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Volume Title: The Financing of Catastrophe Risk

Volume Author/Editor: Kenneth A. Froot, editor

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-26623-0

Volume URL: <http://www.nber.org/books/froo99-1>

Publication Date: January 1999

Chapter Title: Challenges Facing the Insurance Industry in Managing Catastrophic Risks

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Chapter URL: <http://www.nber.org/chapters/c7950>

Chapter pages in book: (p. 149 - 194)

Challenges Facing the Insurance Industry in Managing Catastrophic Risks

Paul R. Kleindorfer and Howard C. Kunreuther

The private insurance industry feels that it cannot continue to provide coverage against hurricanes and earthquakes as it has done in the past without opening itself up to the possibility of insolvency or a significant loss of surplus. This concern stems from a series of natural disasters in the United States since 1989 that have resulted in unprecedented insured losses.

Figure 4.1 depicts the magnitude of the catastrophic losses experienced by the insurance industry in the United States from 1961 to 1995. The graphic change from 1989 is obvious. Prior to the occurrence of Hurricane Hugo in 1989 (insured losses in that year were over \$4 billion), the insurance industry had never suffered any losses from a single disaster of over \$1 billion. Since that time, it has had ten disasters that have exceeded this amount (“Catastrophes” 1996).

Hurricane Andrew was the most severe disaster that the insurance industry has experienced to date. It swept ashore along the Florida coastline in August 1992, causing insured losses from wind damage that topped \$15 billion.¹ Had

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Special thanks go to Risk Management Solutions of Menlo Park, California, for providing the authors with the data to construct the model city and analyze the effect of earthquakes on property damage. Weimin Dong, Pierre Lemaire, and Christopher Warren were extremely helpful in constructing the different modules that characterize the earthquake-simulation model. They and Rick Anderson also provided valuable assistance in data analysis. Jacqueline Meszaros, Gilbert White, and Peter Zweifel provided helpful comments on an earlier draft of the paper. The authors are especially grateful to our discussants, James Garven and Dwight Jaffee, and to the conference participants for their comments on the paper. The authors acknowledge partial financial support for this paper from National Science Foundation grant 524603. They acknowledge partial financial support for this paper from the NBER Project on the Financing of Property/Casualty Risks.

1. Water damage to insured property is covered by the government-based National Flood Insurance Program.

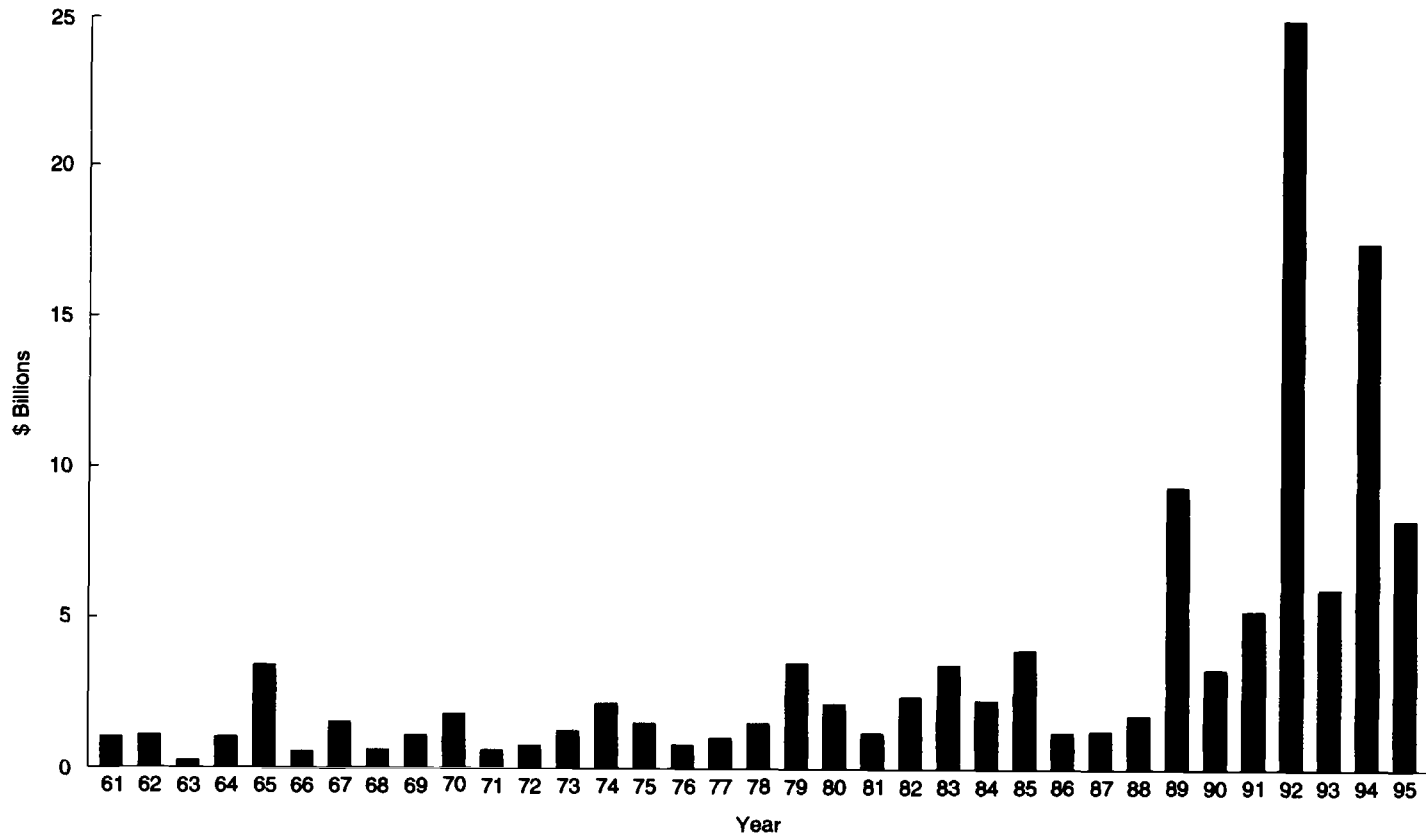


Fig. 4.1 Insured catastrophe losses in 1995 dollars

Source: Insurance Services Office (1996, 4).

the storm taken a more northerly track and hit downtown Miami and Miami Beach, total insured damage could have approached \$50 billion. The storm forced the insurance industry to recognize that it might be subject to losses in the future way beyond any figures previously imagined.²

On the West Coast of the United States, insured damage from the Northridge Earthquake of January 1994 exceeded \$12 billion. Had a similar quake hit central Los Angeles, the insured bill could have been over \$50 billion. The Kobe Earthquake in Japan, which occurred exactly one year after Northridge, caused substantially more damage, with estimates of the costs of repair at well over \$100 billion. Since very few structures were insured, the cost to the insurance industry was relatively small (\$1 billion) (Scawthorn, Lashkari, and Naseer 1997). A repeat of the earthquake that destroyed Tokyo in 1923 could cost between \$900 billion and \$1.4 trillion today (Valery 1995).

The change in the character of these disasters in recent years and the specter of megacatastrophes in the future raise two fundamental questions: (1) What steps can be taken to reduce the losses from future disasters? (2) Who can and should pay for the costs of these events when they occur?

This paper suggests an approach to evaluating the role of insurance and other policy instruments for managing the catastrophic risk problem. The next section provides an overview of why traditional reinsurance mechanisms are limited in their ability to cover recent losses. It also indicates how pooling arrangements at the state and federal levels have attempted to fill this void as well as the need for new sources of funds from the capital markets.

Section 4.2 stresses the importance of understanding the decision processes of the key interested parties concerned with catastrophic losses and their interaction with each other. On the basis of this descriptive characterization of the problem, section 4.3 proposes a conceptual framework for examining a set of alternative strategies by taking advantage of information technology, expanded databases, and modeling approaches now being used to analyze catastrophic risks. Section 4.4 utilizes this framework to examine the role that two policy instruments, reinsurance and mitigation, can play in dealing with catastrophic losses for a "model city" in California. The concluding section suggests ways to expand these analyses to include alternative decision rules and policy instruments in structuring and evaluating new approaches to managing catastrophic risks.

4.1 Need for New Funding Sources

Insurers have traditionally protected themselves through private reinsurance contracts whereby portions of their losses from a catastrophic disaster are cov-

2. Six years prior to Andrew, an industry-sponsored study had been published, indicating the effect of two \$7 billion hurricanes on property-casualty insurance companies. The report indicated that no hurricane of that magnitude had ever occurred before but that "storms of that dollar magnitude are now possible because of the large concentrations of property along the Gulf and Atlantic coastlines of the United States" (AIRAC 1986, 1).

ered by some type of treaty or excess-loss arrangement. To illustrate, consider an excess-of-loss protection policy between a private insurer and a reinsurer where a 300/100 excess-loss layer was provided. This arrangement means that, if losses from a specific earthquake exceed \$300 million, the reinsurer will cover the next \$100 million in losses. The insurer is responsible for covering losses above \$400 million. The \$300 million is designated as the *attachment point*, and the other end of the range, \$400 million, is specified as the *limit*. The difference between these two points defines the amount of reinsurance in force. In return for this protection, the insurer pays the reinsurer a prespecified premium.

4.1.1 Role of Reinsurance

Following the recent catastrophic disasters, insurers have been demanding more reinsurance coverage, but they are having a difficult time obtaining the layers that they require at prices that they consider affordable. If insurers were allowed to charge higher premiums on their own policies, many would need less reinsurance and would accept higher attachment points. However, regulatory constraints, such as obtaining prior approval by the state insurance commissioner of rate changes, limit insurers' ability to raise premiums to levels that they feel reflect the risk. For example, in Florida, restrictions have been placed on rates that can be charged on homeowner's coverage (which covers wind damage) in areas of the state affected by hurricanes (Lecomte and Gahagan 1998).

Given the limitations on the amount of reinsurance that insurers can afford to purchase, they have been greatly concerned with the maximum probable losses that they may experience from a severe hurricane or earthquake with their current book of business. This concern is *not* unfounded. Nine insurance companies were insolvent as a result of Hurricane Andrew, adding to the financial burden of other insurers who were assessed for the claims of the insolvent firms by the Florida Insurance Guarantee Fund. In fact, these post-Andrew assessments led to a tenth company becoming insolvent (Conning & Co. 1994).

Many insurers writing earthquake coverage in California have also been concerned with the possibility of insolvency or a significant loss of surplus following another major earthquake. Although there are no formal rate restrictions by the state Insurance Department, companies feel constrained on how high a rate they can charge and still maintain their credibility with the public. Furthermore, they have been limited in the amount of reinsurance that they have been able to obtain owing to the capacity limits of the worldwide reinsurance market (Insurance Services Office 1996). In fact, shortly after the Northridge Earthquake, Standard and Poor's Insurance Rating Service identified ten insurance companies that would be in danger of failing if another major natural disaster occurred in California (Insurance Services Office 1994).

The U.S. Congress is now considering proposals for providing federal

excess-loss reinsurance. The National Economic Council has recommended that the federal government offer *catastrophe-reinsurance contracts* that would be auctioned annually. The proposal would establish a program in which the Treasury would auction a limited number of excess-of-loss contracts covering industry losses between \$25 and \$50 billion from a single natural disaster. Insurers, reinsurers, and state and national reinsurance pools would be eligible purchasers (Lewis and Murdock 1996).

4.1.2 Emergence of State Pools

During the past five years, several states have established pools to provide either coverage or additional capacity following disasters. The first such arrangement was in Hawaii, where a hurricane relief fund was established after Hurricane Iniki (1992) to provide windstorm coverage for residential and commercial property. In Florida, a joint underwriting association was established in 1992 following Hurricane Andrew to issue policies to those homeowners who were refused coverage by private insurers. Today, this residual market mechanism is the state's third-largest property insurer, having underwritten almost 900,000 policies and exposing itself to \$100 billion in potential losses, much of that in southern Florida (Scism 1996).

The Florida Hurricane Catastrophe Fund was created in 1992 with trust funds reimbursing insurers for a portion of their losses from future severe hurricanes. Above a predetermined retention level, insurers are provided with reinsurance benefits from the fund following a future catastrophic disaster. The current cash balance of the fund will *not* enable it to provide adequate protection to insurers for hurricanes as costly as Hurricane Andrew (Insurance Services Office 1996).

