the expected life of the property.

The following two hypothetical scenarios illustrate two RMMs measures that can be undertaken either by residents or by government:

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Scenario 1: Robert Shaker resides in a home in California and is considering reducing the losses from a future earthquake by bolting the structure so that it is on a solid foundation.

Scenario 2: The Honduras government is concerned with damage to one of its water treatment plants from flooding of a major river and wishes to take steps to mitigate future flood damage to the structure.

The next Section 2 probes deeper into Scenario 1 by examining the decision processes of homeowners with respect to the adoption of RMMs in US. Section 3 then turns to an analysis of Scenario 2 by considering the opportunities facing governments in developing countries regarding the adoption of RMMs. In Section 4, there is a discussion of how insurance and new financial instruments can be linked with mitigation to encourage its adoption. Section 5 examines the importance of improving risk estimates for encouraging the adoption of cost effective RMMs. Section 6 makes the case for a public–private partnership for increasing the adoption of mitigation measures and providing funding for loss recovery. Section 7 suggests directions for future research.

2. Adoption of RMMs by homeowners

2.1. Empirical studies

The empirical data on studies of mitigation adoption in hazard-prone areas of US suggest that individuals are not willing to invest in RMMs despite the rather large damage that they and/or their friends and neighbors suffered from recent disasters. For example, after Hurricane Andrew in Florida in 1992, the most severe economic disaster in US, most residents in hurricane-prone areas appear not to have made improvements to existing dwellings that would reduce the amount of damage from another storm [1].

Measures, such as strapping a water heater with simple plumbers tape, can normally be undertaken by residents at a cost of under $5 in materials and 1 h of their own time [2]. This RMM can reduce damage by preventing the heater from toppling during an earthquake, creating gas leaks and causing a fire. Yet residents in earthquake-prone areas are not adopting these and other mitigation investments. A 1989-survey of 3500 homeowners in four California counties subject to the hazard reported that only between five and nine percent of the respondents in each of these counties adopted any loss reduction measures [3].

2.2. Why the limited interest?

There are a number of reasons why a homeowner will decide not to invest in loss prevention measures:

2.3. Underestimation of probability

Some individuals may perceive the probability of a disaster causing damage to their property as being sufficiently low that the investment in the protective measure will not be justified. For example they may relate their perceived probability of a disaster (p) to a threshold level (p^*) unconsciously set, below which they do not worry about the consequences at all. If they estimate $p < p^*$, then they assume that the event "will not happen to me" and take no protective actions. This decision to ignore events where $p < p^*$ may be justified by individuals who claim that there is a limited amount of time available to worry about protecting oneself against hazards facing us. By setting a threshold level, p^*, individuals can devote their attention to events where p is sufficiently high to be a source of worry and concern. Such a rule is also easy to explain and justify to others because of its simplicity.

2.4. Short term horizons

Individuals may have relatively short time horizons during which they want to recoup their investment in an RMM. Even if the expected life of the house is 25 or 30 years, the person may only look at the potential benefits from the mitigation measure over the next 3–5 years. They may reason that they will not be residing in the property for longer than this period of time and/or that they want a quick return on their investment before adopting the measure.

2.5. Aversion to up-front costs

If people have budget constraints then they will be averse to investing in the up-front costs associated with protective measures simply because they feel they cannot afford these measures. It is not unusual for one to hear the phrase "We live from payday to payday" when asked why a household had not invested in protective measures.

2.6. Expectation of disaster assistance

Individuals may have little interest in investing in protective measures if they believe that they will be financially responsible for only a small portion of their losses should a disaster occur. If their assets are relatively limited in relation to the potential loss, then these individuals may feel they that they can walk away from their destroyed home without being financially responsible. Similarly, if residents anticipate liberal disaster relief from the government should they suffer damage, then they would have less reason to invest in an RMM.

In summary, many property owners are reluctant to invest in cost-effective RMMs because they mis-process information on the potential benefits, feel they will only have to bear a portion of the cost if a disaster occurs and/or do not have financial resources. In addition they may not have knowledge of these measures and may fear that the contractor will not do the job properly. Developers may further exacerbate such non-adoption behavior by believing (perhaps correctly) that they are unable to recover the costs of RMMs by increasing the selling prices for the structures [4].

