MANAGING CATASTROPHIC RISKS THROUGH INSURANCE AND MITIGATION

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I. INTRODUCTION

Insurance is the only policy tool in the analyst's repertoire that can reward individuals for taking loss reduction measures in advance of a disaster by giving them lower premiums while at the same time providing these same policyholders with compensation should they suffer losses from the insured event. In theory insurers could refuse to provide coverage against certain events unless the prospective policyholder undertook certain protective measures to lower the potential losses from the risk in question. Although this was common practice with respect to fire coverage in the 19th century, insurers have been reluctant to do deny coverage on these grounds today.

This paper examines the impact the role that insurance and other policy tools can play in encouraging property owners to take steps to reduce losses from natural hazards such as earthquakes, floods and hurricanes and the impact that these measures will have on the solvency of insurers Three basic questions will be addressed in this regard:

(1) What are the necessary and sufficient conditions for property owners to want to adopt cost-effective risk mitigation measures (RMM)s?

(2) What impact will mitigation measures have on the profitability and insolvency of insurers and their willingness to pass the expected reduction in losses to property owners?

(3) What is the appropriate role of building codes, third party inspections and enforcement mechanisms in encouraging the adoption of mitigation measures on property?

The next section of the paper focuses on the demand side by developing a simple model for determining when property owners should adopt cost-effective measures and provides empirical evidence as to why most individuals do not utilize this model. Section III turns to the supply side and investigates under what conditions insurers will want to promote mitigation through premium reductions. It also explores the linkage between mitigation and insurers' need for financial protection through reinsurance and/or capital market instruments that have recently been introduced. The importance of building codes as a necessary means of enforcing mitigation in a hazard management program is examined in Section IV. The concluding section proposes a plan of research for evaluating the importance of insurance coupled with mitigation and other policy tools for reducing future disaster losses.

II DEMAND FOR MITIGATION MEASURES BY PROPERTY OWNERS

Investments in RMMs involve an upfront cost in exchange for a stream of benefits accruing over time in the form of reduced expected losses. For example, if one were to brace the concrete foundation of ones house it might cost the property owner $1500. Should an severe earthquake occur in the vicinity of the property the damage might be reduced by $20,000 if the house is prevented from toppling off its foundation. These expected benefits accrue over the lifetime of the property.

Theoretical Analysis

Discounted utility theory introduced by Samuelson (1937) and derived axiomatically by Koopmans (1960) has been the dominant approach for modeling such intertemporal problems when future outcomes are known with certainty. The basic concept is that people act as though they utilize an exponential discount function for evaluating a sequence of deterministic outcomes in each period *t [x(t)]* over a time horizon of T periods. For investments in RMMs when outcomes are specified by a probability distribution, individuals must decide how much money to expend money today to reduce the consequences over a T period horizon where there is a probability p_i of outcome $x_i(t)$, i=1...n occurring in any period $t \in T$ assuming a discount rate of r (e.g. r=.10). Appendix 1 develops a more formal model indicating how much an individual is willing to pay for an RMM if her objective is to maximize discounted expected utility.

To illustrate the tradeoffs that a property owner is willing to make in determining how much to invest in an RMM, suppose that the cost of bracing the concrete foundation of your house is $1500. The reduction in damage to the house if it does not topple off its foundation is $20,000. The RMM reduces the annual probability of an earthquake causing the structure from toppling off its foundation from p_i = 1/20 to p_i^* = 1/40. If the individual is risk neutral, the expected annual benefits of the RMM is (1/20-1/40) $20,000 = $500. If the homeowner expects to live in the property for a 10 year period and has a discount rate of r, then the discounted expected benefits for this measure is $\sum_{t=1}^{10} \$500/(1+r)^t$. Table 1 shows the maximum willingness to pay (WTP) as the time horizon changes from 1 year to 20 years and the discount rate (r) is either 10% or 20%. As one can see a person is willing to pay $500 if she only considers the benefits for 1 year; the amount rises to $4682 if the time horizon is 20 years and the discount rate is 10%. Note that these dollar figures are based on an assumption that the investment in an RMM is **not** capitalized in the value of the house.

INSERT TABLE 1 HERE

Experimental Data

To determine how much an individual is willing to pay for a protective measure we conducted a set of controlled experiments in Pennsylvania and California. (Kunreuther, Onculer, and Slovic 1997). Subjects were asked to specify the maximum they were willing to pay for bracing the concrete foundation of their house if they plan to live in the house for exactly 5 years. They were then asked to specify a maximum WTP if the expect to live in the house for exactly 10 years. Table 2 presents the distribution of these WTP figures for 84 students at the University of Pennsylvania, half of whom were not given a cost of this measure and the other half of whom were given a price of $1500 for the RMM.

INSERT TABLE 2 HERE

The data reveal that only 12 percent of the individuals would be willing to pay over $2000 for the measure if the price was not given and they expected to live in the house for 5 years. The proportion in this category increases to 18% for the group who were given a price of $1500. In other words, a relatively small proportion of subjects based as if they made decisions based on benefit-cost comparisons using a reasonable discount rate. More specifically Table 1 indicates that a risk-neutral person should be willing to pay as much as $2,085 if their discount rate was 10 percent and they expected to live in their house for 5 years. When the time horizon is lengthened to 10 years the maximum WTP from Table 1 with r=10% increases to $3,380. Yet only 7% of the subjects who were not given the price chose to spend more than $3,000; the percentage jumps to 17% for the class when the price was given at $1,500.

The comparative data on different time horizons (5 years and 10 years) enables one to determine the discount rate implied by the difference in subjects' maximum WTP. For example, if a person expects to live in the house for 10 years then Table 1 suggests they should be willing to pay almost $1300 ($3380- $2085) for the RMM if their discount rate was 10%. If the difference between the two prices was somewhat less than this amount, then the implied discount rate would be higher than 10%.