Since 1985, insurers in California have been required to offer earthquake coverage to anyone who has a homeowner's policy with them. This created few problems until after the Northridge Earthquake, when many insurers felt that they could not risk selling any more earthquake policies in the state. In 1995, the California Insurance Department surveyed insurers and learned that up to 90 percent of them had either placed restrictions on the sale of new homeowner's policies or stopped selling these policies completely (Roth 1998).

As a result of this lack of availability of homeowner's insurance following the Northridge Earthquake, a state-run earthquake-insurance company was proposed. In September 1996, the state legislature approved the formation of the California Earthquake Authority (CEA), which provides coverage to homeowners with a 15 percent deductible. The CEA is an innovative arrangement that reflects a combination of both private and public funding to cover the insured losses from a catastrophic disaster.

Table 4.1 depicts the different layers of coverage to finance the \$10.5 billion funding requirement, assuming that all licensed insurance companies in the market participated. *Insurers' liability* is limited to \$6 billion (\$1 billion in start-up assessments, \$3 billion for the first layer of coverage to pay claims

Table 4.1 Structure of the California Earthquake Authority: Capacity Participation

Layer		Total (\$ billion)
\$2 billion	Industry-contingent assessment (after the earthquake)	\$10.5
\$1.5 billion	Berkshire Hathaway	8.5
\$1 billion	Policyholder-contingent assessment	7
\$2 billion	Reinsurance (no reinstatement)	6
\$3 billion	Industry-contingent assessment (after the earthquake)	4
\$1 billion	Industry assessment (to start the program)	1

Source: Roth (1998).

after an earthquake, and another \$2 billion if the insured damage exceeds \$8.5 billion). The other layers are funded by either *reinsurance* (\$2 billion); *policyholder assessment* (\$1 billion), to cover a loan from the bond market; or Berkshire Hathaway (\$1.5 billion) (Roth 1998).

4.1.3 Potential Role of the Capital Markets

In the past few years, considerable interest has been shown by investment banks and brokerage firms in developing new financial instruments for providing protection against catastrophic risks (Jaffee and Russell 1996). Their objective is to find ways in which investors will be as comfortable trading new securitized instruments covering catastrophic exposures as they would the securities of any other asset class. In other words, catastrophe exposures would be treated as a new asset class.

Litzenberger, Beaglehole, and Reynolds (1996) have simulated ten thousand scenarios for a hypothetical ten-year catastrophe bond where the investor receives a coupon of 14.57 percent (nine hundred basis points above Treasury bonds) over the life of the bond. If the loss ratio exceeds 20 percent in any calendar year, the bond expires, and the investor receives half the principal. The average rate of return for these bonds under these simulations was 7.47 percent when random samples were taken from a lognormal distribution. This compares with an average return of 5.61 percent for a ten-year high-yield bond. Froot et al. (1995) computed the returns that an investor would have earned by providing capital to fund excess-of-loss reinsurance contracts during the period 1970–94. They found that an investor would have earned returns of 224 basis points above the Treasury bill rate during this entire period. In the best and worst years over this time horizon, the *excess return* would have been 7.5 percent and –22.1 percent, respectively.

Until 1997, there has been relatively little interest by the investment community in these new instruments. But the picture appears to be changing. Recently, USAA successfully floated a catastrophe bond that has two layers of debt: one layer is subject to interest forgiveness should USAA suffer a loss in excess of

\$1 billion from a class 3, 4, or 5 hurricane; the other layer has both principal and interest at risk.³ The \$400 million targeted capacity was oversubscribed, partly because investors are now more familiar with these types of instruments, but also because of the very high return on the investment. Another catastrophe bond based on California industry losses has been put together by Swiss Re, Credit Suisse, and First Boston for dealing with catastrophic earthquake losses (Doherty 1997).

We feel that there are several reasons why the investment community has been slow to embrace these new capital market instruments. For one thing, the risks of catastrophic losses from natural disasters are highly uncertain, causing investors to focus on the high variance in losses. This concern has been heightened by the recent projections of future losses from hurricanes and earthquakes, which far exceed any disasters that have occurred until now. In addition, these are risks with which the investment community has no prior history or experience. Hence, there are currently no standards or ratings for evaluating the quality of a particular instrument. Finally, and perhaps most important, any innovation takes time to be adopted. There is generally a long process between the time a new product is introduced and the time there is a market for it, particularly if there are long-standing relationships between the two key interested parties—insurers and reinsurers (Wind 1982).

4.2 Understanding Decision Processes of the Key Stakeholders

In order to develop a strategy for managing catastrophic risks, one must characterize the nature of the hazards as well as understand the behavior of the interested parties concerned with the consequences of these events. The risks associated with earthquakes and hurricanes fall into the class of low-probability, high-consequence (LP-HC) events. There is considerable ambiguity and uncertainty associated with predicting both the *probability of the event* occurring at a specific time and place and the *resulting losses* to the affected community (Hanks and Cornell 1994). Experts often disagree on these risk estimates. There is not sufficient evidence from past events or scientific models to reconcile these differences.

Hazard-risk maps have been drawn for both earthquakes and hurricanes, but they provide only rough guidelines as to the likelihood and potential damage from specific events. A case in point is the medium-intensity Northridge Earthquake, where the actual losses were considerably more than what was predicted by experts. Certain structures, notably steel-framed buildings with moment-resisting frames, failed even though they had been considered outstandingly good at handling earthquakes prior to Northridge (Valery 1995).

3. The interest rate was 273 above LIBOR for the first layer of debt and 576 for the more risky second layer.

4.2.1 Simplified Decision Rules

The ambiguity associated with these events, coupled with the limited information-processing capabilities of individuals, has led potential disaster victims and insurers to utilize simplified decision rules that differ from such normative models of choice as expected-utility theory or cost-benefit analysis (Camerer and Kunreuther 1989). These choice processes need to be taken into account in designing strategies for managing catastrophic events.

Residents in hazard-prone areas often exhibit one of two reactions with respect to LP-HC events. If they have not experienced the specific disaster and do not know friends and neighbors who have been in these events, then many believe that "it will not happen to me." This perception of the risk is equivalent to treating the probability of the hurricane or earthquake as if it were zero. These residents will have no interest in voluntarily purchasing insurance or investing in mitigation measures (Kunreuther 1996).

Individuals who have experienced a disaster or are concerned about the possibility of severe losses in the future because of the media and/or personal knowledge are likely to purchase insurance voluntarily and/or invest in mitigation measures. One factor that restrains property owners from incurring the upfront costs of loss-reduction measures is their unusually short time horizons. This may be due to the inability of people to project benefits over a long period of time and/or budget constraints that preclude large investments unless they pay off rapidly. For example, if it costs \$1,000 to bolt a structure to its foundation and the expected annual reduction in losses is \$300,⁴ then, even with an annual discount rate as high as 15 percent, the investment will pay off in five years.⁵ However, if a homeowner compares the \$1,000 investment with the one-year saving of \$300, then he will not want to invest in this measure.

Insurers are also concerned with ambiguity and uncertainty in determining whether they want to offer coverage and, if so, what premiums to charge against particular risks. For earthquakes and hurricanes, where the insurer is likely to have a portfolio of policies concentrated in one area, then the insurer will experience either feast (no hurricanes) or famine (a hurricane hitting the area where it has sold many policies). For such correlated risks, the insurer is concerned, not only with the uncertainty of the probability of a loss, but also with the magnitude of claims should a single disaster occur.

In fact, a series of interviews conducted with insurers following Hurricane

4. The expected annual loss is determined by multiplying the probabilities of disasters of different magnitudes by the resulting damage. For example, if the annual probability of an earthquake affecting one's home was one in fifty and the savings in damage from bolting the house to the foundation was \$15,000, then the expected annual reduction in losses is \$300 (i.e., $1/50 \times \$15,000$), assuming that this was the only earthquake that could damage the house.

5. The expected benefit from the mitigation measure over a period of five years is $\sum \$300/(1 + d)^t$, or \$1,005, using an annual discount rate of $d = 15$ percent.

Andrew and the Northridge Earthquake indicated that a key factor influencing their decision-making process regarding how many policies to write is their probable maximum loss (PML) should a catastrophic disaster occur.⁶ In many hazard-prone regions, a number of insurers would like to reduce their current PMLs, in part because the A. M. Best Company has begun to include PML exposures as a part of its rating of insurer capability ("Catastrophes" 1996).

One of the questions that every insurer asks is whether earthquake risks are insurable. In his definitive study, which sheds light on this question, Stone (1973) indicated that firms are interested in maximizing expected profits subject to two constraints, representing the survival of the firm and the stability of its operation. The insurance underwriter operationalizes the survival constraint by choosing a portfolio of risks so that the estimated probability of insolvency is less than p_1 . The stability constraint focuses on the combined loss and expense ratio (LR) for each year. Insurers define a target level (LR*) that represents an upper limit on this ratio and requires the probability that LR exceed LR*) to be less than p_2 .⁷

A simple example illustrates how these two constraints would be utilized by an insurer in determining whether the earthquake risk is insurable. All houses in the earthquake area are assumed to be identical, and the insurance premium on each structure is therefore set at P . Suppose that the Shaker Insurance Company had A dollars in current surplus and wanted to determine the number of policies it would be able to sell and still satisfy the above two constraints. The maximum number of policies (n_1) that would satisfy the *survival constraint* is determined by

$$\text{probability}[(\text{total losses} > n_1P + A)] < p_1.$$

The maximum number of policies (n_2) satisfying the *stability constraint* is determined by

$$\text{probability}[(\text{total losses} + \text{expenses})/n_2P > \text{LR}^*] < p_2.$$

Whether the Shaker Company will view the earthquake risk as insurable depends on whether the fixed cost of developing the product is sufficiently low that it can make a positive expected profit. This in turn depends on how large the values of n_1 and n_2 are for any given premium P . Note that Shaker also has the freedom to change its premium. A larger P for any prespecified loss structure will increase the values of n_1 and n_2 but will lower the demand for coverage. Shaker will decide *not* to offer earthquake coverage if it believes that it

6. These interviews were conducted by Jacqueline Meszaros as part of a National Science Foundation study (see Meszaros 1997).

7. In their analysis of insurance pricing of catastrophic risks, Dong, Shah, and Wong (1996) modify the stability constraint by formulating it as the probability that LR exceeds LR* by x percentage points (e.g., 4 percent) is less than p_2 .

cannot attract enough demand at any premium structure to make a positive expected profit using the survival and/or stability constraints as restrictions on how many policies it is willing to offer.

The decision rules utilized by insurers in setting premiums for coverage are a function of how ambiguous and correlated the risks are. Studies of actuaries and underwriters of primary insurers and reinsurers reveal that both these factors play a key role in their premium-setting decisions. A survey of 463 actuaries concerning a defective-product scenario where the probability of loss was varied and there was a perfectly correlated risk revealed that the median premium that they would charge was anywhere from two to ten times larger if the probability was ambiguous than if it was well specified (Hogarth and Kunreuther 1992). In another survey, when underwriters in primary and reinsurance companies were given scenarios of an earthquake risk with well-specified probabilities and losses as well as scenarios where the risk was ambiguous and uncertain, the responses were similar to those of the actuaries. The mean premium was 50 percent higher for primary underwriters and 40 percent higher for reinsurer underwriters for the case where the probability of a loss was ambiguous and the magnitude of the loss was uncertain than when the risk was well specified (Kunreuther et al. 1993).

4.2.2 Nested Decision Structures

Another feature of the choice process that needs to be taken into account when developing strategies is the interconnectedness between the different policy instruments and the stakeholders associated with the management of catastrophic risks. To illustrate how policy instruments are nested, consider the relation between mitigation and insurance. If building codes are enforced for all structures in hazard-prone areas, future disaster losses are likely to be reduced significantly. This will have several desirable effects. First, it will reduce the magnitude of the losses from future disasters and hence enable insurers to provide additional coverage to propertyowners. This will decrease the need for reinsurance and for funds from other sources, such as the capital market and state pools. If rates are based on risk, it will also enable insurers to offer propertyowners coverage at lower premiums for the same amount of coverage.

The National Flood Insurance Program (NFIP), created by Congress in 1968 in response to mounting flood losses and increasing costs to the general taxpayers through disaster relief, illustrates the interaction of a set of policy tools for dealing with this hazard. To encourage communities to participate in the program, and to maintain the property values of structures, those residing in the area prior to the issuance of a flood-insurance rate map had their premiums subsidized. New construction was charged an actuarial premium reflecting the risks of flood (Interagency Flood Plain Management Review Committee 1994).

