"Linking Insurance and Mitigation to Manage Natural Hazard Disaster Risk"

99-07-15

Howard Kunreuther

LINKING INSURANCE AND MITIGATION TO MANAGE NATURAL DISASTER RISK

Howard Kunreuther

July 1999


---

1 Special thanks to two anonymous referees for their helpful comments on an earlier version of this paper. I have benefited greatly from discussions with my colleagues from the Wharton *Managing Catastrophic Risk Project* on topics covered in the paper: Vivek Bantwal, Peter Burns, David Croson, David Cummins, Neil Doherty, Patricia Grossi, Robert Klein, Paul Kleindorfer, Robert Meyer and Tony Santomero. Partial support from NSF Grant # 524603 and the Wharton Risk Management and Decision Processes Center is gratefully acknowledged. Portions of the paper are based on an invited paper presented at the Fifth Alexander Howden (Australia) Conference on Disaster Insurance, Gold Coast August, 1997.

The insurance industry has suffered very large losses in the past 10 years from natural disasters and has the potential for experiencing even greater losses in the future. This paper examines the role that insurance coupled with cost-effective risk mitigation measures (RMMs) can play in managing the risks from natural disasters. Large insurers have incentives to provide premium reductions to encourage RMMs if the allowable premiums are sufficiently high that they can ass the savings in losses to the property owner or if they are required to continue to their current policyholders with coverage. Small insurers also have incentives to encourage their policyholders to adopt mitigation measures through premium reductions so as to reduce their chances of insolvency from a large-scale disaster. They may also want to consider purchasing reinsurance to cover a portion of their excess losses. Well-enforced building codes can complement insurance by forcing the adoption of cost-effective RMMs. They may be needed because many property owners underestimate the risks from disasters. In addition, mitigation measures not only reduce losses to the property itself but may produce positive externalities by reducing other costs of a disaster. The paper concludes by outlining the roles that financial institutions, real estate developers and municipalities can play in developing incentives for the adoption of cost-effective RMMs and suggesting directions for future research.
Linking Insurance and Mitigation to Manage Natural Disaster Risks

Howard Kunreuther
July 1999

1. Introduction

The insurance industry is now fully aware that they are highly vulnerable to potential losses from natural disasters. Insured losses from Hurricane Andrew, which swept ashore along the Florida coastline in August 1992, topped $15 billion. If the storm had taken a more northerly track so it would have hit downtown Miami and Miami Beach, total insured damage could have approached $50 billion. (Insurance Research Council and Insurance Institute for Property Loss Reduction 1995). Insured damage from the Northridge earthquake in southern California exceeded $12 billion. Had a similar quake hit central Los Angeles the insured bill could have been over $50 billion. A large quake in central Tokyo could have cost over $800 billion. (Giles 1994)

Companies now recognize that they will have to turn to risk mitigation measures (RMMs) to reduce their chances of insolvency from future catastrophic events. For example, studies following Hurricane Andrew estimated that 25 percent of the $15 billion insured damage from the disaster could have been prevented had building codes been enforced (Insurance Research Council and Insurance Institute for Property Loss Reduction (1995). A group of insurers formed the Insurance Institute for Property Loss Reduction (IIPLR) in the early 1990s. This independent, nonprofit organization, 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. The substantial interest today by insurers in loss prevention measures to reduce natural disaster damage by has a parallel in the automobile arena, when insurers created the Institute for Highway Safety whose principal mission is to design safer cars.

This paper focuses on when insurers would want to encourage individuals to adopt cost-effective RMMs using premium reductions as an incentives to reduce their chances of insolvency and/or improve their future expected profits. A cost-effective risk mitigation measure (RMM) is defined to be one where the expected discounted benefits in the form of reduced losses exceeds the upfront cost of the measure. Section 2 addresses why insurers are concerned with potential insolvencies from future natural disasters. Section 3 then turns to the positive role that RMMs can play in improving the profitability of large insurers and addressing the insolvency concerns of small insurers. Section 4 focuses on the role of building codes in dealing with misinformation problems of property owners and reducing externalities. In Section 5 I explore other incentives for encouraging
mitigation using insurance as a vehicle. The concluding section discusses future research directions.

2. Insurers Concern with Insolvency

A principal reason that mitigation is of central importance to insurers today is their fear of insolvency from future natural disasters. Mayers and Smith (1982) used modern finance theory to challenge the assumption that insurers are risk neutral with respect to losses. Employees of an insurance firm may be risk averse due to the costs of finding another job if their company becomes insolvent so that the insurer will want to charge higher premiums against risks with potentially catastrophic losses to reflect this concern. In fact, risk aversion is one reason that property/liability companies are willing to purchase reinsurance at premiums that exceed their actuarial risks. (Mayers and Smith 1990).\(^1\)

Insurers will also have incentives to limit their risk of insolvency to the extent that they have acquired franchise value that can only be recouped if they remain in business. Research suggests that the managers of mutual insurance companies should be able to exercise greater discretion in promoting the safety of their companies than stock insurers. In fact, the owners of stock insurance firms with low levels of capital and little franchise values may have an incentive to incur excessive risks (Cummins, 1988).\(^4\)

With respect to decision making in an insurance firm, Stone (1973 a, b) suggested that an underwriter who wants to determine the premium to charge will first focus on keeping the probability of insolvency below some threshold level \((q^*)\). One reason that an insurer would want to do this is to improve its ability to set higher premiums and hence improve its cash flow. More specifically, suppose that the insurer has a portfolio of \(N\) policies, each of which can lead to a loss \(L\). Then the underwriter will recommend a premium \(P\) so that the probability of insolvency would be less than \(q^*\).

