*Chapter 15*

# Incentives for Mitigation Investment and More Effective Risk Management: The Need for Public-Private Partnerships

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This chapter focuses on the type of incentives necessary to encourage the adoption of mitigation measures to reduce disaster losses.[1] The word "mitigation" will be treated synonymously with "loss prevention." Most risk mitigation measures (RMMs) have the following characteristics. There is an upfront investment cost (C) incurred by either a property owner or 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 prespecified length of time (T). The value of T is often the expected life of the property.

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

*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 Honduran government is concerned with damage to one of its water treatment plants from flooding and wishes to mitigate future damage to the structure from a major river in the country.

The next section probes more deeply into Scenario 1 by examining the decision processes of homeowners with respect to the adoption of RMMs in the United States. The chapter then turns to an analysis of Scenario 2 by considering the opportunities facing governments in developing countries regarding the adoption of RMMs. This is followed by a discussion of how insurance and new financial instruments can be linked with mitigation to encourage its adoption. The chapter then indicates the importance of improving risk estimates to encourage the adoption of cost-effective RMMs and makes the case for a public-private partnership to increase the adoption of mitigation measures and provide funding for loss recovery. The concluding section suggests directions for future research.

## Adoption of RMMs by Homeowners

The empirical data on studies of mitigation adoption in hazard-prone areas of the United States suggest that individuals are not willing to invest in RMMs despite the rather large damage that either 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 the United States, most residents in hurricane-prone areas appear not to have made improvements to existing dwellings that could reduce the amount of damage from another storm (Insurance Institute for Property Loss Reduction 1995).

Measures, such as strapping a water heater with simple plumber's tape, can normally be done by residents at a cost of under $5 in materials and one hour of their own time (Levenson 1992). This RMM can reduce damage by preventing the heater from toppling during an earthquake, creating gas leaks and causing a fire. Yet these and other mitigation investments are not being adopted by residents in earthquake-prone areas. A 1989 survey of 3,500 homeowners in four California counties subject to the hazard reported that only between 5 percent and 9 percent of the respondents in each of these counties adopted any loss reduction measures (Palm and others 1990).

## Why the Limited Interest?

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

*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. 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 themselves against hazards. By setting a threshold level, p*, individuals can devote their attention to events for which 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.

*Short-term horizons.* Individuals may have relatively short time horizons over 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 look at the potential benefits from the mitigation measure only over the next 3 to 5 years. He or she may reason that they will not be residing in the property for longer than this time and/or that want a quick return on investment before adopting the measure.

*Aversion to upfront costs.* If people have budget constraints, they will be averse to investing in the upfront costs associated with protective measures because they feel they cannot afford these measures. It is not unusual to hear "We live from payday to payday" when a person is asked why a household has not invested in protective measures.

*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, 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, they have less reason to invest in an RMM.

In summary, many property owners are reluctant to invest in cost-effective RMMs, because they misunderstand information on the potential benefits, feel they will have to pay only 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. Such nonadoption behavior may be exacerbated by developers who may believe (perhaps correctly) that they are unable to recover the costs of RMMs in increased selling prices for the structures (Kleindorfer and Kunreuther 1999).

## 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 floodproof a water 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 person 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 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.

## 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 floodproofing of a water treatment plant. To undertake such an analysis, it is necessary to assess the flooding 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 floodproofing. They can then construct a probability-damage matrix in a framework such as the one depicted in table 1.

If the only losses incurred from flooding were the costs of repairing the water treatment plant, 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 be multiplied by the probability of this type of flood occurring. One would sum all the figures to obtain the expected benefits from floodproofing for any given year.

**Table 1 Probability-damage matrix to water treatment plant**

| *Flood height of river* | *Probability of flood height* | *Damage with floodproofing* | *Damage without floodproofing* |
|---|---|---|---|
| Data to be supplied by user | | | |

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 discount rate. This would enable one to determine the expected discounted benefit of floodproofing the plant. The mitigation measure would be considered attractive if the total costs of floodproofing the water treatment plant were *less* than its expected discounted benefits.