To prevent development of structures in highly hazard-prone areas, communities can remain in the NFIP only if they develop certain ordinances re-

stricting the construction of houses in high-hazard areas or if residents are required to meet standards according to which they are protected against floods with an annual probability of one in one hundred or greater. As a condition for receiving grants or loans for the acquisition, construction, or improvement of structures located in the one-hundred-year floodplain, the propertyowner must purchase flood insurance. However, evidence from a U.S. General Accounting Office study indicates that this requirement has not been routinely enforced. A survey in Texas following a major flood in 1989 revealed that 79 percent of the damaged properties that had been required to purchase flood coverage were uninsured at the time of the disaster (U.S. General Accounting Office 1990).⁸

Turning to the stakeholders, the decision processes of one interested party will affect the behavior of another group, which will influence the choices of a third party, etc. A change in a given policy or program must be carefully structured to reflect this nested decision structure (Kleindorfer, Kunreuther, and Schoemaker 1993). The challenges associated with reducing disaster losses through mitigation measures illustrate this point. There is considerable empirical evidence that 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 and to develop building codes that are well enforced.

Other stakeholders have good financial reasons not to implement these measures. *Real estate agents* have no reason to provide prospective buyers with information on the hazards associated with living in a particular structure that does not meet the building code. They are supported implicitly by the *current owner*, who wants to sell his 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 he does not think about the risks associated with future disasters.

The problem is compounded by *developers and contractors*, who want to build structures as cheaply as possible so that they can sell them more easily and remain competitive. Until recently, *insurers and reinsurers* have generally not been sensitive to the design of structures when they issue coverage against wind or earthquake damage. Hence, inspections are not required as a condition for insurance. In setting premiums for structures in hazard-prone areas, insurers do not know whether specific mitigation measures have been put in place. To the extent that local and state governments do *not* enforce codes through inspections of individual structures,⁹ this represents a type of *ex ante* moral hazard.

One might expect *banks and financial institutions* to be sensitive to the

8. More details on proposals for linking alternative policy instruments for dealing with the flood hazard can be found in the Interagency Floodplain Management Review Committee (1994) report.

9. For a more detailed discussion of *ex ante* moral hazard, see Pauly (1974), Marshall (1976), Shavell (1979), and Dionne and Harrington (1992).

structural design of the property when issuing a mortgage, but they generally do not require any certification that the property meets current building codes. In informal discussions, one hears the comment that a bank cannot remain competitive if it is the only one demanding that the property be inspected. One can also speculate that managers employed by financial institutions do not worry about the possibility of a future disaster or are convinced that victims will receive sufficient disaster assistance to maintain their mortgage payments. In addition, most banks send their mortgages to the secondary market, where the new lending institution may have limited knowledge of the hazard in question.

The upshot of this set of dynamics is that many homes are likely to be constructed in such a way that they do not meet code. Insurance experts have indicated that 25 percent of the insured losses from Hurricane Andrew could have been prevented through better building-code compliance and enforcement (Insurance Information Institute 1995). One question that naturally arises is whether insurers working closely with financial institutions and public-sector agencies can encourage propertyowners to adopt cost-effective mitigation measures by offering premium reductions for safer houses and requiring that homes be inspected before a policy is issued. The effect of such a strategy could significantly reduce future losses from natural disasters.

4.2.3 Summary

Given the nature of the decision processes and the degree of nestedness between the different stakeholders, there may be new roles for the private market and the public sector to play in helping manage the problems of catastrophic risk. For example, if individuals are reluctant to incur up-front costs of mitigation measures that promise to be cost effective in the long run, there is an opportunity for insurers and banks to join forces to alleviate this concern. One way to do this is for the insurer to lower premiums, reflecting the expected reduction in future losses, and for banks to provide the propertyowner with a low-interest loan over the life of the mortgage for financing mitigation expenses. It is very likely that the annual loan payments will be less than the premium reduction, thus guaranteeing that every knowledgeable homeowner will want to adopt cost-effective mitigation measures.

Different stakeholders can also join forces in promoting new financial instruments to supplement reinsurance for protecting insurers against catastrophic losses. Here, the challenge is to convince investors that their chances of suffering large losses are relatively small compared to the expected return on their investment. This process is not an easy one, particularly if the investment community is unfamiliar with the types of risks against which they would be providing protection. The ambiguity associated with estimating future losses and the conflicts between experts on their assumptions for developing catastrophe models leave investors somewhat confused about what they are getting themselves into if they decide to commit funds to some of these new

financial instruments. As we will indicate in the next section, there are opportunities for examining expert differences in a systematic manner. Such analyses may alleviate some of the concerns of potential investors.

4.3 A Conceptual Framework for Analyzing Alternative Programs

4.3.1 New Advances in Risk Assessment, Information Technology, and Catastrophe Modeling

There is now an opportunity to evaluate alternative strategies for managing the risks from natural disasters by taking advantage of a set of new developments in the areas of risk assessment (RA), information technology (IT), and catastrophe modeling (CM). Turning first to RA, by merging information derived from past records of earthquakes and hurricanes with an increased understanding of the characteristics of these hazards, scientists have been able to reduce our uncertainty about forecasting future events. With respect to damage estimation, engineers can now better characterize the performance of different types of structures during hurricanes of different wind speeds and earthquakes of different magnitudes and intensities.¹⁰

On the IT side, the development of faster and more powerful computers enables us to examine extremely complex phenomena in ways that were impossible even five years ago. Large databases can easily be stored and manipulated so that large-scale simulations of different disaster scenarios under alternative policy alternatives can now be undertaken.

Finally, new advances in CM provide an opportunity to combine scientific risk assessments with historical records to estimate the probabilities of disasters of different magnitudes and the resulting damage to the affected region. A catastrophe model is the set of databases and computer programs designed to analyze the effect of different scenarios on hazard-prone areas. The information can be presented in the form of *expected annual losses* based on simulations run over a long period of time (e.g., ten thousand years) or the effect of *specific events* (e.g., worst-case scenarios). Several firms have developed catastrophe models and provide detailed analyses of their databases to the various parties concerned with these risks (e.g., insurers, reinsurers, government agencies, and disaster-prone communities).

4.3.2 Nature of Modules

These new advances in RA, IT, and CM provide the impetus for constructing a framework for examining alternative approaches to managing catastrophic risks. Below, we describe the different modules that are depicted graphically in figure 4.2.

10. For a more detailed discussion of new advances in seismology and earthquake engineering, see FEMA (1994) and Office of Technology Assessment (1995).

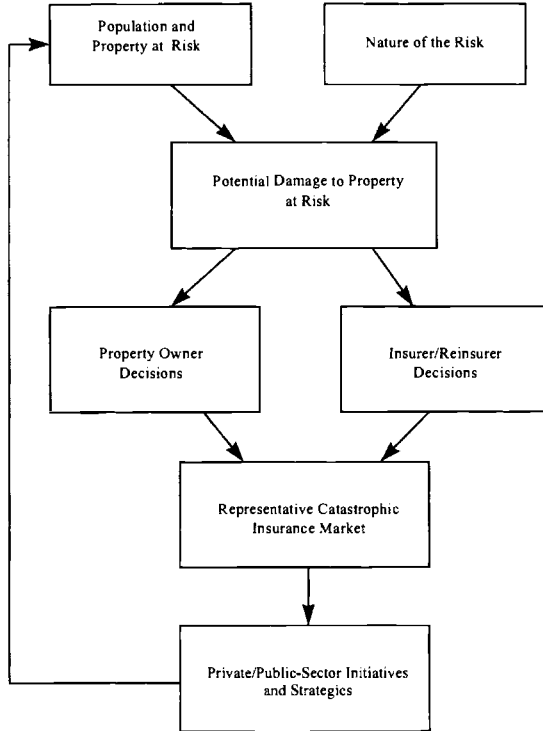


Fig. 4.2 Framework for analyzing catastrophic risks

One must first characterize the *population and property at risk*. For the natural hazards problem, this involves constructing a community or region consisting of homes, businesses, and other properties that are subject to future disasters. More specifically, we want to know the design of each structure, whether specific mitigation measures are in place or could be utilized, the precise location of the structure in relation to the hazard (e.g., distance from an earthquake fault line or proximity to the coast in a hurricane-prone area), and other risk-related factors.

The second module consists of the elements that characterize the *nature of the risk*, namely, the probability that disasters of specific magnitudes will occur and the resulting losses to structures in harm's way. These first two modules provide the ingredients for a module labeled *potential damage to property at risk*, which characterizes the potential damage to individual structures and the model cities from a specific type of hazard.

The *propertyowner decisions* module consists of a set of decision rules utilized by propertyowners in making choices regarding the purchase of insurance and the adoption of loss-prevention measures. The module will build on our understanding of the decision processes of individuals with respect to LP-HC

events. For example, if homeowners consider purchasing insurance only if they perceive the probability of the event to be greater than some critical value p^*), then one must incorporate risk perceptions as part of the decision-process module and determine how these perceptions are formed. In addition, one will need information on residents' and businesses' income and assets, their attitudes toward risk, and their expectations of public subsidies and assistance following a disaster.

The *insurer/reinsurer decisions* module characterizes the decision processes utilized by insurers and reinsurers in underwriting residential and commercial property by building on recent empirical studies of the decision processes of underwriters, actuaries, and other insurance executives. In particular, there is a need to understand the factors that encourage or inhibit the insurance industry from providing coverage against losses due to hurricanes, earthquakes, and other natural disasters.

A module characterizing a *representative catastrophic insurance market* will be developed consisting of propertyowners, prototypical insurance companies (e.g., small, medium, large), and reinsurers. Books of business for each company will be generated under various assumptions about the supply of and demand for insurance and alternative regulatory policies and risk-management strategies of insurers and reinsurers.

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 effect of different disasters on the insurer's profitability, solvency, and performance. Such analyses may also enable one to price the costs of different types of financial instruments on the basis of simulated loss experience over time. This information could be translated into prices of these financial instruments reflecting both the expected loss and the variance in these estimates. One could also examine the role of the public sector in regulating rates and providing protection against catastrophic losses.

Finally, the *private/public-sector initiatives and strategies* module will evaluate alternative programs and institutional arrangements between the private and the public sectors. These strategies, which range from information, incentives, and insurance to building codes and land-use regulations, will be important inputs to the modules characterizing propertyowner and insurer/reinsurer decisions. For example, if banks and financial institutions require certain mitigation measures as a condition for a mortgage, this has implications for the way in which propertyowners make decisions and also affects insurer/reinsurer decision processes.

In examining these measures, one must consider the agendas and decision processes of the concerned interested parties in the private and public sectors. What values and agendas do these stakeholders bring to the table? How do they interact with each other? What programs and policies do they favor for reducing future losses and paying for disasters that occur, and why?

The analyses of these issues often involve questions of equity and efficiency. Who should pay for the costs of natural disasters? What is the appropriate level and nature of regulatory oversight of catastrophe-insurance markets? Are other regulatory measures needed to encourage mitigation and prefinancing? Should we restrict individuals from residing in hazard-prone areas or require them to adopt mitigation measures? How do we deal with low-income families who cannot afford the costs of insurance and prevention measures? These and other related questions need to be addressed in developing a strategy for managing catastrophic risks.

4.4 Prototype Analysis Using the Conceptual Framework

To provide insight into the interaction of policy instruments and outcomes, we have constructed a “model city” in California that is subject to possible damage from earthquakes. Four prototypical insurance companies provide coverage to the propertyowners in the city. In this community, we assume that all residents and businesses would like to purchase earthquake insurance but that not all of them can obtain coverage. If the insurer is concerned with the possibility of insolvency, it will limit the amount of coverage that it provides, and some propertyowners will be unprotected. For this analysis, we are assuming that the insurer will determine how much coverage it offers by focusing on a survival constraint similar to the one characterizing insurers’ behavior in section 4.2 above.

Two policy options will be examined in this analysis: *the availability of reinsurance for and effect of reinsurance on primary underwriters* and *the adoption of mitigation measures* by propertyowners. The amount and pricing of available reinsurance are, of course, likely to be the result of complex market and regulatory interactions that are not explored explicitly here. Our interest is in understanding the aggregate effect of reinsurance on expected and worst-case results for various classes of propertyowners in the model city and for insurance companies operating there. Similar comments apply for mitigation in that we do not study the pricing, the detailed decision processes, or the regulatory requirements associated with mitigation, only the aggregate effects of several exogenously imposed scenarios for mitigation adoption. More detailed models for both reinsurance and mitigation are the subjects of ongoing research using the model city framework introduced here.

