

Mitigation and Financial Risk Management for Natural Hazards*

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ABSTRACT

The importance of public-private partnerships for disaster management has been stimulated by catastrophic losses from natural disasters in the United States and other parts of the world. Hurricane Andrew which created damage to Miami and Dade/County, Florida in September 1992 and California's Northridge earthquake together cost the insurance industry (US\$28 billion) and an additional US\$17.6 billion. The Kocaeli earthquake in Turkey in August 1999, which caused over 19,000 confirmed fatalities with massive disruptions to the economy of Western Turkey, has led to a recognition by the Turkish government, industry and the public of the urgent need to develop and enforce better building standards.

This paper explores disaster management strategies for reducing losses from natural disasters and providing financial resources to victims of these devastating events in both developing countries and emerging economies. More specifically, it will examine programs that involve the private sector such as insurance and capital market instruments (e.g. Act of God bonds) in combination with public sector programs such as regulations and standards (e.g. well-enforced building codes).

In developing and evaluating these programs the paper addresses the following three questions:

- (1) How can one utilize risk assessment methodologies for estimating the potential damage and the uncertainties surrounding these figures for earthquakes of different magnitudes and intensities?
- (2) What role can loss prevention measures, insurance and new financial instruments play in reducing losses from future earthquakes and providing funds for recovery?
- (3) How can one utilize model cities for evaluating the linkages between risk management strategies that involve both the public and private sectors for dealing with large-scale earthquakes?

1. INTRODUCTION

The importance of public-private partnerships for disaster management has been stimulated by losses from catastrophes in the United States and other parts of the world. Hurricane Andrew that created damage to Miami and Dade/County, Florida in September 1992 and California's Northridge earthquake together cost the insurance industry (US\$28 billion) and the government an additional US\$17.6 billion. The Kocaeli earthquake in Turkey in August 1999, which caused over 17,000 confirmed fatalities with massive disruptions to the economy of Western Turkey, has led to recognition by the Turkish government, industry and the public of the urgent need to develop and enforce better building standards (Wilczynski and Kalavakonda 2000).

This paper explores risk management strategies for reducing losses from natural disasters and providing financial resources to victims of these devastating events in both developing countries and emerging economies. More specifically, it will examine programs that involve the private sector such as insurance and capital market instruments (e.g. Act of God bonds) in combination with public sector programs such as regulations and standards (e.g. well-enforced building codes). The focus of attention will be on the earthquake problem but the concepts are relevant to other natural and technological disasters as well.

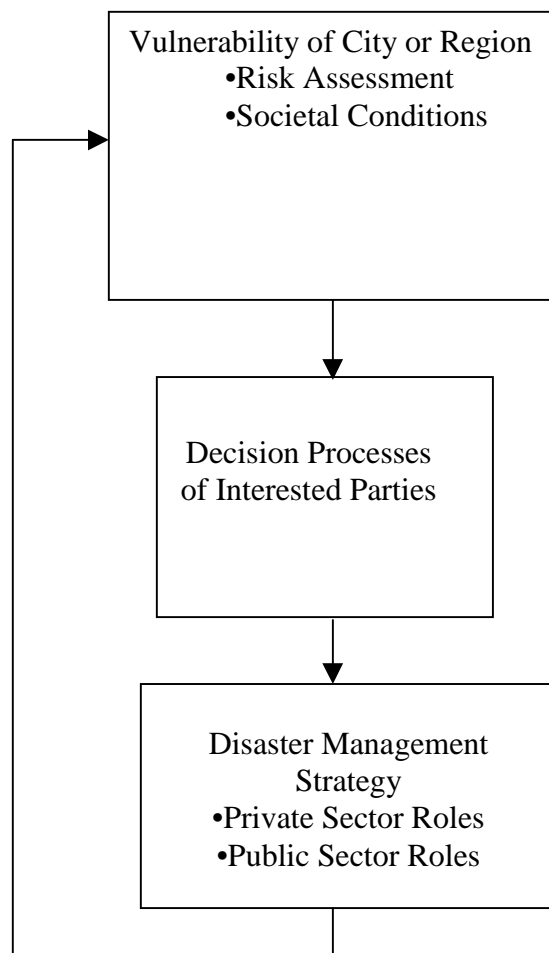
Figure 1 depicts a framework for analyzing this problem. It builds on concepts developed in a report by the Heinz Center (1999) and by Kleindorfer and Kunreuther (1999). The vulnerability of a community or region includes the potential for direct damage to residential, commercial and industrial property, other facilities such as schools, hospitals, and government buildings as well as infrastructure damage to highways, water, gas, electricity and other lifelines. Any disruption of infrastructure such as loss of the water supply or electric power can cause indirect losses by interrupting business activity, forcing families to evacuate their homes and causing emotional stress to families. One also has to consider the exposure of the population to the hazard and potential number of fatalities and injuries to different socioeconomic groups.

The ingredients for evaluating the vulnerability of a city or region to natural hazards are risk assessment and societal conditions. Ideally a *risk assessment* specifies the probability of events of different intensities or magnitudes occurring and the impact of the direct and indirect impacts of these events to the affected interested parties. *Societal conditions* include human settlement patterns, the built environment, day-to-day activities and the institutions established to deal with natural hazards.

Before developing a disaster management strategy one needs to understand the decision processes of the key stakeholders. The term decision processes refers to the type of information and data collected by individuals, groups and/or organizations (either private or public) and how they are utilized in making choices. For example, if a family is considering whether to bolt its home to a foundation to reduce future losses from a severe earthquake, what information does it collect on both the hazard itself and the potential damage with and without this mitigation measure? What type of decision rule(s) does the family utilize in determining whether or not to invest in this mitigation measure? What type of data and decision rules do firms utilize in evaluating the cost-effectiveness of different mitigation measure? How do the strategies of firms

regarding adoption of mitigation measures relate to their profit objectives as well as their financial concerns should they suffer large losses from catastrophic events? What factors influence the public sector's decisions as to what regulations and standards they should issue relative to protection against the damage from natural disasters? What is the basis for their actions regarding the types of financial assistance provided to victims of these catastrophes? Unless we understand the nature of the decision processes of these and other interested parties, it will be difficult recommending specific programs or policies that are likely to be implemented.

Figure 1: Framework for Analysis



Based on an understanding of the vulnerability of the city or region and the decision processes of the key interested parties, one needs to develop a strategy for reducing losses and providing financial protection to victims of future disasters. This strategy will normally involve a combination of private and public sector initiatives which include insurance and new financial instruments as well as well-enforced building codes and land-use regulations. These measures will differ from country to country depending on the current institutional arrangements and existing legislation and laws.

This paper applies the above framework to Oakland, California, one of three cities that the Wharton Managing Catastrophic Risk project has been studying over the past four years.¹ The focus is on the potential losses to a hypothetical insurance company providing earthquake policies to homeowners residing in Oakland. This specific analysis illustrates the more general challenge of how to combine risk assessment methodologies with risk management programs for reducing damage and providing financial protection against natural disaster losses in the future.

The next portion of the paper examines the different components of the above framework. Section 2 provides a perspective on the vulnerability of a city or region and the importance of the loss exceedance probability curve as an integrating concept. Sections 3 and 4 focus on the decision processes of two key interested parties affected by natural disasters—firms and homeowners. Section 5 discusses a risk management strategy involving mitigation and risk transfer mechanisms. The conceptual framework depicted in Figure 1 is then illustrated in Section 6 by focusing on a hypothetical insurance company providing protection to homeowners in Oakland. The concluding section outlines a set of future research issues on hazards.

2. VULNERABILITY OF A CITY OR REGION

In determining the vulnerability of a city or region one needs to know the design of each structure (e.g. residential, commercial, public sector) and infrastructure, whether specific mitigation measures are in place or could be utilized, and their location in relation to the hazard. (e.g., distance from an earthquake fault line or proximity to the coast in a hurricane-prone area) as well as other risk-related factors. The loss exceedance probability (EP) curve provides a way of depicting this damage in a systematic manner.