Empirical studies of underwriters pricing decisions reveal that risks with more uncertain losses or greater ambiguity will cause them to want to charge higher premiums for a given portfolio of risks. (Kunreuther et al 1995). The situation will be most pronounced for highly correlated losses, such as earthquake policies sold in one region of California.

A safety-first model of underwriter behavior is consistent with the Mayers and Smith (1990) rationale as to why insurance firms want to purchase reinsurance. In fact, a rule that focuses on keeping the chances of insolvency below \(q^*\) explicitly recognizes the role that risk plays in the decision process and the role that mitigation measures and

---

\(^1\) Doherty and Tinic (1982) have argued that demand for reinsurance is generated by insurers anticipating policyholders' aversion to bankruptcy.

\(^4\) I am grateful to one of the referees of this paper for pointing this out.
reinsurance can play in alleviating these concerns. A more formal model for the
underwriter’s decision process based on a safety first model is specified in Appendix 1.

Interview data with several insurance companies in the United States concerned with the
impact of recent natural disaster losses on their future activity provides evidence that
firms follow a safety first model. In the aftermath of Hurricane Andrew and the
Northridge earthquake, company executives indicated that they were concerned that they
could not survive a future catastrophe given their current portfolio and the amounts of
reinsurance coverage that they could obtain at reasonable prices. In other words they felt
that their chances of insolvency based on their current portfolio exceeded their threshold
level of concern (q*).

When insurers are in this position they can pursue one or more of the following options to
reduce their chances of insolvency. They can try and reduce the number of policies they
write in catastrophe-prone areas. They can request from the relevant state insurance
commissioners that they be allowed to raise their premium P to current and/or future
policyholders. They can encourage their policyholders through economic incentives or
require them to adopt mitigation measures as a way of reducing future claim payments.
Insurers can also try and obtain more reinsurance coverage and/or raise more capital to
hold as reserves.

In practice state regulation often precludes insurers from canceling as many policies as
they would like and raising premiums. Since Hurricane Andrew the percentage of
homeowners policies in Florida that an insurer can cancel or nonrenew in any one year is
required to be less than 5 percent statewide and 10 percent in any one county. Permitted
rate increases have also been less than what insurers would like to charge (Lecomte and
Gahagan 1998). These restrictions have led to new developments in the state. There
have been cross-subsidies between policyholders with property owners on the coast being
cross-subsidized by those who reside in less hazard-prone areas regions of the state.
(Klein 1997). In addition residual markets, state catastrophe funds and guarantee funds
have been created and have lead to a form of risk-sharing between insurers.

---

5 These observations are based on a series of personal interviews with insurers and reinsurers conducted by
Jacqueline Meszaros as part of a National Science Foundation study to the University of Pennsylvania.
6 See Kleffner and Doherty (1996) for a more detailed analysis of the impact of the relative costs of these
measures and the characteristics of the insurers who use them. Russell and Jaffe (1997) discuss the
impact of catastrophes on the cash flow management problem and how current tax law prevents insurers
from accumulating reserves to fund catastrophe losses.
7 For more detail on the role that regulation plays in the rating setting process for risks of natural disasters
see Klein 1998.
8 During the 1996 Florida state legislative session companies were allowed to accelerate nonrenewals. An
insurer, with approval of the commissioner could use its entire quota of nonrenewals allowed through June
1, 1999 in the first year. Several major insurers filed for permission to do that, and those filings were
approved.
3. Linking Mitigation With Insurance

There has been considerable research on the decision to invest in loss prevention or RMMs by consumers (Ehrlich and Becker (1972), Dionne and Eeckhoudt (1985) and Kunreuther and Kleffner (1992). Those who have insurance coverage will want to invest in mitigation measures if the premium reduction is large enough to justify the extra costs of investing in the loss prevention measure. The question we are addressing in this paper is what type of premium incentives will insurers want to provide to their policyholders to encourage them to adopt RMMs? The answer depends both on the surplus of the insurer, the rate structure as well as the concerns that both the insurer and policyholder have with insolvency.

To motivate the discussion I construct a simple example of an insurer who wants to determine how much coverage to provide against the earthquake risk. A concrete example has the virtue of showing the impact that loss prevention can have on insurers behavior and the resulting tradeoffs between profitability and insolvency. We first examine the case of a large insurer who has sufficient surplus that the probability of insolvency under its current portfolio of risks is less than \( q^* \). Hence its only rationale for encouraging its policyholders to adopt mitigation measures is to improve its profitability. We then turn to a small insurer where the insolvency constraint is operative. Now the insurer faces a tradeoff between encouraging its policyholders to adopt mitigation or purchasing reinsurance to reduce its loss payments following a disaster.

An Illustrative Example

Consider an insurer who provides full earthquake coverage for a single type structure (e.g., a wood frame home). The insurer estimates the chances of an earthquake in the region to be \( p = 1/100 \). The insurer will incur a loss (\( L' \)) if an RMM is adopted and a loss (\( L'' > L' \)) if it is not mitigated. For this example, \( L' = $200,000 \) and \( L'' = $250,000 \) so the RMM reduces damage by $50,000 should a quake occur. Based on this information the insurer can calculate the expected loss for a structure with mitigation which is

\[
E(L') = \frac{1}{100} ($200,000) = $2000
\]

or the expected loss without mitigation which is

\[
E(L'') = \frac{1}{100} ($250,000) = $2500
\]

In other words the expected annual benefit from mitigation is $500.

Suppose that an insurer has written \( N \) 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 given there is less than perfect correlation between losses. Table 1 provides a set of 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 1 HERE
The question for the insurer is what premium to charge the property owner to encourage her to adopt mitigation with the objective of maximizing expected profits while keeping the probability of insolvency (q) below some threshold level (q*). For purposes of this example, let q* = 1/120.