3. Adoption of mitigation by governments

For public sector agencies to determine whether it is worthwhile to invest in a specific mitigation measure they will want to undertake some type of benefit–cost analysis. Consider the decision on whether a government agency in Honduras should flood-proof a water

Table 1
Probability–damage matrix to water treatment plant

Flood height of river	Probability of flood height	Damage with flood proofing	Damage without flood proofing

treatment plant to prevent future damage to the building. One first needs to determine the costs associated with a specific set of mitigation measures. These include the relevant materials as well as the persons, power and time associated with making the plant more flood resistant. It is not easy to specify precise figures for these expenditures, so it is useful to put some bounds around the estimates to reflect the degree of uncertainty surrounding them. This will enable the government to evaluate the desirability of a particular mitigation measure under a wide variety of cost assumptions.

3.1. Estimating the direct benefits of a mitigation measure

Mitigation measures reduce the direct and indirect impacts to the region following a disaster. Both of these effects need to be specified in evaluating the flood proofing of a water treatment plant. In order to undertake such an analysis it is necessary to assess the flood hazard. Hydrologists and engineers need to determine the probability that the river in question will rise to certain levels and estimate the resulting direct damage to the water treatment plant with and without flood proofing. They can then construct a probability–damage matrix such as the one depicted in Table 1.

If the only losses incurred from flooding were the costs of repairing the water treatment plant, then it would be a relatively simple matter to calculate the expected benefits from the mitigation measure. One would compare the damage to the plant for floods of different heights with and without flood proofing the structure. The reduction in damage associated with each flood height would then be multiplied by the probability of this type of flood occurring. One would then sum all the figures to obtain the expected benefits from flood proofing for any given year.

It is then necessary to consider the number of years that the plant would be operational and discount each future year's benefit to the present time period by using some agreed-upon discount rate. This would enable one to determine the expected discounted benefit of flood proofing the plant. The mitigation measure would be considered attractive if the total costs of flood proofing the water treatment plant were less than its expected discounted benefits.

3.2. An illustrative example

For simplicity, and without loss of generality, assume that there is only a single type of flood that can occur on the river and that the probability of such an event and the resulting losses are constant over time. We can characterize the problem as to whether the government should mitigate the water treatment plant by defining the following terms: C: up-front cost of mitigation measure; p: annual probability of flood (e.g. $p = 1/100$); L: damage to water treatment plant without flood proofing (e.g. $L = 500$); L': damage to water treatment plant with flood proofing (e.g. $L' = 300$); d: annual discount rate (e.g. $d = 0.10$); T: relevant time horizon (e.g. $T = 10$ years).

The decision as to whether or not to invest in an RMM is determined by comparing the cost of mitigation (C) with the expected discounted benefits ($E(B)$). Assume that if a flood occurs in the river within the T year time horizon the water treatment plant will be restored to its pre-disaster condition and be functional again as it was prior to the disaster. Then, $E(B)$ can be characterized as follows:

$$E(B) = \sum_{t=1}^{T} \frac{p(L - L')}{(1 + d)^t} \tag{1}$$

To illustrate with a simple example, consider the figures presented with the notation above. Eq. (1) now becomes:

$$E(B) = \sum_{t=1}^{T=10} \left(\frac{1}{100}\right) \frac{500 - 300}{(1.10)^t} \tag{2a}$$

$$E(B) = \sum_{t=1}^{T=10} \frac{2}{(1.10)^t} = 12.3 \tag{2b}$$

On the average the mitigation will yield 2 worth of direct expected benefits each year (i.e. (1/500) (500−300)), so that over the 10-year time horizon it will yield total discounted expected benefits of 12.3. If the mitigation measure costs less than 12.3, then it is cost-effective for the government to flood proof the structure based on an analysis of directed expected benefits. If the water treatment plant were expected to last for more than 10 years then $E(B)$ would of course be greater than 12.3.

3.3. Indirect benefits of mitigation measures

Floods and other disasters produce indirect or secondary impacts over time, such as family trauma and social disruption, business interruptions and shortages of critical human services that need to be considered in evaluating specific mitigation measures. The costs of some indirect impacts are easy to quantify, such as the expenditures associated with providing bottled water to residents because the water treatment plant is not functioning. Other indirect impacts are less easy to determine and quantify. For example, how do you put a value on the loss of "community" associated with wholesale destruction of neighborhoods, on stress to families due to loss of homes or on fear and anxiety about having another home destroyed in a future flood [5]?

