"Managing Catastrophic Risks Through Insurance and Mitigation"

97-08-01

Howard Kunreuther

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Making Progress with Business Continuity Planning for Natural Disaster Management
Neil R. Britton

About the Editors

About the Contributors

Conference Contributors

Conference Participants
ABSTRACT
This paper examines the role that insurance and other policy tools can play in encouraging property owners to take steps to reduce losses from natural hazards and the impact that these measures will have on the solvency of insurers. Experimental data suggest that property owners are reluctant to incur the upfront costs of risk mitigation measures. On the other hand, insurance 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 economic incentives unless they are forced to provide coverage to individuals in hazard-prone areas and/or they face insolvency constraints. 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 hazard management program. The paper suggests that building codes can address property owners’ misperceptions of and misinformation on the risk. The paper concludes that there are benefits to be derived from the adoption of cost-effective mitigation and well-enforced building codes to all the interested parties affected by natural disasters.

INTRODUCTION
Insurance is the only policy tool in the analyst’s repertoire that can reward individuals both before and after a disaster. Insured individuals can receive lower premiums for taking loss reduction measures prior to a disaster, while at the same time receiving claims payments should they suffer losses from the insured event. In theory, insurers could refuse to provide coverage 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 nineteenth century, insurers have been reluctant to deny coverage on these grounds today.

This paper examines 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 are addressed:
• What are the necessary and sufficient conditions for property owners to want to adopt cost-effective risk mitigation measures (RMMs)?

• 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 in the form of premium reductions?

• 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. It provides empirical evidence as to why most individuals do not utilise this model. The discussion then 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 a fourth section. 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.

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 one's house it might cost the property owner $1500. Should a 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 modelling such inter-temporal problems when future outcomes are known with certainty. The basic concept is that people act as though they utilise 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 today to reduce the consequences over a T period horizon. There is a probability \( p_i \) of outcome \( x_i(t) \), \( i = 1 \ldots n \) occurring in any period \( t \in T \). The protective measure is assumed not to enhance the value of the product itself. Thus, the selling price of a house will not be increased by investing in an earthquake protective measure. An annual discount rate of \( r \) (for example, \( r = 0.10 \)) is used to compute the present value of the expected benefits over time. Appendix 1 develops a more formal model, indicating how much an individual is willing to pay for an RMM if her objective is to maximise 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 his 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) \times$20 000 = $500. If the homeowner expects to live in the property for 10 years and has an annual discount rate of \( r \), then the discounted expected benefits for this measure is:

\[
\sum_{t=1}^{10} \frac{$500}{(1 + r)^t}
\]

Table 1 shows the maximum willingness to pay (WTP) as the time horizon changes from one year to 20 years and the discount rate \( r \) is either 10% or 20%. A person is willing to pay $500 if she only considers the benefits for one year. This 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 capitalised in the value of the house. If the property value was fully enhanced because of the RMM, then the WTP should reflect the discounted expected benefits of the measure and be independent of the length of the time horizon.

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 based on an RMM identical to the one which generated the WTPs depicted in Table 1 (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 five years. They were then asked to specify a maximum WTP if they expect to live in the house for exactly 10 years. Table 2 presents the distribution of these WTP figures for 84 students at
Table 1. Maximum willingness to pay (WTP) for mitigation as a function of time horizon and annual discount rate.

<table>
<thead>
<tr>
<th>Time Horizon (in years)</th>
<th>Discount Rate 10%</th>
<th>Discount Rate 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>5</td>
<td>$2085</td>
<td>$1793</td>
</tr>
<tr>
<td>10</td>
<td>$3380</td>
<td>$2513</td>
</tr>
<tr>
<td>20</td>
<td>$4682</td>
<td>$2917</td>
</tr>
</tbody>
</table>

Source: Kunreuther, Onculer and Slovic (1997).

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.

The data reveal that only 12% 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 five 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 acted 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 $2085 if their discount rate was 10% and they expected to live in their house for five years. When the time horizon is lengthened to 10 years, the maximum WTP from Table 1 with \( r = 10\% \), increases to $3380. Yet, only 7% of the subjects who were not given the price chose to spend more than $3000; the percentage jumps to 17% for the group where the price was given at $1500.

A comparison of the weighted average for the WTPs reveals there was little significant difference between the maximum prices individuals were willing to pay when the price of the RMM was given and when it was not specified as shown in Table 3.
Table 2. Distribution of maximum willingness to pay (WTP).