## An 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 = upfront cost of mitigation measure
p = annual probability of flood (for example, p= 1/100)
L = damage to water treatment plant without floodproofing (for example, L = 500)
L' = damage to water treatment plant with floodproofing (for example, L' = 300)
d = annual discount rate (for example, d = .10)
T = relevant time horizon (for example, T = 10 years).

The decision as to whether 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 on the River within the T year time horizon, the water treatment plant will be restored to its predisaster condition. Then [E(B)] can be characterized as follows

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

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

$$E(B) = \sum_{t=1}^{T=10} (1/100)(500-300)/(1.10)^t \qquad (2a)$$

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

On average the mitigation will yield 2 worth of direct expected benefits each year, 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, it is cost effective for the government to floodproof the structure based on an analysis of directed expected benefits. If the water treatment plant were expected to last for more than 10 years, E(B) would of course be greater than 12.3.

### *Indirect Benefits of Mitigation Measures*

Over time floods and other disasters produce indirect or secondary impacts—such as family trauma and social disruption, business interruptions and shortages of critical human services—which 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 does one put a value on the loss of "community" associated with wholesale destruction of neighborhoods, on stress on families due to loss of homes, or on fear and anxiety about having another home destroyed in a future flood (Heinz Center 1999)?

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

- Provision of bottled water and toilet facilities to 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 were functional because of floodproofing, this would be an added benefit of investing in this measure.
- If businesses were interrupted because of the damage to the water treatment plant and the lack of fire protection, as in the Midwest floods of 1993, this would be an additional indirect cost of the flood. Businesses forced to close temporarily 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 to prosper (Heinz Center 1999).

If a functioning water treatment plant could have prevented some of these business interruptions, these would be considered an additional benefit of floodproofing the structure. To the extent that other businesses in Honduras not affected by the disaster fill the gap caused by nonfunctioning businesses, 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, this is a loss to Honduras.

The above examples illustrate what economists term *externalities* 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. The hospital costs and loss of work time from their drinking impure water would be an additional cost of the damaged water treatment plant.

## Financial Incentives to Encourage Mitigation

### *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 above.

By using the example in Section 3, one can *illustrate* how insurance could be used to encourage the government to floodproof its water treatment plant. Assuming that an insurer would provide full coverage, it would pay for repairing the entire damage to the plant if a flood occurred. If the government decided not to floodproof the water treatment plant, the actuarially fair insurance rate would be determined by multiplying the probability of a flood (that is, 1/100) by the resulting damage to the plant (that is, 500). The resulting rate would be 5. If the plant were floodproofed, the actuarially fair rate would be 3 (that is, 1/100 x 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 2 to reflect the expected annual reduction in claims it would have to pay the government for repairing damage to the water treatment plant.

### *Role of CAT Bonds*

Many developing countries do not have active private insurance markets. In these cases governments may need to rely on other ex ante risk transfer mechanisms to provide them with financial protection against disaster losses. Catastrophe or 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 Honduran 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 1 in 100. There is a 99/100 probability that there will be no damage to the water treatment plant. This 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 (Canabarro and others 1998).[2] 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 all his or her principal (that is, 100). The other 99 percent of the time, the investor gets back her principal plus interest, which will normally be above the market rate to reflect the risk of losing its principal.[3]

For the Honduran 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 5 percent. The Honduran 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 .99 it will get an annual return of .05 on its investment, and with probability .01 it will have to pay for the damage to the plant. Alternatively, the investor can receive a .05 return on a risk-free security. Let A be the amount of the bond to cover the water plant be damaged. To determine the value of r, the investor computes

$$.99\,r\,(A) - .01\,(A) = .05\,(A)$$

$$r = .06/.99 = .0606$$

The expected benefits of investing in a mitigation measure can now be easily determined. If the water treatment plant were not mitigated, the Honduran 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 by the government would be .0606(500. =30.3). If, on the other hand, the plant had been floodproofed, a bond of only 300 would be issued, and the annual expenditure would be .0606(300) =18.2. The Honduran 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 Honduran government to verify the damage to the water treatment plant. In the above example the government issued a bond under the assumption that it knew that the damage would respectively be 300 and 500 with and without floodproofing. 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 it would receive the maximum amount of payment for repairing damage.