Constructing a Loss EP Curve

A loss EP curve depicts the probability that a certain level of loss will be exceeded on an annual basis. Using probabilistic risk analysis (PRA), one combines the set of events that could produce a given dollar loss and determines the resulting probability of this loss occurring. Based on these estimates, one can construct the mean exceedance probability curve depicted in Figure 2. By its nature, the EP curve inherently incorporates uncertainty in the probability of an event occurring and the magnitude of dollar losses. This uncertainty is reflected in the 5% and 95% confidence interval curves in Figure 2.

¹ The three cities, their associated modeling firm and hazard in parentheses are: Miami/Dade County, FLA (Applied Insurance Research, -hurricanes); Long Beach, CA (EQE, earthquakes); Oakland, CA (Risk Management Solutions, earthquakes).

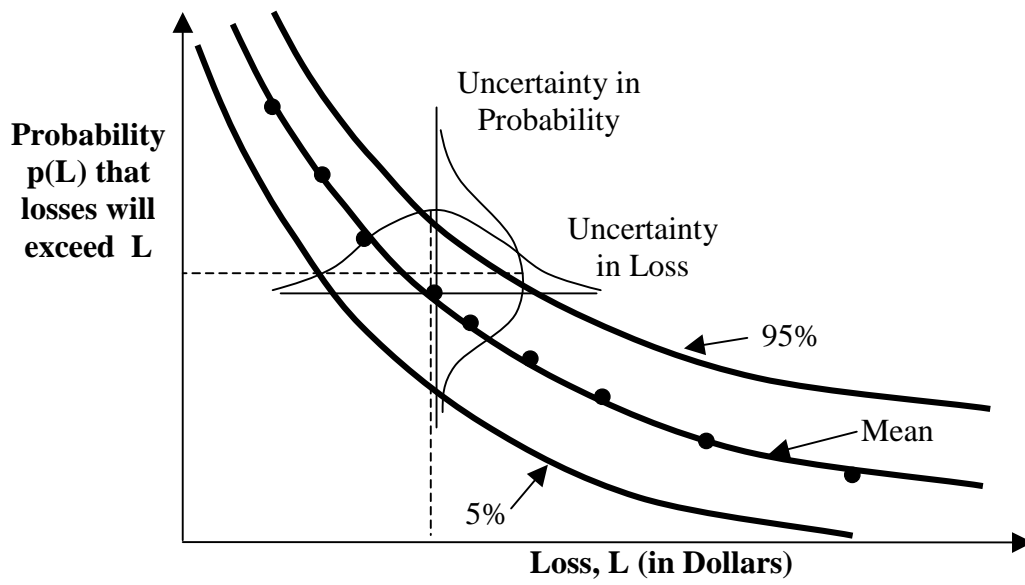


Figure 2. Example of Loss Exceedance Probability Curves

The loss EP curve is the key element for evaluating a set of risk management tools. The accuracy of the EP curves depends upon the ability of natural hazard experts, economists and structural engineers to estimate the impact of events of different probabilities and magnitudes on the performance of different structures.

The Loss EP Curve as an Integrating Concept

The following elements are necessary if one is to construct a loss EP curve as an integrating concept for linking risk assessment with risk management strategies for reducing the vulnerability of a city or region.

Nature of the Problem To begin the analysis, it is important to specify the nature of the problem one is studying and to indicate why it is considered important. Normally, the problem of concern is a weather-related hazard where there is some likelihood (often small) that there will be a high impact event which produces severe economic consequences. The problem considered in Section 5 is how an insurer can protect itself against the financial losses from a severe earthquake in a hazard-prone city—Oakland, CA. The insurer's goal is to reduce its chances of insolvency while still being profitable.

Characterizing the Risk One needs to rely on expert judgment to estimate the chances of certain events occurring and their potential consequences. In utilizing these estimates, it is valuable to have a notion of the degree of uncertainty surrounding these figures. Below, we will focus on a series of earthquake events, their probabilities, and the economic consequences to homes in Oakland.

Parties Affected by the Risk One needs to specify the relevant parties affected by the risk. Suppose the analysis is being undertaken for a company who is concerned with potential losses from a weather-related hazard. Then the loss EP curve will depict the potential losses to the firm from a series of events, such as earthquakes of different magnitudes and intensities. If other stakeholders are involved in helping to cover these losses (*e.g.*, an insurer, reinsurer or financial institution), then one will need to construct a loss EP curve for these parties as well. In Section 5 a loss EP curve is constructed for an insurer providing financial protection to homeowners against earthquakes in Oakland.

Decision Processes of Parties The use of the loss EP curve depends on the type of information collected by the relevant parties and the types of decision rules that are utilized by them. For example, a company concerned with the possibility of insolvency will turn to its loss EP curve to estimate the probability that its losses will exceed some given magnitude. In Section 5 one can see how the loss EP curve is used to estimate the probability that earthquakes in Oakland will create losses to an insurer that exceed a certain dollar value.

Strategies for Risk Bearing, Mitigation and Risk Transfer The loss EP curve enables one to construct and evaluate the impact of alternative strategies for dealing with the consequences of weather-related disasters. These strategies incorporate a set of policy tools that include the following: risk bearing (*e.g.*, having enough surplus on hand and diversification of activities to cover potential losses), mitigation (*e.g.*, investing in a measure to reduce future disaster losses), and risk transfer (*e.g.*, use of insurance, reinsurance and catastrophe bonds to lay-off a portion of one's risk to others).

Some of these strategies can be implemented through the private sector in a financially attractive manner (*e.g.* long-term loans for mitigation coupled with lower insurance premiums and/or lower deductibles) while others may require public sector intervention (*e.g.* well enforced building codes). Section 5 evaluates the impact of a requirement that homeowners invest in a cost-effective mitigation measure (as a condition for insurance) on the insurer's performance. The insurer's probability of insolvency will be examined with and without the use of risk transfer mechanisms, such as reinsurance and catastrophe bonds.

3. FIRMS' DECISION PROCESSES AND STRATEGIES ²

The recent literature in economics suggests that firms are generally risk averse and hence are concerned with non-diversifiable risks such as catastrophic losses from natural disasters (Mayers and Smith, 1982). Suppose a firm is risk averse and there are transaction costs associated with bankruptcy. Then, the firm will want to purchase protection against catastrophic losses at higher premiums than implied by their expected losses³, even when their shareholders can eliminate this risk through their own portfolio diversification. Firms are also likely to be ambiguity averse. In other words, they are concerned with the uncertainty regarding the probability of a loss occurring (Kunreuther, Hogarth and Meszaros, 1993).

Importance of Safety-First Constraints and Shareholder Concerns

One way to reflect the firm's risk aversion and ambiguity aversion is a safety-first model first proposed by the French economist Roy (1952). Such a model can be contrasted with a value maximization approach to firm behavior. A safety-first model explicitly concerns itself with insolvency when a firm makes a decision as to how much protection it would like to have against catastrophic losses and how much it is willing to pay to protect itself against this possibility. James Stone (1973) utilized a form of this safety-first model to characterize insurers' underwriting decisions. More specifically he postulated that the underwriter's objective is to charge a premium that maximizes the firm's expected profits subject to the following constraint: the probability of the claims from a disaster exceeding the insurer's total assets (*i.e.*, the firm becomes insolvent) is less than some prespecified value α^* . This safety-first model still appears to characterize insurers' behavior today and will be used in evaluating alternative strategies for an insurer in Section 6.

² Portions of this section reflect material presented in Hebbbar (2001). He examines the tensions between satisfying the demands of stockholders as well as the firm's concerns with insolvency.

³ Expected loss is defined as the probabilities of loss amounts from disaster(s) of different magnitudes in a given year, each multiplied by the losses sustained, and then summed.