Table 3 depicts the implied discount rates for the cases where either the price of the RMM was not given and when it was given to the students. The data provide a very clear picture of three types of individuals for either design condition. One group (approximately 14%) exhibits behavior which suggests that they utilize reasonable discount rates ($r \leq .20$) in their decision on how much to pay for RMMs. There is then a gap between $.20 < r < .50$ and another group (between 48% and 50%) whose WTP implies discount rates greater than .50. Finally approximately 1/3 of the respondents do not change their maximum WTP at all, despite a doubling in time horizon. About half of the individuals in this group, labeled as "infinite" in Table 3, increase their probability of undertaking the RMM as T increases from 5 to 10 years; the other half do not change either probability of purchase and maximum WTP amounts.

INSERT TABLE 3 HERE

A survey of 252 individuals visiting the Exploratorium museum in San Francisco provide confirming evidence for the above experiment. Now three different time horizons were utilized for obtaining the maximum WTP when the price of the quake measure was given at $1500. As shown in Table 4 only 14% of the respondents exhibited behavior consistent with reasonable discount rates when T was extended from 5 to 10 years; the percentages increase to over 25% when the horizons were lengthened from 10 to 20 years and from 5 to 20 years. As in the earlier experiment a significant proportion of the respondents had either high discount rates (the mean value of r varied between .67 and .74 depending on the values of T). The last columns in Table 4 indicate that a significant number of individuals did not change their maximum WTP as the time horizon was increased. For the case where the length of time in the house was extended from 5 to 10 years, 45 percent of the subjects maintained the same price for the protective measure. (Kunreuther, Onculer and Slovic 1997)

INSERT TABLE 4 HERE

These high discount rates are consistent with empirical findings from Lowenstein and Prelec (1992) when the outcomes are known with certainty. In addition, they imply that when the future benefits are uncertain then there is a significant group of individuals who are not willing to change the maximum price they are willing to pay for the measure even when T changes either because they cannot afford to pay more and/or they are myopic.

Empirical Data

The empirical data on studies of mitigation adoption in hazard-prone areas of the United States provide additional confirming evidence on this point. Even after Hurricane Andrew in Florida in 1992, the most severe disaster in the United States, most residents in hurricane-prone areas along the Atlantic and Gulf Coasts appear not to have made improvements to existing dwellings that could reduce the amount of damage from another storm. A July 1994 telephone survey of 1241 residents in six cities revealed that 37 percent of those interviewed indicated that they had made some improvement to their residence. (Insurance Institute for Property Loss Reduction 1995). Studies of the added costs of materials and labor for hurricane-resistant designs have indicated that it will add no more than 4-5 percent to the cost of a new home and that this additional expense is not substantial relative to the added benefits of safety and security (Unnewehr 1994).

With respect to investing in RMMs to reduce quake damage, a 1989 survey of 3,500 homeowners in four California counties subject to the hazard, damage, only between 5 and 9 percent of the respondents in each of these counties reported adopting any LRMs (Palm et. al. 1990). A follow-up survey of residents affected by the October 1989 Loma Prieta earthquake by Palm and her colleagues 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).

III ENCOURAGING MITIGATION BY INSURERS

Historical Perspective

Loss prevention has long been an important part of the insurer's mission to provide protection against risk. The best example of using insurance as a viable means of reducing risk and providing compensation after a loss comes from the factory mutual insurance companies founded in the early 19th century in New England. The mutuals required inspections of the factory both prior to issuing a policy and after one was in force. Poor risks had their policies canceled; premium reductions were given to factories that instituted loss prevention measures.

As the mutual companies gained experience with fire risks they set up research departments to determine what factors caused fires and how they could prevent them. For example, the Boston Manufacturers worked with lantern manufacturers to encourage them to develop safer designs and then advised all policyholders that they had to purchase lanterns from those companies whose products met their specifications. In many cases, insurance would only be provided to companies that adopted specific loss prevention methods. For example one company, the Spinners Mutual, only insured risks where automatic sprinkler systems were installed. The Manufacturers Mutual in Providence developed specifications for fire hoses and advised mills to buy only from companies that met these standards. (Bainbridge 1952).

Until recently insurers have not actively promoted the use of mitigation measures for reducing losses from natural disasters. Uniform premiums were generally specified for certain types of structures in hazard-prone areas without incentives to property owners such as lower premiums and/or lower deductibles to encourage them to adopt these measures. For example, in Australia no account has been taken of differing vulnerabilities to the hazards of particular buildings so that the good risks were expected to subsidize the bad risks. (Walker 1996). In New Zealand the Earthquake Commission and its predecessor charged the same blanket rate for earthquake coverage for all buildings despite the fact that there were major improvements in the earthquake resistance of buildings constructed since the 1970s. (Walker and Fipenz 1997).

Insurers in the United States have not provided financial incentives for homeowners to mitigate their structures. In fact, due to regulatory rate restrictions in the United States, rates of been subsidized in hazard-prone areas such as the coast of Florida. (Klein 1997). The combination of uniform rates across structures with premiums below actuarially fair levels in high hazard areas has a twofold negative impact on the need for mitigation: the level premium implies that RMMs produce no benefits and the subsidized rate provides incentives for a property owner to buy insurance protection which reduces their need for mitigation since they are covered by insurance should a disaster cause damage to their structure.

Three major developments in the past 10 years have changed the insurance industry's attitude toward mitigation. First, there have been increasing catastrophic losses from natural disasters in recent years so that companies now recognize that they will have to turn to mitigation to reduce their chances of insolvency from future catastrophic events. Prior to 1988 the insurance industry worldwide had never experienced a loss great than $1 billion from a single event. Since that date, 15 disasters have exceeded this figure and are likely to be considerably higher in the future. (Kunreuther and Roth in press). Studies have estimated that 25 percent of the insured damage from Hurricane Andrew (which totalled more than $15 billion) could have been prevented had building codes been enforced (Insurance Research Council and Insurance Institute for Property Loss Reduction (1995)

The second development has been the new advances in information technology (IT) and risk assessment which enable insurers to estimate the chances and potential losses of future disasters and catastrophic events more accurately than in the past and reward those who adopt mitigation measures with lower premiums . On the IT side, the development of faster and more powerful computers enables one to examine extremely complex phenomena in ways that were impossible even five years ago. Scientific advances in risk assessment have reduced the uncertainty associated with predicting the chances and consequences of these LP-HC events. Insurers and reinsurers are now developing strategies for managing their portfolios, which now includes mitigation, so as to avoid sufficiently large losses which cause an unacceptable loss of surplus (Insurance Services Office 1996).

