"Should Earthquake Mitigation Measures be Voluntary or Required?"

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Should Earthquake Mitigation Measures Be Voluntary or Required?

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Abstract
This paper examines whether or not one should require homeowners to adopt cost-effective loss reduction measures (LRMs) on residential structures in earthquake prone areas. Congress is considering requiring homeowners in earthquake-prone areas to purchase earthquake insurance as a condition for a federally insured mortgage but is still debating what action should be taken regarding mitigation. We show that the incentive to voluntarily adopt LRMs is reduced if homeowners are covered by full insurance rather than being uninsured. This result holds even if individuals have accurate information on the risk and maximize expected utility. The empirical evidence indicates that few homeowners adopt mitigation measures whether they are insured or uninsured. Most individuals do not behave as if they maximize expected utility and instead seem to employ simplified decision rules which suggest that mitigation measures are unnecessary or too costly in relation to the perceived benefits. These findings suggest that it may be necessary to strengthen building codes and/or require the adoption of mitigation measures on existing structures in return for reduced earthquake insurance premiums.

1. Introduction
This paper explores the question as to whether cost-effective loss reduction measures (LRMs) should be voluntary or required on residential structures which are subject to earthquake hazards. The answer depends upon whether the homeowner is insured and the nature of the consumer decision processes, as well as the relevant benefits and costs of the loss reduction measures. These issues are of some importance today, given the concern by Congress on what role mitigation measures should play in a private-federal earthquake insurance program.

After characterizing the problem context (Section 2), we investigate the relationship between the purchase of insurance protection against earthquakes and the incentive to adopt mitigation measures to reduce property losses. As shown in Section 3, even if homeowners collect accurate information on the risk and maximize expected utility, they will have less incentive to adopt hazard mitigation measures voluntarily if they are required to purchase...
full insurance rather than if they remained uninsured.

Empirical studies on consumer decision processes suggest that relatively few homeowners, even if uninsured, are likely to voluntarily adopt LRMIs. These data, discussed in Section 4, suggest that it may be necessary to impose some type of requirements if one wants homeowners to adopt specific LRMIs. Section 5 provides a more detailed analysis of the nature of the benefits and costs of two LRMIs using actual data from studies undertaken for the California Department of Insurance and the Federal Emergency Management Agency (FEMA).

The final section discusses the policy implications of these findings. We conclude that, in order to achieve widespread adoption of cost-effective LRMIs, it will be necessary to impose certain regulations (e.g., building codes) or mortgage requirements, since homeowners are not likely to voluntarily adopt mitigation measures. Incentive systems, such as low interest loans, may be necessary, given the budget constraints of many homeowners who will be forced to adopt certain mitigation measures.

2. Problem Context: Potential Losses from Earthquakes

There has been a recognition by scientists for many years that a catastrophic earthquake could cause monumental damage if it was centered in a highly populated region. However, it took the Loma Prieta earthquake that shook the San Francisco region in October 1989 to graphically highlight to the general public the possible damage from such an event. The quake, which registered 7.1 on the Richter scale, caused an estimated $10 billion in property losses in the Bay Area (Bea and Mielke 1990). Should a catastrophic quake of the severity and location of the 1906 San Francisco earthquake reoccur, the damage is likely to be considerably greater.

The Loma Prieta earthquake spurred the federal government to consider for the first time the need for requiring the adoption of LRMIs on public buildings. In January 1990, the President issued Executive Order 12699 which requires 25 federal agencies to issue regulations over the next three years to adhere to cost-effective seismic construction standards on new federal buildings or structures that are federally assisted or regulated (Litan 1991).

Turning to residential structures, in a seismically active state such as California, some loss reduction requirements have been imposed. For example, in 1986 the California legislature passed the Unreinforced Masonry Building Law requiring that local governments undertake an inventory of unreinforced masonry buildings and establish earthquake hazard mitigation programs for these structures by January 1, 1990. Approximately one million occupants in 25,000 structures are affected by this law. As of June 30, 1990, approximately 60 percent of the affected jurisdictions had substantially complied with this law (Tubbesing 1990).

In other states, such as Washington, Missouri, and Tennessee, which have the potential for serious earthquakes, there has been considerable resistance to instituting seismic building codes for residential structures, despite studies showing their importance in reducing future losses. Few residents have adopted any mitigation measure voluntarily because they do not perceive an earthquake to pose a credible threat (Drabek et al. 1983).
3. Tradeoffs Between Insurance and LRM Adoption

The relationship between loss prevention behavior and market insurance was first investigated in the seminal piece by Ehrlich and Becker (1972). They show that market insurance has two opposite effects on the incentive to adopt LRMs. On the one hand, it discourages the adoption of loss prevention measures because it reduces the difference between the incomes in disaster and nondisaster states of the world. On the other hand, it encourages individuals to adopt mitigation measures if the insurance premiums reflect the decrease in expected loss.