This problem of *moral hazard* can be dealt with by relating the payouts from CAT bonds to an objective index (for example, flood height) rather than to actual damage. There may be some *basis risk* associated with these type of bonds to the extent that the actual losses differ from those predicted by the index. 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. Details on the nature of these type of bonds and a comparison with nonindexed bonds and/or reinsurance can be found in Doherty (1997), Freeman (1999), Croson and Kunreuther (1999), and Insurance Services Office (1999).

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 issuing them to private investors at higher rate. This 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 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 require the Bank to provide subsidized disaster assistance, a role it felt it had to play following the 1977 Polish floods (World Disaster Report 1998).

## Improving Risk Estimates to Encourage Mitigation

An important step in encouraging property owners and government to adopt loss prevention measures is to improve estimates of the risks associated with natural disasters. There are two principal reasons why the relevant interested parties, such as insurers, reinsurers, investors, and organizations such as the World Bank, will benefit from improved estimates of the risk associated with these events.

First, 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 portfolios to reduce the chances of insolvency. Second, 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 risk estimates provided to them.

In setting rates for catastrophe risks, insurers traditionally have looked backward by relying on historical data to estimate future risks. This procedure is likely to work well if there is a large data base of past experience that forms the basis for extrapolation into the future. However, low-probability-high consequence events generally have a relatively small historical data base. 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]

Advances in information technology have encouraged catastrophe modeling, because they enable simulation of a wide variety of 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 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 (Insurance Services Office 1996).

Today a growing number of catastrophe models have been used 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 to generate its results. Hence, they have highlighted the need for a better understanding as to why these models differ and for attempts to reconcile these differences more scientifically.

## Policy Implications: Need For A Public-Private Partnership

This section suggests ways that the public and private sectors can work together to reduce future losses from natural disasters. Specifically, I proposed three public-private partnership programs to encourage cost-effective risk mitigation measures and provide funds to cover losses from catastrophic disasters: (1) building codes, (2) premium reductions linked with long-term loans for mitigation, and (3) broadened protection against catastrophic losses.

In the many developing countries that lack a well-functioning private insurance market, governments 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.

### 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, but 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 damage the building. If the insurer is unaware of how well the building is constructed, 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 giving it a seal of approval would provide the property owner with more accurate information.

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 to only those structures that are given a certificate of disaster resistance.[6]

Cohen and Noll (1981) 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 externalities 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 quake itself. 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 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, this additional cost that needs to 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. After a disaster occurs, the additional expense from not having mitigated is 500. If the annual chance of the disaster occurring is p =1/100, the annual expected extra cost to the taxpayer of not mitigating is 1/100 x 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 percent were used. Should there be a large number of households that need 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 (Britton 1989). 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 and others (1992, pp. 65-66) 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.

## 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 simple: 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 upfront cost of mitigation due to budget constraints. 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 payback period identical to the life of the mortgage. For example, a 20-year loan for $1,500 at an annual interest rate of 10 percent would result in payments of $145 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 $145, the homeowner would have lower total payments by investing in cost-effective mitigation than by not doing so (Kunreuther 1997).

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 of relocating 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.

### *Broadening Protection against Catastrophe Losses*

New sources of capital from the private and public sectors could provide insurers, reinsurers, and governments with funds against losses from catastrophes. They range from capital market instruments to insurance pools to federal solutions.