<table>
<thead>
<tr>
<th>% of Individuals in Each Category</th>
<th>Price Not Given</th>
<th>Price Given = $1500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 Years</td>
<td>10 Years</td>
</tr>
<tr>
<td>$0-$500</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>$501-$1000</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>$1001-$1500</td>
<td>45%</td>
<td>17%</td>
</tr>
<tr>
<td>$1501-$2000</td>
<td>31%</td>
<td>36%</td>
</tr>
<tr>
<td>$2001-$2500</td>
<td>5%</td>
<td>14%</td>
</tr>
<tr>
<td>$2501-$3000</td>
<td>5%</td>
<td>14%</td>
</tr>
<tr>
<td>Over $3000</td>
<td>2%</td>
<td>7%</td>
</tr>
</tbody>
</table>

No of subjects = 42

Source: Kunreuther, Onculer and Slovic (1997).

Table 3. Differences between WTP when cost of RMM is given and not given.

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price not given</td>
<td>Price given = $1500</td>
</tr>
<tr>
<td>5 years</td>
<td>10 years</td>
</tr>
<tr>
<td>$1665</td>
<td>$1818</td>
</tr>
</tbody>
</table>

Source: Kunreuther, Onculer and Slovic (1997).

These data imply that subjects were not significantly influenced by the $1500 figure when they were asked to determine how much they were willing to pay for the mitigation measure.
The comparative data on different time horizons (five years and 10 years) enabled 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 is somewhat less than this amount, then the implied discount rate would be higher than 10%.

Table 4 depicts the implied discount rates for the cases where the price of the RMM was not given (Group 1) and when it was given to the students (Group 2). The data provide a very clear picture of three types of individuals which do not differ significantly between the two groups. One set (approximately 14% of the total sample for either group) exhibits behaviour suggesting that they utilise reasonable discount rates (r ≤ 0.20) in their decision on how much to pay for RMMs. There is then a gap between 0.20 < r < 0.50; the majority of the sample populations (52% for Group 1 and 56% for Group 2) gave WTPs for the five and 10 year time horizons which implied discount rates greater than 0.50. Finally, approximately 34% and 30% of the respondents in Groups 1 and 2 respectively did not change their maximum WTP at all, despite a doubling in time horizon. About half of the individuals in this set, labelled as ‘infinite’ in Table 4, increase their probability of undertaking the RMM as T increases from five to 10 years; the other half do not change either the probability of purchase or the maximum WTP amounts.

A survey of 252 individuals visiting the Exploratorium museum in San Francisco provides confirming evidence for the above experiment. Now three different time horizons were utilised for obtaining the maximum WTP when the price of the earthquake measure was given at $1500. As shown in Table 5, only 14% of the respondents exhibited behaviour consistent with reasonable discount rates when T was extended from five to 10 years; the percentages increase to over 25% when the horizons were lengthened from 10 to 20 years and from five 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 0.67 and 0.74 depending on the values of T). The last column in Table 5 indicates 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 five to 10 years, 45% of the subjects maintained the same price for the protective measure (Kunreuther, Onculer and Slovic, 1997).

These high discount rates are consistent with empirical findings from Lowenstein and Prelec (1992), when future outcomes are known with certainty. In fact 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
Table 4. Implied discount rates for maximum willingness to pay (WTP).

<table>
<thead>
<tr>
<th>Price not given Group 1</th>
<th>Price given = $1500 Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount Rate</td>
<td>% Individuals</td>
</tr>
<tr>
<td>0-10%</td>
<td>6%</td>
</tr>
<tr>
<td>10-20%</td>
<td>8%</td>
</tr>
<tr>
<td>20-50%</td>
<td>0%</td>
</tr>
<tr>
<td>50-60%</td>
<td>4%</td>
</tr>
<tr>
<td>60-70%</td>
<td>14%</td>
</tr>
<tr>
<td>70-80%</td>
<td>20%</td>
</tr>
<tr>
<td>80-90%</td>
<td>14%</td>
</tr>
<tr>
<td>90-100%</td>
<td>0%</td>
</tr>
<tr>
<td>infinite* (No change in WTP)</td>
<td>34%</td>
</tr>
</tbody>
</table>

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

Source: Kunreuther, Onculer and Slovic, 1997.

measure, even when T changes. This may be due to budget constraints, myopia or the belief that the cost of the RMM is fully capitalised in the selling price of the property value.
Table 5. Percentage of subjects following different decision rules in making decisions regarding adoption of protective investments consistent.