Even with their concerns with insolvency, firms need to determine how they can satisfy their shareholders concerns that they receive a positive return on assets (ROA)⁴ in any given year. An insurance company could increase its ROA by raising the selling price of its policies, thereby collecting more premiums. However, if it increased this premium rate too much, the demand for insurance would fall, limiting the number of policies the insurer could write. Hence, an insurer must meet its safety-first constraint while maximizing return on assets and assuring sufficient demand.

Demand for insurance is not only a function of the premium rate, but also of policy features such as deductible level and insurance cap. For example, if an insurer is currently writing policies with 10% deductibles, a policyholder will be responsible for any losses up to 10% of the value of his home. If his home is worth \$200,000, the insurer will not pay for any damages less than \$20,000. The insurer covers all losses greater than this level. If the insurer raises the deductible to 20%, the policyholder will now be responsible for twice as much loss, or damages up to \$40,000. As the deductible increases, the policyholder's⁵ demand for insurance falls.

Suppose the insurer instead wrote policies with no deductible but instated an insurance cap of \$150,000 on the maximum insured value per structure. Now the policyholder is responsible for losses between \$150,000 and \$200,000 (the value of the structure). If the insurer lowers the insurance cap to \$100,000, the policyholder is now responsible for losses between \$100,000 and \$200,000. A reduction in the level of insurance cap will decrease demand for insurance as long as the cap is low enough to affect policyholders.⁶ Insurers must guarantee that there is adequate demand for their policies. Consequently, they must monitor the premium rate, the deductible level and the insurance cap level.

Developing Risk Management Strategies to Satisfy Conflicting Objectives

The safety-first model and profit/value maximization approach can be used together in evaluating risk management strategies. Due to the cost of the risk transfer instrument and the reduction in premiums collected, a downward shift in the loss distribution in order to meet a safety-first constraint will result in a lower return on assets for a fixed percentage book of business.⁷ The tradeoffs between the safety-first and return on assets can make some books of business infeasible even if mitigation or risk transfer mechanisms are used. For example, suppose purchasing a catastrophe bond reduces an insurer's insolvency probability below the target level, but brings about a negative return on assets. This catastrophe bond strategy is infeasible because the insurance company's shareholders require a positive return on assets. If the insurer is not able to net a positive return on assets with any strategy, the risk is not insurable.

The analyses conducted for this paper assume that a typical insurer is decentralized and has little control over the number of policies its agents sell. Thus, the number of policies written is

⁴ Return on Assets equals Expected Profits divided by Assets.

⁵ Assuming that the policyholder is averse to catastrophe risk, and is not forced to purchase earthquake insurance at a stated deductible (as a condition for mortgage, etc.)

⁶ That is, increasing the insurance cap from \$1 Million to \$2 Million will not likely have a significant effect on demand, since the cap will not impact most policyholders.

⁷ Assume that the premium rate is unchanged (*i.e.* demand is unaffected).

independent of the insurer's particular risk management strategy. For example, the insurer's decision to issue a catastrophe bond or selectively underwrite should not affect the number of policies agents sell if the premiums remain the same. Most of the analyses below fix the number of policies written under all strategies at an arbitrary level.

A firm concerned with managing catastrophe risk is likely to have a series of low probability-high consequence (lp-hc) events in its loss distribution. High consequence events are those that threaten the solvency of a firm. In other words, the magnitude of loss from the lp-hc event is greater than the firm's surplus. These lp-hc events show up as an elongated right tail in the graph of the Loss EP curve. For example, due to the catastrophic potential of earthquakes in Northern California, an insurance company with a randomly selected book of business in Oakland is likely to face significant lp-hc events.

Suppose the surplus of the firm (i.e. the initial assets plus the total premiums collected) is greater than the loss on the EP curve corresponding to the target insolvency probability ($EP(L_{TR}) = \alpha^*$, where α^* is the target insolvency probability and L_{TR} is the corresponding target ruin loss). Then the safety-first constraint is satisfied and a reasonable level of solvency is guaranteed. For example, if $\alpha^* = .01$ and $L_{TR} = \$1$ million, then the firm requires that its surplus be greater than \$1 million. More generally, the safety-first constraint can be expressed as:

$$\text{Probability (Surplus } \leq L_{TR}) \leq \alpha^*$$

where Surplus = Initial Assets + Total Premiums Collected

As the magnitude of lp-hc losses increases, L_{TR} increases and the firm is less likely to meet the safety-first constraint. For example, if the insurer changes its strategy by only insuring in a high-hazard earthquake area of Oakland rather than in lower risk areas of the city and continues to write the same number of policies as before, then for $\alpha^* = .01$ its L_{TR} might increase from \$1 million to \$ 2 million. Given the nature of the safety-first constraints in industries like insurance, even firms with minimal catastrophe loss exposure are likely to face some difficulty in meeting the target insolvency probability on randomly selected books of business.

A profit, or value maximization model mandates that firms optimize their returns on investment, making expensive risk reduction and risk transfer instruments less attractive because they significantly reduce the return on assets. If firms operate in competitive environments where demand is elastic, they cannot increase the price of their product (i.e. raise the total amount of premiums collected) without reducing demand. Consequently, firms must actively choose a book of business that has a relatively low exposure to lp-hc events. At this point, risk reduction and risk transfer mechanisms may prove effective in managing the tradeoffs of the constraints.

In summary, it is important to understand that the feasibility of a particular risk management strategy depends on the nature and specifications of the constraints. Therefore, one must carefully select appropriate constraints and their related parameters (e.g. α^* , L_{TR}).

Strategies for Reducing Insurer Losses

One way to reduce the chances of insolvency is to shift the EP curve downward so that the chances of catastrophic losses are reduced to an acceptable risk level. In addition insurers can utilize risk transfer mechanisms to shift their catastrophic losses to another party, such as a reinsurer or investor in catastrophic bonds.

Underwriting and Mitigation Strategies An insurer can institute a variety of underwriting decision rules, each of which will have different effects on the shape of the Loss EP curve. Some strategies shift the entire curve to lower loss levels, reducing catastrophic losses as well as expected losses and hence premiums. The ideal strategy would reduce the losses in the right tail, and keep the losses in the left tail fixed. This way, the insurer can continue to charge similar premiums since the expected loss has not fallen by a large amount, and will still see improvements in the probability of insolvency.

One approach would be to raise deductible levels so that the payouts from any disaster would decrease. Another alternative would involve setting a cap on the maximum insured value of each structure in its book of business. A deductible has an impact on losses from disasters of any magnitude. An insurance cap, on the other hand, affects claims when there are large losses to individuals by placing a limit on the maximum claims payment to the homeowner. If homeowners, like insurers, wish to manage their exposure to catastrophes, they would prefer a deductible to an insurance cap. Although a low value for the insurance cap reduces the losses to the insurer, it is likely to be met with decreased demand for insurance.

Selective underwriting strategies can further reduce the insurer's insolvency probability. The firm can selectively choose which risks to include in issuing policies rather than insuring a randomly selected book of business from high-hazard areas. For example, the insurer's central office can instruct its agents only to sell policies to homeowners whose structure values fall in a predetermined range such as those less than \$150,000. This particular underwriting rule effectively creates a cap on possible losses by limiting policies to less expensive homes. Alternatively, the central office can restrict its agents to selling policies in certain geographic areas.

Another way for insurers to reduce its insolvency probability would be to adopt loss reduction (mitigation) measures. In essence, the mitigation measure shifts the EP curve downward to reflect the lower probability of losses from the case when no loss reduction

measures were in place. For instance, if a building code is instituted in an area, requiring homeowners to take mitigation measures, all insurers benefit from the reduction in the EP curve. If no regulations are in place, the insurer can selectively issue policies only on mitigated structures. Loss reduction measures reduce the chance of the firm becoming insolvent, making the safety-first constraint easier to meet.