4.4.1 General Model Structure

The structure of the prototype analysis is shown in figure 4.3. First, the structure of the model city is specified. Then scenario variables are set. These variables, together with a model characterizing the earthquake hazard (i.e., the RWP model described below), give rise to a loss distribution, $F(L) = \Pr\{\text{loss} \leq L\}$, and the associated exceedance probability (EP) function, $EP(L) = \Pr\{\text{loss} > L\} = 1 - F(L)$. For a given insurance company, the EP function is,

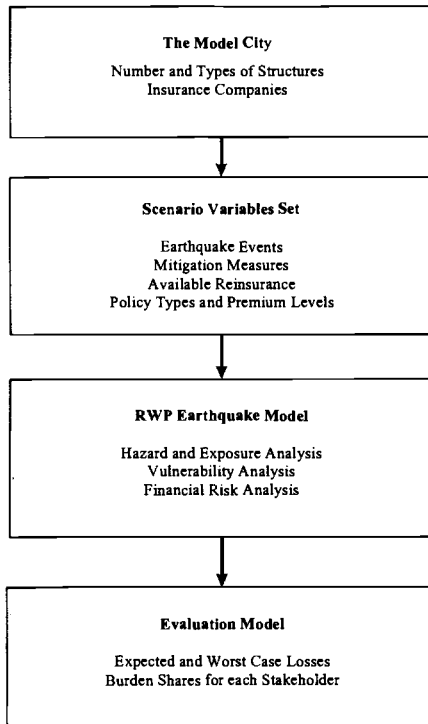


Fig. 4.3 General structure of the model

of course, a function of the number and type of properties insured, mitigation levels, coverage limits, amount of reinsurance, and events (location, number, and severity of earthquakes) that are used to generate loss exposures. The EP functions for all insurance companies and for uninsured properties provide the foundation for evaluating expected and worst-case consequences of the assumed scenario. The structure of the model is depicted in figure 4.3. Let us consider each of its elements in more detail.

4.4.2 Construction of Model City

The model city is a virtual mirror of Oakland, California, in terms of number, types, and mix of structures. As noted above, the insurance market consists of four hypothetical companies: company LG (large), company M (medium), company S (small), and company O (other or none of the above). All properties are initially assigned to precisely one of these companies, on a random basis, but matching some prespecified criteria for the book of business in question. Hence, the books of business of companies LG, M, S, and O cover every property in the city.

One may think of these initially assigned books of business as the maximum

Table 4.2 Composition of Books of Business by ATC Classification

	Small	Medium	Large	Other	Model City
Wood frame	3,077	6,214	0	53,154	62,445
Light metal	1,384	2,778	0	23,144	27,306
Unreinforced masonry wall	10	25	0	147	182
Reinforced concrete (RC) shear wall with frame	50	230	1,192	882	2,354
RC shear wall without frame	22	93	456	380	951
Reinforced masonry shear wall	3	9	82	59	153
Reinforced masonry shear wall with frame	38	211	1,031	775	2,055
Braced steel frame	6	35	114	115	270
Moment steel frame (perimeter)	9	38	180	149	376
Moment steel frame (distributed)	6	38	137	110	291
Ductile RC frame (distributed)	0	15	28	77	120
Nonductile RC frame (distributed)	0	136	282	919	1,337
Precast concrete (non-tilt-up)	0	0	0	2	2
Precast concrete (tilt-up)	0	0	2	2	4
Total number of structures	4,605	9,822	3,504	79,915	97,846

(or full-coverage) book of business that each of the four companies can write in the city. As we will note below, however, companies may cover only a fraction of their “full-coverage” book of business, depending on the amount of coverage they wish to offer in the city. Let $P(x)$ = the probability that a structure will be assigned to company x . To construct the initial or full-coverage books of business, each structure of the model city was randomly assigned to a specific book of business according to the following rules: (a) If the structure is classified as *commercial*, it is assigned as follows: $P(LG) = .50$, $P(M) = .10$, $P(S) = .02$, and $P(O) = .38$. (b) If the structure is classified as *industrial*, it is assigned as follows: $P(LG) = .20$, $P(M) = .10$, $P(S) = .00$, and $P(O) = .70$. (c) If the structure is classified as *residential*, it is assigned as follows: $P(LG) = .00$, $P(M) = .10$, $P(S) = .05$, and $P(O) = .85$. Tables 4.2 and 4.3 provide information on the specification of the model city and of the insurance companies’ initial books of business (by ATC [Applied Technology Council] class and occupancy type).

Levels of Mitigation. Alternative types and levels of mitigation are assumed as part of the model scenario. The level of mitigation can vary from 0 to 100 percent of applicable structures for each type of mitigation. We will be examining three levels in our analysis: 0, 50, and 100 percent. Full (100 percent) mitigation assumes that every structure in the model city is rehabilitated to the level of the current code, with lower levels of mitigation (e.g., 50 percent) having costs proportional to the full mitigation costs (e.g., 50 percent of these full costs). For older structures, rehabilitation can be quite expensive. For those

Table 4.3 Composition of Books of Business by Occupancy Type

	Small	Medium	Large	Other	Model City
Permanent dwelling: family housing	3,149	6,383	376	54,259	64,167
Retail trade	33	78	187	539	837
Professional, technical, and business services	5	20	80	76	181
Entertainment and recreation	1	6	34	43	84
Unspecified	1,417	3,335	2,827	24,998	32,577
Total number of structures	4,605	9,822	3,504	79,915	97,846

already at current code, no further expense is required. Mitigation costs are based on those of a sample of rehabilitated structures (of the various types outlined in tables 4.2 and 4.3) in Los Angeles, which are then revised to take account of construction methods, materials, labor, and building-permit fees in other locales.¹¹

Availability and Type of Reinsurance. We assume that excess-loss reinsurance is available that requires the primary insurer to retain a specified level of risk and covers all losses between the attachment points of the reinsurance policy. Thus, reinsurance policies are of the following form: the reinsurer pays all losses in the interval L_0 to L_1 , where $L_1 - L_0$ is restricted to be no greater than some maximum reinsurance coverage.¹² As explained in more detail in appendix A, we assume that each insurance company is required to retain a certain percentage of its risk, where the retention level is defined as a percentage of worst-case losses.

Insurance and Reinsurance Premium Levels. We assume that full earthquake coverage is available, with a prespecified deductible, at a rate proportional to the expected loss of the property covered. The same premium structure is assumed for reinsurance rates, that is, proportional to the expected loss associated with the reinsurance contract in question. The proportionality or loading factors for primary coverage and for reinsurance may be different, of course.

4.4.3 The RWP Model and EP Functions

In appendix B, we describe the structure of the RWP software that was used to obtain probabilistic damage estimates from earthquakes of different magni-

11. These figures were provided to us by Risk Management Solutions. We will use the midpoint (or average) of the sample estimates of mitigation costs in our analysis. Low estimates (corresponding to the .1666 fractile of the sample distribution) of mitigation costs run about 25 percent of the midpoint values, and high estimates (corresponding to the .8333 fractile of the sample distribution) of mitigation costs run about double the midpoint values.

12. For additional details on the structure of reinsurance policies, see app. A.

Table 4.4 Base-Case Parameters

Parameter	Base-Case Value (\$ million)
Company S assets	100
Company M assets	200
Company LG assets	400
Deductible (%)	10
Worst-case probability	.01
Target ruin probability	.01
Insurance loading factor (%)	100
Reinsurance loading factor (%)	150
Maximum reinsurance available for company S	50
Maximum reinsurance available for company M	100
Maximum reinsurance available for company LG	200
Required burden (<i>b</i>) (%)	10

tudes and intensity for structures in the model city. Essentially, the probability distribution of losses (and the associated EP function) for any given book of business is determined by simulating the effects of the set of earthquake events that could effect the model city over a specified interval of time, a single year for our analysis. Such events are differentiated by location, magnitude, and type of earthquake. The losses from the assumed set of earthquake events can then be stochastically summed to obtain a histogram and cumulative distribution of losses arising from these events, together with the associated EP function. These loss distributions can be derived for any specific set of properties and, in particular, for the books of business of the prototypical insurance companies of interest to us in the model city. Note that a separate model run is required whenever the characteristics (e.g., mitigation levels or building type) of the properties underlying the EP function are changed.

4.4.4 Evaluation

The evaluation phase considers the total expected and worst-case losses for each stakeholder group, where worst-case losses are computed for an EP value of .01, with the result that *worst case* here means that the probability of exceeding these losses is .01. Of course, insurers and reinsurers may use “target ruin probabilities” that are considerably smaller than .01 in computing needed reserves and coverage limits. For insured propertyowners, losses include expenses prior to a disaster (premiums and mitigation costs) as well as repair costs that they must incur personally (i.e., deductibles on their insurance policy). The losses of uninsured propertyowners consist of mitigation costs plus repair costs. For society as a whole, total losses include the cost of mitigation plus total property losses from the disaster as well as any transactions costs resulting from insolvencies and their consequences.

The base-case parameters for the analyses that follow are given in table 4.4. Note that we have varied the asset levels of the small, medium, and large com-

Table 4.5 The Effect of Mitigation Level on Expected and Worst-Case Losses (\$millions)

	Mitigation Level		
	0%	50%	100%
Small-pool losses:			
Expected losses	25.9	22.4	18.9
Total worst-case loss	369.9	323.5	277.1
Insurer's worst-case loss	264.2	225.0	187.0
Mitigation costs	.0	6.9	13.8
Medium-pool losses:			
Expected losses	67.0	58.0	49.0
Total worst-case loss	912.3	800.4	688.4
Insurer's worst-case loss	654.8	559.9	467.2
Mitigation costs	.0	16.3	32.5
Large-pool losses:			
Expected losses	133.6	115.4	97.2
Total worst-case loss	1,549.9	1,362.2	1,174.6
Insurer's worst-case loss	1,139.7	977.0	816.2
Mitigation costs	.0	30.2	60.5
Other-pool losses:			
Expected losses	280.4	242.6	204.9
Total worst-case loss	4,576.8	3,996.9	3,416.9
Insurer's worst-case loss	3,195.1	2,714.9	2,246.3
Mitigation costs	.0	81.6	163.3
Model city losses:			
Expected losses	506.9	438.4	369.9
Total worst-case loss	7,408.9	6,438.0	5,557.1
Insurer's worst-case loss	5,253.8	4,476.8	3,716.7
Mitigation costs	.0	135.0	270.1

panies. Premiums are determined by calculating the expected annual losses from earthquakes and adding a loading factor of 100 percent. If reinsurance is available to companies, the maximum amount varies depending on the size of the insurer. The lower attachment point is determined for each company by requiring that the company be able to take on 10 percent of the losses from a worst-case event for the company's insured book of business.

To begin, let us consider the effect of the level of mitigation on total losses. These results are shown in table 4.5 for the full book of business for each of our four insurance companies and for levels of mitigation of 0, 50, and 100 percent; where 100 percent means that all model city properties have been rehabilitated to current code for each structural type. To make mitigation costs comparable with insurance costs and losses (all of which are annual), we annuitize total mitigation costs, using an interest rate of 10 percent.¹³ Note in partic-

13. Thus, for the small company pool, which consists of 4,605 structures of various types, the (typical or midpoint) total mitigation cost to bring these all to current code was \$137.5 million. With a discount rate of 10 percent, this leads to an annuity of \$13.8 million, as shown in table

ular that we do not check each structure to determine whether particular mitigation measures are cost effective. Rather, the analysis assumes that structures in a particular class adopt mitigation measures appropriate to that class on a random basis, with the percentage of adoption (0–100 percent) being specified in the scenario. A structure-by-structure cost-effectiveness approach would, of course, yield significantly lower total costs than our one-size-fits-all approach.

In table 4.5, we have tabulated the expected and worst-case losses for the four respective insurance pools (the first two entries under each heading) and for the entire model city. We have also listed the insurer's worst-case loss. This is different from the total worst-case loss since we assume as our base case (see table 4.4) that there is a 10 percent deductible on each policy. The consequence of this is that total worst-case losses will contain both the insurer's worst-case loss as well as the first risk layer, deductible losses, assumed by the propertyowners. Thus, the difference between the second and the third entries under each heading (total worst-case loss minus insurer's worst-case loss) represents worst-case deductible losses for the respective full insurer pool (actual worst-case deductible losses will be less if the insurer does not offer coverage to the whole pool).

We see from table 4.5 that, as the level of mitigation increases, both expected and worst-case losses decrease. Note that the expected losses and the worst-case losses tabulated here are simply the total losses in the indicated insurance pool (small, medium, large, or other) and do not include mitigation costs, which are tabulated separately in table 4.5.

