“Challenges in Providing Information for Decision Making”

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CHALLENGES IN PROVIDING INFORMATION FOR DECISION MAKING

In developing a disaster information network there are a set of challenges with respect to providing information on the nature of the hazard, the potential losses that may result from future disasters and the development of strategies for reducing this damage. This section discusses some of the issues associated with presenting information to interested users so that those on the dissemination end are aware of the concerns and limitations of those on the receiver side who have to process these data.

Presenting Information on the Role of Uncertainty

Advances in information technology have encouraged catastrophe modeling which 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 reinsurance 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.

**Institutional Arrangements and Decision Processes**

Any hazard-prone area has a set of interested parties concerned with the impact of hazards on their well-being in both the short and long-run. The interaction of these different parties with each other depends upon formal and informal institutional arrangements, the type of information available and how it is presented to them and the programs and policies in place.

To illustrate here are some of the key interested parties and their principal concerns with respect to natural hazards:

- **Homeowners**: Their principal concern is to reside in a structure that can withstand the forces of nature.

- **Renters**: They have similar concerns to the homeowners except that they are not financially responsible for the repair of their dwelling should it be damaged by a disaster.

- **Commercial Enterprises**: Business and industrial establishments are not only concerned about the damage to their structures but the impact that a disaster will have on their ability to operate in the future (i.e., their business interruption due to the disaster).

- **Banks and financial institutions**: They are concerned with the ability of the property owner to continue making payments after a disaster on the mortgages which they have financed. If the property owner declares bankruptcy, then the bank may be left holding a piece of property with limited economic value.

- **Construction industry**: Their primary interest is in building affordable housing so that there is sufficient demand for these dwellings or buildings.

- **Insurance and reinsurance industry**: Their principal interest is in providing protection against the losses from natural disasters using rates based on risk while being mindful of the financial impact that a catastrophic disaster will have on their balance sheets.
- **Environmental groups:** They have an interest in preserving environmental quality and the appropriate balance of the ecosystem in both the long and short-run.

- **Municipalities:** Their principal interest is in designing safe communities that are sufficiently resilient after a disaster so that they do not have to rely on an enormous amounts of state and federal aid.

- **State and federal disaster agencies:** Their principal interest is in building disaster-resistant communities so that they will not have to pay an enormous amounts of state and federal aid after a disaster.

**Q: ARE THERE OTHER STAKEHOLDERS THAT SHOULD BE MENTIONED HERE?**

A change in any given policy or program has to be carefully structured to reflect the interaction between the different stakeholders and their nested decision structure (Kleindorfer et al., 1993). To illustrate, consider the challenges associated with reducing disaster losses through mitigation measures. Relatively few *homeowners* adopt loss-reduction measures even if they are relatively inexpensive and promise to yield sufficient benefits to justify the cost (Palm, 1995). One solution to this problem is to inform individuals of the dangers of living in specific areas. Other stakeholders have good financial reasons *not* to implement this measure. *Real estate agents* have no reason to provide prospective buyers with information on the hazards associated with living in a particular structure that fails to meet the building code. They are supported implicitly by the *current owner* who wants to sell the property at as high a price as possible. Furthermore the potential buyer may have little interest in knowing about the design of the structure if they do not think about the risks associated with future disasters.

**Understanding Decision Processes**

Individuals process information in ways that are often different from what is considered to be rational by theories of choice which rely on unrealistic assumptions with respect to the ability of
individuals to collect and process information (Thaler 1991). Unless one understands what types of data are collected in addressing a particular problem and how it is utilized by the concerned individuals or groups, one may find that a proposed set of strategies are not likely to perform in the way that would be predicted by these theories. These points are illustrated below by looking at two areas of decision making: the demand for insurance and the demand for loss prevention measures. We then show the implications for policy on how information is presented by looking at the performance of the National Flood Insurance Program.

**Demand for Insurance**

There is a lack of interest by many individuals in voluntarily purchasing insurance because they underestimate the probability of the event occurring, use sequential models of choice and may misestimate the losses. More specifically, many residents in hazard-prone areas feel that the event **will not happen to me** even though the scientific data suggests that there is a some likelihood that there structure will suffer some, possibly severe, damage in the next 5 or 10 years. If people perceive the probability to be below a given threshold level, they are not likely to worry about it and hence feel that it is not necessary to buy insurance to protect themselves against the event. This is what we mean by a sequential model of choice. There is an increase in the demand for coverage following disasters because the event is salient in many people’s mind, so that its perceived probability exceeds the threshold level of concern. At that time many individuals react by estimating future losses to be much higher than the experts believe them to be. There is considerable evidence supporting this behavior by individuals (Palm 1998). The factors which determine the demand for insurance when individuals have the freedom to specify coverage limits are still not well understood, although recent controlled experimental
studies provide insight into consumer decision processes. For example, there is evidence that framing manipulations impact on how consumers determine whether to purchase coverage and how much to pay. Some of these effects are the vividness of a projected event by the media, incorporating rebates so that the policyholder feels he has experienced a gain if he doesn’t collect on his policy and the status quo serving as a reference point for deciding between options. Data from insurance markets indicate that these same effects occur when actual insurance decisions are made (Johnson et al. 1993). These findings suggest that one needs to rethink the theory of consumer choice regarding insurance and consider factors influencing the decision process when determining what information should be presented and what policies should be made.

**Demand for Loss Prevention Measures**

There is considerable empirical evidence suggesting that few property owners have been willing to invest funds in cost-effective mitigation measures in hazard-prone areas. In a 1989 survey of 3,500 homeowners in four California counties subject to earthquake damage, only between 5 and 9 percent of the respondents in each of these counties reported adopting any LRM (Palm et al. 1990). A follow-up survey of residents affected by the October 1989 Loma Prieta earthquake by Palm and her colleagues and the Northridge earthquake of 1994 revealed that only 10 percent of homeowners invested in any type of structural loss-reduction measure whether or not they were affected by recent earthquakes in the State (Palm 1995).

The empirical evidence suggests that property owners underestimate the risk given their lack of interest in adopting these measures. Another factor which may lead to an under-investment in cost-effective mitigation measures is the short-time horizons or extremely high discount rates that individuals (both potential buyers and current owners) utilize in evaluating the expected benefits of protective measures. For this reason, certain investments will not be viewed as
cost-effective by those residing in hazard-prone areas, even though they are deemed as financially attractive by the bank, insurer or public sector agency (e.g. FEMA) who take into account the expected length of the life of the structure in evaluating specific mitigation measures. A third factor, which may limit the ability of the homeowner or businessman to invest in a protective measure, is budget constraints. For example, if the cost to reinforce ones structure is $1500 and the savings on ones annual insurance premium is only $500, then the investment may be viewed as unaffordable even if the expected benefits over a 5 year time horizon would more than justify the cost.