Risk Transfer Mechanisms

Risk transfer mechanisms complement underwriting strategies and mitigation measures by enabling an insurer to survive financially should it suffer a catastrophic loss. More specifically, the firm would use its EP curve to determine how much protection it would need to reduce its probability of insolvency below the target ruin probability α^* . The more risk averse the firm is, the more it will need to use risk transfer instruments to protect itself against large losses, and the more it is willing to pay for this protection. Like mitigation, risk transfer instruments reduce the probability of insolvency. However, insurance companies pay premiums to purchase risk transfer instruments. Two risk transfer mechanisms are discussed below:

Indemnity Contracts Risk-averse firms may want to purchase an indemnity contract to cover losses above a certain amount. For a corporation, the normal indemnity contract is an insurance policy; for an insurer, the typical indemnity contract is an excess-of-loss reinsurance policy that provides coverage against unforeseen or extraordinary losses. A typical excess-of-loss reinsurance contract requires the primary insurer to retain a specified level of risk and then covers all losses between an attachment point (L_A) and exhaustion point (L_E) on the exceedance probability curve (Figure 3). In other words, the indemnity contract is of the following form: the reinsurer pays all losses in the interval L_A to L_E with a maximum payment of $L_E - L_A$. In return for this protection, the insurer pays the reinsurer a premium. A firm can significantly improve its risk exposure if it purchases an indemnity contract on its right tail (lp-hc) losses. This paper will not consider indemnity contracts in analyzing the impact of risk transfer instruments on insurer performance.

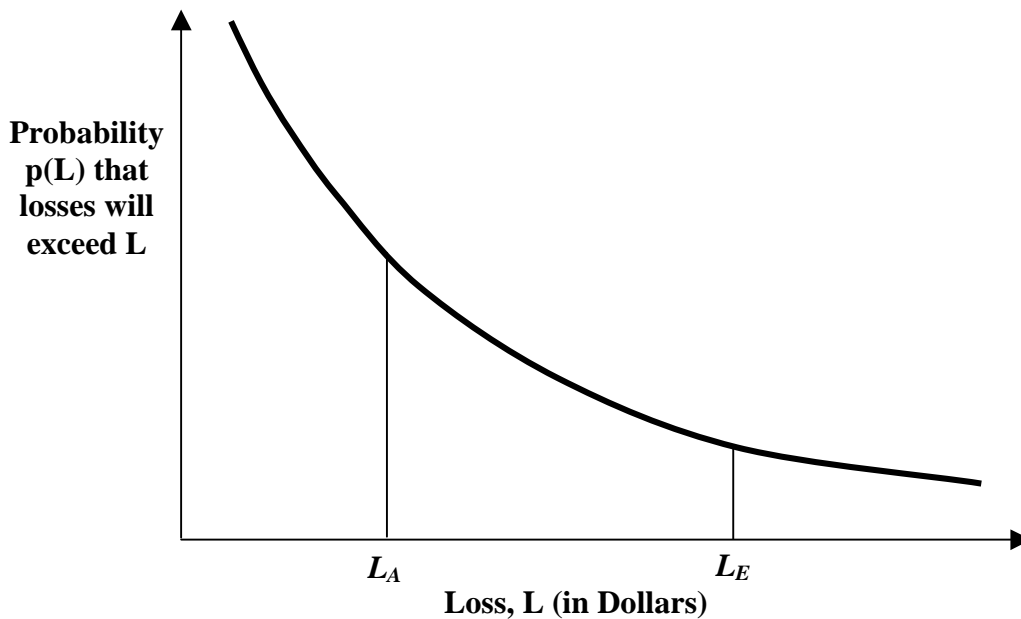


Figure 3: Indemnity Contract and Loss EP Curve.

Index-Based or Parameterized Contracts As an alternative to an indemnity contract, a firm may want to utilize an index-based or parametric contract to obtain needed funds should a severe disaster occur. Today, a commonly utilized parametric contract is an indexed catastrophe-linked bond (henceforth referred to as a *cat bond*). A cat bond requires the investor to give

money up front that will be used by the firm if some type of triggering event occurs. In exchange for a high return on investment, the investor faces the possibility of losing either a portion or its entire principal investment. The amount paid out to the firm (*i.e.* the ceding company) depends on how the cat bond is constructed and this amount is specified in advance of the triggering event. Notably, the firm does not face any credit risk from the cat bond; the money to pay for the losses is already in hand.⁸

Many of the cat bonds being issued today are tied to a disaster-severity index (*e.g.*, covering damage from a certain earthquake magnitude event within a specified region) rather than to the firm's actual losses.⁹ Since these parameters are normally independent of the firm's actual losses, payments can be made to the firm immediately after the disaster occurs rather than being subject to the time delay necessary to compute actual losses, as in the case of insurance or reinsurance. Hence indexed cat bonds reduce the amount of moral hazard in loss estimation. On the other hand, such a cat bond creates *basis risk*. Basis risk refers to the imperfect correlation between the actual losses suffered by the firm and the payments received from the cat bond. Insurance sold to firms or excess-of-loss reinsurance to insurers has very little basis risk because there is a direct relationship between the loss and the payment delivered by the reinsurance instrument.

In May of 1999, a parametric-based contract to cover the loss from an earthquake was purchased by Oriental Land, a Japanese company that is best known as the owner and operator of Tokyo Disneyland. This cat bond provides \$100 million to the company should an earthquake of a specific magnitude occur in the vicinity of Tokyo. The Japanese Meteorological Agency determines the measurement of event magnitude. The magnitude which qualifies a given quake for payments to Oriental Land is higher as the locations of its epicenter becomes more remote from Tokyo Disneyland. These bonds represent the first direct access of the capital markets by a corporation seeking catastrophe risk financing (Standard & Poors, 2000).

An effective cat bond can benefit an insurer by reducing the effects of the lp-hc events in the right tail of the Loss EP curve. By paying the insurer only for lp-hc events, a cat bond basically reduces the right tail losses. Since total annual insurance premiums are collected based on a certain "loading factor"¹⁰, f_{ins} , times annual expected losses from the hazard to the insurer, a reduction in the right tail reduces expected losses and hence reduces insurance premiums. Because the high consequence events in the right tail occur with low probabilities, it is possible to cut right tail losses by a large amount while reducing expected losses by a relatively small amount. Consequently, insolvency probability would fall significantly for only a small decrease in premiums. In this case, the annual profits to the insurer, defined as $\text{Profits} = \text{Total Premiums} - \text{Expected Losses} + \text{Payments to Insurer from CB} - \text{Price of CB}$, will also not suffer after the purchase of a reasonably priced cat bond.¹¹

⁸ The investor's up front investment is generally placed in a trust, and paid to the ceding company in the case of a triggering event. This implies that the ceding company is only able to reinvest proceeds from cat bond premiums in liquid securities at approximately the risk free rate.

⁹ For more details on the structure of recent cat bonds, see Insurance Services Office (1999).

¹⁰ This "loading factor" was previously referred to generally as a premium rate.

¹¹ However, note that if the price of the cat bond is too high, profits could be negative. Hence, the return on assets would also be negative and the strategy would be infeasible to the shareholders of the insurance company.

In the illustrative example, it will become evident that cat bonds are expensive risk transfer alternatives in today's market. Investors demand abnormally high returns on the bonds, making them costly relative to reinsurance. Hence an indexed cat bond must be well-parameterized with very little basis risk in order to be attractive to an insurer. The illustrative example for the hypothetical Oakland insurer will utilize parametric trigger cat bonds linked to both earthquake magnitude and epicenter location. The payment of the cat bond to the insurer for each set of triggering events is based on the difference between the insurer's expected losses from only the set of triggering events and the expected losses from all events. If some sets of triggering events have extraordinarily high payments to the insurer, the cat bond becomes unreasonably expensive.