A third development has been the formation of the Insurance Institute for Property Loss Reduction (IIPLR), an independent, nonprofit organization formed by the property-casualty insurance industry to encourage actions which reduce deaths, injuries, property damage and economic losses from natural disasters. IIPLR has supported a number of studies for evaluating mitigation measures for reduces damage to property from floods, earthquakes and hurricanes. It was a driving force behind the creation of the Building Code Effectiveness Grading Schedule (BCEGS). This rating system, administered by the Insurance Services Office measures how well building codes are enforced in communities around the United States. IIPLR has also established partnerships with other organizations, such as the Federal Emergency Management Agency and the United States Geological Survey, to encourage mitigation (Insurance Institute for Property Loss Reduction 1997).

Theoretical Treatment

There is good reason for the insurance industry to actively promote mitigation today given their concern with the possibility of insolvency from future disasters. The tension that insurers face is how to reflect the reduced risks of losses through reduced premiums to property owners in the face of regulatory restrictions on how much they can charge and to whom they must provide coverage. We will illustrate these points by constructing a hypothetical example which illustrates the potential benefits of mitigation for large and small insurers with and without reinsurance as a function of the demand for coverage. A more formal model illustrating the tradeoffs appears in Appendix 2.

Consider an insurer who provides coverage for a single type structure (e.g. a concrete home) and faces a loss (L') if a risk mitigation measure is adopted and a loss (L">L') if it is. For this example, L' =$200,000 and L"= $250,000 so the RMM reduces damage by $50,000 should a quake occur. The insurer estimates the chances that an earthquake will occur in the region and damage any given insured property to be p = 1/100. Based on this information the insurer can calculate the expected loss for a structure with mitigation [E(L')= 1/100 ($200,000) =$2000] or without mitigation [E(L")= 1/100 ($250,000) =$2500]. In other words the expected annual benefit from mitigation is $500.[1]

Suppose that an insurer has written N=100 earthquake policies on this type structure in a given region of the country and has calculated the probability that n or more homes will be damaged by the quake give there is not a perfect correlation between losses. Table 5 provides the relevant annual probabilities and respective values of L" and L' for 0 to 8 losses for the case where an insurer has written N= 100 earthquake policies.

INSERT TABLE 5 HERE

The insurer's objective is to set premiums so as to maximize expected profits subject to an insolvency constraint. Stone (1973) formalized these concepts by suggesting that an underwriter who wants to determine the conditions for a specific risk to be insurable will first focus on keeping the probability of insolvency (q) below some threshold level (q*). For this illustrative example suppose that q*= 1/100. The question which the insurer must address is what premium to charge the property owner to encourage her to adopt mitigation with a clear objective of maximizing expected profits while still meeting its insolvency constraint.

Behavior by Large Insurers To begin the analysis consider the large insurer who has enough initial capital and premium income so it is not concerned with the insolvency constraint. Let S_L represent the large insurer's initial surplus and premium income from charging the actuarially fair premium without mitigation. In the context of the data in Table 5 suppose that S_L= $1.2 million.. In this case the insurer will still have positive capital on hand unless it suffered more than four losses when mitigation is not adopted. The probability of this happening is 1/125 so that the insurer has satisfied its insolvency constraint since q*=1/100.

For this reason the insurer's sole objective is to maximize expected profits. It has no desire for reinsurance since it not concerned with reducing the chances of insolvency. Suppose the insurer has the freedom to charge whatever rate the market will bear. In a purely

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[1] Note that the $500 saving from mitigation is identical to the one in the example above except that in this case the probability of damage from a quake is lower (1/100 rather than 1/40) and the actual savings should a quake occur higher ($50,000 rather than $20,000)

competitive market, where premiums reflect actuarial costs and there are no administrative charges, this implies that the insurer will charge a premium $P' = E(L') = \$2000$ if mitigation is adopted and $P'' = E(L'') = \$2500$ when mitigation is not utilized.

Suppose that a property owner has purchased coverage at the actuarial rate when no mitigation is in place. Let M be the maximum premium that the property owner will pay and still be willing to adopt mitigation. If $M > P'$, then the insurer will offer a policy with mitigation where the premium will range between P' and M depending on the degree of allegiance the customer has to its current company. If customers are reluctant to search for other insurance companies due to high transaction costs, then the price of insurance with mitigation will be closer to M. When search costs are low, the insurer will charge a premium closer to P' so as not to lose its customer base. Thus if $M = \$2200$ insurers will offer policies for mitigated homes that range from \$2000 to \$2200.

One of the great benefits of mitigation is a reduction in q. Specifically, if the large insurer was able to encourage all its customers to adopt an RMM, and had $S_L = \$1.21$ million then from Table 5, its probability of insolvency with mitigation is seen to be $q = 1/180$ since it can now absorb six losses rather than only four. From an insurer's vantage point mitigation truncates the worst case scenarios by reducing the losses on individual structures.

Suppose the large insurer was forced to provide insurance to its 100 policyholders at a premium (P_R) below the actuarial cost but still had enough surplus on hand to satisfy the insolvency constraint. Now its attitude toward providing premium reductions for mitigation will be somewhat different than when it had the freedom to charge whatever rate it desired. Since the insurer is losing money on each of these policies (in an expected value sense) it will only provide limited (if any) premium reductions for mitigation if homeowners were **required** to adopt these measures. For example, if $P_R = \$2300$, then the maximum premium reduction the insurer would provide would be \$300 to reduce the cost to the policyholder to $P' = \$2000$. If $P_R < \$2000$ then in this case the insurer would provide **no** premium reduction since it would still be losing money on this property even if mitigation were adopted.

On the other hand, if the property owner was **not required** to adopt a mitigation measure, then the insurer would want to encourage him with some premium reduction as long as it was forced to provide coverage. In fact, to minimize its expected loss the large insurer would be willing to reduce the premium by as much as $P'' - P' = \$500$. Of course, the insurer would only provide this incentive to its existing policyholders. The firm would refuse any new clients unless they adopted mitigation and in this case would charge them at least \$2000 for a policy.