Neglecting the costs of insolvencies, we see that, for this scenario, total social cost (the sum of gross costs plus mitigation costs) increases in expected-value terms as mitigation increases but decreases significantly in terms of worst-case losses. This suggests that purely random prioritization of mitigation or total rehabilitation will not be effective in expected-value terms. However, even random prioritization may have significant benefits in avoiding insolvencies and in reducing worst-case losses. Put differently, assuming the usual convex shape of mitigation cost effectiveness, these initial results suggest that the social optimum will require less than 100 percent mitigation and some prioritization of mitigation targets to assure cost effectiveness. Other aspects of reducing the tail losses through mitigation will be discussed below.

Let us now examine in a bit more detail the consequences of mitigation for companies LG, M, and S, with and without reinsurance available. The results for these cases are given in tables 4.6–4.8. Each of these tables analyzes one of the companies LG, M, and S under three mitigation levels assumed (0, 50, and 100 percent) and under two reinsurance scenarios (no reinsurance and reinsurance levels as specified in table 4.4 above). (Note that the prefix *E* means

4.5. This annuitization will be a good approximation to annual costs if the structure and the mitigation undertaken enjoy a long life into the future. Shorter lives of the property or the mitigation or higher discount rates would imply higher effective annual mitigation costs.

Table 4.6 Small Company Case (\$millions)

	Mitigation Level					
	0%		50%		100%	
	No Reins	Reins	No Reins	Reins	No Reins	Reins
Insurance outcomes:						
% insured	40.4	59.8	47.3	70.0	56.7	84.1
Insurance premiums	6.8	10.0	6.4	9.5	5.9	8.8
E-cost of claims	3.4	3.8	3.2	3.6	3.0	3.5
Worst-case loss for S	106.8	158.0	106.4	157.5	106.0	157.3
Limits (L_0 and L_1) of reinsurance policy	N.A.	15.8	N.A.	15.8	N.A.	15.7
Reinsurance premiums	N.A.	2.1	N.A.	1.8	N.A.	1.5
Expected outcomes:						
Cost of mitigation	.0	.0	6.9	6.9	13.8	13.8
E-deductible loss for insured propertyowners	7.1	10.5	7.4	10.9	7.7	11.5
E-cost to insured propertyowners	13.9	20.5	17.1	25.2	21.4	31.9
E-cost to uninsured propertyowners	15.4	10.4	15.4	8.8	14.2	5.2
E-cost to all propertyowners	29.3	30.9	32.5	34.0	35.6	37.1
Worst-case outcomes:						
WC-deductible loss for insured propertyowners	42.7	63.2	46.6	69.0	51.1	75.8
WC-cost to insured propertyowners	49.5	73.2	56.3	83.3	64.8	96.2
WC-cost to uninsured propertyowners	220.4	146.8	174.1	99.1	126.0	46.3
WC-cost to all propertyowners	269.9	222.0	230.4	182.5	190.8	142.5

Note: N.A. = not applicable.

“expected”—e.g., E-cost of claims is the expected cost of claims for those who are insured—and that the prefix WC-means “worst case.”) As the results are similar for each company, we focus in table 4.7 on company M results (see tables 4.2 and 4.3 above for the book of business that M covers). In table 4.9, we also provide “per capita figures” corresponding to company M. These were obtained by noting from table 4.2 that there are a total of 9,822 properties insured in M’s total pool. Since at each level of coverage we are assuming that a random portfolio of these properties is chosen, we can provide per capita results simply by dividing the respective quantities (e.g., expected losses) by the fraction of the 9,822 properties involved in generating the quantity in question (e.g., dividing by the number of properties represented in the aggregate expected-loss figure). For example, consider the E-cost of claims with no reinsurance and 50 percent mitigation. The total expected losses for this are shown

Table 4.7 Medium Company Case (\$millions)

	Mitigation Level					
	0%		50%		100%	
	No Reins	Reins	No Reins	Reins	No Reins	Reins
Insured outcomes:						
% insured	32.7	47.6	38.1	55.6	45.5	66.4
Insurance premiums	14.1	20.6	13.3	19.4	12.4	18.1
E-cost of claims	7.1	5.0	6.7	4.7	6.2	4.3
Worst-case loss for M	214.1	311.7	213.3	311.3	212.6	310.2
Limits (L_0 and L_1) of reinsurance policy	N.A.	31.2	N.A.	31.1	N.A.	31.0
Reinsurance premiums	N.A.	8.9	N.A.	8.3	N.A.	7.8
Expected outcomes:						
Cost of mitigation	.0	.0	16.3	16.3	32.5	32.5
E-deductible loss for insured propertyowners	14.8	21.6	15.4	22.5	16.1	23.5
E-cost to insured propertyowners	28.9	42.2	34.9	51.0	43.3	63.2
E-cost to uninsured propertyowners	45.1	35.1	46.0	33.0	44.4	27.4
E-cost to all propertyowners	74.0	77.3	80.9	84.0	87.7	90.6
Worst-case outcomes:						
WC-deductible loss for insured propertyowners	84.2	122.6	91.6	133.6	100.6	146.9
WC-cost to insured propertyowners	98.4	143.2	111.1	162.1	127.8	186.6
WC-cost to uninsured propertyowners	613.9	478.0	505.5	362.6	392.9	242.2
WC-cost to all propertyowners	712.3	621.2	616.6	524.7	520.7	428.8

Note: N.A. = not applicable.

as \$6.7 million in table 4.7 (row 3). The percentage of full coverage offered under the no-reinsurance, 50 percent mitigation scenario is (see row 1 of table 4.7) 38.1 percent, or 3,742 of the 9,822 properties at risk. Hence, the per capita figure for E-cost of claims is \$6.7 million/3,742 = \$1,790, as shown in table 4.9 (row 3).

Now consider the results under each heading in tables 4.7 and 4.9.

Percentage Insured. As the level of mitigation increases, the EP function shifts downward. Thus, company M, which is assumed to operate under a PML rule, is able to expand its coverage while still keeping within its target ruin probability. Similarly, with increased availability of reinsurance, company M can expand its coverage (even though M is paying a reinsurance premium of 150 percent times the expected value of the losses covered by the reinsurance).

Table 4.8 Large Company Case (\$millions)

	Mitigation Level					
	0%		50%		100%	
	No Reins	Reins	No Reins	Reins	No Reins	Reins
Insurance outcomes:						
% insured	38.1	56.3	44.3	65.5	52.6	78.1
Insurance premiums	34.5	51.0	32.1	47.5	29.4	43.7
E-cost of claims	17.3	19.8	16.0	19.0	14.7	18.1
Worst-case loss for LG	434.2	641.7	432.8	639.9	429.3	637.5
Limits (L_0 and L_r) of reinsurance policy	N.A.	64.2	N.A.	64.0	N.A.	63.7
Reinsurance premiums	N.A.	9.4	N.A.	7.9	N.A.	6.2
Expected outcomes:						
Cost of mitigation	.0	.0	30.2	30.2	60.5	60.5
E-deductible loss for insured propertyowners	33.7	49.7	35.0	51.8	36.4	54.1
E-cost to insured propertyowners	68.2	100.7	80.5	119.1	97.6	145.1
E-cost to uninsured propertyowners	82.7	58.4	81.1	50.2	74.7	34.5
E-cost to all propertyowners	150.9	159.1	161.6	169.3	172.4	179.6
Worst-case outcomes:						
WC-deductible loss for insured propertyowners	156.4	230.9	170.4	252.2	188.5	279.9
WC-cost to insured propertyowners	191.0	281.9	215.9	319.5	249.7	370.9
WC-cost to uninsured propertyowners	958.9	677.4	774.2	480.4	585.4	270.5
WC-cost to all propertyowners	1,149.9	959.3	990.1	799.9	835.2	641.3

Note: N.A. = not applicable.

Insurance Premiums and Expected Cost of Claims. As the level of mitigation increases, both premium income and the expected cost of claims decline. These reductions occur in spite of the fact that M is offering greater coverage in the model city. Clearly, the lower losses due to mitigation more than compensate for the risks of increased coverage.

Worst-Case Loss for M. This is the worst-case loss for insurer M for its full book of business times the percentage of that book (see row 1 of table 4.7) that M insures. Per capita figures simply divide this loss by the number of insured properties. Let us illustrate the links between various quantities in tables 4.5 and 4.7. We do this for the case of 0 percent mitigation and no reinsurance, where the worst-case loss for the entire medium pool (see table 4.5) is 912.3. And this sum contains deductible losses of 257.5, leaving M with a worst-case

Table 4.9 Medium Company Case Per Capita Outcomes (\$)

	0%		50%		100%	
	No Reins	Reins	No Reins	Reins	No Reins	Reins
Number of insured properties	3,212	4,675	3,742	5,461	4,469	6,522
Insurance outcomes:						
Insurance premiums (\$/structure)	4,390	4,406	3,554	3,552	2,775	2,775
E-cost of claims	2,211	1,069	1,790	861	1,387	1,549
Worst-case loss for M	66,661	66,670	56,999	57,004	47,572	47,563
Reinsurance premiums	N.A.	1,904	N.A.	1,520	N.A.	1,196
Expected outcomes for property-owners:						
Cost of mitigation per structure	0	0	1,660	1,660	3,309	3,309
E-deductible loss for insured propertyowners	4,608	4,620	4,115	4,120	3,603	3,603
E-cost to insured propertyowners	8,998	9,026	9,326	9,339	9,689	9,691
E-cost to uninsured propertyowners	6,820	6,820	7,567	7,567	8,300	8,300
E-cost to all propertyowners	7,534	7,870	8,237	8,552	8,929	9,224
Worst-case outcomes for property-owners:						
WC-deductible loss for insured propertyowners	26,216	26,223	24,478	24,464	22,511	22,524
WC-cost to insured propertyowners	30,637	30,629	29,689	29,683	28,597	28,612
WC-cost to uninsured propertyowners	92,875	92,875	85,147	85,147	77,394	77,394
WC-cost to all propertyowners	72,521	63,246	62,777	53,421	53,014	43,657

Note: N.A. = not applicable.

insured loss of $912.3 - 257.5 = 654.8$ (again shown in table 4.5) under the assumption that M insures the entire medium pool. But, as we see from row 1 of table 4.7, M insures only 32.7 percent of this full book of business, leading to a worst-case loss for M's actual book of business of $.327 \times 654.8 = 214.1$ and a worst-case deductible loss of $.327 \times 257.5 = 84.2$, as shown in table 4.7.

Reinsurance Premiums and Limits. Reinsurance premiums also decline as the level of mitigation increases, owing to the downward shifting of the EP function. Note that we have assumed that maximum reinsurance coverage is not reduced as mitigation is increased (and expected losses are reduced). Note that the reinsurance limit of \$100 million is always attained, a result of the fact that M is insuring less than its full book of business (and would prefer to insure more, save the PML constraint).

Cost of Mitigation. The cost of mitigation naturally increases as the level of mitigation increases. Note that the cost figure given here is the total cost for the entire initial book of M's business, only a fraction of which (see the first row of table 4.7) is actually insured.

Deductible Losses (either Expected or Worst Case) for Insureds of M. As the level of mitigation increases and the level of insurance coverage offered increases, so will deductible losses (the first risk layer) arising from this expanded coverage (see table 4.7). Reinsurance will further increase coverage and therefore increase deductible losses for insureds.

Cost to Insured Propertyowners (either Expected or Worst Case). Neglecting any costs of insolvency, the cost to insured propertyowners is their deductible loss plus their premium plus mitigation costs. These expected costs increase, and the worst case costs decline, as the level of mitigation increases. This is the result of the random prioritization of mitigation; that is, mitigation has not been applied here in a cost-effective manner for the structures in this book of business. Availability of reinsurance expands coverage dramatically and causes total expected costs to all insured propertyowners to increase. The reader may note from table 4.9 that on a per capita basis total expected costs increase with the availability of reinsurance.

Costs to Uninsured Propertyowners (either Expected or Worst Case). The cost to uninsured propertyowners is just the sum of their mitigation cost plus their losses. For example, in the case with 50 percent mitigation and no reinsurance, we see from table 4.5 that the E-cost of medium-pool losses is 58.0 and that mitigation costs are 16.3. We can determine from row 1 of table 4.7 that the percentage of uninsured propertyowners in M's pool is $100 - 38.1$ percent = 61.9 percent. Thus, the E-cost to uninsured propertyowners is $.619 \times 16.3 + .619 \times 58.0 = 46.0$, as shown in table 4.7.