In evaluating the benefits of a specific mitigation measure it is important to consider these indirect impacts. Here are a few examples that one will want to take into account when undertaking such an analysis of flood proofing a water treatment plant

- Provisions of bottled water and toilet facilities of those residences who are not able to receive water because the treatment plant has been damaged. The need for these provisions may last for a number of days or weeks so the cost could be extensive. If the water treatment plant was functional because of flood proofing, then this would be an added benefit of investing in this measure.

- If businesses were interrupted because of the damage to the water treatment plant, as in the Midwest floods of 1993, then this would be an additional indirect cost of the flood. Those businesses forced to close have immediate cash flow problems. Employees lose work, and customers who must go elsewhere for goods and services may not return when the business reopens. Other businesses require a certain amount of commercial activity in their geographic area in order to prosper [5].

If a functioning water treatment plant could have prevented some of these business interruptions, then these would be considered an additional benefit of flood proofing the structure. To the extent that other businesses in Honduras not affected by the disaster fill in the gap opened up by non-functioning businesses, then this is a transfer rather than a loss. If Honduras needs to rely on imports from other countries because their own businesses cannot provide goods and services, then this is a loss to Honduras.

The above examples illustrate what economists term externalities was associated with damage to a particular facility. The damage to the water treatment plant created a set of losses to residents and businesses specifically because they could not receive pure water. Suppose there were some people who drank contaminated water because they were not able to get their normal water supply and as a result contracted some disease. Then the hospital costs and loss of work time from their drinking impure water would be an additional cost of the damaged water treatment plant.

4. Financial incentives to encourage mitigation

4.1. Role of insurance

Insurance can be used as an incentive for encouraging governments and private citizens to invest in mitigation measures. More specifically, if a private insurer were to offer coverage against repairing damage to the water treatment plant, it would base its premium on the figures in the probability–damage matrix specified in Table 1.

By using the example in Section 3 one can illustrate how insurance could be utilized to encourage the government to flood-proof its water treatment plant. Assume that an insurer would provide full coverage, so it would pay for repairing the entire damage to the plant if a flood occurred. If the government decided not to flood-proof the water treatment plant, then the actuarially fair insurance rate would be determined by multiplying the probability of a flood (i.e. 1/100) by the resulting damage to the plant (i.e. 500). The resulting rate would be five. If the plant were flood-proofed, then the actually fair rate would be three (i.e. $((1/100) \times 300)$. This means that the expected annual reduction in damage from investing in mitigation is $(1/100)\ (500 - 300) = 2$. Thus, the insurer could reduce its premium for flood coverage by two to reflect the expected annual reduction in claims it would have to pay the government for repairing damage to the water treatment plant.

4.2. Role of capital market instruments

In many developing countries there is not an active private insurance market. In these cases the government may need to rely on other ex ante risk transfer mechanisms to provide them with financial protection against disaster losses. New capital market instruments such as catastrophe bonds (henceforth referred to as cat bonds) represent an alternative to insurance for offering funds to aid the recovery effort. Cat bonds also can provide an incentive to encourage the adoption of cost-effective mitigation measures by lowering the interest rate that the government will have to pay for purchasing these bonds.

Consider the following scenario to motivate the analysis of the supply and demand of cat bonds. The Honduras government wants to obtain 500 worth of protection against the possibility of damage to one of its water treatment plants from floods in the next year. The chances that a flood will occur and cause damage of 500 is estimated by experts to be one in 100; there is a 99/100 probability that there will be no damage to the water treatment plant. This situation provides an opportunity for an institutional investor to purchase a cat bond whose payoff is tied to the flood losses to the water treatment plant.

To illustrate the terms of such a cat bond, we use a simple one-period model as described in a recent Goldman Sachs Fixed Income Research report [6]. [1] The investor is assumed to buy the Honduras cat bond at the beginning of the risk period at par (100). At the end of the risk period (1 year in this case), the investor will receive an uncertain dollar amount. With probability 1/100, the government will incur damage of 500 to its water treatment plant. This will trigger losses on the bond in which case the investor would lose his entire principal (i.e. 100). The other 99% of the time, the investor gets back his or her principal plus interest that will normally be above the market rate to reflect the risk of losing its principal. [2]

In order for the Honduras government to issue these bonds to private investors it will have to pay a high enough return to private investors to cover the risk of flood damage to the water treatment plant. Suppose that the risk free interest rate is five percent. The Honduras government wants to determine how high an interest rate (r) it should charge so that the investor will get the same expected return as if his money were in a risk free security.