In addition to internal organizational concerns with insolvency noted above, an insurer may be required to show the regulator that it is financially viable by having a probability of insolvency which is q* or less. Furthermore policyholders may be willing to pay a higher premium if they know that the chances of the insurer becoming insolvent is reduced. 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 lower credit risks leads to higher premiums then this provides insurers with an additional economic rationale to encourage homeowners to adopt RMMs.

**Behavior by a Large Insurer**

Consider a large capitalized insurer, Alpha, who has enough initial capital and premium income so it is not concerned with the insolvency constraint and does not require reinsurance. Let $S_L$ represent Alpha’s financial resources which consists of its initial surplus and premium income based on charging the actuarially fair premium without mitigation. In the context of the data in Table 1 suppose that $S_L$ = $1.2$ million. In this case Alpha will still have positive capital on hand unless it suffered more than four losses with no structures mitigated (i.e. $L = L’$). The probability of this occurring is $1/125$, so that the insurer has satisfied its insolvency constraint.

For this reason, Alpha’s sole objective is to maximize expected profits and it has no desire to purchase reinsurance. Suppose Alpha has the freedom to charge whatever rate the market will bear. This implies that the insurer will charge a premium at least as high as its expected loss so that $P \geq E(L') = $2000 if mitigation is adopted and $P'' \geq 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 minimum premium reduction from $P''$ that will lead the property owner to adopt mitigation. If $M < P'' - P'$, then Alpha will offer a policy with mitigation where the premium will range between $P'$ and $P'' - M$. The actual premium depends on the competitive nature of the market and the extent of search by customers. Thus if $M = $300, insurers will offer policies for mitigated homes that range from $2000 to $2200.9

---

9 If $M > P'' - P'$, then the homeowner will *not* have an incentive to mitigate. If the RMM is cost-ineffective, then there is good reason why the property owner should not want to adopt it. On the other hand, individuals may choose not to incur the upfront costs of an RMM because of budget constraints or insufficient appreciation of the long-term benefits of loss reduction due to short time horizons or hyperbolic discounting. Section 5 addresses ways to make cost-effective RMMs more attractive to the homeowner.
Turning to the impact that mitigation has on reducing $q$, suppose Alpha was able to encourage all its customers to adopt an RMM, and had $S_i = 1.2$ million. From Table 1 its probability of insolvency with mitigation is reduced to $q = 1/180$ since it can now absorb six losses rather than the four losses it was able to cover when an RRM was not adopted. From an insurer’s vantage point, mitigation truncates the worst case scenarios by reducing the losses on individual structures.

Suppose that the regulator set a maximum premium ($P_R$) below the actuarial cost but Alpha was not forced to provide coverage to those who wanted it. If $P_R < P'$ then it would not offer any coverage even if the homeowner adopted mitigation since it would be losing money on the insurance policy. If, on the other hand, $P_R > P'$, then Alpha will be willing to offer coverage to those who mitigate at a premium reduction as high as $P - P'$. For those who do not mitigate it would only offer them a policy if $P_R > P'$.

If Alpha was forced to provide coverage to its existing policyholders, then it would still want to offer a premium reduction as an incentive for them to adopt mitigation no matter what $P_R$ the regulator set. In fact, to minimize its expected loss Alpha would be willing to reduce its premium by as much as $P' - P' = 500$.

**Behavior by Small Insurers**

In addition to encouraging mitigation through premium reductions, reinsurance can be utilized to reduce the chances of insolvency for smaller insurers impacted by the insolvency constraint. Consider an excess of loss reinsurance contract for dealing with catastrophic risks. The primary insurer would be responsible for all losses up to a specified amount and the reinsurance company would reimburse the insurer for a layer of losses up to some pre-specified maximum dollar figure. For example, if the reinsurance contract specified $5$ million in excess of $1$ million and the total losses were $10$ million, then the primary insurer would pay the $10$ million in losses, and the reinsurer would reimburse the insurer for $5$ million of this amount. Had the insured loss been below $1$ million, then the insurer would be responsible for all of it.

**Behavior with No Moral Hazard**  We first discuss the case where the insurer behaves in the same way as if it did not have reinsurance so that there is no moral hazard. The same example used for evaluating Alpha’s pricing strategy can illustrate the maximum amount that a small capitalized insurer would pay for reinsurance if it were forced to insure its current policyholders. We define a small capitalized 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

---

10 An excellent summary of alternative reinsurance arrangements can be found in McIsaac and Babbel (1995).
is that a regulatory authority requires them to show that they have enough surplus on hand to be solvent in case actual losses are greater than expected losses.

The necessity of meeting insolvency conditions provides a partial explanation as to why some insurers are willing to pay high prices for reinsurance. Let $S_s$ represent the surplus of a small capitalized company called Beta. It has financial resources of $S_s = \$700,000$ consisting of its initial surplus ($A_s = \$450,000$) and premium income ($\$250,000$) based on selling 100 earthquake policies at premium $P^* = \$2,500$ with no mitigation in place. If Beta has to maintain its current portfolio, then it will not meet its insolvency constraint. As seen from Table 1, 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 $q = 1/80 > q^* = 1/120$. By turning to the reinsurance market for an excess loss treaty, Beta can lay off some of its claims and should be willing to pay a relatively high price to do so.

Suppose that Beta 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. This type of treaty arrangement would reduce its probability of insolvency from $q = 1/80$ to $q = 1/120$, 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 costs? and (2) How much could the reinsurer charge Beta for such a policy based on Beta’s need to meet an insolvency constraint?