Impact of Decision Processes on Performance of National Flood Insurance Program

The development of the National Flood Insurance Program (NFIP), enacted by Congress in 1968 indicates the importance of understanding individual decision making process when presenting information to individuals and designing a program. When the NFIP was designed in the 1960s there was a general feeling by economists and policy analysts that homeowners in hazard-prone areas would want to purchase coverage because the premiums were highly subsidized by the federal government. As it turned out there was very limited voluntary demand for coverage primarily because individuals believed the chances of a disaster causing damage to their property was so low that it was not worth concerning oneself with protection. (Kunreuther et al 1978). As a result Congress was forced to modify legislation in 1973 making flood insurance a condition for any federally insured mortgage in high-hazard prone areas.

Even with this stipulation there were many banks that did not enforce this ruling so that most individuals who should have been protected were not. A survey conducted in Texas following a major flood in 1989 revealed that 79 percent of the owners of damaged properties required to
purchase flood coverage were uninsured at the time of the disaster. (U.S. General Accounting Office 1990). This led to the passage of the National Flood Insurance Reform Act of 1994 which requires that lenders who establish escrow accounts for hazard insurance and taxes include flood insurance premiums as part as the package and stipulates penalties on banks who do not comply with the requirements. (Pasterick 1998).

To date homeowners in hazard-prone areas have been reluctant to undertake mitigation measures to reduce future losses from disasters because they feel it will not happen to me coupled with a reluctance to incur the upfront cost associated with the investment in these protective activities. Their behavior has been reinforced by other interested parties associated with the property. Many insurers are reluctant to provide significant premium reductions to encourage mitigation measures in hazard-prone areas because they feel their state-regulated rates are too low. Individual banks and financial institutions do not want to require mitigation measures as a condition for a mortgage because it would reduce their ability to compete for these loans in the private market. Contractors and developers will not voluntarily incur the additional costs of making a home safer from disasters because they feel it will raise the price of the structure and make it more difficult to sell the property. Public sector organizations recognize the importance of promoting mitigation but recognize that it is difficult to do so without considerable assistance from the private sector who may not have incentives to join forces. This is the challenge facing the Federal Emergency Management Agency (FEMA) who has made mitigation a cornerstone of its policy.
Tools and Products for Integrating Information

There are a set of systematic approaches, such as decision analysis and benefit-cost analysis, which have been proposed for helping decision makers evaluating alternative strategies for reducing losses. These techniques rely on a set of assumptions regarding the types of information that individuals collect and how they utilize it. It is important to recognize when developing a strategy for providing information what data individuals and policy makers actually consider in making their choices. Below we illustrate this point by first indicating the assumptions that these approaches rely on for collecting and processing information and and then pointing out some of the open issues that will have a clear impact on what data may be relevant to those who actually make decisions.

Stages Of Analysis

Here are the different steps that are recommend in undertaking policy analyses for problems where there are a number of different potential alternatives and key interested parties.

- Specify the Problem
- Identify Alternative Options
- Specify Key Interested Parties
- Indicate Ways Individuals Collect Information
- Specify Decision Processes of Stakeholders
- Specify Relevant Attributes
- Valuation of Attributes
- Evaluation of Alternatives

Each of these steps are briefly discussed below with emphasis on the implications for presenting and disseminating information to the relevant interested parties.
Specify the Problem

Most research on decision making focuses on how problems are solved. However, if one has not solved the appropriate problem, then the most elegant solution is of no practical value. The following aspects need to be considered when determining what information to collect and share with key interested parties.

- **Why is this an important problem for study?** One needs to provide a rationale for why one wants to investigate this particular question and what is likely to emerge from such a study. In other words, the readers of this report need to be convinced that this is an important problem to address.

- **What hypotheses are being tested regarding behavior?** One needs to examine a set of specific hypotheses and why they are important for the problem at hand. What would one do differently if an hypothesis is confirmed or disconfirmed? By addressing this question at the outset one is in a position to determine what data needs to be collected and analyzed.

- **How can one test the hypotheses with the data?** One needs to have a clear understanding of how accurate the data are for testing specific hypotheses. How easy is it to obtain the data and how will these data be used? If it is difficult to obtain accurate information for testing a specific hypotheses one needs to recognize this at the outset and focus on questions that can be answered with sufficient accuracy that they will be useful for policy.
Identify Alternative Options

One needs to specify the alternative options that are being considered. One of these is frequently the *status quo*. This is a critical option since there are often very large costs associated with change. Furthermore the status quo is often the reference point for evaluating how well other alternatives perform. If there is sufficient political dissatisfaction with all of the other options and/or high transaction costs associated with changing from the status quo, then the current program will be maintained.

It is useful to identify as many alternatives as possible to deal with the problem at hand. There are a number of different ways that one can generate alternatives in a somewhat systematic fashion.

- **Link Option to Objectives**  It is important to consider the main objectives of the problem and determine how what alternatives are likely to meet these objectives. By being explicit with respect to these objectives one is more likely to be able to create a set of relevant alternatives than if one just tries to consider options in a vacuum.

- **Scenario Construction**  One important way of generating alternatives and a technique that we will be illustrating in more detail below is the construction of scenarios or use cases. More specifically a scenario characterizes a set of specific events which indicate what can happen
if a disaster occurs as well as ways of preventing certain events from occurring. Each scenario may suggest a set of alternatives for avoiding the particular situation.

- **Brainstorming**  In this approach individuals in a group setting suggest a set of options for consideration without by criticized by others as to their feasibility. One might begin this process by asking “Wouldn’t it be nice if...?” or “Wouldn’t it be awful if...?”

*Specify Key Interested Parties*

It is important to specify all the important stakeholders who are concerned about the problem at hand so they can be involved in the construction of alternatives for consideration as well as generating strategies for dealing with the issue. To determine which individuals or groups have standing, it is necessary to decide at what level the analysis should be undertaken. If the project is evaluated at the level of a specific state (e.g. California), then only residents in this state are considered. If, on the other hand, one is viewing the alternatives from a national perspective (e.g. the United States), then the costs and benefits of the citizens of the entire country will be incorporated in the analysis.

Each of the parties has their own agenda and a set of values which reflect their concerns. Frequently these values and concerns lead to conflicts between the different interested parties. To defend their positions each of the stakeholders is likely to use their favorite experts to defend their position, focusing on issues of risk as a common element if the issue is one of health or safety of a given population. Often the experts differ between themselves on their estimates of the risk To the extent that data on probabilities and outcomes are available, this may help settle
these differences. For many low probability events there may not be sufficient information to is
often difficult to draw statistically valid conclusions from the existing data base. This needs to be
made clear in any analyses that follow.

*Indicate Ways Individuals Collect Information*

There are very high costs of collecting data on any specific problem which is one reason why
there is a tendency to maintain the status quo (Samuelson and Zeckhauser 1988). It important to
clearly understand why type of data an individual is likely to collect for the specific problem at
hand and how costly it will be for him or her to obtain these data. With new information
technology (IT) it is easier to collect information but there is considerably more data from which
to choose. There may be opportunities to provide assistance to people in getting certain data or
presenting in an attractive and easily accessible form. The scarce resource for people today is
attention and time rather than data and we need to be aware of this should we pose solutions that
require a large amount of data collection and analysis by the affected individuals.