To determine r, the investor knows that with probability 0.99 it will get an annual return of 0.05 on its investment and with probability 0.01 it will have to pay for the damage to the plant. Alternatively, the investor can receive a 0.05 return on a risk free security. Let A be the amount of the bond to cover the water plant should it be damaged. To determine the value of r then the investor simply computes:

$$0.99r(A) - 0.01(A) = 0.05(A), \quad r = \frac{0.06}{0.99} = 0.0606$$

The expected benefits of investing in a mitigation measure can now be easily determined. If the water treatment plant were not mitigated then the Honduras government would have to issue a bond with a value of $A = 500$ to reflect the costs of repairing the water treatment plant following a disaster. The annual expenditure on the bond in terms of interest payments

[1] Note a one-period model ignores issues of multiple cash flows, applicable reinvestment rates, and the term structure of interest rates. Actual cat bonds, for example, often make coupon payments semi-annually.

[2] See [7] for more details on catastrophic bonds and a discussion as to why the interest rates are so high.

by the government would be $0.0606 \times 500 = 30.3$. If, on the other hand, the plant had been flood-proofed, then a bond of only 300 would be issued and the annual expenditure would be $0.0606 \times 300 = 18.2$, and the Honduras government could save $12.1(30.3 - 18.2)$ per year by mitigating the water treatment plant.

One challenge in issuing the type of catastrophe bond described above is the ability of the Honduras government to verify the damage to the water treatment plant. In the above example, they issued a bond under the assumption that they knew that the damage would respectively be 300 and 500, with and without flood proofing. In reality, it is difficult to estimate these figures and there may be an incentive for the public agency operating the water treatment plant to distort the damage, so that they would receive the maximum amount of payment following an earthquake.

This problem of moral hazard can be dealt with by having the pay-outs from cat bonds related to an objective index (e.g. flood height) rather than actual damage. There may be some basis risk associated with these types of bonds.[3] Recent catastrophe bonds issued to insurers have been based on an index, but there has not been any actual experience to evaluate the nature of the basis risk. More details on the nature of these type of bonds and a comparison with non-indexed bonds and/or reinsurance can be found in [8–11].

In many countries, such as Honduras and other parts of Central America, where the government cannot easily afford the premium on insurance or the interest on the cat bond, there may be an important role for organizations who provide loans to developing countries, such as the World Bank. More specifically, the World Bank could serve as a broker by purchasing these bonds from developing countries at a subsidized interest rate and then issuing them to private investors at a higher rate. These mechanisms would enable the countries to obtain the bonds at low cost to them while protecting the World Bank's investments in these countries for health, education and general welfare. Funds for these purposes could easily be diverted to disaster recovery if the country did not have other sources of relief, such as from a cat bond.

By having an organization such as the World Bank as the broker between investors and the developing country at risk, it might also avoid or reduce the stigma that might arise if private individuals or institutions were to collect high interest rates from poor countries through cat bonds.[4] Furthermore, the issuance of a cat bond by the World Bank would reduce the need for the organization to provide subsidized disaster assistance, a role they felt they had to play following the Polish floods of 1997 [13].

5. Improving risk estimates to encourage mitigation

An important step in encouraging property owners and the government to adopt loss prevention measures is to improve our estimates of the risks associated with natural disasters. There are two principal reasons why the relevant interested parties, such as insurers,

[3] Basis risk refers the imperfect correlation between the actual losses suffered and the payments received from the cat bond.

[4] The argument on "the other side of the coin" is that if the World Bank were to subsidize the interest rate on cat bonds, it would necessarily involve the use of resources that would be used for disaster relief or responding to the pressing needs of the world's poor [12].

re-insurers, investors and organizations such as the World Bank, will benefit from improved estimates of the risk associated with these events.

For one thing, by obtaining better data on the probabilities and consequences of these events, insurers will be able to more accurately set their premiums and tailor their portfolio to reduce the chances of insolvency. Secondly, providing more accurate information on the risk also reduces the asymmetry of information between insurers and other providers of capital such as reinsurers, the financial investment community and lending organizations such as the Word Bank. These groups are more likely to obtain and supply capital if they are more confident in the estimates of the risks provided to them.