<table>
<thead>
<tr>
<th></th>
<th>Reasonable discounting</th>
<th>Myopia behaviour</th>
<th>Maximum WTP remains the same</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r \leq 20$</td>
<td>$r &gt; 20$</td>
<td></td>
</tr>
<tr>
<td>5 years -</td>
<td>14 %</td>
<td>41 %</td>
<td>45 %</td>
</tr>
<tr>
<td>10 years</td>
<td>$r = 0.10$</td>
<td>$r = 0.72$</td>
<td></td>
</tr>
<tr>
<td>10 years -</td>
<td>27 %</td>
<td>34 %</td>
<td>39 %</td>
</tr>
<tr>
<td>20 years</td>
<td>$r = 0.13$</td>
<td>$r = 0.67$</td>
<td></td>
</tr>
<tr>
<td>5 years -</td>
<td>30 %</td>
<td>38 %</td>
<td>32 %</td>
</tr>
<tr>
<td>20 years</td>
<td>$r = 0.12$</td>
<td>$r = 0.74$</td>
<td></td>
</tr>
</tbody>
</table>


Empirical Data

The empirical data on studies of mitigation adoption in hazard-prone areas of the USA suggest that individuals are not willing to invest in mitigation measures despite the rather large damage that either they and/or their friends and neighbours suffered from recent disasters. For example, after Hurricane Andrew in Florida in 1992, the most severe disaster in the USA, most residents in hurricane-prone areas appear not to have made improvements to existing dwellings. A July 1994 telephone survey (1241 residents in six hurricane-prone areas along the Atlantic and Gulf Coasts) revealed that 37% 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 labour for hurricane-resistant designs indicate that it will add no more than 4%-5% 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).

A 1989 survey of 3500 homeowners in four California counties subject to earthquakes revealed that, only between 5%-9% of the respondents in each of these counties reported adopting any loss reduction measures (Palm, Hodgson, Blanchard and Lyons, 1990). A follow-up survey by Palm and her colleagues of residents affected by the October 1989 Loma Prieta earthquake in San Francisco, and the Northridge earthquake of 1994 in Los Angeles, revealed that only 10% of homeowners invested in any type of structural loss reduction measure whether or not they were affected by
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<thead>
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<tbody>
<tr>
<td></td>
<td>$r \leq 20$</td>
<td>$r &gt; 20$</td>
<td></td>
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<td>14 %</td>
<td>41 %</td>
<td>45 %</td>
</tr>
<tr>
<td>10 years</td>
<td>$r = 0.10$</td>
<td>$r = 0.72$</td>
<td></td>
</tr>
<tr>
<td>10 years</td>
<td>27 %</td>
<td>34 %</td>
<td>39 %</td>
</tr>
<tr>
<td>20 years</td>
<td>$r = 0.13$</td>
<td>$r = 0.67$</td>
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<td>38 %</td>
<td>32 %</td>
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recent earthquakes in the state (Palm, 1995). Strapping a water heater costs approximately $75, and can prevent large amounts of damage by preventing the heater from toppling during an earthquake and causing a fire. Yet few property owners have taken this inexpensive step. This behaviour implies that individuals do not believe that investing in the RMM will increase their residence’s property value.

Another reason why some individuals may not have invested in mitigation measures is, they expected to be protected by their insurance coverage following a disaster. This would be especially likely in hurricane areas where property owners with a mortgage are normally required to purchase a policy that covers wind damage. It would be less probable in earthquake-prone areas of California where less than 30% of residential dwellings had earthquake insurance at the end of 1994 (Roth, in press). Of course, if insurers reduced premiums for those who adopted RMMs then policyholders would have an economic incentive to consider these measures prior to a disaster. We now turn to this topic.

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 nineteenth century in New England, USA. The mutuals required inspections of the factory both prior to issuing a policy and after one was in force. Poor risks had their policies cancelled and 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. One company, the Spinners Mutual, only insured those structures 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. Hence, the good risks are expected to subsidise 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, 1997).

Insurers in the USA have not provided financial incentives for homeowners to mitigate their structures. In fact, due to regulatory rate restrictions in the USA, rates have been subsidised 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: First, the level premium implies that RMMs produce no benefits. Second, the subsidised rate provides incentives for a property owner to buy insurance protection. This 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, so that companies now recognise 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 greater than $US1 billion from a single event. Since that date, 15 disasters have exceeded this figure (Kunreuther and Roth, in press). Studies have estimated that 25% of the $US15 billion insured damage from Hurricane Andrew in Florida, could have been prevented had building codes been enforced (Insurance Research Council and Insurance Institute for Property Loss Reduction, 1995).