4. HOMEOWNERS' DECISION PROCESSES AND STRATEGIES

In order to develop alternative risk management strategies for natural disasters, it is important to understand when homeowners voluntarily invest in a cost-effective risk mitigation measure (RMM). The definition of *cost-effective* in this paper is related solely to structural damage to the property. In other words, one determines whether the expected discounted benefits as measured by the reduction in damage to the house exceeds the cost of the mitigation measure. Those measures that meet this criterion will certainly be viewed as desirable when one takes into account other direct and indirect benefits to the property owner(s), such as saving lives, reducing injuries and the pleasure of not being forced to leave one's home after a disaster.

To illustrate, consider a standard RMM for earthquakes: reinforcing crippled walls and bolting a house to a foundation. Although the upfront expense normally runs from US\$1,000 to US\$3,000, it yields sufficient expected benefits to be cost-effective for many homes in earthquake prone areas in California. Yet in a 1989 survey of 3,500 homeowners in four California counties subject to earthquake damage, only between 5 and 9 percent of the respondents in each of these counties reported adopting this or any other earthquake mitigation measure (Palm et. al. 1990). A follow-up survey of residents affected by the October 1989 Loma Prieta earthquake and the Northridge earthquake of 1994 revealed that only 10 percent of homeowners invested in any type of structural loss-reduction measure whether or not they were affected by recent earthquakes in the State (Palm 1995).

There are at least five reasons why homeowners do not appear to want to invest in cost-effective RMMs. The importance of these factors will vary across different regions and may change over time depending on the area's disaster history and the response from the public sector following the most recent event.

Short Time Horizons Individuals may have relatively short time horizons over which they want to recoup their investment in a mitigation measure. Even if the expected life of the house is 25 or 30 years, the person may only look at the potential benefits from the measure over the next 3 to 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.

High Discount Rates The need for a quick return is also consistent with having a high discount rate regarding future payoffs. Loewenstein and Prelec (1992) propose a behavioral model of choice whereby the discount function is hyperbolic, rather than exponential. Their model appears

to explain the reluctance of individuals to incur the high immediate cost of energy-efficient appliances in return for reduced electricity charges over time (Hausman, 1979; Kempton and Neiman, 1987).

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^*) 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

Aversion to Upfront Costs If people have budget constraints then they will be averse to incurring the upfront costs associated with a protective measure simply because they feel they cannot afford it. One often hears the phrase "We live from payday to payday" when asked why a household has not invested in protective measures. (Kunreuther et al. 1978).

Truncated Loss Distribution 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 their estimated 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, they would have less reason to invest in a cost-effective mitigation measure.

5. DEVELOPING A DISASTER MANAGEMENT STRATEGY

There are several different strategies for reducing future losses from natural disasters and providing protection for victims of natural disasters that complement each other. These range from mitigation measures prior to a disaster, the use of warnings and evacuation plans to reduce loss of lives and damage at the onset of an event and recovery strategies such as insurance and financial assistance following a disaster. This paper examines three policy tools as part of a disaster management strategy: well-enforced building codes for mitigating losses, indemnity contracts and indexed-based or parameterized cat bonds.

Well-Enforced 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 measure and/or underestimate the probability of a disaster occurring. If a family is forced to vacate its property because of damage that would have been prevented if a building code had been in place, then this additional cost needs to be taken into account by the public sector when evaluating the cost-effectiveness of an RMM from a societal perspective.

Cohen and Noll (1981) provide an additional rationale for building codes. When a structure collapses it may create externalities in the form of economic dislocations that are beyond the

physical damage 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 structures not affected by the earthquake in the first place.

There are several key interested parties who can enforce building codes. Banks and financial institutions could require an inspection of the property to see that it meets code before issuing a mortgage. Similarly insurers may want to limit coverage only to those structures that meet the building code. Inspecting the building to see that it meets code and then providing it with a seal of approval provides accurate information to the property owner on the condition of the house. It also signals to others that the structure is disaster-resistant. This new information could translate into higher property values if prospective buyers took the earthquake risk into consideration when making their purchase decisions.

Indemnity Contracts

As discussed above one way for firms to obtain protection against catastrophic losses is for them to purchase an indemnity contract against claim payments above a certain amount. In the case of insurers, a common indemnity contract is excess-of-loss reinsurance that provides coverage against unforeseen or extraordinary losses to the insurer. For all but the largest primary insurers, a reinsurance-tied strategy is a prerequisite for offering insurance against hazards where there is the potential for catastrophic damage. An unusually severe set of claim payments can make even a well-capitalized insurer insolvent even if the firm is, on average, profitable. A natural disaster with intense local effects, such as an earthquake, thus raises problems for insurers who cover multiple customers in a given geographic area because of the high correlation among the losses in their portfolio.

If insurers were allowed to charge higher premiums on their own policies, many would need less reinsurance. Regulatory constraints in the United States, such as obtaining prior approval by the State Insurance Commissioner on rate changes, limit insurers ability to raise premiums to levels that they feel reflect the risk. For example, in Florida following Hurricane Andrew in 1992, there were restrictions placed on rates that could be charged on homeowners coverage (which covers wind damage) in areas of the State affected by hurricanes (Lecomte and Gahagan 1998).

Indexed Based or Parameterized Cat Bonds

In contrast to an indemnity contract where the entity providing protection (e.g. the reinsurer) can become insolvent if it suffers catastrophic losses, the firm does not face any credit risk from an indexed based cat bond. The money to pay for the losses is already in hand.¹² On the other hand, such a cat bond creates *basis risk*. Basis risk refers to the imperfect correlation between the actual losses suffered by the firm and the payments received from the cat bond. Insurance sold to firms or excess-of-loss reinsurance to insurers has zero basis risk because there is a direct relationship between the loss and the payment delivered by the reinsurance instrument.

¹² The investor's upfront investment is generally placed in a trust, and paid to the ceding company in the case of a triggering event. This implies that the ceding company is only able to reinvest proceeds from cat bond premiums in liquid securities at approximately the risk free rate.

6. AN ILLUSTRATIVE EXAMPLE

The framework depicted in Figure 1 and developed in more detail above is illustrated by turning to the city of Oakland, CA. Consider the DTE (Down to Earth) Insurance Company who is offering financial protection to residential property owners against damage from an earthquake in Oakland. DTE has a fixed book of business and wants to determine the impact of requiring a cost-effective mitigation measure on certain homes in the Oakland area so as to reduce the firm's claims payments following an earthquake. DTE also needs to determine the effect of purchasing indemnity contracts (e.g. reinsurance) as well as indexed cat bonds on both its profitability as well as insolvency probability should a severe earthquake occur. The loss EP curve enables one to examine the financial impact of these different strategies on DTE.

The DTE Insurance Company's Book of Business and Loss EP Curve

The DTE Insurance Company has a book of business (BOB), which consists of wood-frame homes in different parts of the city. DTE imposes a 10% deductible on its residential clients. Homes constructed prior to 1940 are assumed to have unbraced cripple walls (*i.e.*, the walls between the foundation and first floor diaphragm) and are inadequately bolted to the foundation. The damage to these homes from an earthquake in the future can be reduced if the cripple walls are braced and the structure is bolted adequately to its foundation.. The composition of the book of business by year of construction for the DTE Company is given in Table 1. Structures whose age was unknown are assumed to fall into the Pre-1940 or Post-1940 period with the same likelihood as for the known structures.¹³

Table 1: Composition of Book of Business for DTE Insurance Company

Year Built	Number of Structures
Construction Age Unknown	259
Pre-1940	3,091
Post-1940	1,650
Total	5,000

Table 2 specifies the parameters for the DTE insurance company. We assume that full insurance coverage against damage from the disaster is available, with a 10 percent deductible. The (annual) premium charged is proportional to the expected loss (per year) for the property covered¹⁴ and then multiplied by a loading factor (in this case 1.0) to reflect the administrative costs associated with marketing and claims settlement. In other words, for this analysis, property

¹³ Thus, 169 of the 259 unknown structures in DTE's book of business are assumed to be constructed prior to 1940 reflecting the ratio of pre-1940 to all known structures (3091/(1650+3091)) in their BOB. These 169 were therefore eligible for mitigation.