In setting rates for catastrophic risks, insurers have traditionally looked backwards by relying on historical data to estimate future risks. Such procedures are likely to work well if there is a large database of past experience to form the basis for extrapolation into the future. Low probability-high consequence events generally have a relatively small historical database. In fact, many technological and environmental risks are associated with new processes, so that past performance data are lacking. One thus has to rely on scientific modeling and epidemiological data to estimate these risks.

Fortunately, there is considerable scientific work undertaken in the areas of natural, technological and environmental hazards to provide estimates of the probabilities and consequences of events of different magnitudes. [5] The advances in information technology have encouraged catastrophe modeling because it is possible to simulate a wide variety of different scenarios that reflect the uncertainties in these estimates of risk. For example, it is feasible to evaluate the impact of different exposure levels by insurers on both expected losses as well as maximum possible losses by simulating a wide range of different estimates of seismic events using the data generated by scientific experts. Similar studies can be undertaken to evaluate the benefits and costs of different building codes and loss prevention techniques [18].

Today there are a growing number of catastrophe models that have been utilized to generate data on the likelihood and expected damage to different communities or regions from disasters of different magnitudes or intensity. Each model uses different assumptions, different methodologies, different data and different parameters in generating their results. Hence, the need for a better understanding as to why these models differ and attempts to reconcile these differences in a more scientific manner than has been done up until now.

6. Policy implications: need for a public–private partnership [6]

In this section, I suggest ways that the public and private sectors can work together to reduce future losses from natural disasters. Specifically three public private partnership programs will be proposed that can encourage cost effective risk mitigation measures (RMMs)

[5] For example, with respect to earthquakes, a discussion of new advances in seismology and earthquake engineering can be found in [14,15]. Regarding technological hazards, the Wharton Risk Management and Decision Processes Center is now compiling a very comprehensive data base on the impact of large-scale catastrophic accidents on health and safety risks [16]. With respect to environmental risks to health, such as groundwater contamination, data bases have been assembled which open up opportunities for providing insurance protection on risks that recently had previously been considered uninsurable by firms in the industry [17].

[6] This section is taken from [4].

and provide funds for covering losses from catastrophic disasters: (1) building codes, (2) premium reductions linked with long-term loans for mitigation and (3) broadening protection against catastrophic losses.

In many developing countries there is not a well-functioning private insurance market. In these countries the government could play an important role by providing protection against future damage from disasters through a tax on property owners. If the tax rate reflected the hazard risk, it would play a role similar to insurance and the phrase "tax rate reduction" would replace "premium reduction" as part of the proposed program.

6.1. Role of building codes

Building codes mandate that property owners adopt mitigation measures. Such codes may be desirable when property owners would otherwise not adopt cost-effective RMMs because they either misperceive the benefits from adopting the RMM and/or underestimate the probability of a disaster occurring.

Suppose the property owner believes that the losses from an earthquake to the structure is 20 and the developer knows that it is 25 because the home is not well constructed. There is no incentive for the developer to relay the correct information to the property owner because the developer is not held liable should a quake cause damage to the building. If the insurer is unaware of how well the building is constructed, then this information cannot be conveyed to the potential property owner through a premium based on risk. Inspecting the building to see that it meets code and then providing it with a seal of approval provides more accurate information to the property owner.

One way to encourage the adoption of cost-effective mitigation measures is for banks and financial institutions to provide a seal of approval to each structure that meets or exceeds building code standards. The success of such a program requires the support of the building industry and a cadre of qualified inspectors to provide accurate information as to whether existing codes and standards are being met. Insurers may want to limit coverage only to those structures that are given a certificate of disaster resistance.

Cohen and Noll [19] provide an additional rationale for building codes. When a building collapses it may create externalities in the form of economic dislocations and other social costs that are beyond the economic loss suffered by the owners. These may not be taken into account when the owners evaluate the importance of adopting a specific mitigation measure. For example, if a building topples off its foundation after an earthquake, it could break a pipeline and cause a major fire that would damage other homes not affected by the earthquake in the first place. In other words, there may be an additional annual expected benefit from mitigation over and above the reduction in losses to the specific structure adopting this RMM. All financial institutions and insurers who are responsible for these other properties at risk would favor building codes to protect their investments.