The first question can be answered using the data from Table 1. The reinsurer is only concerned with the probability of Beta suffering three or more losses, in which case it will have to pay Beta $\$250,000$. The probability of such an event occurring is $p = 1/80$. Hence the actuarially fair reinsurance premium is $R = 1/80 (\$250,000) = \$3,333$. Beta, on the other hand, is willing to pay considerably more for such a policy to meet its insolvency constraint. With $S_s = \$700,000$ it will theoretically be willing to pay up to $\$200,000$ for such a policy if it still will make positive expected profits on other lines of coverage.11 This is shown in Appendix 2 for an insurer who wants to determine the maximum it would have to pay to meet the insolvency constraint imposed by the regulator.

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 capitalized 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 and the tradeoffs between making a quick profit tomorrow vs maintaining a long-term relationship with the insurer by charging a reasonable price for excess loss coverage.

11 The small insurer is not making any positive expected profits on earthquake coverage by assumption. The premiums without mitigation are simply the expected losses.
One way of avoiding reinsurance charges is for insurers like Beta to provide premium reductions to their policyholders as a way of encouraging them to adopt mitigation measures. In the above example, if Beta 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 1. In this situation, the $700,000 that Beta has in surplus will be able to pay for the claims associated with 3 losses ($600,000). Hence Beta will not need to purchase reinsurance to meet the regulator’s concern with insolvency if its policyholders adopt RMMs.

As shown in Appendix 2 Beta may be willing to provide a sufficiently large premium reduction to encourage mitigation by its policyholders to satisfy the insolvency constraint, that it will lose money on its earthquake book of business. The only reason to agree to pay this premium is if it costs the insurer less than reinsurance and it enables Beta to make sufficient expected profits on other risks to more than offset the expected earthquake losses, so the insurer wants to stay in business.

The maximum discount that Beta would be willing to give its policyholders to encourage them to adopt an RMM depends on Beta’s current surplus relative to potential claims in the future. The detailed calculations are shown in Appendix 2. The informal argument can be summarized as follows. Beta wants to show the regulator that it has $S_s = $600,000 on hand to 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 assuming that its expected profits from this and other lines of coverage was still positive.

This means that Beta would be willing to reduce the premiums for each of its policyholders by up to $1,000 if that is what it took to convince their policyholders to adopt a mitigation measure and Beta would still be making a positive. Since the actuarially fair reduction in premiums based on Table 1 is only $500, Beta would be willing to reduce its premiums to reduce its expected loss on its earthquake book of business in order to meet its insolvency constraint. Of course, when reinsurance is available, Beta 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.

**Behavior with Moral Hazard.** In setting their premiums, reinsurers are concerned with problems of ex ante and ex post moral hazard. Ex ante moral hazard occurs when the primary insurer fails to take actions to reduce future losses or takes actions that increase losses simply because the reinsurer cannot monitor the insurer’s behavior.[ Pauly (1974), Marshall (1976), Shavell (1979) and Dionne and Harrington (1992).] Ex post moral hazard arises when the insurer relaxes its loss settlement process because it knows that the reinsurer will cover some of its claims. [Spence and Zeckhauser (1971) and Dionne and Harrington (1992)]

Below we focus only on ex post moral hazard. More specifically the insurer considers skimping on its claims processing because it can pass some of the loss payments to the
reinsurer. To keep the analysis simple all policyholders are assumed to be identical and each one experiences the same loss from the disaster. The primary insurer incurs two types of expenditures: (1) an administrative cost for processing claims and adjusting the losses and (2) the claims payments from the losses themselves. Both these costs will increase as the number of losses increases. When the primary insurer bears all the losses itself, then it will diligently process the claims and adjust the losses at a cost of \( C_i \) if there are \( i \) losses from the disaster. It would then incur total insurance claims costs of \( iL \).

If the reinsurer were to cover the entire set of losses, then the primary insurer would shirk in its claims-adjusting process and incur a cost of \( C^*_i \), causing each loss to increase to \( L^* > L \). To examine the financial implications of this type of ex post moral hazard, the primary insurer will be assumed not to shirk if it must absorb the entire difference in the loss costs itself. This implies that

\[
i(L^* - L) > C_i - C^*_i \quad \text{for all } i \quad (1)
\]

With an excess loss treaty, the reinsurer has the opportunity to reduce the ex post moral hazard by arranging the lower and upper attachment points so that the primary insurer will bear enough of the costs of shirking at both the front end and the back end to want to behave more responsibly. The lower attachment point means that the primary insurer is responsible for any losses below this amount (i.e. a deductible on a reinsurance policy). The upper attachment point refers to the upper limit of the reinsurers excess loss contract. If an insurer experiences losses above that amount, then it must bear the residual losses.

Suppose that the insurer has an excess loss treaty with the reinsurer whereby the insurer pays for the first \( D \) dollars of the loss, the reinsurer pays the next \( R \) dollars and then the primary insurer is responsible for any loss above \( D+R \). The insurer faces the following tradeoff. If it is negligent in its claims adjustment process it can reduce its costs by \( C_i - C^*_i \) but now faces higher loss costs, some of which may be shifted to the reinsurer. If total losses are below \( D \), then the primary insurer bears the extra loss cost on its own; if total losses are between \( D \) and \( D+R \) then both the insurer and reinsurer share the extra loss costs; any losses above \( D+R \) are borne by the insurer. Hence the primary insurer will not want to shirk if the savings from the administrative costs are wiped out by higher expenditures at either the front and/or back ends.

If the reinsurer offers an excess loss contract, there are two conditions when the primary insurer will not want to shirk because the increase in loss costs exceed the savings in administration costs:

*Condition 1:* If the losses after shirking from the disaster are below \( D \) (i.e. \( iL^* < D \)). In this case the insurer must bear the entire claims costs itself.