*Specify Decision Processes of Stakeholders*

As point out above, it is important for us to understand how individuals are likely to behave
when dealing with problems which involve risk and uncertainty. What information do they
collect; how do they process the data and what rules of thumb or heuristics do they utilize in
making choices. One particularly challenging question is how to deal with the issue of moral
hazard. By moral hazard we mean behaving in a riskier fashion because the affected individuals
feel that they are better protected than they were in the past. In the context of natural hazards, if city officials and residents believe that their community is so well protected by a levee or dam that they could not be flooded in the future, they may expand the area without any concern for the hazard. Should a catastrophic event occur that tops the levee or breaks the dam, the damage is much worse than it would have been had these decision makers recognized that such an event could happen to them.

More generally, by understanding the decision processes of individuals and groups (i.e. their probability biases and simplified decision rules) we can design strategies that are likely to achieve the desired set of objectives. (See Kahneman, Slovic and Tversky (1984) for a set of readings on probability biases and Kahneman and Tversky (1989) for a descriptive theory of choice under uncertainty). Furthermore, it will often be necessary to combine a set of different alternatives which reflect ways to deal with the behavior of individuals. For example, given the moral hazard problem one strategy for reducing losses from disasters may be to design safer structures while at the same time impose restrictions on people's actions such as well-enforced building codes and land-use regulations. (Burby 1998).

Specify Relevant Attributes

One of the key steps in developing a strategy for dealing with a particular problem is to specifying the relevant attributes that are important to at least one of the key interested parties. More specifically one needs to specify the benefits and costs that need to be considered. Some of these attributes will be easily quantifiable such as the costs of designing a safer structure. Other attributes are more qualitative in nature and hard to evaluate such as the long-run impact of a
disaster on the environment. Other attributes, such as the impact of specific alternatives on fear, dread or other emotions, may be important elements of the problem. Value tree analysis is a very promising approach for eliciting the various attributes of the key interested parties and combining them in a systematic fashion. (Von Winterfeldt 1987).

If there is uncertainty associated with the analysis then one has to assign probabilities to the different states of nature (e.g. disaster, no disaster) and the resulting outcomes to the relevant stakeholders if this state of nature actually occurs. If the alternative involves multiple time periods then one has to specify the outcomes that occur in each of these future periods and use a social discount rate to convert these benefits and costs to present value.

Valuation of Attributes

Once the attributes have been specified then one needs to quantify these impacts and attach some dollar or utility value to them for each of the affected individuals using techniques such as multi-attribute utility analysis. (See Keeney and Raiffa 1976). Sometimes these values can be determined directly, such as the cost associated with constructing a project. Other valuation procedures are more controversial, such as valuing a human life. (See Viscusi (1993) for a discussion of these issues). With respect to qualitative measures, such as environmental impact, economists have utilized contingent valuation procedures to elicit an individuals' "willingness to pay" (WTP) for changes in the quantity and quality of goods.
The field of contingent valuation is fraught with problems in trying to determine willingness to pay for certain goods. (See Diamond and Hausman (1994) and Baron (1997) for a discussion as to why one has to be cautious in relying on WTP values.) For example:

**Embedding** --- WTP for cleaning up 10 lakes or 1000 lakes. Many people give the same amount when they are asked how much they are willing to pay to clean up 10 lakes or 1000 lakes.

**Framing** --- Asking people to questions in different ways and getting different WTP responses

**Valuing non tradeable items** --- forcing people to put values on items that they don’t want to trade (e.g. wedding ring)

**Situation-specific values** --- valuing lives may depend on situation (e.g. saving an identifiable victim from a disaster rather than investing in protective measures for reducing losses which do not have specific individuals attached to them ) (Identifiable vs. statistical lives)

**Evaluation of Alternatives**

Once each of the attributes are evaluated, some type of weighting procedure indicating the relative importance of each attribute is required to aggregate these impacts so that one can approximate how each alternative will affect society as a whole. This is a difficult question since each of the interested parties is likely to have a different weighting scheme for the relative importance of each attribute in evaluating different alternatives. Decision analysis (see von Winterfeldt and Edwards (1986) and cost-benefit analysis (see Boardman et al. 1996) are two related approaches for evaluating different alternatives in a systematic fashion.
Designing a Strategy

In designing a strategy for reducing losses from natural disasters one has to consider not only the benefits and costs there are two key questions that need to be addressed:

- Who should bear the costs of reducing losses from future natural disasters?
- Who should pay for the losses caused by natural disasters?

There are two criteria normally utilized in addressing these two questions: efficiency and equity. By efficiency we mean the allocation of economic resources to maximize social welfare. Social welfare is defined by the citizenry and thus may vary from one political entity to another.

Equity refers to concerns with fairness and the distribution of resources. An equitable distribution of resources may require the special treatment of certain individuals or groups at the expense of others. One key question that needs to be addressed in this domain is how much weight should be given to each of the interested parties when designing a strategy.

Open Issues

Below we have listed a set of open issues that need to be considered by in the development of global disaster information network.

Types Of Data Made Available To Users

- What types of information should be presented to potential users on what scientists know about the risks associated with specific natural hazards (e.g. the probability of the disaster occurring, the nature of the losses with and without specific mitigation measures)?
• How should one present information to users which reflects disagreement among scientific experts on the risks of the hazard and the costs associated with specific strategies for reducing losses?

• If certain strategies are robust over a wide range of estimates how can this information be presented so it will be useful for decision makers?

**Tools And Products For Integrating Information**

• Can one utilize systematic approaches, such as benefit-cost analysis, to enable decision makers to evaluate alternative strategies for reducing losses?

• How can one use new information technologies, such as the World Wide Web, for determining what information decision makers feel are important to consider in specifying and evaluating different strategies? This will enable one to capture sets of benefits and costs that might not otherwise be considered in dealing with a specific problem.

• What tools and products are most useful for updating data on benefits, costs and strategies as new information becomes available?

**Improving Utilization Of Disaster Information For Decision Makers**
• How can we determine what information specific decision makers would like to have available for evaluating and implementing specific strategies for loss reduction?

• How can one incorporate the decision processes of the key interested parties in developing relevant strategies for reducing losses. For example, if decision makers are myopic for a variety of reasons (e.g. limited terms of office) how should one take this into account in developing alternative strategies and providing information to decision makers?

• How can use new technology for getting feedback on how useful specific information is likely to be to decision makers and how useful it actually has been?

• How can use the disaster information network to determine what additional information might be useful as one learns over time?

• How can one communicate success stories from some communities or regions to others so they can learn and build on this experience?