Behavior By Small Insurers We define a small insurer to be an entity where the insolvency constraint is binding so that it is forced to sacrifice some expected profits to make sure that q=q*. One way of viewing the concern with q* of these insurers is that a regulatory authority requires them to show that they have enough surplus on hand to be solvent in case of unexpected losses.

As we will see below, the concern with meeting insolvency conditions may help explain the very high price that some insurers are willing to pay for reinsurance. Let S_S represent the surplus of the small company. Now consider the Smally Company with surplus S_S= $700,000 based on initial surplus (A_S =$450,000) and premium income of $250,000 based on selling 100 earthquake policies at premium P"=$2,500 with no mitigation in place . If Smally has to maintain its current portfolio, then it will not meet its insolvency constraint. More specifically we see from Table 5 that should it suffer 3 quake losses, it will have claims totalling $750,000 which exceeds S_S by $50,000. The probability of suffering 3 or more losses is q= 1/80 > q*=1/100. By turning to the reinsurance market for an excess loss treaty, Smally can lay off some of its claims and would be willing to pay a relatively price to do so.

Suppose that Smally negotiated an excess of loss treaty with a reinsurer for $250,000 excess of $500,000 to cover the costs of the third loss should an earthquake occur.[2] This type of treaty arrangement would reduce its probability of insolvency from q=1/80 to q=1/00, thus satisfying the regulator's concern with insolvency. Two questions naturally emerge: (1) How much would the reinsurer want to charge for such a policy based on actuarial principles? and (2) How much could the reinsurer charge Smally for such a policy based on Smally's concern with insolvency?

The first question can be answered using the actuarial data from Table 5. The reinsurer is only concerned with the probability of Smally suffering three or more losses, in which case it will have to pay Smally $250,000. The probability of such an event occurring is p=1/80. Hence the actuarially fair reinsurance premium is R= 1/80 ($250,000) = $3,333. Smally, on the other hand, is willing to pay considerably more for such a policy to meet its insolvency constraint. Specifically, with S_S =$700,000 it will theoretically be willing to pay up to $200,000 for such a policy, as shown in Appendix 2. Even with such a high reinsurance premium it will still be solvent with 3 losses or less since its total claim payments would be limited to $500,000; the regulator will tolerate the possibility of 4 or more losses since the probability of such an event is q=1/100.

Of course, no insurer would ever pay anything close to $200,000 for a policy which only promises them $250,000 with a probability of p=1/80. On the other hand, the small insurer is very likely to be willing to pay the reinsurer somewhat more than the actuarial fair premium of $3,333. How much the reinsurer will actually charge for this excess loss protection depends on the degree of competition in the market. If there is a long-term relationship built up between Smally and a specific reinsurer, then this firm has more flexibility in charging a higher premium than if Smally is shopping for protection. The

[2] For an excellent summary of alternative reinsurance arrangments see McIsaac and Babbel (1995).

emergence of new financial instruments makes it more attractive for Smally to widen its circle for protection and may lower reinsurance prices in the future.

One way of avoiding reinsurance charges is for insurers like Smally to encourage their policyholders to adopt mitigation measures through premium reductions. In the above example if Smally were able to induce all of its policyholders to mitigate their home, then their losses from an earthquake is given in the last column of Table 5. In this situation Smally will have more than enough surplus assets on hand to pay for 3 losses and will not need to purchase reinsurance to meet the regulator's concern with insolvency.

Due to its concern with insolvency, Smally would be willing to give its policyholders a substantial premium reduction to encourage them to adopt a mitigation measure. The detailed calculations are shown in Appendix 2. The informal argument can be summarized as follows. Smally wants to show the regulator that it will have S_S=\$600,000 on hand so it can cover at least three earthquake losses when mitigation is in place. Since S_S =700,000 it will be able to reduce its total premium by as much as \$100,000 and still meet this constraint. This means that it will be willing to reduce the premiums for each of its policyholders by up to \$1,000 if they will adopt a mitigation measure. Since the actuarially fair reduction in premiums is only \$500, Smally would be willing to incur an expected loss on its earthquake book of business in order to meet its insolvency constraint. Of course, when reinsurance is available, Smally will make tradeoffs between the reinsurance premium it will have to pay for coverage and the premium reduction it will offer property owners in exchange for mitigation.

Conclusions on Insurer Behavior To summarize the findings regarding insurer behavior, under a market system the premium which an insurer is willing to charge for encouraging mitigation depends on the following factors: its surplus (S), the maximum amount the homeowner is willing to pay for mitigation (M), the regulated premium (P_R) compared to the actuarially fair premium if mitigation is in place (P"), the concern that insurers have with the probability of insolvency (q*) and the degree of competition between insurers and reinsurers.

In addition, the above analysis suggests the importance of understanding the role of insurance regulation in promoting mitigation through such incentives as premium reductions. If the regulatory agency requires insurers to provide coverage to a group of policyholders, then it becomes important to let them charge rates based on actuarial risk. If insurers are not permitted to do so, they will have little incentive to encourage mitigation if they feel that their policyholders will either go elsewhere or drop their coverage. In fact, the insurer wants to do everything it can to make the policyholder leave them. If, on the other hand, an insurer knows that it is stuck with the policyholder, then it will want to encourage him to adopt mitigation, even when the premium is required to be subsidized by the regulator. The basic rule in this case is a simple one: if the premium reduction is less than the savings in expected claim payments due to mitigation, it is a desirable action to promote.

Small insurers face an additional problem in that they are required to meet insolvency constraints. There are good reasons for regulators to insist on such conditions since consumers may have a difficult time determining whether a insurer is operating in a financially responsible manner. Large companies also favor these guidelines, since they are normally held accountable for paying off claims of insolvent companies through residual pools. On the other hand, when small insurers are forced to meet these constraints they are likely to be willing to pay premiums to reinsurers far in excess of actuarially-based rates and encourage mitigation by offering larger than actuarially fair premium discounts. In both cases their behavior is designed to eliminate large losses at the expense of expected profits.