*Condition 2:* If the losses without shirking are above \( D+R \) (i.e. \( iL > D+R \)). In this case the insurer bears all the *extra costs* of shirking itself.
On the other hand, the insurer will always want to shirk if it can pass on enough of the excess in loss costs to the reinsurer to justify the savings in administrative costs. Let $TC(S) =$ the total costs to the insurer of shirking and $TC(NS) =$ the total costs to the insurer of not shirking. Given Conditions 1 and 2, then the primary insurer will incur the following costs when it shirks and doesn’t shirk:

$$TC(S) = \min \{iL^*,D\} + \max \{0,iL^*-R\} + C^*_i$$  \hspace{1cm} (3)

$$TC(NS) = \min \{iL, D\} + \max \{0, iL-R\} + C_i$$  \hspace{1cm} (4)

The primary insurer will always want to shirk whenever $TC(S) < TC(NS)$. This implies that shirking will always occur whenever the increase in loss costs is less than the savings in administrative costs from shirking as shown by the following inequality derived from (3) and (4):

$$[\min \{iL^*,D\}- \min \{iL, D\}] + \max \{0,iL^*-R\} - \max \{0, iL-R\} < C_i - C^*_i$$  \hspace{1cm} (5)

A simple example illustrates when shirking becomes worthwhile. Suppose that $i=10$, $L^*=100$, $D=50$ and $R=850$. The total cost of shirking is 200. The LHS of (5) is 150 reflecting the extra costs that the insurer has to pay above $D+R$ for shirking with the reinsurer incurring an extra cost of 50. Whenever $C_i - C^*_i > 150$ then the insurer will want to shirk.\(^{12}\) In general, as $D$ increases and $R$ decreases the primary insurer will have less incentive to shirk because it will have to bear a larger proportion of the losses itself. In other words, larger deductibles and lower maximum coverage limits placed by the reinsurer reduce the possibility of ex post moral hazard by the primary insurer.\(^{13}\)

When there are shortages of claims adjustors, then as the number of losses increases the settlements will be expected to become more generous particularly if there is additional pressure on the insurers to settle more quickly to help the community back on its feet. Reinsurers will now have higher payments for reasons having nothing to do with ex post moral hazard unless insurers are even more generous in making claims when they are reinsured than when they have to bear the costs themselves.

4. Role Of Building Codes

---

\(^{12}\) Note that if the reinsurer sets $D+R > 1000$ then it will cover the entire amount of the losses above the deductible whether the insurer shirks or doesn’t shirk. In this case whenever $C_i > C^*_i$ the insurer will want to shirk.

\(^{13}\) The relationship between the reinsurer and insurer is similar to that between the insurer and a policyholder.
The above analysis implicitly assumed that insurers would encourage property owners to undertake RMMs through premium reductions. There would be no need for building codes if the following set of conditions were met in practice: Homeowners have perfect information on the risks associated with natural disasters and invest in cost-effective mitigation measures because they maximize their discounted expected utility. Insurers utilize the information on the risk from natural disasters to price their coverage and provide premium discounts to those who adopt these RMMs. Finally, all the costs from disasters are allocated to specific individuals and property. It is precisely because none of these conditions are fulfilled in practice that building codes serve a useful purpose as shown below.

Addressing Misinformation Problems

Property owners may fail to adopt cost-effective RMMs either because they have budget constraints, underestimate the benefits from adopting the RMM and/or the probability of a disaster occurring (Kunreuther 1996). To illustrate these points, suppose a family only feel it can only afford $300 for investing in a measure which costs $2,000. The homeowner may perceive the probability of an earthquake causing damage to his or her home next year to be 1/500, while experts estimate it to be 1/100. They may compute the expected discounted benefits from the mitigation measure only over the next several years while the relevant time horizon is the expected length of life of the structure. Furthermore, the homeowner may have difficulty assessing a home’s hazard resistance in the absence of code enforcement.

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 misinformation that potential property owners have regarding the safety of the structure. 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 building is constructed, then this information cannot be conveyed to the

---

14 Alternatively codes could have specified that structures meet certain requirements but there was poor enforcement of these regulations.
potential property owner through a premium based on risk. Inspecting the building to see that it meets code provides accurate information to the property owner.

**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** Suppose that an unbraced structure had a 20 percent chance of toppling in an earthquake, 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., .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 unbraced to be charged a higher fire premium by their insurers to reflect the additional hazard from living next to the unprotected house. In fact, this additional premium should be charged to the unprotected structure that 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 have to be charged this extra premium. Alternatively the house that caused the pipeline to burst could be liable for the damage to the other structures but this also does not have a legal basis today in the United States.

The relevant point for this analysis is that when there are additional annual expected benefits from mitigation that cannot be captured through premiums by private insurers, then well-enforced building codes may be necessary. All financial institutions and insurers who are responsible for the 10 other properties at risk would favor building codes to protect their investments and/or reduce the insurance premiums they would otherwise have to charge for coverage against fire following earthquake.

**Social Costs Arising from Property Damage** If a family is forced to vacate its home because of damage from 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 family is expected to need

---

13 If insurance was provided by the government rather than the private sector then this problem would not exist. The government would have an incentive to charge the unprotected home a premium reflecting the additional risk caused to other homes from not bracing its foundation.
food and shelter for t days (e.g. t = 50) at a daily cost of D = $100. Then the additional expense after a disaster occurs from not having mitigated 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 x D (i.e., 1/100 x 50 x $100 = $50). Although this may not appear to be a very large figure, it amounts to an expected discounted cost of over $560 for a 30 year period if an 8% discount rate is utilized. Should there be a large number of households that need to be provided with food and shelter, these costs could be substantial.