¹⁴ Expected loss to the insurer is defined as the probabilities of earthquakes of different magnitudes, each multiplied by the loss sustained minus the deductible and then summed.

owners are charged premiums that are twice the expected losses to the insurer. If DTE insured all 5,000 homes in Table 1 (*i.e.* had a full BOB) the premiums would be \$3.4 Million. A fixed cost of \$300,000 reflects insurance company payments (*e.g.* rent), which are independent of the number of insurance policies that are sold. DTE recovers its fixed costs within its premiums.

Table 2: DTE Insurance Company Parameters

Parameter	Value
Company Assets	\$ 4.5 Million
Deductible %: (expressed as a fraction of the value of property)	10%
Insurance loading factor:	1.0
Premiums For Full BOB	\$ 3.4 Million
Fixed Costs	\$300,000

Based on its concern with insolvency, DTE will want to limit the number of insurance policies that it writes in Oakland due to the high correlation among losses should a major earthquake occur in the area. More specifically, we assume that DTE focuses on worst-case losses in determining their book of business (BOB). A worst-case loss (WCL) is defined as a disaster where the probability of exceeding a certain dollar amount is at a predetermined target ruin probability, α^* , that reflects its safety-first concern.

The loss EP curve for DTE depicts the chances that aggregate claims exceed certain dollar magnitudes, based on earthquake damage to a set of insured structures in the company’s portfolio. If DTE offered other types of coverage, the loss EP curve could be expanded to these risks. For example, the loss EP curve could include commercial and other occupational building losses, as well as the loss of future economic activity due to business interruption or other disruptions (*e.g.*, water or electrical power outages).

Building Codes DTE could reduce its future claims by requiring, as a condition for insurance, that the owners of homes built prior to 1940 bolt their house adequately to its foundation and brace its cripple walls.¹⁶ In effect, DTE would be imposing a more recent building code on pre-1940 homes and would enforce it by refusing to issue insurance unless the measures were adopted. If banks required earthquake insurance as a condition for a mortgage, then DTE would have some leverage in making mitigation a requirement for coverage.

Reinsurance Turning to DTE’s concern with catastrophic losses from earthquakes, it will purchase an excess of loss reinsurance contract that has an attachment point (L_A) where there is a

¹⁵ See footnote 2 for definition of expected loss.

¹⁶ These mitigation measures have been shown to be cost-effective for homes of this type given the range of earthquakes that are possible in Oakland, CA.

4 percent chance that the losses will exceed this amount when there is no mitigation in place. The exhaustion point (L_E) is determined so that the chances of DTE's losses exceeding this amount is 3 percent when no pre-1940 homes are mitigated. More specifically DTE's reinsurance contract has a value of $L_A = \$5.93$ million and $L_E = \$8.27$ million. DTE must pay a premium that reflects the risks that the reinsurer faces plus a loading factor of 100 percent. Thus if the expected losses to the reinsurer over the interval $L_E - L_A$ was \$40,000 then DTE would pay the reinsurer \$80,000 in premiums.

Catastrophe Bonds--- Insurers can issue a parameterized indexed cat bond where they would receive payments according to a predetermined measurement schedule. More specifically DTE issues a catastrophe bond that pays investors an interest premium in exchange for guaranteed funds based on the occurrence of a disaster of a given intensity or magnitude. The amount of funds given to the insurer is based on an index (e.g. an earthquake of 7.5 on the Moment Magnitude scale) so it likely will not be perfectly correlated to actual claim payments.

Suppose that DTE issues a \$10 million Total Face Value cat with a 10% annual coupon. If the risk-free interest rate (LIBOR) is 5.5% then the spread above this rate for this cat bond is 4.5% (10%-5.5%). At the beginning of the year DTE will receive \$10 million from investors and immediately reinvest this amount in a risk free investment earning \$550,000 (i.e., 5.5% x \$10 million). Insurers will pay investors guaranteed coupon payments of \$1 million (i.e., 10% x \$10million) so that the price to the insurer for interest rates over LIBOR is \$450,000 (\$1million-\$550,000)

Table 3 depicts the structure of two different cat bonds for Oakland depending on whether or not a building code was in place. When there were no pre-1940 homes mitigated, then the total face value of the cat bond was \$30 million and the price to the insurer for a higher interest rate than LIBOR was \$1.34 million. When homes were mitigated then the insurer only required a cat bond with face value of \$18.5 million, since catastrophic losses were reduced. As shown in the payout schedule for the cat bonds, when there was no mitigation in place insurers would receive \$29.196 million if an earthquake occurred in Oakland that had a magnitude between 7.0 and 7.5 on the MMI scale. Interestingly enough the payout was only \$1.058 million when earthquakes greater than 7.5 registered on the scale. The smaller figure was due to the relatively few residential structures in those portions of Oakland where earthquakes of this magnitude or greater could occur.

Table 3 Structure of Cat Bond for Oakland
(All Dollar Amounts in US\$ Thousands)

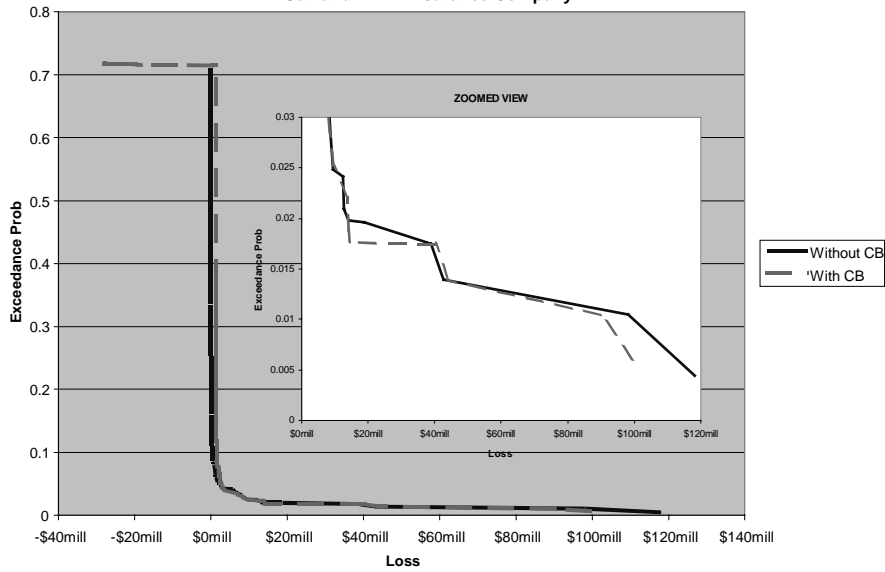
Parameters	0% Mitigation	100% Mitigation
<i>Total Face Value</i>	\$30,000	\$18,500
<i>Price to Insurer over LIBOR</i>	\$1,342	\$832
<i>Cat Bond Return to Investor</i>	9.97%	10%

<i>Magnitude of Quake</i>	<i>Probability</i>	0% Mitigation Payout to Insurer	100% Mitigation Payout to Insurer
< 7.0	98.0%	\$0	\$0
[7.0-7.5]	1.8%	\$29,196	\$18,279
[7.5-max]	0.2%	\$ 1,058	\$ 203