Costs to All Property Owners (either Expected or Worst Case). This is just the sum of all costs to insured and uninsured propertyowners in company M's pool. For this pool, expected costs are minimized at no mitigation and no reinsurance, while the opposite is true of worst-case costs. The key here is that expected costs increase as insurance coverage increases since there is a significant loading factor on expected losses to obtain premiums charged. The optimal mitigation and reinsurance level for social welfare will, of course, depend on the degree of risk aversion of propertyowners.

While we have discussed only company M in detail, the results for the other companies and for the total losses and the overall portfolio of insurance offered in the model city are quite similar. The analysis presented above considers only

the effects of mitigation and the availability of reinsurance. It is straightforward to consider other effects as well, by explaining the effect of decision parameters or scenarios variables on outcomes, for example, the effect of changing any of the base-case assumptions and parameter values given in table 4.4. As it turns out, many of these results are quite intuitive. For example, if target ruin probabilities are reduced, indicating more conservative behavior of insurance companies, insurance coverage will be reduced in the model city. Again, if reinsurance rates are increased, or if the terms of reinsurance are made otherwise less favorable (e.g., a larger retention rate is required), then direct insurance coverage will be reduced. Finally, if additional reinsurance is made available, for example, because of new government guarantee programs, then additional insurance coverage will be offered.

A key driver for the specific results obtained above is the set of earthquake events that underlie the probabilistic structure of annual losses through the resulting exceedance probability function. More generally, our assumptions on pricing, on mitigation adoption, and on other aspects of the decision processes of the economic agents involved are central factors in determining the outcomes of our analysis. Many of these are the focus of ongoing studies based on the model city framework developed here.

The results of this prototypical analysis highlight the basic points made earlier in this paper. It is critical to understand the nestedness that exists between various policy instruments and scenario variables and the decision processes of the economic agents involved. If, for example, cost-effective mitigation is available, it has a double effect. First, it will be attractive for propertyowners to adopt. Second, because of its effect on both expected losses and the tail of the exceedance probability function, it will lead to increased availability and affordability of insurance and reinsurance. This will yield significant efficiency gains in both an expected (*ex ante*) sense as well as in the worst case (*ex post*). The complexity of this nestedness supports reliance on decentralized decision making and market forces where possible. It should also be clear, however, that science-based and credible risk-assessment procedures are critical to the outcome of this process. Otherwise, one or more of the economic actors involved could be significantly biasing decisions that have nested consequences. The ultimate outcome could undermine the market or the viability of the agents involved.

4.5 A Proposed Program for Dealing with Catastrophic Risks

In this concluding section, we describe a strategy for managing catastrophic risks that builds on the analysis in the previous section and suggests the types of analyses that can be undertaken using the conceptual framework outlined above. One must involve other stakeholders and policy instruments to complement the use of insurance in reducing losses while providing protection once a disaster occurs. The program consists of the following four elements: im-

proving risk estimates, evaluating alternative mitigation measures, encouraging the adoption of mitigation measures, and broadening protection against catastrophic losses.

4.5.1 Improving Risk Estimates

There are two principal reasons why insurers will benefit from improved estimates of the risks associated with catastrophes. By obtaining better data on the probabilities and consequences of these events, insurers will be able to set their premiums more accurately and tailor their portfolio to reduce the chances of insolvency. Providing more accurate information on the risks also reduces the asymmetry of information between insurers and other providers of capital, such as reinsurers and the financial investment community. Investors are more likely to supply capital if they are more confident in the estimates of the risks provided to them by the insurers.

Today, there are a growing number of catastrophe models that have been utilized to generate data on the likelihood of and expected damage to different communities or regions from disasters of different magnitudes or intensities. Each model uses different assumptions, different methodologies, different data, and different parameters in generating its results. These conflicting results make it difficult for investors to feel comfortable investing their money in financial instruments associated with catastrophic risk. In order to better understand why these models differ, we must attempt to reconcile these differences in a more scientific manner than has been done until now. For example, bringing the leading modelers together with financial institutions to discuss how their data are generated may reduce the mystery that currently surrounds these efforts.

Another way to make the investment community more comfortable is to be as conservative as possible in estimating future losses when developing an exceedance probability (EP) curve. This will make it highly likely that the actual damage will be less than the predicted amounts. By simulating a number of different loss scenarios using an EP curve, one can determine the prices that would have to be charged to the insurer or reinsurer purchasing specific financial instruments in order to yield an attractive rate of return to investors. This type of analysis should enable one to contrast the relative benefits and costs of act-of-God bonds with traditional reinsurance and other ways of financing catastrophic losses, such as purchasing options on the Chicago Board of Trade, purchasing federal reinsurance, or negotiating finite risk arrangements.

4.5.2 Evaluating Alternative Mitigation Measures

Mitigation is a desirable way to manage catastrophic risks because it alleviates the problem at the source. If experts were able to design a completely hurricane-proof structure, there would be no need for insurance against this risk. This is a desirable objective, but one highly unlikely to be achieved in practice.

The first step is to determine which mitigation measures are likely to be cost effective. This is not easy to do in practice, as illustrated by the case of shutters. Storm shutters can be an effective measure to protect a building during a hurricane; however, someone must close and secure them prior to the hurricane. Furthermore, they must meet current wind-resistance standards and be properly installed. Finally, by themselves, shutters may reduce losses slightly, but, if combined with complete wall protection, an aerodynamic roof structure, and good roof-to-wall and wall-to-foundation connections, the benefits could be substantial.¹⁴

The second step is to examine the effect of specific mitigation measures on the reduction in losses through simulations similar to the ones described above. One can then undertake sensitivity analyses by examining the effect of a specific mitigation measure on different EP curves and other design features of the property. Such analyses will then translate into estimated reductions in expected losses. This should enable insurers to pass on the savings to the property-owner in the form of reduced premiums, lower deductibles, and/or higher limits of coverage.

4.5.3 Encouraging the Adoption of Mitigation Measures

It is often necessary to undertake audits and inspections in order to avoid problems of moral hazard and adverse selection. With respect to properties at risk, one way to encourage the adoption of cost-effective loss-reduction measures is to have them incorporated in building codes and provide a seal of approval to each structure that meets or exceeds these standards. To institutionalize such a procedure, financial institutions could require an inspection and certification of the facility against natural hazards as a condition for issuing a mortgage. This process would be 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 and a cadre of well-qualified inspectors to provide accurate information as to whether existing codes and standards are being met. To reduce their losses from disasters, insurers may want to limit coverage only to those structures that are given a seal of approval. If budget constraints prevent propertyowners from investing in these mitigation measures, then the bank can provide funds through a home-improvement loan with a payback period identical to the life of the mortgage.

4.5.4 Broadening Protection against Catastrophic Losses

New sources of capital from the private and public sectors have the possibility of providing insurers with guaranteed funds against losses from catastrophic events so as to alleviate their concerns that they may be insolvent from

14. We are indebted to George Segelken of CIGNA for providing us with this example.

the next major disaster. Some instruments provide funds to the insurer should they suffer a catastrophic loss. J. P. Morgan and Nationwide Insurance successfully negotiated such a transaction, Nationwide borrowing \$400 million from J. P. Morgan. This money was placed in a trust fund composed of U.S. Treasury securities. Nationwide pays a higher than normal interest rate on these funds in return for having the ability to issue up to \$400 million in surplus notes to help pay for the losses should a catastrophe occurs (Kunreuther 1998). As pointed out above, such instruments as the USAA act-of-God bonds have recently been floated, and other catastrophic bonds are now being initiated (Doherty 1997).

The multiyear catastrophic bonds that 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 in 1992 enable an insurer to hedge against underwriting risk by attracting capital from insurance and noninsurance segments of the economy (Cummins and Geman 1995; Harrington, Mann, and Niehaus 1995).¹⁵ The Catastrophic Risk Exchange (CATEX) creates a marketplace where insurers, brokers, and the self-insured can swap units of their catastrophe risks by region and peril. For example, an insurer could swap units of California earthquake for Florida windstorm (Insurance Services Office 1996).

The evaluation of these instruments through the simulations described above may provide an understanding of the opportunities of using a combination of insurance, reinsurance, financial instruments, and government-related programs to encourage cost-effective mitigation and infuse new capital into the system. Insurers could supplement traditional reinsurance with these guaranteed sources of funding when their losses exceed a certain level. This would relax (implicit or explicit) solvency constraints and stimulate additional coverage in high-risk areas.

Finally, we note that simulation modeling of the sort proposed here 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 insurance and reinsurance companies, public officials, and propertyowners in determining levels of mitigation, insurance coverage, and other protective activities. Achieving an integrated understanding of the aggregate effect of these decision processes and the underlying hazards has been our central focus. We have argued that better risk-assessment tools, including the advances in the micromodeling of hazards and

15. To date, the Chicago Board of Trade has not had much success in selling these futures contracts. Recently, it introduced a new option based on the value of an index compiled by Property Claim Services. For more details on these options, see Culp (1996, 31–42).

mitigation measures described in the present paper, hold considerable potential for increasing our understanding of these issues and promoting the design of better programs for catastrophic risk management.

Appendix A

Decision Rules for Insurance and Reinsurance

This appendix describes the rules used for making insurance and reinsurance decisions in the simulation studies undertaken for the model city. We focus first on the insurance companies in the model city and describe how these companies are assumed to decide on the size of their book of business (the extent of the coverage they offer in the model city) and the amount of reinsurance they purchase. Premium levels are assumed to be set on the basis of a fixed loading on expected losses. We consider two basic approaches: a safety-first approach based on a specified probable maximum loss (or PML) rule and a related expected-utility-maximization rule.

Assumptions concerning the Book of Business for Insurers

We assume that each insurer begins with a base-case book of business, which is a set of properties that it might consider insuring in the model city. For the small, medium, large, and other insurer, this base-case book of business serves as the reservoir of risks that the insurer may take on. If the insurer can take on its full book of business, it is assumed to do so (i.e., it is assumed that the loading factors associated with premiums provide a fair return on reserves invested to cover the associated risks). If, however, the insurer chooses not to offer this full coverage in the model city (e.g., because it cannot meet its target ruin probability or PML at the full book of business), then we assume that the insurer reduces its coverage until its desired coverage limit is reached.

To compute various quantities of interest, we need the distribution of the random variable of losses for an insurance company as its book of business changes. For analytic convenience, we assume that coverage reduction is accomplished in a random order in each category of property insured: if the insurer is insuring a book of business of “size” $\alpha \in [0, 1]$ and its original or full book of business faced a loss distribution of L , then the random variable of losses $L(\alpha)$ when its book of business is of size $\alpha \in [0, 1]$ is just $L(\alpha) = \alpha L$. Thus, denoting the cumulative probability distribution function (cdf) of $L(\alpha)$ by $F(x; \alpha) = \Pr\{L(\alpha) \leq x\}$, we see that $\Pr\{L(\alpha) \leq x\} = \Pr\{\alpha L \leq x\} = \Pr\{L \leq x/\alpha\}$, with the result that $F(x; \alpha) = F[x/\alpha]$, where F is the cdf of the original full book of business for the insurer. Naturally, F will depend on a number of factors, including mitigation, amount of deductibles, and other policy provisions. The key point is that, once F has been derived for the original

full book of business for an insurer, the cdf for any other size book of business is analytically available.

PML Rule without Reinsurance

Define the exceedance probability (or EP) curve for losses for a particular insurer with book of business of size $\alpha \in [0, 1]$ as $EP(x; \alpha) = \Pr\{L(\alpha) > x\} = 1 - F(x; \alpha) = 1 - F[x/\alpha]$. Thus, interpreting the PML rule as taking on the maximum-size book of business that does not produce an exceedance probability in excess of a given “target ruin probability,” we determine the size of the book of business offered by a PML insurer when no reinsurance is available as the solution α^* to

$$1 - F\left[\frac{A + \alpha\rho_0}{\alpha}\right] = p^*,$$

where A = initial reserves; ρ_0 = premium income from the full book of business for the insurer in question, or $(1 + l_i) \times$ expected losses of the full book of business (so $\alpha\rho_0$ is the premium income for the book of business of size α); l_i = insurance-policy loading factor; and p^* = target ruin probability.