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. 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. Their report suggests that selective building codes for certain structures could be beneficial, in the light of these additional economic benefits.

5. Encouraging Mitigation Through Other Incentives and Regulations

Private insurance coupled with building codes can be important components of a program for reducing losses from natural disasters while providing financial protection for those who suffer damage. This section discusses ways to supplement these two policy tools with other measures through the active involvement of other interested parties notably financial institutions, real estate community and the community itself.

Premium Reductions Linked with Long-Term Loans

As shown in Section 3 insurance premium reductions for undertaking loss prevention measures can encourage property owners to adopt them. However, they may be reluctant to adopt these measures due to budget constraints. Building codes do not solve the affordability issue so that one may want to turn to banks and financial institutions for a creative solution to this problem.

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. Consider the following example, where the cost of bracing the roof on property in a hurricane-prone coastal area is $1,500. If the meteorologists’ best estimate of the annual probability of a hurricane is p = 1/100, and the reduction in loss from bracing the roof is $27,500, then the expected annual benefit is $275. A 20-year loan for $1,500 at an annual interest rate of 10 percent would result in payments of $145 per year. If the annual insurance premium reduction reflected the
expected benefits of the mitigation measure (i.e., $275), then the insured homeowner will have lower total payments by investing in mitigation than not undertaking the measure.

Banks and financial institutions normally require homeowners insurance as a condition for a mortgage. In the above example the property owner would not have to think twice about taking out a home improvement loan since this would reduce the total annual payments by $130. On the other hand, if insurance were not required, as is the case today with earthquake coverage, then long-term loans may still not be effective in encouraging the adoption of mitigation measures and one might have to rely primarily on code enforcement. Even if insurance is required but the regulated rates are not based on risk, then the insurer may have no financial incentive to reduce the price of coverage to reflect the full gains from mitigation. For example, if the premium reduction were less than $145 per year, then the property will have no financial incentive to take out a loan unless she felt there were other benefits from mitigation aside from the property damage reduction from a future hurricane.

Many poorly constructed homes are owned by low-income families who cannot afford the costs of mitigation measures on their existing structure. Equity considerations argue for providing this group with low-interest loans and grants so that they can either adopt cost-effective mitigation measures or relocate to a safer area. Since low-income victims are likely to receive federal assistance to cover uninsured losses after a disaster, subsidizing these mitigation measures can also be justified on efficiency grounds.

**Seals of Approval on Structures Meeting Code**

Cost-effective risk-reduction measures should be incorporated in building codes and a seal of approval should given to each structure that meets or exceeds the code. A seal of approval provides accurate information to the property owner and forces the developer and real estate agent to let the potential buyer know why the structure has not been officially approved for safety. It may have the added benefit of increasing the property value of the home, since buyers should be willing to pay a premium for a safer structure.

Banks and financial institutions could require that structures be inspected and certified against natural hazards as a condition for obtaining a mortgage. This inspection, which would be a form of buyer protection, is similar in concept to termite and radon inspections normally required when property is financed. The success of such a program requires the support of the building industry, of realtors, and of a cadre of well-qualified inspectors providing accurate information on the condition of the structure.

Evidence from a July 1994 telephone survey of 1241 residents in six hurricane-prone areas along the Atlantic and Gulf Coasts supports this type of program. 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).

Community-based insurance incentives

One way to encourage communities to develop and enforce building codes is to provide insurance premium reductions to all policyholders in the area based on the stringency of the standard. The more effective a community program is in reducing future disaster losses, the greater the insurance premium reduction.

Such a Community Rating System (CRS) was created by the Federal Insurance Administration in 1990 as a way to recognize and encourage community flood plain management activities that exceed the minimum National Flood Insurance Program (NFIP) standards (Pasterick, 1998). Inspired by the CRS, the Institute for Business and Home Safety (IBHS) helped create the Building Code Effectiveness Grading Schedule (BCEGS) for use in adjusting private sector insurance premiums. This rating system administered by the Insurance Services Office, measures how well building codes are enforced in communities around the United States. Although it is not yet implemented, the goal of the program is that property located in communities that have well-enforced codes will benefit through lower insurance premiums.

Tax Incentives for Mitigation

One way for communities to encourage its residents to engage in mitigation measures is to provide them with tax incentives. For example, if a family lowered the chances of its home being damaged from a hurricane by installing a mitigation measure, it would get a rebate on its state taxes to reflect the lower costs for disaster relief. Alternatively ones property taxes could be lowered for the same reason.

In practice, communities often create a monetary disincentive to invest in mitigation. A property owner, who improves his home by making it safer, is likely to have the property reassessed at a higher value and hence have to pay higher taxes. California has been cognizant of this problem and voters passed Proposition 127 in 1990 which exempts seismic rehabilitation improvements to buildings from being reassessed to increase property taxes.

The City of Berkeley has taken an additional step to encourage home buyers to retrofit their newly purchased homes by instituting a transfer tax rebate. The city has a 1.5 percent tax levied on property transfer transactions; up to one-third of this amount can be applied to seismic upgrades during the sale of property. Qualifying upgrades include foundation repairs or replacement, wall bracing in basements, shear wall installation, water heater anchoring and securing of chimneys. Since 1993 these programs have been applied to 6,300 houses, representing approximately $4.4 million in foregone revenues to the city. (Earthquake Engineering Research Institute 1998).
The principal reason for utilizing tax rebates to encourage mitigation is because of the externalities associated with these measures. As pointed out above, these added benefits cannot be captured through insurance premium reductions which normally cover damage only to the property. Taxes are associated with a broader unit of analysis such as the community, state or even federal level. To the extent that the savings in disaster costs relate to these units of government, tax rebates are most appropriate.