To the extent that regulators allow insurers to reduce their portfolio of risks in hazard-prone areas and these insurers actually do so, the insolvency constraint will not be as important a force in the premium-setting decision. New financial instruments may also place competitive pressures on reinsurers to reduce their rates so this will aid insurers in how much they have to pay for protection against catastrophic losses.

IV ROLE OF BUILDING CODES

Consider the following scenario. Homeowners had perfect information on the risks associated with natural disasters and invested in cost-effective mitigation measures because they maximized their discounted expected utility. Insurers and reinsurers utilized this information on risk to price their products and provided premium discounts to those who adopted mitigation meausres. All the costs of disasters could be allocated to specific individuals and property. Then there would be no need for building codes. It is precisely because these conditions are not fulfilled in practice that building codes are required. In this section we explore two principal functions that building codes serve

Correcting Misperception and Misinformation of the Risk

Building codes force property owners to adopt mitigation measures when they would otherwise not do so because they misperceive the benefits from adopting the RMM and/or have underestimate the probability of a disaster occurring. As indicated in Section II individuals often truncate the expected benefits from the mitigation measure due to myopia and high discount rates. There is also empirical evidence that they underestimate the chances of a disaster or behave as if the disaster “will not happen to me” in which case they would have no interest in investing in any loss reducing measures. (Camerer and Kunreuther 1989).

If these property owners were forced to cover their own disaster losses then one might contend that they have only themselves to blame for not taking preventive action. However, all taxpayers bear some of the costs of the recovery from damaged property through low interest federal loans and grants. Hence there is an economic justification to all citizens to design structures to be safer.

There is also limited interest by engineers and builders in designing safer structures if it means incurring costs that they feel will hurt them competitively. Interviews with structural engineers concerned with the performance of earthquake-resistant structures indicate that they have **no** incentive to build structures that exceed existing codes because they have to justify these expenses to their clients and would lose out to other engineers who did not include these features in the design (May and Stark 1992). Without building codes, they would even be less interested in undertaking measures that will enable the structure to withstand the forces of a disaster.

Well-enforced building codes correct any misinformation that potential property owners have regarding the safety of the structure. For example, suppose the property owner believes that the losses from an earthquake to the structure is L'= $20,000 and the developer knows that it is L" = $25,000 because it is not well constructed. There is no incentive for the developer to relay the correct information to the property owner because the developer is not held liable should a quake cause damage to the building. If the insurer is unaware of how well the the building is constructed, then this information cannot be conveyed to the potential property owner through a premium reflecting risk. 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.

Evidence from a July 1994 telephone survey of 1241 residents in six hurricane prone areas on the Atlantic and Gulf Coasts provides supporting evidence for some type of seal of approval. Over 90 percent of the respondents felt that local home builders should be required to follow building codes, and 85 percent considered it very important that local building departments conduct inspection of new residential construction. (Insurance Institute for Property Loss Reduction 1995).

Reducing Externalities

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 may not be taken into account when the owners evaluate the importance of adopting a specific mitigation measure. Consider the following examples of externalities:

Triggering Damage to Other Structures If a building topples off its foundation after an earthquake it could break a pipeline and cause a major fire which would damage other homes that were not affected by the earthquake in the first place. This type of damage has a direct impact on the pricing of insurance in a hazard-prone area.

To see this point consider the following illustrative example building on the scenario developed in Section II. Suppose that an unbraced structure that toppled in a severe earthquake had a 20 percent chance of bursting a pipeline and creating a fire which would severely damage 10 other homes, each of which would suffer $40,000 in damage. Had the house been bolted to its foundation this series of events would not have occurred.

The insurer who provided coverage against these fire-damaged homes under a standard homeowner's policy would then have had an additional expected loss of $80,000 (i.e., .2x10x$40,000) due to the lack of building codes requiring concrete block structures to be braced in earthquake prone areas. One option would be for homes adjacent to those that are not mitigated to charged a higher fire premium to reflect the additional hazard from living next to the unprotected house. In fact, this additional premium should be charged to the unprotected structure which caused the damage, but this cannot legally be done. Hence, each of the 10 homes that are vulnerable to fire damage from the quake would be charged this extra premium.

The relevant point for this analysis is that there is an additional annual expected benefit from mitigation over and above the reduction in losses to the specific structure adopting this RMM. All financial institutions and insurers who are responsible for these other properties at risk would favor building codes to protect their investments and/or reduce the insurance premiums they charge for fire following earthquake .

Social Costs Arising from Property Damage If a family is forced to vacate their property because of damage to a quake which would have been obviated if a building code had been in place, then this is an additional cost which needs to taken into account when determining the benefits of mitigation. Suppose that the property is expected to need food and shelter for t days (e.g. t = 50) at a daily cost of D = $30. Then the additional expense from not having mitigated after a disaster occurs is t x D (i.e., 50 x $100 = $5000). If the annual chances of the disaster occurring is p =1/100, then the annual expected extra cost to the taxpayer of not mitigating is p x t xD (i.e., 1/100 x 50 x $100 = $50). Although this may not appear to be a very large amount, it amounts to an expected discounted cost of over $560 for a 30 year period if an 8% discount rate were utilized. Should there be a large number of households that need to be provided with food and shelter, these costs could mount rapidly.

In addition to these temporary food and housing costs, the destruction of commercial property could cause business interruption losses and the eventual bankruptcy of many firms. The impact on the fabric of the community and its economic base from this destruction could be enormous. In a study estimating the physical and human consequences of a major earthquake in the Shelby County/Memphis, Tennessee area, located near the New Madrid fault, Litan et al. (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.

The study estimates that the regionalized gross national product savings from the use of mitigation measures (i.e. retrofitting existing buildings) could increase the total economic benefits by approximately 75 percent. In their study of Shelby County, they still found the benefit-cost ratio associated with comprehensive retrofitting of all buildings to be below 1.0. However, their study suggests that selective building codes for certain structures could be beneficial, particularly in the light of these additional economic benefits.

V. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This section summarizes the principal findings of the paper and proposes a plan of research which will enable us to more fully understand the role that mitigation can play in conjunction with other policy tools for managing natural disasters.