If a family is forced to vacate its property because of damage that would have been obviated if a building code had been in place, then this is an additional cost that needs to be taken into account when determining the benefits of mitigation. Suppose that the household is expected to need food and shelter for 50 days at a daily cost of 10. Then the additional expense from not having mitigated after a disaster occurs is 500. If the annual chances of the disaster occurring is $p = 1/100$, then the annual expected extra cost to the taxpayer of not mitigating is (1/100) $\times$ 500 = 5. This gives rise to an expected discounted cost of over 56 for a 30-year period if an annual interest rate of 8% were utilized. Should there be a large number of households that need to be provided with food and shelter, these costs could mount rapidly.

In addition to these temporary food and housing costs, the destruction of commercial property could cause business interruption losses and the eventual bankruptcy of many firms. The impact on the fabric of the community and its economic base from this destruction could be enormous [20]. In a study estimating the physical and human consequences of a major earthquake in the Shelby County/Memphis, Tennessee area, located near the New Madrid fault, Litan et al. [21] found that the temporary losses in economic output stemming from damage to workplaces could be as much as $7.6 billion based on the magnitude of unemployment and the accompanying losses in wages, profits and indirect "multiplier" effects.

6.2. Premium or tax reductions linked with long-term loans

Premium or tax reductions for undertaking loss prevention methods can be an important first step in encouraging property owners to adopt these measures. The basic rule in this case is a simple one: if the premium or tax reduction is less than the savings in expected claim payments due to mitigation, it is a desirable action for the insurer or government to promote the measure.

Suppose homeowners are reluctant to incur the up-front cost of mitigation due to budget constraints. Then one way to make this measure financially attractive to the property owner is for the bank to provide funds for mitigation through a home improvement loan with a pay-back period identical to the life of the mortgage. For example, a 20-year loan for $1500 at an annual interest rate of 10% would result in payments of $170 per year. If the annual premium reduction from insurance or the tax reduction by the government reflected the expected benefits of the mitigation measure and was greater than $170, then the homeowner would have lower total payments by investing in cost-effective mitigation than not doing so [22].

Many poorly constructed homes are owned by low-income families who cannot afford the costs of mitigation measures on their existing structure nor the costs of reconstruction should their house suffer damage from a natural disaster. Equity considerations argue for providing this group with low interest loans and grants for the purpose of adopting cost-effective RRMs or for them to relocate to a safer area. Since low-income victims are likely to receive federal assistance after a disaster, subsidizing these mitigation measures can also be justified on efficiency grounds.

6.3. Broadening protection against catastrophic losses

Advances in information technology have led to the development of sophisticated hazard simulation models that allow insurers, re-insurers, and financial institutions to estimate the probability and losses from natural disasters. [7] Results from these models have shown that

[7] Applied Insurance Research (AIR), EQE, and Risk Management Solutions (RMS) are leading modeling firms who are research partners in Wharton's Managing Catastrophic Risk project. See [18] for an overview of catastrophic risk modeling.

the losses from these events could easily exceed $100 billion in losses. In fact, a repeat of the earthquake that destroyed Tokyo in 1923 could cost between $900 billion and $1.4 trillion today [23].

To avoid the possibility of insolvency or a significant loss of surplus, insurers have traditionally utilized reinsurance contracts as a source of protection. Reinsurance does for the insurance company what primary insurance does for the policyholder or property owner — that is, it provides a way to protect against unforeseen or extraordinary losses. In a reinsurance contract, one insurance company (the re-insurer, or assuming insurer) charges a premium to indemnify another insurance company (the ceding insurer) against all or part of the loss it may sustain under its policy or policies of insurance. While the reinsurance market is a critical source of funding for primary insurers, the magnitude of catastrophic losses makes it implausible for them to adequately finance a mega-catastrophe. Though total insurance capital was slightly over $400 billion in 1999, Cummins and Doherty [24] found that "a closer look at the industry reveals that the capacity to bear a large catastrophic loss is actually much more limited than the aggregate statistics would suggest."

The confluence of these factors has led investment banks and brokerage firms to market new types of insurance-linked securities such as catastrophe bonds (cat bonds) for providing protection against catastrophic risks. Their objective is to find ways to make investors comfortable trading new securitized instruments covering catastrophic exposures, just like the securities of any other asset class. In other words, catastrophe exposures would be treated as a new asset class. This solution looks promising given the fact that the $26.1 trillion U.S. capital market is more than 75 times larger than the property/casualty industry [11].