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THE ROLE OF INSURANCE IN MITIGATING LOSSES FROM CATASTROPHIC RISKS

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ABSTRACT

Triggered by this increase in insured losses from natural disasters property-casualty insurance companies in the United States are taking loss prevention seriously as part of their mission. This paper examines the impact that risk mitigation measures can have on improving the solvency position of insurers who provide coverage against these hazards. A safety-first model of behavior suggests that insurers are now more concerned than ever with the possibility of insolvency from future catastrophic events. Large insurers will have incentives to provide premium reductions to encourage mitigation if the rate structure provides them with an incentive to pass the savings in losses to the property owner and/or if they are required to provide coverage to their current policyholders. Small insurers will examine the tradeoffs between the cost of reinsurance and how much they will have to pay property owners in premium reduction in deciding how to meet their solvency constraints. One factor that influences reinsurers’ pricing decisions is ex post moral hazard. Building codes can supplement voluntary adoption of mitigation as a way of reducing the recovery costs from natural disasters. The paper concludes by proposing a hazard management program for catastrophic risks where insurance is linked with other policy tools.
The Role of Insurance in Managing Catastrophic Risk

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1. Introduction

Insurance has the potential to encourage individuals to take added protection by lowering premiums while still providing financial protection to policyholders should they suffer losses. In recent years insurers have not promoted loss prevention activities with premium incentives on property coverage but their attitude is now changing. The severe losses that the industry has suffered in recent years from natural disasters has been a wake-up call to the industry that they are highly vulnerable in hazard-prone areas of the country. Many are concerned that they will not survive the next big disaster. As a result they are trying to find ways of reducing future losses by encouraging property owners to adopt mitigation measures, turning to new financial instruments for protection against catastrophic losses while at the same time reducing the amount of coverage they are offering in hazard-prone areas.

This paper focuses on the role that insurers can play in encouraging loss prevention activities against damage from natural disasters in conjunction with other interested parties in the private sector notably banks and financial institutions. We begin the discussion by briefly reviewing recent trends which show why the natural disaster problem has become a major issue for insurers and reinsurers in the past 10 years. Section 3 develops a safety-first model which appears to characterize insurers behavior and highlight why they are concerned with potential insolvencies from future natural disasters.

Section 4 of the paper illustrates under what conditions a large insurer with sufficient capital to protect itself against catastrophic losses will want to promote mitigation through premium reductions without having to rely on reinsurance for protection. The following section examines the plight of a smaller insurer who is financially constrained so that it wants its policyholders to adopt mitigation measures to lower the chances of insolvency and/or it must be purchase some reinsurance. One reason that insurers have an incentive to promote mitigation through premium reductions is because reinsurers will charge high premiums due to moral hazard problems.

The last part of the paper suggests the role of other policy tools and interested parties that can work with insurers in promoting mitigation measures while providing additional financial protection against catastrophic losses. Section 5 focuses on building codes as a way of reducing property losses as well as other recovery costs from natural disasters. The concluding section proposes a hazard management program for catastrophic risks and discusses future research directions.
The principal message that emerges from this analysis is that insurance is a potentially powerful tool for dealing with catastrophic risks but it needs assistance in the following ways. State regulatory commissions need to recognize the importance of setting rates based on risk so insurers can encourage mitigation through premium reductions. Other stakeholders, such as banks and financial institutions, contractors and developers can play a key role in encouraging the adoption of cost-effective mitigation measures to reduce future losses. Capital market instruments, such as Act of God Bonds, may serve an important role in supplementing reinsurance to cover catastrophic losses from future large-scale disasters. Taken together these stakeholders and policy instruments may form the basis for a cost-effective hazard management program.

2. The Natural Disaster Problem Today

Since 1989 insurance and reinsurance firms have suffered losses from natural disasters in the United States that have wreaked havoc with their balance sheets. Figure 1 depicts the magnitude of the catastrophic losses experienced by the insurance industry in the United States from 1949 to 1997 (in 1997 dollars). The drastic change in insured losses from these events since 1988 is obvious. Prior to Hurricane Hugo in 1989 (where insured losses were over $4 billion), the insurance industry had never suffered any loss of over $1 billion from a single disaster. Since that time they have had 10 disasters which exceeded this amount. (Kunreuther and Roth Sr. 1998).

Two recent major disasters had a particularly strong impact on the industry. 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 of Property Loss Reduction 1995). Insured damage from the Northridge, California earthquake of 1994 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 mitigation 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).
Historically, loss prevention has long been an important part of the insurer’s mission to provide protection against risk. The best example of insurance being used as a viable means of reducing risk and providing compensation after a loss comes from the factory mutual insurance companies founded in the early 19th century in New England. The mutuals required inspections of the factory both prior to issuing a policy and after one was in force. Poor risks had their policies canceled; premium reductions were given to factories that instituted protective measures. In many cases, factory mutual insurance companies would only provide coverage to companies that adopted specific mitigation measures. For example, the Spinners Mutual only insured risks where automatic sprinkler systems were installed. (Bainbridge 1952).

Triggered by this increase in insured losses from natural disasters property-casualty insurance companies in the United States are again taking loss prevention seriously as part of their mission. 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 in loss prevention measures from natural disaster damage by insurers today has a parallel in the automobile area when insurers created the Institute for Highway Safety whose principal mission is to design safer cars.

3. Insolvency Concerns of Insurers

As pointed out above, one 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 and must be concerned with non-diversifiable risks such as the possibility of catastrophic losses from disasters. More specifically, employees of an insurance firm may be risk averse due to the costs of finding another job if their company becomes insolvent. Then the firm will want to charge higher premiums than implied by the expected losses due to the possibility of catastrophes, even when their shareholders can costlessly eliminate this risk through their own portfolio diversification. These arguments also may explain the demand for reinsurance by property/liability companies (Mayers and Smith 1990).³

Insurers are also likely to be ambiguity averse in that they are concerned with the uncertainty regarding the probability of a loss occurring. Underwriters make their decision regarding whether a particular risk is insurable by utilizing the actuary’s

³ Doherty and Tinic (1982) have argued that demand for reinsurance is generated by insurers anticipating policyholders’ aversion to bankruptcy.
recommended premium as a reference point. They then focus on the impact of a major disaster on the probability of insolvency. In other words, underwriters are first concerned with the firm’s safety and then with profit maximization.

Stone (1973 a, b) formalized these concepts by suggesting that an underwriter who wants to determine the conditions for a specific risk to be insurable will first focus on keeping the probability of insolvency below some threshold level (q*). More specifically, suppose that the insurer has a portfolio of N policies, each of which can create a loss L. Then the underwriter will recommend a premium P so that the probability of insolvency would be less than q*. Risks with more uncertain losses or greater ambiguity will cause underwriters to want to charge higher premiums for a given portfolio of risks. The situation will be most pronounced for highly correlated losses, such as earthquake policies sold in one region of California. A more formal model for the underwriter’s decision process based on Berger and Kunreuther (1994) is specified in Appendix 1.