Principal Findings

There are several conclusions that emerge from this analysis of the role of mitigation measures in dealing with catastrophic losses. For one thing, property owners are reluctant to incur the upfront costs of risk mitigation measures because they either misperceive risks, are myopic and/or face severe budget constraints. On the other hand, premium reductions for undertaking loss prevention methods can be an important first step in encouraging property owners to adopt these measures. Due to regulatory constraints on pricing, insurers will *not* voluntarily provide these incentives unless they are forced to provide coverage to individuals in hazard-prone areas and/or face insolvency constraints.

The analyses also indicate why small insurers, who are concerned with meeting insolvency constraints, may be forced to pay high prices for reinsurance when mitigation is not in place. For this reason alone, they will want to provide unusually high premium discounts to encourage their current policyholders to adopt mitigation to reduce the losses from a catastrophic disaster. These imperfections on the demand and supply side imply that building codes and enforcement mechanisms are a necessary ingredient for developing a workable strategy for making mitigation an integral part of a disaster management program.

The analyses in the paper were designed to show that there are benefits derived from the adoption of cost-effective mitigation to many of the interested parties affected by natural disasters. Both property owners and insurers will have their total discounted expected losses reduced over the life of the property and public sector agencies will have less need to provide disaster assistance. Mitigation will also encourage reinsurers to reduce their rates: encouraging policyholders to adopt RMMs provides an additional option for small insurers to meet insolvency constraints and puts pressure on resinsurers not to charge too high a premium.

Well-enforced building codes that incorporate cost-effective mitigation measures will enable the real estate community and developers to promote safer structures without having to concern themselves with competitive pressures in their pricing decisions. There is an additional benefit of building codes in that it deals with misperceptions and misinformation on the risk and reduces the negative externalities to the large community associated with the destruction or damage of buildings from a disaster.

Future Research Directions

Encouraging Adoption of Cost-Effective Mitigation Measures With respect to future directions for research there is a need to specify the types of cost-effective mitigation measures that could be applied to new and existing structures and how they can be made part of a hazard management program. Only then can insurers, builders, and financial institutions work together to incorporate these measures as part of building codes and provide property owners with appropriate rewards for adopting them.

Consider the example in Section II where the cost of bracing a house is $1500 and the annual expected reduction in damage is $500. If homeowners are reluctant to incur the upfront cost of mitigation, then one way to make this measure financially attractive to the property owner is for the bank to provide funds for mitigation through a home improvement loan with a payback period identical to the life of the mortgage. For example, a 20 year loan for $1500 at an annual interest rate of 10 percent would result in payments of $145 per year. If the annual premium reduction from insurance reflected the expected benefits of the mitigation measure (i.e. $500) then the insured homeowner will have lower total payments by investing in mitigation than not undertaking the measure.

To implement such a program, banks have to be convinced that they it is in their financial interest to market home improvement loans for purposes of mitigation. They are much more likely to do so if insurers provide appropriate premium reductions to make such a loan attractive to the mortgagee. For insurers to want to take this step, they will want to have the freedom to charge insurance premiums which reflect the disaster risk rather than being forced to offer coverage at subsidized rates. This may involve changes in the insurance regulatory environment.

Micro-Model Simulations A broader strategy for undertaking research in this area would involve the analysis of the impact of disaster or accidents of different magnitudes on different structures. In order to determine expected losses and the maximum probable losses arising from worst case scenarios, it may be necessary to undertake long-term micro-model simulations. For example, one could examine the impacts of earthquakes or hurricanes of different magnitudes on the losses to a community or region over a 10,000 year period. In the process one could determine expected losses based on the probabilistic scenario of these disasters as well as the maximum possible loss during this period based on a worst case scenario.

By constructing large, medium and small *representative* insurers with specific balance sheets, types of insurance portfolios, premium structures and a wide range of potential financial instruments, one could examine the impact of different disasters on the insurer's profitability, solvency and performance through a simulation. Such an analysis may also enable one to evaluate the performance of different mitigation measures and building codes on certain structures in the community on both expected losses as well as worst case scenarios. One could also consider the impact that reinsurance will have on both the insurer's expected profits and insolvency with and without RMMs in place. An example of the application such an approach to a model city in California facing an earthquake risk can be found in Kleindorfer and Kunreuther (in press).

Turning to the new instruments from the capital market one could compare their relative attractiveness to reinsurance for different types of insurers who have specific risks in place. For example, the recent Act of God Bonds issued by USAA is similar in form to a proportional reinsurance contract above a retention level. From USAA's point of view it may be priced more attractively than a comparable reinsurance contract.[3] One would expect that the price of reinsurance will fall in the future given these and other financing and hedging instruments against catastrophic risk unless there are certain features of reinsurance that would prevent the price from declining, as discussed in Froot (1997).

Two very important outcomes would emerge from such simulations. First, it should be possible to rank the importance of different financial instruments for different type firms. For example, large firms may prefer Act of God bonds while smaller ones may want to rely on excess loss reinsurance due to the high transaction costs associated with floating a Act of Bond which requires a large enough amount to make it attractive to the insurer. 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. Secondly, investors could determine whether the market price which emerged from this simulation would be sufficiently attractive for them to provide investment capital to support certain capital market instruments.

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 apply not only to the traditional issues of capital markets and the insurance sector, but also to the decision processes of (re-)insurance companies, public officials and property owners in determining 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 natural hazards and their mitigation.

A current research program jointly being undertaken by the Financial Institutions Center and the Risk Management and Decision Processes Center at the Wharton School,

[3] See Doherty (1997) for more details on these and other recent financial instruments

University of Pennsylvania is addressing all the above issues. In the context of this Conference on Financial Risk Management for Natural Catastrophes we are particularly interested in understanding the impact of different institutional arrangements in other countries on the role that insurance coupled with mitigation and other policy tools can play in reducing losses from future natural disasters.