In June 1997 the insurance company, USAA, floated act-of-God bonds that provided them with protection should a major hurricane hit Florida. A 2-year cat bond was put together by Swiss Re Capital Markets and Credit Suisse First Boston in July 1997. The loss triggers were tied to California insurance industry earthquake losses based on the Property Claims Insurance index for the state. Since that time there have been a number of other cat bonds issued in Japan and other countries. For more details see the Insurance Services Office [11].

Turning to the role of the public sector, Lewis and Murdock [25] developed a proposal that the federal government offer *catastrophe reinsurance contracts*, which would be auctioned annually. The Treasury would auction a limited number of excess-of-loss (XOL) contracts covering industry losses between $25 billion and $50 billion from a single natural disaster. Insurers, re-insurers, and state and national reinsurance pools would be eligible purchasers.

Another proposed option is for the government to provide protection against catastrophic losses. Governments could purchase cat bonds from either the private sector or organizations such as the World Bank. In countries where there is an active private insurance industry, insurers would be assessed premium charges in the same manner that a private reinsurance company would levy a fee on insurers for providing protection to them against large losses.

7. Conclusions and suggestions for future research

This paper makes a case for the importance of cost-effective mitigation and new sources of funding for loss recovery from natural disasters which takes advantage of recent developments in information technology and the emergence of new financial instruments. As shown with the two examples, the type of governance structure and the nature of the different institutional arrangements will determine the country's disaster management strategy.

For example, in US the private sector can play an important role helping to reduce disaster losses and providing financial protection through insurance coupled with mortgage requirements imposed by banks and financial institutions. The public sector can aid this effort through building codes that are well enforced. In emerging economies, such as Honduras, government will have to take the lead in providing incentives for mitigation measures and financial protection because there are not well-developed private insurance markets.

The World Bank can play an important role in this effort by requiring the government to protect itself against large-scale disaster losses by purchasing cat bonds as a condition for other loans unrelated to natural disasters to boost their economy. In this way the countries will be able to obtain the needed capital to cover these large losses and the World Bank will not have diverted these other loans to the recovery effort. This seems like a sensible strategy for a bank to follow if they want to protect their investments.

There are a set of open questions as to the types of incentives insurers and government can provide to individuals who invest in loss mitigation measures, and what types of financial instruments can supplement or replace traditional insurance and reinsurance coverage. A strategy for undertaking research in this area would involve the analysis of the impact of disaster of different magnitudes on a set of structures, industrial plants or their equipment.

In order to determine expected losses and the maximum probable losses arising from worst case scenarios, it may be necessary to undertake long-term simulations. For example, one could examine the impacts of earthquakes of different magnitudes on the losses to a community or region over a 10,000-year period. In the process one could determine expected losses based on the probabilistic scenario of earthquakes as well as the maximum possible loss during this period based on a worst-case scenario.

By constructing large, medium and small representative insurers with specific balance sheets, types of insurance portfolios, premium structures and a wide range of potential financial instruments, one could examine the impact of different disasters and accidents on the insurer's profitability, solvency and performance through a simulation. Such an analysis may also enable one to evaluate the risks associated with different types of financial instruments provided to different sized insurers with a given portfolio.

These data could be used to determine the return an investor would require to provide capital for supporting each instrument. The selling prices of different types of financial instruments would reflect both the expected loss and variance in these loss estimates to capture risk aversion by investors. One could also examine the role of the government in regulating rates and providing protection against catastrophic losses. [8]

Two very important outcomes would emerge from such simulations. It should be possible to rank the importance of different financial instruments for different type firms. Thus, small firms may prefer finite risk products while larger ones may want to rely on excess loss reinsurance due to a more attractive price for a pre-specified amount of protection. These simulation results could be compared with analytic studies of the performance of these instruments. If there were major differences it would be important to understand why they

[8] Kleindorfer and Kunreuther [4] discusses how this approach can be applied to an analysis of earthquake and hurricane risks facing specific cities in US.

exist. Secondly, investors could determine whether the market price that emerged from this simulation would be sufficiently attractive for them to provide investment capital to support certain instruments.

This is a very exciting time for the private and public sector to explore new opportunities for dealing with catastrophic risks. Each country will have its own set of institutional arrangements for developing a strategy for reducing future losses and having adequate funds for recovery. If insurance and new financial instruments such as cat bonds, can be used as a catalyst to bring key interested parties to the table, it will have served an important purpose in helping society deal with the critical issue of reducing losses and providing protection against natural disasters.

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