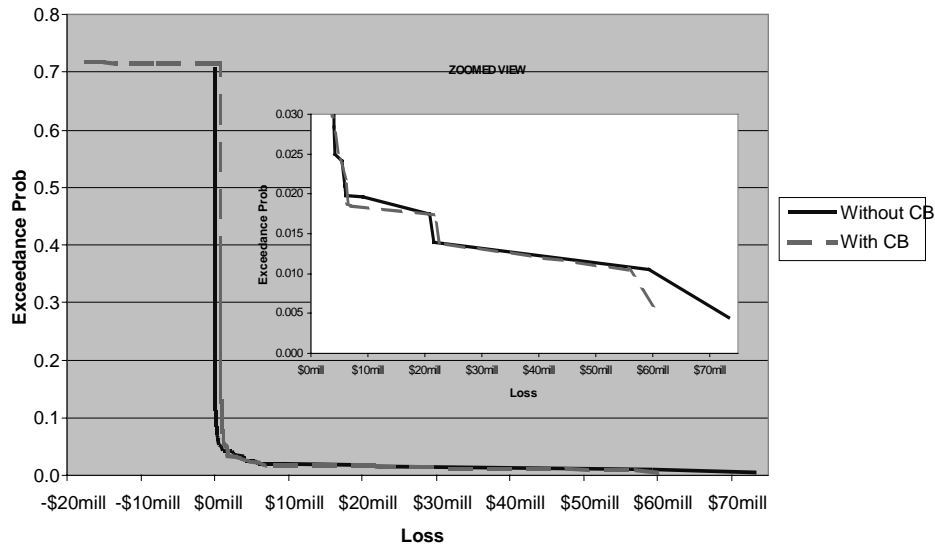
Performance of Alternative Risk Management Strategies There are eight different strategies which could be undertaken by DTE using the above three policy tools depending on whether or not one had well-enforced building codes, reinsurance and cat bonds in place.¹⁸ Building codes and cat bonds will lower the exceedance probability curves for DTE from the strategy of no building code and no available cat bonds. Building codes reduce the damage to pre-1940 homes from earthquakes. Cat bonds provide insurers with pre-determined payments as a function of the magnitude of the earthquake and independent of the actual damage. Hence they will reduce the losses over what they otherwise might have been. Insurers have to pay for this protection in the form of interest rates substantially above LIBOR. Figure 4a depicts the EP curves with and without cat bonds when **no** mitigation is in place for pre-1940 homes. Figure 4b examines the EP curves with and without cat bonds when a building code is in place for pre-1940 homes.

¹⁸ These eight strategies reflect the eight possible combinations of the 3 different policy tools (building codes/no building codes; reinsurance/no reinsurance; cat bonds/ no cat bonds). For example one strategy would be Building codes, reinsurance, no cat bonds.

**Figure 4a: EP Curves Without Mitigation, With and Without Cat Bond, 10% Deductible
Oakland: DTE Insurance Company**



**Figure 4b: EP Curves With Mitigation, With and Without Cat Bond, 10% Deductible
Oakland: DTE Insurance Company**



The analyses of the performance of the impact of mitigation, reinsurance and cat bonds on the DTE Insurance Company in Oakland reveals some interesting findings as shown in Table 4

Table 4: Summary of Results:
DTE Insurance Company
Oakland

	0% Mitigation			
	w/o Reinsurance		w/ Reinsurance	
	<i>w/o Cat Bond</i>	<i>w/ Cat Bond</i>	<i>w/o Cat Bond</i>	<i>w/ Cat Bond</i>
Insolvency Prob	3.19%	2.87%	2.44%	2.22%
Expected Profit	\$1,680	\$898	\$1,604	\$822
Worst Case Loss	(\$114,660)	(\$96,173)	(\$112,468)	(\$93,981)

	100% Mitigation			
	w/o Reinsurance		w/ Reinsurance	
	<i>w/o Cat Bond</i>	<i>w/ Cat Bond</i>	<i>w/o Cat Bond</i>	<i>w/ Cat Bond</i>
Insolvency Prob	1.98%	1.89%	1.98%	1.76%
Expected Profit	\$954	\$473	\$905	\$424
Worst Case Loss	(\$71,449)	(\$58,254)	(\$69,990)	(\$56,794)

Impact of Mitigation An analysis of the expected loss reduction for Oakland reveals that bracing the crippled wall and bolting pre-1940 houses to their foundation is a cost-effective RMM. For very severe earthquakes in Oakland this mitigation measure reduces the worst case losses (WCL) by approximately 40% whether DTE purchases reinsurance and/or cat bonds. It also reduces the insolvency probability to below 2% whether or not reinsurance and cat bonds are in place

Impact of Reinsurance As expected, reinsurance reduces the insolvency probability of DTE but its expected profits are also reduced because DTE is assumed to have 100 percent BOB. If the insurer were able to write more coverage because it had reinsurance, then profits could actually be higher. In other words, the reinsurance would expand the insurer's capacity.

Impact of Cat Bonds Turning to the impact of cat bonds on the insolvency and profitability of DTE, we obtain the following results, Cat bonds reduce the insolvency probability by almost 0.2 percent when there is no reinsurance or mitigation in place and reduced the insolvency probability only by 0.1 percent when both reinsurance is purchased and mitigation is in place. Cat bonds reduced WCLs by about \$20 million with no mitigation and by about \$10 million with mitigation. However, the cat bonds also reduced the profitability of the insurer so that they may not be very attractive to them at the current price.

7. CONCLUSIONS

This paper stresses the importance of private insurance as a catalyst for reducing losses in the future and covering much of the losses from catastrophic risks such as natural disasters. Such a strategy takes advantage of recent developments in information technology and the emergence of new capital market instruments to deal with non-diversifiable catastrophic risks. These two major changes open up opportunities for residents and firms to undertake cost-effective loss protection measures, while at the same time providing a financial cushion to insurers concerned with the possibility of insolvency. Insurers should thus be able to play a more important role in the future in helping to manage catastrophic risks.

A combination of building codes, reinsurance and indexed cat bonds can form a useful strategy for reducing losses to property owners as well as insurers and the investment community. The success of a disaster management program requires the active involvement of a number of interested parties from the private sector such as insurers, banks and financial institutions, realtors, and builders and contractors. For example, the implementation of mitigation measures requires inspections by certified personnel. Banks and financial institutions can play a role in this process by making their mortgage and related loans conditional on such an audit. Insurers can offer lower premiums for those adopting these mitigation measures. It also requires that government officials enforce building codes.

With new sources of capital from the Bermuda market, there is an opportunity for reinsurance to provide more protection against insurers' potential losses. The actual demand for such coverage will depend on the cost of the reinsurance relative to other forms of protection. With respect to new financial instruments, the interest rate on cat bonds has to be sufficiently low so that insurers will want to issue them but high enough for investors to want to purchase them.¹⁹ We discuss ways that this might occur in the next section of the paper

One also needs to determine what the appropriate role of the public sector is in providing financial protection against large losses. Public sector agencies have a role in providing assistance to low-income families so that they can adopt cost-effective mitigation measures, and so that they can recover after a disaster. The government may want to provide catastrophic reinsurance to insurers if the private sector does not offer sufficient coverage.

The reluctance of the insurance industry to cover losses from earthquakes in California led to the formation of the California Earthquake Authority which is a state-run insurance company funded by the insurance and reinsurance industry will limited liability.²⁰ Lewis and Murdoch (1996) 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 reinsurance protection against catastrophic losses. Private insurers would build up the fund by being assessed premium charges in

¹⁹ See Bantwal and Kunreuther (2000) for some of the reasons why cat bonds are priced as high as they are today.

²⁰ See Roth, Jr. (1998) for a more detailed discussion on the formation and status of the California Earthquake Authority.

the same manner that a private reinsurance company would levy a fee for excess-loss coverage or other protection. The advantage of this approach is that resources at the federal government's disposal enable it to cover catastrophic losses without charging insurers the higher-risk premium that either reinsurers or capital market instruments would require.