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. By explicitly characterizing the underwriter’s behavior in this way, one can then examine the role that reinsurance and other financial instruments can play in alleviating these concerns. The empirical evidence based on surveys of underwriters suggests that insurers will set higher premiums when faced with ambiguous probabilities and uncertain losses. [Kunreuther et al. (1995)]

Interview data with several insurance companies in the United States concerned with the impact of recent natural disaster losses on their future activity provides additional evidence that firms follow a safety first model. Prior to Hurricane Andrew and the Northridge earthquake, these insurers were not worried about the potential impact of losses to their portfolio from severe hurricanes and earthquakes and hence did not attempt to restrict coverage and/or make the case for higher premiums because of the likelihood that they would become insolvent. Hence they did not focus on the survival constraint in their insurance decisions.

In the aftermath of these two disasters, company executives have modified their view and are concerned that they cannot survive a future catastrophe given their current portfolio and the amount of reinsurance coverage that they can obtain at a reasonable price. In other words they feel that the chances of insolvency based on their current portfolio exceeds their threshold level of concern (q*). Hence they either want to reduce the

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4 Actuaries normally determine a premium based on expected value by assuming that the probability and loss are known. They then increase this value to reflect the amount of perceived ambiguity in the probability and/or uncertainty in the loss.

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 on “The Role of Insurance and Regulation in Dealing with Catastrophic Risk.”
number of policies they write in catastrophe-prone areas, raise their premium P if they are forced to provide coverage to all N policyholders, and/or obtain more reinsurance coverage.

In fact, state regulation may preclude insurers from raising premiums and canceling as many policies as they would like. In such cases their risk of insolvency may be above q*. In Florida, for example, since Hurricane Andrew, the percentage of homeowners policies 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. This moratorium will be in effect until at least June 1, 1999. (Lecomte and Gahagan 1998).^6

Rates have also been subsidized in hazard-prone areas such as the coast of Florida (Klein 1997). Insurers who offer coverage in the state are also forced to share in the future losses of those individuals who buy coverage from a Residential Joint Underwriting Association (JUA). These JUAs were set up to provide coverage to those homeowners who could not purchase or renew their policy from a private insurer. Hence they generally represent a higher risk and their premiums may not reflect this (Lecomte and Gahagan 1998).

4. Encouraging Mitigation By Large Insurers

One way that the insurer can reduce its future losses and hence its probability of insolvency when it is forced to provide coverage to N policyholders is by encouraging policyholders to adopt risk mitigation measures (RMMs). Saying that insurers want property owners to adopt loss prevention measures does not necessarily imply that they will provide them with monetary incentives to promote this investment activity. In fact, uniform premiums have been generally specified for certain types of structures in hazard-prone areas whether or not they have adopted mitigation measures.

The combination of uniform rates across structures with premiums below actuarially fair levels in high hazard areas has a twofold negative impact on the need for mitigation: the level premium implies to the general public that mitigation measures do not really reduce losses, and the subsidized rate provides incentives for a property owner to buy insurance protection. This reduces their financial need for mitigation, since insurance covers their losses should a disaster cause damage to their structure.

Under what circumstances will large insurers want to offer premium reductions as a way of inducing those at risk to adopt cost-effective loss reduction measures? The answer to this question depends both on both the surplus of the insurer, the rate structure as well as the concern that the insurer and policyholder has with insolvency.

^6 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.
An Illustrative Example

Consider a large insurer who provides earthquake coverage for a single type structure (e.g., a concrete home). The insurer estimates the chances that an earthquake will occur in the region and damage any given insured property to be \( p = 1/100 \). The insurer will incur a loss \((L')\) if a risk mitigation measure (RMM) is adopted and a loss \((L''\) 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 \( \mathbb{E}(L') = 1/100 (\$200,000) = \$2000 \) or without mitigation \( \mathbb{E}(L'') = 1/100 (\$250,000) = \$2500 \). 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 relevant annual probabilities and respective values of \( L'' \) and \( L' \) for 0 to 8 losses for the case where an insurer has written \( N = 100 \) earthquake policies.

INSERT TABLE 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 \( q* = 1/100 \).

Aside from internal organizational concerns with insolvency, a 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, then there is even a stronger argument for insurers to encourage homeowners to adopt RMMs to reduce their future claims payments.

Behavior by Largecap

Consider a large capitalized insurer, Largecap, who has enough initial capital and premium income so it is not concerned with the insolvency constraint and does not require reinsurance. Let \( S_0 \) represent Largecap’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 \( S_0 = \$1.2 \) 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”. 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 maximize 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'') -$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 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 recognize 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.

**Impact of Mitigation on Insolvency**

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_1 =$1.21 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 Largecap was forced to provide insurance to its 100 policyholders at a premium ($P_x$) below the actuarial cost but still had enough surplus on hand to satisfy the insolvency constraint. Now its attitude toward providing premium reductions for mitigation will be somewhat different than when it had the freedom to charge whatever rate it desired. Since 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 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 minimize its expected loss Largecap would be willing to reduce its premium by as much as $P' - P = $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-run.

**Summary of Findings**

To summarize the findings, the premium which a large 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 (P₀) 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 recognizes 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 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 subsidized. 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.

4. **Role of Mitigation and Reinsurance For Smaller Insurers**

Reinsurance can also be utilized to reduce the chances of insolvency for smaller insurers impacted by the insolvency constraint. A typical reinsurance contract for dealing with catastrophic risks is an excess of loss treaty where 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

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7 An excellent summary of alternative reinsurance arrangements can be found in McIsaac and Babbel (1995).
amount. Had the insured loss been below $1 million, then the insurer would be responsible for all of it.

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.\(^1\) 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.\(^2\) We will first look at the role that reinsurance can play in dealing with the insolvency constraint and how it compares with mitigation under the assumption that there is no moral hazard. We will then investigate how one can determine under what circumstance a primary insurer has an incentive to exhibit moral hazard and the impact it has on reinsurer behavior.

**Behavior By Small Insurers with No Moral Hazard**

For the case of no moral hazard, an insurer has an incentive to pay a premium in excess of the actuarial risk in order to reduce its probability of insolvency. In the example presented above, the Largecap insurance Company had no incentive to purchase reinsurance since it had sufficient financial resources to cover its claims and have a probability of insolvency \(q < q^*\).

On the other hand, if the insurer had limited resources then reinsurance may be a very attractive as a way of satisfying the insolvency constraints. The same example used for evaluating Largecap’s pricing strategy can illustrate the maximum amount that a small capitalized insurer would pay for reinsurance. 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 is that a regulatory authority requires them to show that they have enough surplus on hand to be solvent in case of unexpected losses.

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 capitalized 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 \(P = $2,500\) 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 1 that should it suffer 3 quake losses, it will have claims totalling \$750,000 which exceeds \(S_s\) by \$50,000. The probability of

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\(^{1}\) For a more detailed discussion of ex ante moral hazard see Pauly (1974), Marshall (1976), Shavell (1979) and Dionne and Harrington (1992).