A second development, triggered by this increase in insured losses from natural disasters, was the formation of the Insurance Institute for Property Loss Reduction (IIPLR) formed by property-casualty insurance companies in the USA. This independent, non-profit organisation, now named the Institute for Business and Home Safety (IBHS), has undertaken research and studies designed to encourage actions which reduce deaths, injuries, property damage, and economic losses from natural disasters. IBHS has supported a number of scientific analyses evaluating the cost-effectiveness of mitigation measures for reducing 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 USA. IBHS has also established partnerships with other organisations, such as the Federal Emergency Management Agency and the United States Geological Survey, to encourage mitigation (Insurance Institute for Property Loss Reduction, 1997).

A third 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 low probability-high consequence events. Insurers and reinsurers are now developing strategies for managing their portfolios, which now include mitigation, so as to avoid sufficiently large losses that cause an unacceptable loss of surplus (Insurance Services Office, 1996).

Finally, insurance companies who have insured residents in hazard-prone areas of the USA, are often forced by regulators to continue to offer coverage to their policyholders in the future whether they want to or not. For example, following Hurricane Andrew, the Florida state legislature enacted a bill which ruled that individual insurers could not cancel more than 10% of their homeowners policies in any county in one year, and could not also cancel more than 5% of their property owners policies statewide for each year between November 1993 and November 1996. Since these insurers were forced to provide coverage, they had an incentive to encourage their policyholders to adopt mitigation measures to reduce their losses.

The question I now want to turn to from a more theoretical perspective is, under what circumstances will these insurers offer premium reductions as a way of inducing those at risk to adopt cost-effective loss reduction measures. The answer to this question depends on both the surplus of the insurer, and the premium structure, as well as the concern that the insurer and policyholder has with insolvency.

**Theoretical Treatment**

As pointed out above, there are a set of reasons why insurance companies want to actively promote mitigation today. The tension they face is how to reflect the reduced risks of losses arising from the adoption of these measures through lower premiums to property owners in the face of regulatory restrictions. We will illustrate these points by
constructing a hypothetical example which illustrates the potential benefits of mitigation for large and small capitalised 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 earthquake coverage for a single type structure (for example, a concrete home). The insurer estimates the chances that an earthquake will occur in the region and damage any given insured property to be \( p = \frac{1}{100} \). The insurer will incur a loss \( (L') \) if a risk mitigation measure (RMM) is adopted and a loss \( (L'' > L') \) if it is not. For this example, \( L' = \$200\ 000 \) and \( L'' = \$250\ 000 \), so the RMM reduces damage by \$50\ 000 should an earthquake occur.

Based on this information the insurer can calculate the expected loss for a structure with mitigation \([E(L')] = \frac{1}{100} (\$200\ 000) = \$2000\), or without mitigation \([E(L'')] = \frac{1}{100} (\$250\ 000) = \$2500\). In other words, the expected annual benefit from mitigation is \$500. Note that the \$500 saving from mitigation is identical to the one in the example in an earlier section. In this case, however, an RMM reduces the magnitude of the loss for a given event which occurs with probability, \( p = \frac{1}{100} \). In the section on demand for mitigation measured by property owners, the RMM reduced the probability of a loss of \$20\ 000 from \( p = \frac{1}{20} \) to \( 1/40 \).

Suppose that an insurer has written \( N = 100 \) earthquake policies on this type of structure in a given region of the country, and has calculated the probability that \( n \) or more homes will be damaged by the earthquake given that there is less than perfect correlation between losses. Table 6 provides a set of relevant annual probabilities and respective values of \( L'' \) and \( L' \) for zero to eight losses for the case where an insurer has written \( N = 100 \) earthquake policies.

The insurer's objective is to set premiums so as to maximise expected profits subject to an insolvency constraint. Stone (1973) formalised 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 \( q^* = \frac{1}{100} \). The question for the insurer is what premium to charge the property owner to encourage her to adopt mitigation with the objective of maximising expected profits while still meeting its insolvency constraint.

Aside from internal concerns with insolvency, an insurer may be required to show the regulator that it is financially viable by having a probability of insolvency which is no higher than \( q^* \). Furthermore, policyholders may determine what premium they are willing to pay based on their estimate of the likelihood that the insurer will become insolvent. If this is the case, an insurer can raise its premium as it reduces its probability of insolvency.
(q). In the analysis which follows it will be assumed that a reduction in q will have no impact on the premium. To the extent that there is such a relationship in practice, there is an even stronger argument than is made below for insurers wanting to purchase reinsurance protection at a given price and/or encouraging homeowners to adopt RMMs reduce their future claims payments.