Role of Liability

The liability system has the potential of being a powerful tool for encouraging key interested parties to enforce relevant standards and regulations. Contractors who did not utilize a building code could be responsible for paying the damage to poorly designed homes battered by a hurricane. Banks who did not require homeowners in high hazard areas to purchase flood insurance, which is required as a condition for a federally insured mortgages, could be forced to pay the claims that the property owner would have collected from his flood policy.

In practice the liability system has not been utilized in this way. However, there are signs that this may be changing. A step in making banks more responsible for enforcing flood insurance requirements was taken by the Flood Disaster Protection Act of 1990 where fines were levied on any financial institution that let a policy lapse. (Pasterick 1998). Florida anticipates developing a statewide building code where contractors who are found to not meet the standards would be fined and lose their license.

6. Future Research Directions

This paper has suggested ways that mitigation can be linked with insurance and other policy tools for reducing future losses from natural disasters. Future research needs to focus on ways of improving estimates of the risk as well as determining what we mean by a cost-effective mitigation measures. These two areas are discussed in turn. The paper concludes by examining the role that micro-model simulations can play in analyzing alternative mitigation and insurance programs.

Improving Estimates of Risk

Insurers will benefit from improved estimates of the risk associated with catastrophes in two ways. First, by obtaining better data on the probabilities and consequences disasters, insurers will be able to more accurately set their premiums and tailor their portfolios to reduce the chances of insolvency. The improved information should enable them to more accurately determine their needs for protection through reinsurance or capital market instruments. Second, more accurate data on risk also reduces the asymmetry of information between insurers and other providers of capital. Investors are more likely to supply additional capital as they become increasingly confident in the estimates of the risks of insured losses from natural disasters.
In setting rates for catastrophic risks, insurers have traditionally looked backwards, relying on historical data to estimate future risks. This process is likely to work well if there is a large database of past experience from which to extrapolate into the future. Low-probability high-consequence events such as natural disasters by their nature make for small historical databases. Thus, there is a need to integrate scientific estimates of the probabilities and consequences of events of different magnitudes with the evidence from past experience.

Advances in information technology have encouraged catastrophe modeling that can simulate a wide variety of different scenarios reflecting the uncertainties in different estimates of risk. For example, it is now feasible for insurers to evaluate the impact of different exposure levels on both expected losses and maximum possible losses by simulating a wide range of different estimates of seismic events using the data generated by scientific experts. Similar studies can be undertaken to evaluate the benefits and costs of different building codes and loss prevention techniques (Insurance Services Office, 1996).

The growing number of catastrophe models has presented challenges to users who are interested in estimating the potential damage to their portfolio of risks. Each model uses different assumptions, different methodologies, different data, and different parameters in generating their projections. Their conflicting results make it difficult for the insurer to know what premiums to set to cover their risks; they also make it difficult for reinsurers and capital market communities to feel comfortable investing their money in providing protection against catastrophic risk. Hence the need for a better understanding as to why these models differ and the importance of reconciling these differences in a more scientific manner than has been done up until now. Bringing the leading modelers together with the insurers, reinsurers, and capital markets to discuss how their data are generated may reduce the mystery that currently surrounds these efforts.

**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.

---

16 I am grateful to Terry van Gilder of Risk Management Solutions, formerly chief underwriter at Chubb, for characterizing the decision process of insurers in this way.

17 For example, new advances in seismology and earthquake engineering are discussed in Federal Emergency Management Agency (1994) and Office of Technology Assessment (1995).
Several programs have been initiated in the past several years which recognize the importance of involving the key stakeholders concerned with disaster losses and developing a set of economic incentives which make the mitigation measures appealing to these concerned parties. The programs also are based on a much broader set of costs and benefits than has been traditionally considered in evaluating mitigation measures. It would be worthwhile to evaluate how well these programs have worked to determine the ingredients for successfully implementing mitigation measures.

**Project Impact**

This FEMA initiative challenges the country to undertake actions that protect families, businesses and communities by reducing the effects of natural disasters. There are three primary tenets of the Project Impact initiative: mitigation is a local issue; private sector participation is essential to mitigation efforts, and mitigation is a long-term effort requiring long-term commitment.

Project Impact seeks to achieve the goal of loss reduction through a community-based partnership consisting of key stakeholders from the private sector, non-profit organizations, and local, state and federal governments. The community must first examine its risk for natural disasters and identify its vulnerabilities to those risks. Next, it must identify and prioritize risk reduction actions and mitigation activities. Finally, the local leaders must build support for these actions and publicize their successes to ensure continued cooperation and support. There are currently 57 Project Impact communities in different stages of development. (Heinz Center in press)

**The Showcase Community Program**

The Institute for Business and Home Safety (IBHS) is an initiative of the insurance industry dedicated to reducing losses from natural disasters. Because much of the impetus for loss reduction must occur at the local level, IBHS has established the Showcase Community Program to operationalize the goals of its strategic plan. The program is designed to help a community reduce its vulnerability to natural disasters.

To support the Showcase Community Program, IBHS has developed Statements of Understanding with a number of groups, including the Central United States Earthquake Consortium (CUSEC), the American Red Cross, the Electric Power Research Institute (EPRI), Disaster Recovery Business Alliance (DRBA), the American Society of Civil Engineers, and the American Society of Home Inspectors. These organizations provide professional expertise, additional personnel, and energy that help to sustain locally driven efforts. In addition, IBHS member companies are engaged in the Showcase Communities program by supporting child daycare center retrofits, sponsoring DRBA activities, providing speakers at community events, and through other activities.

**Micro-Model Simulations**

A broader strategy for undertaking research in this area involves 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 of such an approach to a model city in California facing an earthquake risk can be found in Kleindorfer and Kumreuther (1999).