With respect to capital market solutions, in the past couple of years investment banks and brokerage firms have shown considerable interest in developing new financial instruments for protecting against catastrophic risks. Their objective is to find ways to make investors comfortable trading new securitized instruments covering catastrophe exposure, just like the securities of any other asset class. In other words catastrophe exposure would be treated as a new asset class (Insurance Services Office 1999).

In June 1997 the insurance company USAA floated act-of-God bonds that provided it 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. [Ding—Credit gets an accent grave: / ]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 (Insurance Services Office 1999).

Turning to the role of the public sector, Lewis and Murdoch1996. 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, reinsurers, and state and national reinsurance pools would be eligible purchasers.

Another proposed option is for the government to provide protection against catastrophe losses. Governments could purchase CAT bonds from either the private sector or organizations such as the World Bank to obtain the needed capital to cover these large losses. In countries in which there are active private insurance industries, 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.

## Conclusions and Suggestions for Future Research

This chapter makes a case for the importance of cost-effective mitigation and new sources of funding for loss recovery from natural disasters that takes advantage of recent developments in information technology and the emergence of new financial instruments.

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.

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 10,000 years. 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, through simulation one could examine the impact of different disasters and accidents on the insurer's profitability, solvency, and performance. Such an analysis might 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 catastrophe losses.[7]

Two very important outcomes would emerge from such simulations. It should be possible to rank the importance of different financial instruments for different types of firms. 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 prespecified amount of protection. These simulation results could be compared with analytic studies of the performance of these instruments. If there are major differences, it would be important to understand why they exist. Second, 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.

Future studies could examine the following issues:

- *Regulatory issues.* What impact would rate restrictions on premiums that insurers are allowed to charge in hazard-prone areas have on the availability of coverage and their incentive to encourage mitigation?
- *Uncertainty issues.* There is considerable uncertainty in estimating the probability of disasters of different magnitudes occurring and the magnitude of the resulting losses. How can one incorporate these uncertainties in an analysis of which mitigation measures are cost effective?
- *Tradeoffs between reinsurance and mitigation.* How much reinsurance would have to be purchased to provide sufficient protection to the insurer as a function of the amount of mitigation in place?
- *Impact of mitigation on capital market instruments.* How will loss-reduction measures impact on the ability of the insurance industry to provide coverage without relying extensively on funds from the capital market? Will mitigation reduce the uncertainty of future losses, so that these new financial instruments could be more easily marketed to investors?

This is a very exciting time for the private and public sectors to explore new opportunities for dealing with catastrophe risks. Each country will have its own set of institutional arrangements to develop 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 catalysts to bring key interested parties to the table, they will serve an important purpose in helping society deal with the critical issue of reducing losses and providing protection against natural disasters.

## Notes

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2. 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.

3. See Bantwal and Kunreuther (1999) for details on catastrophe bonds and discussion as to why the interest rates are so high.

4. The contrasting argument is that if the World Bank were to subsidize the interest rate on CAT bonds, subsidization would necessarily involve the use of resources that otherwise would be used for disaster relief or responding to the pressing needs of the world's poor (Dunfee and Strudler 1999).

5. For example, with respect to earthquakes, a discussion of new advances in seismology and earthquake engineering can be found in Federal Emergency Management Agency (1994) and Office of Technology Assessment (1995). Regarding technological hazards, the Wharton Risk Management and Decision Processes Center is compiling a very comprehensive

data base on the impact of large-scale catastrophic accidents on health and safety risks (Kleindorfer, Lowe, and Rosenthal 1997). With respect to environmental risks to health, such as groundwater contamination, data bases have been assembled that open opportunities for providing insurance protection on risks that recently had been considered uninsurable by firms in the industry (Freeman and Kunreuther 1997).

6. For details on ways to make communities disaster resistant see CUSEC 1997.

7. An example of the application of such an approach to a model city in California facing an earthquake risk can be found in Kleindorfer and Kunreuther (1999).

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