\(^{2}\) See Spence and Zeckhauser (1971) and Dionne and Harrington (1992) for a more detailed discussion of ex post moral hazard in the context of insurance problems.
suffering 3 or more losses is \( q = 1/80 \geq q^* = 1/100 \). 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. 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: (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 Smallcap for such a policy based on Smallcap'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 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 \( R = 1/80 (250,000) = 3,333 \). 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 3 losses or less since its total claim payments would be limited to $500,000; the regulator will tolerate the possibility of 4 or more losses since the probability of such an event is \( q = 1/100 \).

Of course, no insurer would ever pay anything close to $200,000 for a policy which only promises them $250,000 with a probability of \( p = 1/80 \). On the other hand, 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. 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 is given in the last column of Table 1. In this situation Smallcap will have more than enough surplus assets on hand to pay for 3 losses and will not need to purchase reinsurance to meet the regulator's concern with insolvency.

Due to its concern with insolvency, 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
summarized as follows. Smallcap wants to show the regulator that it will have $S_5 = \$600,000$ on hand so it can cover at least three earthquake losses when mitigation is in place. Since $S_5 = \$700,000$ it will be able to reduce its total premium by as much as $\$100,000$ and still meet this constraint. This means that it will be willing to reduce the premiums for each of its policyholders by up to $\$1,000$ if they will adopt a mitigation measure. Since the actuarially fair reduction in premiums is only $\$500$, 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.

**Behavior by Small Insurers with Moral Hazard**

We will assume that the insurer is not satisfying its insolvency constraint and thus needs to protect itself against large losses through reinsurance. In this section we examine the ex post moral hazard problem facing reinsurers and its impact on the amount of coverage and premiums it sets. We assume that the reinsurer offers an excess loss contract but that it can set the layers of coverage so that it reduces the ex post moral hazard problem. Monitoring costs are assumed to be so high that the reinsurer does not incur them as a way of reducing the moral hazard problem.

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 costs: (1) an administrative cost for processing claims and adjusting the losses and (2) the claims payments from the losses themselves. Both the costs will increase as the number of losses $i$ 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 insurance claims 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 $C^*_i < C_i$ causing each loss to increase to $L^* = L$, thus displaying ex post moral hazard. To examine the implications 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

$$i(L^* - L) > C_i - C^*_i \quad \text{for all } i$$  \hspace{1cm} (1)

With an excess loss treaty, the reinsurer has the opportunity to reduce the ex post moral hazard since it knows that the primary insurer will have to bear some of the costs of shirking at both the front end and the back end. The front end refers to the first layer of coverage that the primary insurer is responsible for (i.e. a deductible on a reinsurance policy). The back end comes into play if the losses are sufficiently large that they exceed the upper limit of the reinsurers excess loss contract. In general both deductibles and maximum coverage limits placed by the reinsurer reduce the possibility of ex post moral hazard since there is an additional burden placed on the primary insurer.
Suppose that the insurer has an excess loss treaty with the reinsurer whereby it 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 back ends.

There is an additional problem facing the reinsurer. Even if the insurer wanted to adjust claims carefully, it may not be able to do this simply because the demands on the adjustor for quick settlements reduces the care with which they can examine the damaged property. In other words, the losses may be inflated just by virtue of the number of claims from the disaster rather than by shirking on the part of the insurer: the demands on the adjusters will be so large after a catastrophic disaster and this may require hiring less-qualified adjusters to determine the claims and hence they are likely to overestimate them.

**Case 1: No Shortage of Claims Adjusters** Let us first consider the case where there are no shortage of claims adjusters. There are two conditions when the primary insurer will not want to shirk because the increase in loss costs exceed the savings in administrative costs as indicated in equation (1):

Condition 1: If the losses after shirking from the disaster are below $D$. (i.e. $iL^* < D$)

Condition 2: If the losses without shirking are above $D+R$ (i.e. $iL > D+R$).

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. Given Conditions 1 and 2, the primary insurer will incur the following costs when it shirks and doesn’t shirk

Costs of Shirking

\[ \min \{iL^*, D\} + \max \{0, iL^*-R\} + C^*_i \]  

(3)

Doesn’t Shirk

\[ \min \{iL, D\} + \max \{0, iL-R\} + C_i \]  

(4)

Comparing equations (3) and (4) we see that the primary insurer will always want to shirk whenever

\[ \min \{iL^*, D\} - \min \{iL, D\} + \max \{0, iL^*-R\} - \max \{0, iL-R\} < C_i - C^*_i \]  

(5)

This implies that its increases in loss costs is less than the savings in administrative costs
from shirking.

A simple example illustrates when shirking becomes worthwhile. Suppose that $i=10$, $L^*=100$, $L=80$, $D=50$ and $R=300$. The LHS of (5) is 200 reflecting the extra costs that the insurer has to pay above $D+R$ for shirking. Whenever $C_i - C^*_i > 200$ then the insurer will want to shirk. Note that if $D+R > 1000$ then the reinsurer 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. 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, the reinsurer can reduce ex post moral hazard by increasing their deductible and lowering the upper limit of the attachment point.

**Case 2: Shortage of Claims Adjusters** When there are shortages of claims adjusters, then as the number of losses increases the settlements will 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. One would expect both the administrative costs and the actual losses to increase with $i$ due to the inefficiency of the less well trained adjustors. Assume that the difference in loss costs between shirking and not shirking is a function of the number of losses incurred and increases as $i$ increases. Reinsurers will now have higher payments for reasons having nothing to do with moral hazard unless insurers are even more generous in making claims when they are reinsured than when they have to bear the costs themselves.

**Summary**

In this section we introduced reinsurance into the picture and showed that 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 behavior is designed to eliminate large losses at the expense of expected profits.

One reason that reinsurers may charge premiums in excess of actuarial losses is because of ex post moral hazard. By setting high deductibles and relatively low upper limits of coverage they can discourage this behavior by insurers. Catastrophic disasters with a large insured loss will create shortages of adjustors and raise the costs of rebuilding materials, some of which will be borne by reinsurers.

**5. 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 maximize their discounted expected utility. Insurers and reinsurers utilize this information on risk to price their products and provide premium discounts to those who
adopt mitigation measures. All the costs of disasters can be allocated to specific individuals and property. Then there is 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 Information Problems**

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 underestimate the probability of a disaster occurring. There is empirical evidence that they underestimate the chances of a disaster or behave as if the disaster “will not happen to me” in which case they would have no interest in investing in any loss reducing measures while they are living in their structure. (Palm 1995; Kunreuther 1996). In addition, property owners are very reluctant to incur the upfront costs associated with investing in a mitigation measure because they face budget constraints or underestimate the benefits from the measure due to a high discount rate and/or short time horizons regarding the length of time they will reside in the structure. (Kunreuther, Onculier and Slovic in press). These factors suggest that it will be extremely difficult to encourage homeowners to voluntarily adopt mitigation measures unless they are relatively inexpensive and the individuals are concerned with the threat of natural disasters.