PML Rule with Reinsurance

A number of assumptions will be made in this case: (a) Reinsurers will offer a limited amount of coverage $\Delta = L_1 - L_0$, where L_0 is the lower attachment point and L_1 is the upper attachment point of the reinsurance contract. (b) The reinsurer makes the added stipulation that the insurance company retains some fraction b of the worst-case-scenario event. In other words, the lower attachment point $L_0(\alpha) = bL^{WC}(\alpha)$, where $L^{WC}(\alpha)$ is the loss associated with the worst-case event, and $b \in [0, 1]$ is the required retention level. We take the worst-case event to be the loss associated with $EP(x; \alpha) = p^{WC}$ (e.g., $EP[x; \alpha] = .00001$). Thus, $L^{WC}(\alpha)$ is the loss that solves $1 - F[L^{WC}(\alpha); \alpha] = p^{WC}$.

In choosing the amount of reinsurance and the size of the book of business it wishes to purchase (at a fixed loading above expected losses in the reinsurance layer), the insurer will make one of the following choices: (a) If the cap on Δ is not binding, $EP[(L_0 + \Delta)/\alpha; \alpha] = 1 - F[(L_0 + \Delta)/\alpha] < p^*$, then the insurer is assumed to purchase a reinsurance contract with attachment points L_0 and L_1^* , where L_1^* solves $1 - F(L_1^*) = p^*$; that is, the insurer will then take on the entire portfolio, $\alpha = 1$. (b) If the cap on Δ is binding, then the insurer will adjust α until its PML is satisfied. This amounts to finding α^* solving

$$1 - F\left[\frac{A + \alpha\rho_0 - R_{\text{Premium}} + R_{\text{Payoff}}}{\alpha}\right] = p^*,$$

where A = initial reserves; ρ_0 = premiums = $(1 + l_i) \times$ expected losses; R_{Premium} = reinsurance premium = $(1 + l_R) \int_{L_0}^{L_1} [1 - F(L/\alpha)] dL$, where $L_0 = L_0(\alpha) = bL^{WC}(\alpha)$ and $L_1 = L_1(\alpha) = L_0(\alpha) + \Delta$; R_{Payoff} = reinsurance payoff; and p^* = target ruin probability. This may be rewritten as

$$1 - F \left[\frac{A + \alpha p_0 - (1 + l_R) \int_{L_0(\alpha)}^{L_1(\alpha)} \left[1 - F \left(\frac{L}{\alpha} \right) \right] dL + \Delta}{\alpha} \right] = p^*.$$

Note that the integral determining the reinsurance premium determines expected losses between the two attachment points $L_0(\alpha)$ and $L_1(\alpha)$. Once the cdf of losses $F(x)$ is known for the full book of business, it is straightforward to solve the above for the optimal size α for the PML insurer. Note that $L_0(\alpha) = \alpha L_0$, and define L^* by $1 - F(L^*) = p^*$. Then, changing the variable of integration above to $x = L/\alpha$, we can rewrite this expression in the form:

$$A + \alpha p_0 - \alpha(1 + l_R) \int_{L_0}^{\frac{L_1(\alpha)}{\alpha}} [1 - F(x)] dx + \Delta = \alpha L^*.$$

In particular, if $L_1(\alpha) = L_0(\alpha) + \Delta = \alpha L_0 + \Delta$ so that all available reinsurance is purchased, then the upper limit of integration becomes $L_0 + (\Delta/\alpha)$.

Expected Utility Rules

If, instead of a PML choice rule, an insurance company uses an expected-utility rule, similar results to the above are attained. For example, when reinsurance is not available, an expected-utility maximizer would solve for the optimal book of business by solving the following problem:

$$\text{Maximize} \{E[U(A_0 + \alpha p_0 - \alpha L)] | \alpha \in [0, 1]\},$$

where the expectation is with respect to the underlying random variable of losses L . If we assume a CARA utility function, $U(W) = -e^{-\lambda W}$, then the task becomes solving the first-order condition below for α :

$$\int_0^\infty (p_0 - L) e^{\lambda \alpha L} dF(L) = 0,$$

where $p_0 = (1 + l_I) \int_0^\infty [1 - F(L)] dL$. Intuitively, the expected-utility rule mimics the PML rule in that, as risk aversion increases, the optimal book of business α^* decreases, corresponding to an equivalent PML insurer with lower target ruin probability p^* .

The case where reinsurance is available is modeled similarly. Here, the insurer would solve for the optimal α and the optimal amount of reinsurance to purchase by solving

$$\text{Max}_{\alpha \in [0,1]} EU[A_0 + p_0 \alpha - \tilde{L}_I(\alpha) - P(\alpha)],$$

where $P(\alpha) = (1 + l_R) \int_{L_0/\alpha}^{L_1/\alpha} [1 - F(L)] dL$ is the reinsurance premium, and where $L_I(\alpha)$ is the loss exposure for the insurance company given its reinsurance decision, so that

$$L_1(\alpha) = \alpha L \text{ for } \alpha L < L_0(\alpha),$$

$$L_1(\alpha) = L_0(\alpha) \text{ for } L_0(\alpha) \leq \alpha L \leq L_1(\alpha),$$

$$L_1(\alpha) = L_0(\alpha) + \alpha L - L_1(\alpha) \text{ for } L > L_1(\alpha),$$

$L_0(\alpha)$ is constrained by the retention-level requirement that $L_0(\alpha) = bL^{wc}(\alpha)$, and $L_1(\alpha)$ is constrained by the maximum coverage offered, that is, $L_1(\alpha) \leq L_0(\alpha) + \Delta$. Again here, the expected-utility-maximizing rule gives rise to similar behavior as for a corresponding PML rule: as risk aversion increases, the size of the optimal portfolio decreases, and the amount of reinsurance purchased increases.

Appendix B

The RMS-Wharton (RWP) Software

RWP Earthquake is a refined model originally developed at Stanford University and licensed exclusively to Risk Management Solutions (RMS) in 1988. The model simulates earthquakes and the transfer of energy from a rupture to a site and then calculates the damage to insured properties. The RMS modeling framework from which RWP Earthquake is derived is quite general and has been adapted in RWP to study a particular city, the model city, described in the text. RWP assesses three factors when it analyzes earthquake risks: (1) hazard and exposure data; (2) vulnerability; and (3) financial risk.

Hazard and Exposure Data

To calculate loss, RWP must first determine the modified Mercalli intensity (MMI), or the intensity of shaking at a site due to an earthquake. There are three factors in determining the amount of shaking at a site: (1) the earthquake's source; (2) attenuation of seismic energy; and (3) local soil conditions (see fig. 4B.1). The first three items are enough for "what if" types or deterministic types of analyses that do not consider the element of time. To answer the question "How much am I likely to lose in X years?" the fourth factor, recurrence relationship, is needed to estimate how often earthquakes occur.

Earthquake Sources. The first questions that need to be answered in a loss calculation are, Where is the earthquake? and, How big is the earthquake? RWP provides these answers in the form of a database of seismic sources. Each seismic source contains geographic information about a region or geologic structure with the potential to generate earthquakes. It also stores the maximum credible magnitude for an earthquake on that source as well as recurrence

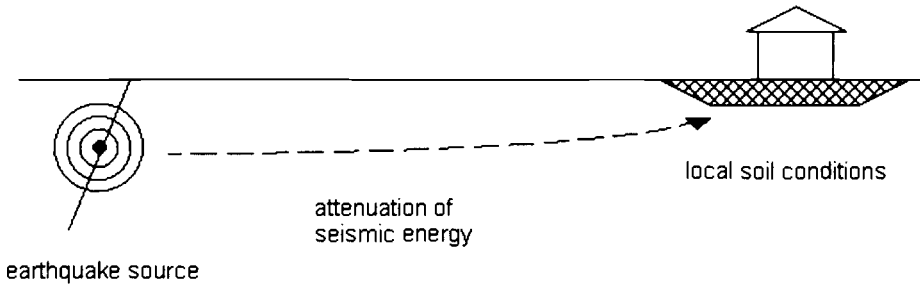


Fig. 4B.1 Determinants of earthquake intensity at a remote site

parameters indicating average occurrence intervals for each event magnitude. This information comes primarily from public data expanded by proprietary sources and research by RMS engineers.

RWP models a seismic source as either a line or an area. Line sources are used when seismicity is associated with a well-defined geologic structure, usually shallow faults with a surface expression. Area sources cover a broader geographic region and treat that area as one unit. These sources assume that earthquakes can occur anywhere within the region with equal probability and are used when seismicity is associated with many faults that individually are too poorly characterized to be modeled by themselves. Area sources are also used when seismicity occurs along a dipping plane (rather than vertically) or when seismicity is not clearly associated with a geologic structure.

Attenuation of Seismic Energy. Once the size of an earthquake and its distance from a location are determined, RWP must calculate how much energy is released at the rupture and, of that energy, how much actually reaches the site. RWP calculates this level of ground shaking using attenuation relations that estimate the drop in energy with distance from an earthquake. These attenuations can differ by the type of earthquake or by region.

An earthquake of a particular magnitude generates ground motion. Peak ground acceleration (PGA) is a measurement of the maximum ground movement at a location. As the distance from an earthquake source increases, the ground movement, or PGA, decreases. RWP calculates the PGA for a location on the basis of the seismic sources and the attenuation of seismic energy.

Local Soil Conditions. The third factor in determining the amount of shaking at a site is the potential amplification of ground motion by soil conditions present at the site. After geocoding a location, RWP retrieves data on the local conditions and potential hazards for that site. The local geology can have a major effect on ground motion. Buildings standing on bedrock will usually sustain less damage than those on water-saturated alluvial deposits or on artificial fill. There are four “soil” classes used in RWP: (1) bedrock; (2) shallow

alluvium; (3) deep alluvium; and (4) bay mud/artificial fill. The names given these classes do not always reflect the true geology at the site but refer to the relative amplification potential of the underlying material.

A simplified analogy helps illustrate how different materials can amplify ground motion. Imagine a plate with a thick chocolate cake on it. Imagine a second, identical plate with a block of Jello of the same size as the cake. Put a box of matches on top of each and then slide the plates back and forth at the same speed. Even though the initial motion is the same, the matchbox on the Jello will shake more violently.

Measures of Ground Shaking. When a fault ruptures, it causes waves of ground motion. One way of measuring the strength of this motion is the PGA, the maximum pulse of ground shaking at a location. Instrumental records from past earthquakes have provided enough data to define PGA-based attenuations for many regions. RWP uses established PGA attenuations wherever possible.

In some regions, however, the limited (or nonexistent) PGA data are not sufficient to define a reliable attenuation. In these cases, ground shaking is given in terms of a subjective scale, the MMI. The MMI is a subjective measure of how severe the damage from an earthquake is on a scale of I–XII. For example, an MMI of II is defined as being felt by few persons at rest, especially on upper floors of tall buildings. An MMI of VI is defined as being felt by all, except drivers of cars, where some heavy furniture moves and there is slight damage to poor-quality masonry, particularly chimneys. Ground shaking in RWP is defined in terms of MMI. RWP converts the level of PGA for a site to MMI and modifies the intensity based on amplification by the local soil conditions. The ultimate outcome of the hazard portion of the earthquake model is the MMI experienced by each location.

Vulnerability Assessment

In the second step of an earthquake analysis, RWP uses information about several factors to assess potential damage resulting from local ground shaking (MMI): the structural characteristics of a location; the type of contents; and the social function of the building. The potential damage is first expressed as the class mean-damage ratio. The class mean-damage ratio is then used to calculate the building mean-damage ratio, the content damage ratio, and the business-interruption-damage ratio. The ultimate outcome of the vulnerability assessment is a determination of the damage distribution or damage curve for a particular building.

Class Mean-Damage Ratio. First, given a particular MMI and a construction class for a specific building, RWP retrieves a class mean-damage ratio. A class damage ratio is the average damage expected for a specific construction class given a particular MMI. A 10 percent class damage ratio means that the cost of repair will be 10 percent of the cost to replace the building completely. The

actual losses to individual buildings may be very different than the class damage ratio. For example, a class damage ratio of 10 percent for a population of one hundred buildings could equate to ten buildings that are total losses and ninety that sustained no damage. Other factors that often help determine the class damage ratio are the number of stories and the occupancy type. The damage ratios are determined by the damage table selected in RWP during an analysis. RWP utilizes the PML table for this purpose.

The PML methodology as expressed in RWP is based on published work performed by Karl Steinbrugge (1982). Dr. Steinbrugge's work has formed the foundation of generally accepted earthquake expected-loss analysis, including the regulatory filings required by the state of California. RMS has used Steinbrugge's intensity versus damage relations as the core of the PML computation performed by RWP. Note that, as defined in RWP, the PML methodology represents a significant improvement over the traditional PML methodology. PML is a more conservative approach; estimated losses will be higher for all construction classes except wood frame.