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 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, University of Pennsylvania is addressing all the above issues. 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.
REFERENCES


Insurance Research Council and Insurance Institute for Property Loss Reduction (1995) Coastal Exposure and Community Protection: Hurrican Andrew's Legacy [Wheaton, Ill (IRC) and Boston (IBHS)]


<table>
<thead>
<tr>
<th>Number of Losses (n)</th>
<th>Probability (# of losses ≥ n)</th>
<th>Loss with No Mitigation (L&quot;)</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>1/120</td>
<td>$ 1,000,000</td>
<td>$ 800,000</td>
</tr>
<tr>
<td>5</td>
<td>1/140</td>
<td>$ 1,250,000</td>
<td>$ 1,000,000</td>
</tr>
<tr>
<td>6</td>
<td>1/160</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 than either all homes would be damaged with probability p=1/100 or no homes would be damaged with p=99/100.
Appendix 1

A Safety-First Model of Underwriter Behavior

Suppose an insurer has N policies associated with a risk and must decide what premium (P) it will charge. Let S be the insurer’s financial resources to pay claims. It consists of its initial surplus (A) plus the premiums from its N policies (NP). The insurer has determined the probability $p_i$ that it will have $i$ losses each with claims payment $L$ from different events.

A safety first model implies that the insurer’s objective is to find a premium $P$ which will

$$\text{Max } [A + NP - \sum p_i L]$$  \hspace{1cm} (1)

subject to the following insolvency constraint

$$8 \sum [A + NP - iL] \leq 0 \leq q^*$$  \hspace{1cm} (2)

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

---

18 More details on this model as well as an empirical test of its descriptive power appears in Berger and Kunreuther (1994).
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 and how much they are willing to pay for reinsurance coverage:

NOTATION

\[ p = \text{annual probability of a loss for a single house} \quad (e.g. \ p = 1/100) \]

\[ L'' = \text{Loss without mitigation} \quad (e.g. \ L'' = $250,000) \]

\[ L' = \text{Loss with mitigation} \quad (e.g. \ L' = $200,000) \]

\[ E(L'') = p \ L'' = \text{Expected Annual Loss without Mitigation} \ (e.g. \ $2500) \]

\[ E(L') = p \ L' = \text{Expected Annual Loss with Mitigation} \ (e.g. \ $2000) \]

\[ P'' = E(L'') = \text{actuarially fair premium without Mitigation} \]

\[ P' = E(L') = \text{actuarially fair premium with Mitigation} \]

\[ M = \text{Minimum premium reduction from P'' for homeowner to adopt mitigation} \]

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 1 presents these data for an illustrative example.
LARGE AND SMALL CAPITALIZED INSURER PREMIUM SETTING PROCESSES

LARGE-CAPITALIZED INSURERS (NO INSOLVENCY CONSTRAINT)

Alpha has \( N \) earthquake policies and must decide what premium \( P_L \) it will charge. Let \( S_L = \text{Alpha's financial resources to pay claims which consists of its initial surplus} (A_L) \) 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 she does.

Alpha’s objective is to choose a premium \( P_L \geq P'' \) so as to

\[
\max \{ A_L + NP_L - \sum_i p_i i L \} \quad (1)
\]

subject to the following insolvency constraint

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

where \( q^* = \text{maximum probability of insolvency that insurer will tolerate} \)

In the example given in the paper, Alpha is assumed to have \( S_L = \$1.2 \text{ million} \) 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 1, (2) will also be satisfied if mitigation is adopted by property owners and \( P_L = P' \).

Hence Alpha will set a premium which maximizes (1). It is interested in reducing the premium from \( P'' \) only if it will 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 these 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 reduce their expected profits on their earthquake business. If \( M < P''-P' \), in an imperfectly competitive market the insurer will charge \( P \geq P'' \) to encourage mitigation.
\[
\text{Prob}\{ \sum_{i=1}^{4} \left[ 700 - R_{\text{max}} - i \cdot L'' \right] + \left[ 700 - R_{\text{max}} - 750 + 250 \right] + \sum_{i=1}^{4} \left[ 700 - R_{\text{max}} - i \cdot L'' + 250 \right] \leq 0 \} \leq .01 \quad (5)
\]

where the figures are in thousands of dollars.

\( R_{\text{max}} \) is determined by finding the value where the surplus of the insurer is exactly zero when there are 3 losses. To see this, note from Table 1 that Beta’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 \( R_{\text{max}} \) is determined by solving:

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

Based on (6) \( R_{\text{max}} = 200 \). This means that, in theory, the insurer is willing to pay as much as $200,000 for reinsurance. Of course, such a payment will yield an expected loss to Beta on its earthquake insurance business since premiums without mitigation reflected the actuarial loss. Beta may still choose to pay a large sum for earthquake reinsurance if it will make sufficient positive expected profits on other risks to want to stay in business. The actual reinsurance premium for this example will be somewhere between $3,333 and this upper limit depending on the degree of competition in the reinsurance market and the expected profits that the insurer can earn on other policy lines.

**Encouraging Mitigation Through Premium Reductions**

As an alternative to reinsurance Beta may actually be willing to set a premium \( p_s \) that is below the actuarially fair rate to encourage its current policyholders to adopt mitigation measures. Claim payments following an earthquake will be reduced and Beta may then be able to meet the insolvency constraint given by (4).

From Table 1 one sees that if \( q^* = 1/100 \) then Beta 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) Beta computes

\[
450,000 - 100 p_s - 600,000 = 0 
\]

This means that \( p_s = 1,500 \), a premium below the actuarially fair value of \( p' = 2,000 \). Thus Beta loses money on its earthquake business to encourage mitigation and satisfy its insolvency constraint.