If these property owners were forced to cover their own disaster losses then one might contend that they have only themselves to blame for not taking preventive action. However, all taxpayers bear some of the costs of the 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 earthquake-resistant structures indicate that they have no incentive to build structures that exceed existing codes because they have to justify these expenses to their clients and would lose out to other engineers who did not include these features in the design (May and Stark 1992). Without building codes, they would even be less interested in undertaking measures that will enable the structure to withstand the forces of a disaster.

Well-enforced building codes correct any misinformation that potential property owners have regarding the safety of the structure where the private market will not convey these data. For example, suppose the property owner believes that the losses from an earthquake to the structure is \( L' = \$20,000 \) and the developer knows that it is \( L'' = \$25,000 \) because it is not well constructed. There is no incentive for the developer to relay the correct information to the property owner because the developer is not held
liable should a quake cause damage to the building. If the insurer is unaware of how well the 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 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 If a building topples off its foundation after an earthquake, it could break a pipeline and cause a major fire which would damage other homes that were not affected by the earthquake in the first place. This type of damage has a direct impact on the pricing of insurance in a hazard-prone area.

To see this point consider the following illustrative example. Suppose that an unbraced structure that toppled in a severe earthquake had a 20 percent chance of bursting a pipeline and creating a fire which would severely damage 10 other homes, each of which would suffer $40,000 in damage. Had the house been bolted to its foundation this series of events would not have occurred. The insurer who provided coverage against these fire-damaged homes under a standard homeowner’s policy would then have had an additional expected loss of $80,000 (i.e., .2x10x$40,000) due to the lack of building codes requiring concrete block structures to be braced in earthquake prone areas.

One option would be for homes adjacent to those that are not mitigated to 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 quake would be charged this extra premium.

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

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

In addition to these temporary food and housing costs, the destruction of commercial property could cause business interruption losses and the eventual bankruptcy of many firms. In a study estimating the physical and human consequences of a major earthquake in the Shelby County/Memphis, Tennessee area, located near the New Madrid fault, Litan et al. (1992, pp. 65-66) found that the temporary losses in economic output stemming from damage to workplaces could be as much as \$7.6 billion based on the magnitude of unemployment and the accompanying losses in wages, profits and indirect “multiplier” effects.

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

5. A Hazard Management Program for Catastrophic Risks

There are several conclusions that emerge from this analysis of the role of mitigation measures in dealing with catastrophic losses. Premium reductions for undertaking loss prevention methods can be an important first step in encouraging property owners to adopt these measures. Due to regulatory constraints on pricing, insurers will not voluntarily provide these incentives unless they are forced to provide coverage to individuals in hazard-prone areas and/or face insolvency constraints.

Small capitalized 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 provides an additional option for small insurers to meet insolvency constraints and puts pressure on reinsurers not to charge too high a premium. One reason that they may raise their premiums somewhat higher than actuarial losses is because of ex post moral hazard.

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

**Elements of a Hazard Management Program**

Private insurance can be an important part of a hazards management program, but this requires a reorientation of its role in preventing losses as well as covering damage from disasters. Fortunately, we can think more broadly about how insurance can help manage these risks in the future because of advances in the technology for analyzing data, and because of the recent availability of capital market funding for supplementing traditional reinsurance. These developments suggest a strategy in which private insurance plays a key role in encouraging cost-effective RMMs while providing protection against the financial consequences of disaster. However, insurance needs to be supplemented by other policy tools. Furthermore other stakeholders have to play a key role in implementing the proposed program.

**Premium Reductions Linked with Long-Term Loans**

Insurance premium reductions for undertaking loss prevention measures can be an important first step in encouraging property owners to adopt them. If homeowners are reluctant to incur the upfront cost of mitigation due to budget constraints, then one way to make this measure financially attractive to the property owner is for the bank to provide funds for mitigation through a home improvement loan with a payback period identical to the life of the mortgage.

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.

The above example also illustrates the robustness of the risk estimates that would still make it desirable for a homeowner with insurance to take out a long-term loan for mitigation. Even if the annual probability of an hurricane is as low as 1/189, the property owner would want to take out the loan. Similarly, if the probability were known to be $p = 1/100$, then the reduction in loss from mitigating could be as low as $14,500$ and the loan would still be attractive because of the benefits from the reduced insurance premium.

*Seals of Approval on Structures Meeting Code* As pointed out in Section 5 building codes may play an important role in reducing future losses from natural disasters that go beyond the damage to the structure. In order to make sure that building codes are enforced it is necessary to inspect the property prior to a disaster. Today many communities have limited enforcement of building codes due to a shortage of inspectors. Those on the Atlantic Coast, particularly in Florida, are more mindful of the need for inspection, given the large number of damaged structures in Hurricane Andrew that failed to meet existing building codes.

Cost-effective risk-reduction measures should be incorporated in building codes and a seal of approval should be 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 inspectors, well-qualified to provide 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

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10 If the probability of an hurricane were 1/189, the annual premium reduction would be $145, the same as the annual loan payment.
11 Kneuher and Kleffner (1992) provide a rationale for strengthening building codes by analyzing the factors which lead individuals to avoid investing in mitigation measures even if they have accurate information on the risk.
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).

Subsidized Loans for Low Income Families Many poorly constructed homes are owned by low-income families who cannot afford the costs of mitigation measures on their existing structure or the costs of reconstruction should their house suffer damage from a natural disaster. Equity considerations argue for providing this group with low-interest loans and grants 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.

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 you have lowered the chances of your home being damaged from a hurricane by installing a mitigation measure, you would get a rebate on your state taxes to reflect the lower costs for disaster relief. Alternatively, your property taxes could be lowered for the same reason. To our knowledge no states or communities have implemented such a system. The closest example to a tax incentive that we are aware of is the community of Berkeley, CA where homeowners who mitigate receive tax rebates when they sell their home. (Personal discussion with Arietta Chakos, City of Berkeley, July 1998). 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 it reassessed at a higher value. This implies that his property taxes will be increased.
The principal reason for utilizing tax rebates to encourage mitigation is because of the externalities associated with these measures. If a house is not damaged because it is elevated or protected in some way, then there are much larger savings to the general community than just the damage from the house. (e.g. these residents do not have to be fed or housed elsewhere). 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.

**Role of the Capital Markets**

In the past couple of years investment banks and brokerage firms have shown considerable interest in developing new financial instruments for protecting against catastrophic risks (Jaffee and Russell, 1996). Their objective is to find ways to make investors comfortable trading new securitized instruments covering catastrophic exposures, just like the securities of any other asset class. In other words, catastrophe exposures would be treated as a new asset class.