Building Mean-Damage Ratio. RWP's next step is to modify the class damage ratio according to four additional types of information to calculate the building mean-damage ratio, or the average damage expected for a specific building. The four additional types of information are the following: (1) secondary building characteristics, such as ornamentation, which can increase or decrease the damage; (2) year of construction or upgrade, information that helps determine building-code requirements and can also increase the damage ratio; (3) landslide and liquefaction, which can increase damage ratios if ground shaking is sufficient to trigger them; and (4) distance to fault, since surface rupture may contribute to the mean-damage ratio if a location lies very close to the fault.

Content Damage Ratio. RWP calculates the content damage ratio by multiplying the building damage ratio by the content modifier. For each class of construction, there are four content modifiers, referred to as *rate grades*. The rate grades range from 1 to 4, with 1 being fragile and 4 being least damageable. Depending on the type of construction entered, RWP multiplies a specific number by the building damage ratio to calculate the contents damage ratio.

Financial Risk Assessment

The final step of the earthquake analysis is to estimate financial risk. RWP used the building mean-damage ratio and the total level of uncertainty to create a damage curve for the building. The uncertainty is determined by the quality of the location data: Is the construction class provided? How many secondary building characteristics are known? At what level is hazard data available? and so on. As the quality of the location data improves, the uncertainty decreases,

resulting in a narrower range of loss estimates. High uncertainty, such as not knowing the construction class of a building, results in a broad damage curve with a wide range of potential losses.

Out of four modes that can be used to determine the financial risk, RWP uses the distributed mode. The distributed mode is the most sophisticated mode that combines the damage curve with the financial structure to produce a weighted average for each layer of the financial structure (e.g., deductible, primary insurance, coinsurance layer, and so forth). In essence, it distributes the potential losses to each layer of the financial structure on the basis of the probability that the loss may penetrate a specific layer. The total specified loss when using the distributed mode equals the total specified loss when using the expected mode, but the loss per layer may differ. The greater the difference, the more uncertainty in the estimation of financial risk.

The distributed mode considers the probability of loss for each particular layer. This mode can produce results that are at first glance confusing. For example, consider the distributed-loss calculation of a \$100,000 deductible in the event of an expected loss equal to \$200,000. Using the expected mode, the loss to the insured would be the full value of the \$100,000 deductible. Using the distributed mode, the loss to the insured may be slightly lower than the \$100,000 deductible after the probabilities of loss have been factored in. Factoring in the probabilities of loss allows the model to reflect the chance, even if it is slight, that the loss may be under the \$100,000 deductible. This causes the probabilistic loss to the insured to be slightly lower than the full amount of the deductible.

As another example, consider a policy with a 10 percent deductible. If the expected loss to the policy were 9 percent, no loss to the policy would be calculated in the expected mode or the percentile mode. However, the distributed mode would factor in the probability that the loss would exceed the expected loss of 9 percent and may show a small loss to the policy. The distributed mode of financial loss assessment allows RWP users to understand the statistically predicted losses for various layers of a policy.

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Comment James R. Garven

Kleindorfer and Kunreuther provide a very useful and insightful approach to evaluating the role of insurance and other policy instruments for managing catastrophic risk. Their findings derive from a sophisticated and highly detailed modeling process that stochastically generates earthquake scenarios for a model city, which in turn specifies the probabilistic structure of losses and corresponding implications for insurer solvency and stability. The Kleindorfer and Kunreuther model does a superb job of capturing the interdependencies that exist between various policy instruments, scenario variables, and decision processes of firms and consumers. Consequently, their model provides a useful

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framework that can be readily expanded to consider the potential role of alternative approaches to funding and mitigation.

In what follows, I will offer some suggestions concerning how the present analysis could be usefully modified and perhaps even extended. Specifically, I will offer comments concerning mitigation incentives, insurer objectives, and an interesting “real-world” application of the Kleindorfer and Kunreuther model.

Incentives for Mitigation

The apparent disregard shown historically by banks and insurers when funding and insuring properties located in catastrophe-prone areas is appalling. As the authors point out, this has increased the severity of losses when catastrophes have actually occurred.

It may be that regulatory complicity (in the form of rate suppression and cross-subsidies) causes consumers to not fully consider the risks associated with investing in catastrophe-prone properties. Consequently, insurance prices may falsely convey the nature of the risks that consumers assume in deciding to build in such areas. The fact that the Florida joint underwriting authority acquired so much market share in so short a period of time is clear evidence of severe adverse selection and obviously very bad news from a mitigation perspective.

Insurance-Company Objectives

The paper takes as given the notion, advanced originally more than two decades ago by Stone (1973), that insurers will seek to maximize the expected return on capital, subject to complying with (arbitrarily parameterized) solvency and stability constraints. Such an approach is logically consistent with recent findings that insurers apparently factor in the probable maximum loss associated with a catastrophe when they determine how many policies to write. Kleindorfer and Kunreuther also show in an appendix that their results are apparently qualitatively robust to alternative specifications of the firm’s objective function; for example, one could apply the expected-utility hypothesis without any apparent loss of generality.

I would encourage the authors to consider as well a financial market setting as an alternative framework for modeling insurer decisions. The adoption of a financial market setting would afford a number of analytic advantages. For example, it would provide an internally consistent framework for introducing such alternative financial instruments as act-of-God bonds and insurance derivatives directly into the analysis. Furthermore, a financial market setting also makes it much easier to consider important incentive effects associated with taxation and solvency. Studies based on financial market models (e.g., Mayers and Smith 1990; Garven and Lamm-Tennant 1997) have shown that insurer willingness to bear risk may be significantly influenced by factors such as asymmetries in the tax code and variation in ownership structure as well as the

risk of insolvency. Furthermore, limited liability and tax asymmetries create “kinky,” option-like payoffs that also convey systematically different risk incentives for stock versus mutual organizations (see Garven 1992). The incentive effects documented in these studies become even more pronounced in the face of catastrophic risks.

An Interesting “Real-World” Application

A very interesting “out-of-the-box” application of the Kleindorfer and Kunreuther model would involve the evaluation of the optimality (or lack thereof) of the California Earthquake Association financial structure (see their table 4.1). Given the conceptual framework provided by the Kleindorfer and Kunreuther model, does the CEA financial structure make sense? If not, would there be better ways to parameterize it from the perspectives of funding and mitigation?

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Comment Dwight Jaffee

Catastrophe insurance in the United States (and other countries) is, generally speaking, not provided by private companies operating in free markets. Instead, government entities and regulators (state or federal) have become major players in virtually all such markets. This is perplexing since standard theory would suggest that insurance for low-probability, high-consequence events should create an active demand (by consumers and business firms seeking to reduce their catastrophe risk) and an aggressive supply (by profit-seeking insurance companies) that would support such a market. An accurate understanding of why private insurance markets for catastrophes fail to operate is critical for evaluating how best to deal with this failure. Otherwise, we cannot know whether the government-based solutions, now adopted for hurricanes in Flor-

ida and Hawaii, for earthquakes in California, and for floods across the United States, are the best available solutions.

This paper, by Paul Kleindorfer and Howard Kunreuther, provides important advances in understanding some of the important elements that are creating the market failure. In particular, the paper makes important contributions in two primary areas. First, it focuses on the decision processes of the key stakeholders and on how the interaction of these processes has made it difficult for private firms to manage catastrophe-insurance risks. Second, it focuses on new methods for modeling catastrophe-risk management. I discuss these in turn.

Behavioral Insurance: The Decision Processes of Stakeholders

Kleindorfer and Kunreuther focus on how the behavior of various stakeholders in the catastrophe-insurance market—the insurance companies, insured individuals, and government regulators—might vary from that implied by expected-utility theory. This research area might be called *behavioral insurance*, in parallel with the new field of behavioral finance. Indeed, insurance market anomalies, such as the failure of private markets for catastrophe insurance, can be as interesting and challenging to explain as the well-known financial market anomalies.

Kleindorfer and Kunreuther on Behavioral Insurance

The authors are persuasive in arguing that behavioral factors may play an important role in explaining the catastrophe market anomaly. For example, they point out that consumers may understate the probability of a catastrophe (“it will not happen to me”) while insurers may operate under a “probable-maximum-loss” constraint to limit their risk of ruin. These factors reduce both the demand for and supply of catastrophe insurance. These factors may also explain why consumers can complain that insurance is too expensive and the companies unfair while at the same time failing to carry out economically sensible mitigation investments.

Kleindorfer and Kunreuther also emphasize that further effects can arise owing to interconnections on a systemwide basis. They point out, for example, that construction firms, local building-code inspectors, homeowners, insurance companies, real estate agents, and mortgage lenders (including Fannie Mae and Freddie Mac) have all chosen to overlook important cases in which homes have not been built to code. This was clearly revealed during Hurricane Andrew as improperly constructed roofs blew away.

The Government and Behavioral Insurance

The authors indicate that the government can be a constructive force in reversing some of the problems of the catastrophe-insurance industry, which is certainly true. On the other hand, it is important to recognize that most government disaster-relief programs create highly adverse incentives both for catas-

trophe insurance and for the ex ante mitigation of the effects of catastrophes. In the extreme case, if the government pays for all uninsured losses, then there is a positive incentive to place activity in risky locations and not to carry private catastrophe insurance. This is not an easy problem to fix since it is difficult for a government to claim, with credibility, that it will not provide disaster relief in the future.

It is interesting in this regard that the Italian government is currently attempting to reduce the budgetary effect of disaster relief by making catastrophe insurance mandatory for all homeowners. Under current proposals, the premiums will be paid through a surtax on other casualty insurance. In this case, the Italian budget may benefit, but, since the premiums will not vary by specific location, the incentive to locate in hazardous areas will continue. On the other hand, different problems are created when individuals are forced to pay directly for mandatory insurance, as illustrated by the number of uninsured motorists and the assigned risk pools in U.S. auto-insurance markets. This all reinforces the authors' basic point that it is important to consider behavioral factors when determining the proper role for government in insurance markets.

New Methods for Modeling Catastrophe-Risk Management

The second primary contribution of the Kleindorfer and Kunreuther paper is a prototype model for managing catastrophe risk, one based on recent developments in risk assessment and information technology. The model measures the exposure to earthquake risk of a city that is a virtual mirror, in terms of the number and mix of structures, of Oakland, California. The model includes an insurance industry (with firms of differing size), reinsurance in alternative amounts, and mitigation in alternative amounts. Model results are generated by Monte Carlo simulations, which determine expected and worst-case losses for each stakeholder group.

Model Results

The model provides reasonable results in terms of the effect of varying the amount and cost of reinsurance available to the insurance companies. In particular, as the cost of reinsurance rises or its availability falls, the insurance companies reduce the amount of primary coverage that they are willing to offer.

The model also provides intriguing results concerning the benefits of mitigation. As expected, the model shows that the worst-case losses decline as the degree of mitigation is improved. However, the model also shows no benefits to mitigation on average, which is surprising. This result arises because mitigation is measured in the model by the degree of adherence to the building codes. In particular, the model ignores potential mitigation that is not code related while including the cost of code-based retrofits that have no mitigation benefits. In other words, properly interpreted, the model is showing that *inefficient* mitigation is not cost effective, certainly a reasonable result. It must remain for

future work, however, to measure the potential benefits of *efficient* mitigation.

Further Comments on the Model

This model is really a remarkable feat, and my hat is off to the authors. Nevertheless, there are features that could be and probably should be improved. I will focus on two key areas, the role of prices in the model and certain missing model features.

The model determines the premium prices for both insurance and reinsurance as a markup over the expected loss for each property. The loading factor for the markup is exogenously determined to be 100 percent. In particular, the premium prices do not necessarily clear the market, and it seems that they are generally below the market-clearing level. It is hard to know how much this affects the model's results for reinsurance and mitigation. In any case, it would be useful to have a version of the model with market-clearing prices. As a related matter, it might also be useful to allow new entry into the insurance market to occur as a function of the profit margins being earned by the current participants.

There are several other features of earthquake-insurance markets that might be useful to incorporate in future versions of the model. I simply list these briefly: (a) As already mentioned, government disaster relief programs create an incentive to locate activity in hazardous areas and not to buy earthquake insurance. (b) Fraud can be an important part of the cost of settling claims. (c) Alternative contracts can provide more or less coverage and be more or less subject to fraud. These ideas illustrate the range of questions that can be potentially answered by such models. I look forward to more results from Kleindorfer and Kunreuther as they continue their research in this area.