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TABLE 1

MAXIMUM WILLINGNESS TO PAY (WTP) FOR MITIGATION AS A FUNCTION OF TIME HORIZON AND ANNUAL DISCOUNT RATE

TIME HORIZON (in years)	**DISCOUNT RATE 10%**	**DISCOUNT RATE 20%**
1	$500	$500
5	$2,085	$ 1,793
10	$ 3,380	$2,513
20	$4,682	$2,917

TABLE 2

DISTRIBUTION OF MAX WILLINGNESS TO PAY (WTP)

% Individuals in Each Category

	Price Not Given		Price Given=$1,500	
	5 Years	**10 Years**	**5 Years**	**10 Years**
$0-$500	5%	5%	7%	4%
$501-$1,000	7%	7%	16%	16%
$1,001-$1,500	45%	17%	43%	44%
$1,501-$2,000	31%	36%	16%	19%
$2,001-$2,500	5%	14%	3%	0%
$2,501-$3,000	5%	14%	3%	0%
$3,000 up	2%	7%	12%	17%
no of subjects =42			No of subjects =42	

TABLE 3

IMPLIED DISCOUNT RATES FOR MAX WILLINGNESS TO PAY (WTP)

Price Not Given		Price Given=$1,500	
Discount Rate	**% Individuals**	**Discount Rate**	**% Individuals**
0-10%	6%	0-10%	8%
10-20%	8%	10-20%	6%
20-50%	0%	20-50%	0%
50-60%	4%	50-60%	6%
60-70%	14%	60-70%	14%
70-80%	20%	70-80%	22%
80-90%	14%	80-90%	14%
90-100%	0%	90-100%	0%
infinite* (No change in WTP)	34%	infinite* (No change in WTP)	30%
no of subjects = 42 * 17%: no change in probability of purchase 17%: increase in probability of purchase		no of subjects = 42 * 15%: no change in probability of purchase 15%: increase in probability of purchase	

TABLE 4

PERCENTAGE OF SUBJECTS FOLLOWING DIFFERENT DECISION RULES IN MAKING DECISIONS REGARDING ADOPTION OF PROTECTIVE INVESTMENTS CONSISTENT

	Reasonable Discounting **r ≤ 20**	**Myopia Behavior** **r > 20**	**Max WTP** **Remains The Same**
5 years- 10 years	14 % r= .10	41 % r= .72	45 %
10 years-20 years	27 % r= .13	34 % r= .67	39 %
5 years- 20 years	30 % r= .12	38 % r= .74	32 %

SOURCE: Kunreuther, Onculer, and Slovic (1997)

TABLE 5

PROBABILITIES OF DAMAGE AND RESPECTIVE LOSSES FOR INSURERS WITH AND WITHOUT MITIGATION IN PLACE

Number of Losses (n)	**Probability (# of losses n)**	**Loss with No Mitigation (L")**	**Loss with Mitigation (L')**
0	1	$ 0	$ 0
1	1/20	$ 250,000	$ 200,000
2	1/40	$ 500,000	$ 400,000
3	1/80	$ 750,000	$ 600,000
4	1/100	$ 1,000,000	$ 800,000
5	1/125	$ 1,250,000	$ 1,000,000
6	1/150	$ 1,500,000	$ 1,200,000
7	1/180	$ 1,750,000	$ 1,400,000
8	1/200	$ 2,000,000	$ 1,600,000

APPENDIX 1

MODELING THE DEMAND FOR PROTECTIVE ACTIVITIES BY PROPERTY OWNERS

Discounted utility theory has been the dominant approach for modeling decisions to invest in protective measures when future outcomes are known with certainty. The basic concept is that people act as though they utilize an exponential discount function for evaluating a sequence of deterministic outcomes in each period *t [x(t)]* over a time horizon of T periods. An individual wants to allocate resources so as to maximize:

$$\sum_{t} \delta(t) \cdot u[x(t)] \qquad (1)$$

where $u[x(t)]$ is a concave ratio utility function and δ is the discount factor for one period with $0 < \delta < 1$. If individuals utilize a discount rate of r then the DU model implies that $\delta(t) = [1/(1+r)]^t$.

For investments in protective measures where outcomes are specified by a probability distribution, individuals must decide whether to expend money today to reduce the consequences over a T period horizon where there is a probability p_i of outcome $x_i(t)$, i=1...n occurring in any period $t \in T$. If the individual's objective is to maximize discounted expected utility (DEU) where DEU is defined as:

$$\begin{aligned} &\sum_{t}\sum_{i} \delta(t) \cdot p_i \cdot u[x_i(t)] \\ &where \sum_{i} p_i = 1 \end{aligned} \qquad (2)$$

Consider a protective measure that costs Z dollars which yields a disutility to the individual of u(-Z). If one invests in this RMM, there is a probability $p^*_i \le p_i$ of a loss $x_i(t)$ in any period t, so that the expected benefits of investing in this protective measure over the time horizon T is given by the discounted expected utility, $[u(B_T)]$, where:

$$u[B_T] = \sum_{t}\sum_{i} \delta(t) \cdot (p_i - p_i^*) \cdot u[x_i(t)] \qquad (3)$$

A person who maximizes DEU will invest in the RMM whenever $u(B_T) + u(-Z) > 0$.

APPENDIX 2

MODELING INSURERS BEHAVIOR WITH RESPECT TO MITIGATION

Consider the following scenario as it relates to insurers decision processes with respect to the premiums they are willing to charge for mitigation:

NOTATION

p = annual probability of a loss for a single house (e.g. p = 1/100)

L” = Loss without mitigation (e.g. L”=$250,000)

L’ = Loss with mitigation (e.g. L’= $200,000)

E(L”) = p L” =Expected Annual Loss without Mitigation (e.g. $2500)

E(L’) = p L’ = Expected Annual Loss with Mitigation (e.g. $2000)

P”= E(L”) = actuarially fair premium without Mitigation

P’= E(L’) = actuarially fair premium without Mitigation

M = Minimum premium reduction from P’ for homeowner to adopt mitigation

ASSUMPTIONS

The insurer provides coverage for a single type structure (e.g. concrete block house) in an earthquake prone area.

The insurer has written N earthquake policies on the single type structure. It may have other insurance policies in force but the concern here is **only** on its earthquake business.

The insurer has calculated the probability that n or more homes will be damaged by a severe quake (i.e. there is not a perfect correlation between losses) and has estimated the resulting losses with and without mitigation in place. Table 5 presents these data for an illustrative example.