One way of developing the specifics of such a catastrophic risk management program involves analyzing the impact of disasters of different magnitudes on property and infrastructure. Long-term simulations could help in estimating expected losses from these events and in projecting the maximum probable losses arising from worst-case scenarios. In order to undertake these simulations one needs to determine exceedance probability (EP) curves based on risk assessments of the particular hazard.

By constructing simulations of large, medium, and small *representative* insurers with specific balance sheets, types of insurance portfolios, and premium structures, one could examine the impact of different events on the insurers' profitability, solvency, and performance under different scenarios regarding future losses. This simulation exercise would enable one to evaluate how mitigation measures and the provision of funds against catastrophic losses by reinsurers and the capital markets affect insurers' profitability and likelihood of insolvency. 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 (1999b).

Such an analysis may also enable one to compare how index-based cat bonds perform relative to indemnity instrument, such as reinsurance, for different types of insurers who have specific risks in place. The data from the simulations could also be used to determine the return an investor would require to provide capital for supporting each instrument. The selling prices of different types of capital market instruments would reflect both the expected loss and variance in these loss estimates to capture risk aversion by investors.

This type of simulation modeling must rely on solid theoretical foundations in order to delimit the boundaries of what is interesting and implementable in a market economy. Such foundations will also apply to research on the traditional issues of capital markets and the insurance sector, and to research on the processes by which insurance and reinsurance companies, public officials, and property owners determine levels of mitigation, insurance coverage, and other protective activities. In the area of catastrophic risks, the interaction of these decision processes, which are central to the outcome, seem to be considerably more complicated than in other economic sectors, perhaps because of the uncertainty and ambiguity of the causal mechanisms underlying the events themselves and their mitigation.

Finally, public sector damage from catastrophic events such as natural disasters often results in a substantial cost to taxpayers. Government officials should be encouraged to purchase insurance for public structures and invest in cost-effective mitigation measures. With respect to natural disasters one way to do this is to change legislation so that recovery funds would not be available unless municipalities implemented cost-effective mitigation measures. Another alternative is to levy property taxes on all community residents to cover losses to public structures from

catastrophic losses. This is a form of community-based insurance, with all residents paying a share in proportion to the value of their property.

7. FUTURE RESEARCH DIRECTIONS

The methodology described above for utilizing financial instruments and mitigation to reduce future disaster losses and providing protection form the basis for future research in this area. Several extensions of the analysis are discussed below.

Cat Bonds Covering Multiple Risks

There is no reason why an indexed or parameterized contract has to be restricted to a single hazard in a single region (*e.g.* an earthquake in Oakland). By constructing a cat bond that combines several uncorrelated hazards, the risk is diversified. Insurers can clearly profit from improved exposure management which geographical diversification brings. Investors in cat bonds also profit since they have a smaller chance of losing a given amount of principal if the maximum amount that the bond pays out is now spread across the uncorrelated risks in different regions or across different types of hazards.

Recently, there have been two such parameterized cat bonds issued. SCOR, the French reinsurer, issued a three year multi-peril bond that covers Japanese earthquakes and fires following an earthquake in Japan, U.S. earthquakes on the mainland and European windstorms in seven different countries (Standard & Poors 2000). In November 2000, the Assurances Generales de France issued a five year parametric cat bond that covers earthquakes causing damage in Monaco and windstorms in continental France or Corsica.

The Wharton Catastrophic Risk Management project is planning to examine multi-peril cat bonds. An example would be a bond covering the DTE company's losses to its portfolio of homes due to earthquake damage in both Oakland and Long Beach, California, as well as hurricane damage in Miami/Dade County, Florida. In this way, there is cat bond protection that covers the potential losses in the three regions. We will want to determine the impact of such a parametric cat bond on the reduction in insolvency probability and profitability of the insurer as well as the risk to the investor. Preliminary results suggest that as one diversifies across areas, the price of the cat bond will decrease substantially for the same protection to the insurer.

Cat Bonds for Weather Risk Transfer

Companies that are in weather-sensitive economic sectors such as energy have recently become interested in protecting themselves against the effect of temperature volatility on their business by transferring some of this risk through cat bonds. The first direct access of the capital markets by a corporation seeking weather risk transfer was with Koch Industries. Depending on the daily temperature at 19 U.S. locations, Koch will receive funds from Kelvin Ltd., a special purpose company domiciled in the Cayman Islands. The two largest components of the exposure are extreme cold in the Northeast during the winter and extreme heat in the south during the summer that affects Koch's energy and agricultural businesses.

The Wharton Cat Risk Management Project is extending the analyses of cat bonds for natural hazards to the general area of weather risk transfer. The basic methodology described above applies, with EP curves playing a central role in integrating science, risk quantification and financial variables. In particular, the events and losses in this case would be those associated with weather-specific events.

Mitigation and Risk Transfer Instruments for Hazards in Emerging Economies

The Wharton Catastrophic Risk Management project plans to extend its research activities to emerging economies. A step in this direction was taken in June 2000 when a group of researchers from Turkey and the United States met at a NATO workshop in Istanbul to begin planning a multi-year study of natural hazards management. The focus will be on Istanbul, Turkey.²¹

The project will examine the nature of the uncertainties surrounding risk estimates and the needed data and infrastructure to support this analysis. This research should enable us to gain further insight into how mitigation coupled with financial instruments can reduce losses and provide funds for recovery from a mega-disaster in an emerging economy. Although the focus is on the earthquake hazard, the concepts will be applicable to other natural hazards that have catastrophic potential, such as floods and hurricanes.

The research will address the following three broad questions:

How can one incorporate risk assessment methodologies constructing EP loss curves and appropriate confidence intervals surrounding these estimates?

What role can mitigation measures and risk transfer instruments play in reducing losses from future disasters and providing funds for recovery?

How can one utilize model cities for evaluating the linkages between risk managements strategies such as investments in risk reduction (mitigation) and risk transfer (new financial instruments) for dealing with large-scale disasters?

Istanbul, Turkey is representative of many metropolitan areas in emerging economies and has the potential for severe losses should another major earthquake occur in the future. The Kocaeli earthquake in August 1999 caused over 19,000 confirmed fatalities with a total economic loss estimated to be at least \$15 billion. There is a recognized need for developing new risk transfer mechanisms given the limited role that insurance has played up-to-date in post-disaster funding. For example, after the recent Kocaeli earthquake, out of the 500,000 housing units that were adversely affected, only 1000 were privately insured.

²¹ For more details on the NATO Workshop, see Kleindorfer (in press).

This research should enable one to examine the impact of different risk management tools for mitigation and recovery as a function of the institutional arrangements within the city and country. Here are some more specific questions we will want to address:

How will the efforts of mitigation perform in Istanbul under earthquakes of different magnitudes? Are there lessons with respect to mitigation measures and building code enforcement in U.S. that are relevant to Istanbul?

What is the performance of different financial instruments given earthquakes of different magnitudes? Given that Istanbul does not have a well-developed insurance industry, it will have to rely primarily on financial instruments and governmental risk-bearing and disaster relief for dealing with future losses in the short run.

What are the lessons from Turkey that may be transferable to other emerging economies in financing recovery from catastrophic losses?

What can we learn from this exercise that could be helpful to U.S. funding agencies, relief agencies and other governmental and non-governmental organization that may have an interest in protecting the viability of emerging economies as a market to the U.S. economy?

Application to Other Low Probability-High Consequence (LP-HC) Events

The framework for analysis and the proposed strategies apply to other hazards and to firms and organizations that are concerned with managing LP-HC events. They could be applied to the following situations:

- The impact that weather patterns could have on the profitability of firms
- The impact that industrial accidents (*e.g.* chemical releases, fires) could have on the future operation of the affected companies
- The impact that environmental incidents (*e.g.* soil contamination from a leaking underground storage tank) could have on the liability of a firm and its future balance sheet
- The impact of economic fluctuations on defined asset bundles such as leased vehicle fleets and credit risks

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