**Behaviour by Large Capitalised Insurers**

To begin the analysis consider a large capitalised insurer, Largecap, which has enough initial capital and premium income so that it is not concerned with the insolvency constraint. Let $S_L$ represent Largecap’s financial resources which consist of its initial surplus and premium income based on charging the actuarially fair premium without mitigation. In the context of the data in Table 6, suppose that $S_L = $1.2 million. In this case, Largecap insurer will still have positive capital on hand, unless it suffered more than four losses when each loss was $L_\text{"}$. The probability of this happening is 1/125 so that the insurer has satisfied its insolvency constraint since $q^* = 1/100$.

For this reason Largecap’s sole objective is to maximise expected profits. It has no desire for reinsurance, because it is not interested in reducing the chances of insolvency. Suppose the insurer has the freedom to charge whatever rate the market will bear. In an imperfectly competitive market where there is imperfect information by consumers and search costs, Largecap will charge a premium that is at least as high as its actuarial costs and administrative charges. This implies that the insurer will charge a premium $P' \geq E(L') = $2000, if mitigation is adopted and $P'' \geq E(L'\text{"}) = $2500, when mitigation is not utilised.

Suppose that a property owner has purchased coverage at the actuarial rate when no mitigation is in place. Let $M$ be the minimum premium reduction from $P''$ that will lead the property owner to adopt mitigation. If $M < P'' - P'$, then Largecap will offer a policy with mitigation where the premium will range between $P'$ and $P'' - M$. 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 $P'' - M$. When search costs are low, Largecap will charge a premium closer to $P'$ so as not to lose its customer base. In addition, if customers are sensitive to the probability of insolvency, they will want to pay more for coverage if they recognise that investments in mitigation by homeowners will reduce q. To illustrate the range of feasible premiums, if $M = $300 insurers will offer policies for mitigated homes that range from $2000 to $2200.

Turning to the impact that mitigation has on reducing $q$, suppose Largecap was able to encourage all its customers to adopt an RMM, and had $S_L = $1.21 million. From Table 6, its probability of insolvency with mitigation is reduced to $q = 1/180$, since it can now absorb six losses.
### Table 6. Probabilities of damage and respective losses for insurers with and without mitigation in place.

<table>
<thead>
<tr>
<th>Number of Losses ( n )</th>
<th>Probability ( # \text{ of Losses} \geq n )</th>
<th>Loss with No Mitigation ( L^0 )</th>
<th>Loss with Mitigation ( L' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>1</td>
<td>1/20</td>
<td>$250,000</td>
<td>$200,000</td>
</tr>
<tr>
<td>2</td>
<td>1/40</td>
<td>$500,000</td>
<td>$400,000</td>
</tr>
<tr>
<td>3</td>
<td>1/80</td>
<td>$750,000</td>
<td>$600,000</td>
</tr>
<tr>
<td>4</td>
<td>1/100</td>
<td>$1,000,000</td>
<td>$800,000</td>
</tr>
<tr>
<td>5</td>
<td>1/125</td>
<td>$1,250,000</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>6</td>
<td>1/150</td>
<td>$1,500,000</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>7</td>
<td>1/180</td>
<td>$1,750,000</td>
<td>$1,400,000</td>
</tr>
<tr>
<td>8</td>
<td>1/200</td>
<td>$2,000,000</td>
<td>$1,600,000</td>
</tr>
</tbody>
</table>

**Note:** The probabilities of losses of 1 or more homes in this table is based on the assumption that there is imperfect correlation between structures that are damaged from an earthquake. If there was perfect correlation then either all homes would be damaged with probability \( p = 1/100 \) or no homes would be damaged with \( p = 99/100 \).

Rather than the four losses it was able to cover when an RMM was not adopted. From an insurer’s vantage point mitigation truncates the worst case scenarios by reducing the losses on individual structures.

Suppose Largecap 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 from that when it had the freedom to charge whatever rate it desired. Since Largecap 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 Largecap would provide no premium reduction, since it would still
be losing money on this property, even if mitigation were adopted. In fact, it would hope that its policyholders would purchase coverage from other insurers.

On the other hand, if the property owners were not required to adopt a mitigation measure, then Largecap would want to encourage them with some premium reduction as long as the insurer was forced to provide coverage to its existing policyholders. In fact, to minimise its expected loss Largecap would be willing to reduce its premium by as much as $500. Largecap would refuse coverage to any potential clients unless they adopted mitigation. In this case they would charge them at least $2000 for a policy in order to not lose money in the long term.