LARGE AND SMALL INSURER PREMIUM SETTING PROCESS

LARGE INSURERS (NO INSOLVENCY CONSTRAINT)

The large insurer has N earthquake policies and must decide what premium (P_L) it will charge. Let S_L = the large insurer's surplus to pay claims which consists of its initial surplus (A_L) plus the premiums from its N policies (NP_L) It has determined the probability p_i that it will have i losses from an earthquake. The size of each loss L will be L" if the property owner doesn't mitigate or L' if he does.

The large insurer's objective is to choose a premium $P_L \leq P''$ so as to

$$\text{Max } [A_L + NP_L - \sum p_i \, i \, L] \qquad (1)$$

subject to the following insolvency constraint

$$\text{Probability} \sum_{i=1}^{8} [A_L + N(P_L) - i\,L] \leq q^* \qquad (2)$$

where q* = maximum probability of insolvency

In the example given in the paper, large insurers are assumed to have S_L = \$1.2 million so that the insolvency constraint given by (2) will be met when mitigation is not in place and a premium $P_L = P''$ is charged. As seen from Table 5, (2) will also be satisfied if mitigation is adopted by property owners and $P_L = P'$.

Hence the large insurer will set a premium which maximizes (1) but is interested in reducing the premium if it will both encourage the property to mitigate their home and increase the insurer's expected profit. The insurer knows that the range of premium reductions that satisfies both conditions is between M and P"-P'. Note that M is the minimum premium reduction from P" that will lead the property owner to adopt mitigation. If M >P"-P' then mitigation will not be encouraged because the insurer will be forced to provide a reduction in premium that will cause them to experience an expected loss on their earthquake business.

If M < P"-P', in a perfectly competitive market the insurer will charge P=P' to encourage mitigation. If the insurer has some monopoly power it will reduce premiums by less than P"-P'.

Example: If M= \$3 P"=25 and and P' = \$20 then the insurer will charge a premium somewhere between \$20 and \$22.

SMALL INSURER (INSOLVENCY CONSTRAINT IS EXCEEDED WITHOUT MITIGATION)

The small insurer has N earthquake policies and must decide what premium (P_S) it will charge. Let S_S = the small insurer's surplus to pay claims which consists of its initial surplus (A_S) plus the premiums from its N policies (NP_S). It has a probability p_i that it will have i losses (L) from an earthquake. The size of each loss L will be L" if the property owner doesn't mitigate or L' if he does.

The large insurer's objective is to choose a premium $P_L \leq P''$ so as to

$$\text{Max } [A_S + NP_S - \sum p_i \; i \; L] \qquad (3)$$

subject to the following insolvency constraint

$$\text{Probability} \sum_{i=1}^{8} [A_S+N(P_S) - i\,L] \leq q^* \qquad (4)$$

where q^* = maximum probability of insolvency

Small insurers are assumed not to have sufficient surplus (S_S) when mitigation is not in place so that the insolvency constraint given by (4) for L=L" will <u>not</u> be met. In the example in the paper S_S = \$700,000 consisting of A_S = \$450,000 and actuarial premiums for 100 policies 100 (P") = \$250,000. The small insurer can either purchase reinsurance and/or encourage mitigation through premium reduction to meet (4). We will briefly examine each of these decisions based on the illustrative example in the paper using the data from Table 5.

Purchasing Reinsurance

Suppose that a reinsurer is willing to provide coverage of \$250,000 to protect the insurer against losses exceeding \$500,000 (i.e. \$250,000 in excess of \$500,000). The reinsurer will suffer a loss of \$250,000 in excess of \$500,000 if there 3 or more losses . This probability is given by 1/80 so that the actuarially fair premium is R =1/80(\$250,000) =\$3,300.

For the example above we can determine the maximum reinsurance premium (R_{max}) the insurer would pay for this excess coverage to satisfy (4). Specifically with \$250 (thousand) in excess of \$500 (thousand) reinsurance, (4) becomes:

$$\text{Prob}\{ \sum_{i=1}^{2}[\$700 - R_{max} - i\,L''] + [\$700 - R_{max} - 750 + 250] + \sum_{i=4}^{8} [\$700 - R_{max} - i\,L'' + 250]\} \leq .01 \quad (5)$$

where the figures are in thousands of dollars.

R_{max} is determined by finding the value where the surplus of the insurer is zero when there are 3 losses. To see this, note from Table 5 that the insurer's surplus will be greater than zero if it suffers 0, 1 or 2 losses and that the probability of suffering four or more losses is less than .01. Hence if $q^*=.01$, the value of R_{max} is determined by solving:

$$\$700-R_{max} -750 +250=0. \quad (6)$$

imply that R_{max} = \$200. This means that, in theory, the insurer is willing to pay as much as \$200,000 for reinsurance. The actual reinsurance premium for this example will be somewhere between \$3,333 and this upper limit.

Encouraging Mitigation Through Premium Reductions

As an alternative to reinsurance the small insurer may actually be willing to set a premium P_S which is below the actuarially fair rate to encourage its current policyholders to adopt mitigation and meet the insolvency constraint given by (4). In other words it will be willing to charge a premium P_S so that individual losses will be L'. Note that we are assuming that the insurer must continue to provide earthquake coverage to its existing policyholders. Otherwise, it would have an incentive to cancel some policies to satisfy (4).

From Table 5 one sees that if $q^*= 1/100$ then the insurer needs to set premiums so it has sufficient surplus to cover 3 losses. With mitigation its claims are reduced from \$750,000 to \$600,000 when 3 structures are damaged. Hence to determine P_S which satisfies (4) one computes

$$\$450,000 -100\, P_S - \$600,000 = 0 \quad (6)$$

This means that P_S = \$1,500, a premium below the actuarially fair value of P'=\$2,000. Thus the small insurer loses money on its earthquake business to encourage mitigation and satisfy its insolvency constraint.

This paper examines the role that insurance and mitigation can play in reducing losses from natural disasters using data collected as part of a large-scale study on catastrophic risk jointly undertaken by the Wharton Risk Management Center in conjunction with Georgia State University and the Insurance Information Institute. The paper graphically demonstrates why disaster losses have increased in the past twenty-five years and the magnitude of the problem today. It then shows how mitigation measures can reduce future losses using data on residential homes from four states facing severe risks fr