In June 1997 the insurance company, USAA, floated act-of-God bonds that provided them with protection should a major hurricane hit Florida. As of this writing, another CAT bond based on California industry losses has been put together by Swiss Re, Credit Suisse, and First Boston for dealing with catastrophic earthquake losses. Multiyear catastrophic bonds, which have recently been proposed, promise a relatively high rate of return compared to high-yield bonds. Other financial arrangements, such as *catastrophic insurance futures contracts* and *call spreads* introduced by the Chicago Board of Trade (CBOT) in 1992 enable an insurer to hedge against its underwriting risk by attracting capital from insurance and non-insurance segments of the economy. (Cummins and Geman, 1995; Harrington, et al., 1995). The Catastrophic Risk Exchange (CATEX) creates a marketplace where insurers, brokers, and the self-insured can swap units of their catastrophic risks by region and peril. For example, an insurer could swap units of California earthquake for Florida windstorm (Insurance Services Office, 1996).
Proposed Federal Solutions

Lewis and Murdoch (1996) developed a proposal that the federal government offer catastrophe reinsurance contracts, which would be auctioned annually. The Treasury would auction a limited number of excess-of-loss (XOL) contracts covering industry losses between $25 billion and $50 billion from a single natural disaster. Insurers, reinsurers, and state and national reinsurance pools would be eligible purchasers. XOL contracts would be sold to the highest bidder above a base reserve price which is risk-based. Half of the proceeds above the reserve price would go into a mitigation fund, with the remainder retained to cover payouts. This federal reinsurance effort would be part of a broader program involving mitigation and other loss reduction efforts.

Another proposed option is for the federal government to provide reinsurance protection against catastrophic losses. Private insurers would build up the fund by being assessed premium charges in the same manner that a private reinsurance company would levy a fee for excess-loss coverage or other protection. The advantage of this approach is that resources at the federal government’s disposal enable it to cover catastrophic losses without charging insurers the higher-risk premium that either reinsurers or capital market instruments would require. If one views the private sector as the first line of attack on the problem, as we do, then one would only want to resort to federal reinsurance as last resort.

Future Research Directions

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.\(^\text{12}\) 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.\(^\text{13}\)

\(^{12}\) 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.

\(^{13}\) For example, new advances in seismology and earthquake engineering are discussed in Federal Emergency Management Agency (1994) and Office of Technology Assessment (1995).
Advances in information technology have encouraged catastrophe modeling which 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.

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 will want to have the freedom to charge insurance premiums which reflect the disaster risk rather than being forced to offer coverage at subsidized rates. This may involve changes in the insurance regulatory environment.

Micro-Model Simulations

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

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

Turning to the new instruments from the capital market one could compare their relative attractiveness to reinsurance for different types of insurers who have specific risks in place. For example, the recent Act of God Bonds issued by USAA, a large US 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.14 One would expect that the price of reinsurance will fall in the future given these and other financing and hedging instruments against catastrophic risk unless there are certain features of reinsurance that would prevent the price from declining, as discussed in Froot (1997).

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

This type of simulation modeling must rely on solid theoretical foundations in order to delimit the boundaries of what is interesting and implementable in a market economy. Such foundations will apply not only to the traditional issues of capital markets and the insurance sector, but also to the decision processes of (re-)insurance companies, public officials and property owners in determining levels of mitigation, insurance coverage and

14 Doherty (1997) provides more details on these and other recent financial instruments.
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

Bainbridge, John (1952) Biography of An Idea: The Story of Mutual Fire and Casualty Insurance (Garden City, NY: Doubleday & Co.)


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


### TABLE 1

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 (# of losses □ n)</th>
<th>Loss with No Mitigation ($L'$)</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 than either all homes would be damaged with probability $p=1/100$ or no homes would be damaged with $p=99/100$. 
Appendix A

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

\[
\text{Max} \ [A + NP - \sum p_i i L] \quad (1)
\]

subject to the following insolvency constraint

\[
\text{Probability}[\sum_{i=1}^{8} (A+NP) - i L \leq 0] \leq q^* \quad (2)
\]

where \( q^* = \text{maximum probability of insolvency} \)
APPENDIX 2

MODELING INSURERS BEHAVIOR WITH RESPECT TO MITIGATION

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

NOTATION

\[ p = \text{annual probability of a loss for a single house (e.g. } p = \frac{1}{100}) \]
\[ L'' = \text{Loss without mitigation (e.g. } L'' = $250,000) \]
\[ L' = \text{Loss with mitigation (e.g. } L' = $200,000) \]
\[ E(L'') = pL'' = \text{Expected Annual Loss without Mitigation (e.g. } $2500) \]
\[ E(L') = pL' = \text{Expected Annual Loss with Mitigation (e.g. } $2000) \]
\[ P'' = E(L'') = \text{actuarially fair premium without Mitigation} \]
\[ P' = E(L') = \text{actuarially fair premium with Mitigation} \]
\[ M = \text{Minimum premium reduction from } P'' \text{ for homeowner to adopt mitigation} \]

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)

Largecap has N earthquake policies and must decide what premium (P_i) 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 \( P_L \geq P'' \) so as to

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

subject to the following insolvency constraint

\[
8 \cdot \text{Probability} \left[ \sum \left[ A_i + N(P_{L}) - i L \right] \leq 0 \right] \leq q^*
\]

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 1, (2) will also be satisfied if mitigation is adopted by property owners and \( P_L = P' \).

Hence Largecap will set a premium which maximizes (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 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.

Example: If \( M = $300 \) \( P'' = $2500 \) and \( P' = $2000 \) then the insurer will charge a premium somewhere between $2000 and $2200.
SMALL CAPITALIZED INSURERS (INSOLVENCY CONSTRAINT IS EXCEEDED WITHOUT MITIGATION)

Smallcap has N earthquake policies and must decide what premium (P_L) 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

\[
\text{Max } [A_s + NP_s - \sum p_i i L] \tag{3}
\]

subject to the following insolvency constraint

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

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

Smallcap is assumed to have insufficient 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 \( S_s = $700,000 \) consisting of \( A_s = $450,000 \) and actuarial premiums for 100 policies 100 (P'') = $250,000. The small insurer can either purchase reinsurance and/or encourage mitigation through premium reduction to meet (4). We will briefly examine each of these decisions, based on the illustrative example in the paper, using the data from Table 1.

Purchasing Reinsurance

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

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

\[
\text{Prob}[ \sum_{i=1}^{8} [S700 - R_{max} - i L''] + [S700 - R_{max} - 750 + 250] + \sum_{i=4}^{8} [S700 - R_{max} - i L' + 250]] \leq .01 \tag{5}
\]
where the figures are in thousands of dollars.

$R_{\text{max}}$ is determined by finding the value where the surplus of the insurer is zero when there are 3 losses. To see this, note from Table 1 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 .01. Hence if $q^* = .01$, the value of $R_{\text{max}}$ is determined by solving:

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

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 $3,333$ 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 1 one sees that if $q^* = 1/100$ then Smallcap needs to set premiums so it has sufficient surplus to cover 3 losses. With mitigation its claims are reduced from $750,000$ to $600,000$ when 3 structures are damaged. Hence to determine $P_S$ which satisfies (4) one computes

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

This means that $P_S = 1,500$, a premium below the actuarially fair value of $P^* = 2,000$. Thus Smallcap loses money on its earthquake business to encourage mitigation and satisfy its insolvency constraint.
Insured Catastrophe Losses in 1997 Dollars

$ billions

30  25  20  15  10  5  0