Behaviour By Small Capitalised Insurers

We define a small capitalised 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 they have enough surplus on hand to be solvent in case of unexpected losses.

As we will see below, the necessity of 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 a small capitalised company called Smallcap. It has financial resources of $S_S = $700 000 consisting of its initial surplus ($A_S = $450 000) and premium income of $250 000 based on selling 100 earthquake policies at premium $P'' = $2500 with no mitigation in place. If Smallcap has to maintain its current portfolio, then it will not meet its insolvency constraint. More specifically, we see from Table 6 that should it suffer three earthquake losses, it will have claims totalling $750 000 which exceeds $S_S$ by $50 000. The probability of suffering three or more losses is $q = 1/80 > q^* = 1/100$. By turning to the reinsurance market for an excess loss treaty, Smallcap can lay off some of its claims and would be willing to pay a relatively high price to do so.

Suppose that Smallcap 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 (an excellent summary of alternative reinsurance arrangements can be found in McIsaac and Babbel, 1995). This type of treaty arrangement would reduce its probability of insolvency from $q = 1/80$ to $q = 1/100$, thus satisfying the regulator’s concern with insolvency. Two questions naturally emerge:

- How much would the reinsurer want to charge for such a policy based on actuarial costs?
• How much could the reinsurer charge Smallcap for such a policy based on Smallcap’s need to meet an insolvency constraint?

The first question can be answered using the actuarial data from Table 6. The reinsurer is only concerned with the probability of Smallcap suffering three or more losses, in which case it will have to pay Smallcap $250 000. The probability of such an event occurring is \( p = 1/80 \). Hence, the actuarially fair reinsurance premium is \( R = 1/80 \times $250 000 = $3333.33 \). Smallcap, 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 three losses or less since its total claim payments would be limited to $500 000; the regulator will tolerate the possibility of four 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, a small capitalised insurer is very likely to be willing to pay the reinsurer somewhat more than the actuarial fair premium of $3333. 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 Smallcap and a specific reinsurer, then this firm has more flexibility in charging a higher premium than if Smallcap is shopping for reinsurance protection. The emergence of new financial instruments makes it more attractive for Smallcap to widen its circle for protection, and may lower reinsurance prices in the future.

One way of avoiding reinsurance charges is for insurers like Smallcap to encourage their policyholders to adopt mitigation measures through premium reductions. In the above example, if Smallcap were able to induce all of its policyholders to mitigate their home, then their losses from an earthquake are given in the last column of Table 6. In this situation Smallcap will have more than enough surplus assets on hand to pay for three losses and will not need to purchase reinsurance to meet the regulator’s concern with insolvency.

Due to its concern with insolvency, Smallcap 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 summarised as follows: Smallcap 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 $1000 if they will adopt a mitigation measure. Since the actuarially fair reduction in premiums is only $500, Smallcap 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, Smallcap 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 Behaviour

To summarise the findings regarding private insurer behaviour, the premium which an insurer is willing to charge for encouraging mitigation depends on the following factors:

- Its surplus (S).
- The minimum reduction the homeowner requires to adopt 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 their ability to raise premiums as q decreases because the consumer recognises that the insurer will be more likely to be able to pay claims should a major disaster occur.

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 regulator requires the premium to be subsidised. 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 capitalised 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 an insurer is operating in a financially responsible manner. Large capitalised companies also favour these
guidelines, since they are normally held accountable for paying off claims of insolvent companies through residual pools. On the other hand, when the Smallcaps of the world are forced to meet these insolvency 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 behaviour 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 capital market 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.

**ROLE OF BUILDING CODES**

Consider the following scenario, homeowners have perfect information on the risks associated with natural disasters and invest in cost-effective mitigation measures because they maximise their discounted expected utility. Insurers and reinsurers utilise this information on risk to price their products and provided premium discounts to those who adopt mitigation measures. All the costs of disasters can be allocated to specific individuals and property. There is, then, 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.

**Addressing Misperception of 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 under-estimate the probability of a disaster occurring. As indicated earlier, individuals often truncate the expected benefits from the mitigation measure due to myopia and high discount rates. There is also empirical evidence that they under-estimate 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 USA taxpayers bear some of the costs of restoring 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 earthquakes-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 be even 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 an earthquake cause damage to the building. If the insurer is unaware of how well the building is constructed, then this information cannot be conveyed to the potential property owner through a premium based on risk. Inspecting the building to see that it meets code and then providing it with a seal of approval provides more accurate information to the property owner.

Evidence from the July 1994 telephone survey (conducted by the Insurance Institute for Property Loss Reduction, 1995) provides supporting evidence for some type of seal of approval. Almost all (95%) of the 1241 respondents indicated that they would pay the additional costs in order to have a builder who followed codes; and 85% considered it very important that local building departments conduct inspection of new residential construction.

**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 instance. 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 an earlier section. Suppose that an unbraced structure that toppled in a severe earthquake had a 20% chance of bursting a pipeline and creating a fire that 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 (that is, 0.2 x 10 x $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 be 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 earthquake 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 favour 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 an earthquake, would have been spared this ordeal if a building code had been in place, then this is an additional benefit of mitigation. Suppose that the property is expected to need food and shelter for t days (for example, t = 50) at a daily cost of D = $100. Then, the additional expense from not having mitigated after a disaster occurs is t x D (that is, 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 x D
(that is, 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% annual discount rate were utilised. 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 (Britton, 1989). In a study estimating the physical and human consequences of a major earthquake in the Shelby County, Memphis, Tennessee area, located near the New Madrid fault, Litan, Krimgold, Clark, and Khadilkar (1992, pp.65-66) found that the temporary losses in economic output stemming from damage to workplaces could be as much as $US7.6 billion based on the magnitude of unemployment and the accompanying losses in wages, profits, and indirect ‘multiplier’ effects.

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

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This section summarises 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 offer 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 capitalised 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 RMMs 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 provide an additional option for small insurers to meet insolvency constraints and puts pressure on reinsurers 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 larger community associated with the destruction or damage of buildings from a disaster.

**Future Research Directions**

- **Encouraging Adoption of Cost-Effective Mitigation Measures**

  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 an earlier section, 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, 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% would result in payments of $145 per year. If the annual premium reduction from insurance reflected the expected benefits of the mitigation measure (for example, $500) then the insured homeowner will have lower total payments by investing in mitigation than not undertaking the measure (Kunreuther, 1997).

To implement such a program, banks have to be convinced that 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 need the freedom to charge insurance premiums which reflect the disaster risk rather than being forced to offer coverage at subsidised rates. This may involve changes in the insurance regulatory environment.

Micro-Model Simulations

A broader strategy for undertaking research in this area would involves the analysis of the impact of disasters 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 of such an approach to a model city in California
facing an earthquake risk can be found in Kleindorfer and Kurreuther (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, a large USA insurer, 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. Doherty (1997) provides more details on these and other recent financial instruments. 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 types of 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 an Act of God bond, which requires a large enough amount to make it attractive to the investor. These simulation results could be compared with analytic studies of the performance of these instruments. If there are major differences it would be important to understand why they exist. Second, investors could determine whether the market price 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 modelling 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 reinsurance and 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, 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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APPENDIX 1

MODELLING THE DEMAND FOR PROTECTIVE ACTIVITIES
BY PROPERTY OWNERS

Discounted utility theory has been the dominant approach for modelling decisions to invest in protective measures when future outcomes are known with certainty. The basic concept is that people act as though they utilise 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 maximise:

\[
\sum_t s(t) \cdot u[x(t)]
\]

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

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 maximise discounted expected utility (DEU) where DEU is defined as:

\[
\sum_r \sum_i \delta(t) \cdot p_i \cdot u[x_i(t)] \\
\sum_i p_i = 1
\]

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 \( p_i^{*} \leq p_i \) of a loss \( x(t) \) 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:

\[
u[B_T] = \sum_i \sum_t \delta(t) \cdot (p_i - p_i^*) \cdot u[x(t)]
\]

A person who maximises DEU will invest in the RMM whenever:

\[u(B_T) + u(-Z) > 0.\]

**APPENDIX 2**

**MODELLING INSURERS BEHAVIOUR 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 (for example, \( p = 1/100 \))

\( L'' = \) Loss without mitigation (for example, \( L'' = \$250,000 \))

\( L' = \) Loss with mitigation (for example, \( L' = \$200,000 \))

\( E(L'') = p \cdot L'' = \) Expected Annual Loss without mitigation (for example, \( \$2500 \))

\( E(L') = p \cdot L' = \) Expected Annual Loss with mitigation (for example, \( \$2000 \))

\( P'' = E(L'') = \) actuarially fair premium without mitigation

\( P' = E(L') = \) actuarially fair premium with mitigation

\( M = \) Minimum premium reduction from \( P'' \) for homeowner to adopt mitigation.

**Assumptions**

The insurer provides coverage for a single type structure (for example, 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 earthquake (that is, there is not a perfect correlation between losses), and has estimated the resulting losses with and without mitigation in place. Table 6 presents these data for an illustrative example.

LARGE AND SMALL CAPITALISED INSURER PREMIUM SETTING PROCESSES

Large Capitalised Insurers (No Insolvency Constraint)

Largecap has N earthquake policies and must decide what premium (P_L) it will charge. Let S_L = Largecap’s financial resources 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.

Largecap’s objective is to choose a premium P_L ≥ P” so as to:

\[
\text{Max} \left[ A_L + NP_L - \sum p_i L \right] \tag{1}
\]

Subject to the following insolvency constraint:

\[
\text{Probability } \left[ \sum_{i=1}^{8} [A_L + N(P_L) - i L] \leq 0 \right] \leq q^* \tag{2}
\]

where q^* = maximum probability of insolvency.

In the example given in the paper, Largecap is 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 6, (2) will also be satisfied if mitigation is adopted by property owners and P_L = P’.

Hence, Largecap will set a premium which maximises (1) but is interested in reducing the premium if it will both encourage the property owner 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 an imperfectly competitive market the insurer will charge \( P \geq P' \) to encourage mitigation.

Example: If \( M = $300 \), \( P'' = $2500 \), and \( P' = $2000 \), then the insurer will charge a premium somewhere between $2000 and $2200.

Small Capitalised Insurers (Insolvency Constraint is Exceeded Without Mitigation)

Smallcap has \( N \) earthquake policies and must decide what premium \( (P_S) \) it will charge. Let \( S_S \) = the small insurer’s financial resources 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:

\[
\text{Max } [A_S + NP_S - \sum p_i L] \tag{3}
\]

Subject to the following insolvency constraint:

\[
\text{Probability } \left[ \sum_{i=1}^{8} (A_S + N(P_S) - i L) \leq 0 \right] \leq q^* \tag{4}
\]

where \( q^* = \text{maximum probability of insolvency} \)

Smallcap is assumed not to have sufficient financial resources \( (S_S) \) when mitigation is not in place so that the insolvency constraint given by (4) for \( L = L'' \) will not be met. In the example in the paper \( S_S = $700 \text{,}000 \), consisting of \( A_S = $450 \text{,}000 \), and actuarial premiums for 100 policies 100 \( (P'') = $250 \text{,}000 \). 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 6.

Purchasing Reinsurance

Suppose that a reinsurer is willing to provide coverage of $250 000, to protect Smallcap against losses exceeding $500 000 (that is, $250 000 in excess of $500 000). The reinsurer will suffer a loss of $250 000, if there are three or more losses. This probability is given by 1/80 so that the actuarially fair premium is \( R = 1/80 (\text{\$250 000\}) = \text{\$3300.} \)
For the example above we can determine the maximum reinsurance premium \( (R_{\text{max}}) \) Smallcap would pay for this excess coverage to satisfy (4). Specifically with $250 000 in excess of $500 000 reinsurance, (4) becomes (where the figures are in thousands of dollars):

\[
\begin{align*}
\text{Prob}\left( \sum_{i=1}^{2} \left[ (250 - R_{\text{max}} - i L^*) + \left[ (700 - R_{\text{max}} - 750 + 250) + \sum_{i=4}^{8} \left[ (700 - R_{\text{max}} - i L^* + 250) \right] \right] \right] \leq 0.01 \right) = 0.01
\end{align*}
\]

\( R_{\text{max}} \) is determined by finding the value where the surplus of the insurer is zero when there are three losses. To see this, note from Table 6 that Smallcap’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 0.01. Hence if \( q^* = 0.01 \), the value of \( R_{\text{max}} \) is determined by solving:

\[
700 - R_{\text{max}} - 750 + 250 = 0
\]

Imply that \( R_{\text{max}} = 200 \). 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 $3333 and this upper limit.

**Encouraging Mitigation Through Premium Reductions**

As an alternative to reinsurance Smallcap 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 Smallcap 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 6 one sees that if \( q^* = 1/100 \) then Smallcap needs to set premiums so it has sufficient surplus to cover three losses. With mitigation its claims are reduced from $750 000 to $600 000 when three structures are damaged. Hence, to determine \( P_s \) which satisfies (4) one computes:

\[
450 000 - 100 P_s - 600 000 = 0
\]

This means that \( P_s = 1500 \), a premium below the actuarially fair value of \( P^* = 2000 \). Thus, Smallcap loses money on its earthquake business to encourage mitigation and satisfy its insolvency constraint.
REFERENCES