The actual impact of the availability of insurance depends on the degree of risk aversion, the loading charge on insurance, and the costs of the mitigation activity relative to the reduction in risk. Building on the Ehrlich and Becker result, several subsequent papers have investigated the impact of risk aversion (Dionne and Eeckhoudt 1985) and loss uncertainty (Hiebert 1989) on the incentive to employ loss mitigation.

In all of these models, an individual chooses either the level of insurance, the level of loss reduction activity, or both, so as to maximize expected utility. The only losses which can occur are to property. Our interest is in determining how the incentive to adopt loss reduction measures with respect to property damage is affected by whether a homeowner is uninsured or fully insured.

The Uninsured Homeowner

Consider the case where the homeowner does not have any insurance coverage and has the opportunity to adopt an LRM to reduce potential property losses from a future earthquake. To keep the analysis simple, without loss of generality, suppose the decision maker (homeowner) considers the possibility of a single earthquake occurring with annual probability $p$ which causes $L$ dollars worth of damage to his home. A loss reduction measure is available which has a per unit cost of $1$. If $r$ units of the measure are adopted, then the possible damage from an earthquake is reduced to $L(r)$ where $L(0) = L$. The function $L(r)$ is assumed to be concave, implying the marginal benefits of mitigation are assumed to decrease as $r$ increases (i.e., $dL(r)/dr < 0$ and $d^2L(r)/dr^2 > 0$).

The homeowner is assumed to be risk averse with a von Neumann Morgenstern utility function given by $U$. The expected utility associated with investing $r$ units of mitigation $E[U(r)]$ is given by

$$E[U(r)] = pU(W - L(r) - r) + (1 - p)U(W - r).$$  \hspace{1cm} (1)

This is a standard model of choice which provides insight into the relationship between the benefits and costs of adopting LRMs and the homeowner’s utility in states of the world. More specifically, the optimal amount of mitigation ($r^*$) which maximizes expected utility when there is no insurance available is determined by setting $dE[U(r)]/dr = 0$, which yields:

$$\frac{U'(W - L(r^*) - r^*)}{U'(W - r^*)} = \frac{1 - p}{p(\left|L(r^*)\right| - 1)}.$$  \hspace{1cm} (2)

This is a familiar result. The RHS of (2) is the contingency price ratio associated with mitigation and is equated to the ratio of the marginal utilities of the disaster to non-disaster states. The homeowner is willing to invest in mitigation up to the point where the perceived
expected marginal benefits of mitigation are equal to the marginal cost. Hence, as the perceived probability of a disaster decreases, the RHS of (2) increases and there is less of an incentive to invest in an LRM. Increasing risk aversion implies that for any given loss L the LHS of (2) will increase thus leading to a larger value of $r^*$. 

A risk neutral homeowner has less incentive to utilize mitigation than a risk averse person, because the perceived benefits from mitigation for the former are not as great. Since the marginal utility of an additional unit of mitigation is independent of wealth for a risk neutral person, the optimal amount of mitigation is determined by setting

$$
\frac{dL(r)}{dr} = \frac{-1}{p}.
$$

(3)

In this case, it is clear that $r^*$ decreases as $p$ decreases, due to the concavity of $L(r)$.

**The Fully Insured Homeowner**

Now suppose that a homeowner is required to purchase earthquake insurance. The most common real-world situations which conform to the assumption of a compulsory policy are where banks or financial institutions require the property owner to purchase sufficient insurance to cover damage up to the face value of the mortgage.

For simplicity, assume that individuals are required to purchase full insurance coverage which will replace all possible losses from an earthquake. What incentive would the homeowner have to invest in LRMs if the required premium is given by $z(r)$, where $z'(r) < 0$? Since an individual with full insurance has the same wealth in either the disaster or non-disaster state, $U(W)$ in (1) is simply $U(W - z(r) - r)$. Optimal mitigation is then determined by minimizing $|z(r) + r|$, which is given by

$$
z'(r) = -1.
$$

(4)

In this case, $r^*$ is determined by setting the marginal reduction in the premium equal to the marginal cost of mitigation. More explicitly, for the case where premiums reflect actuarial risk, we set $z(r) = pL(r)$ and $z'(r) = pL'(r)$. In this case, the optimal amount of mitigation to undertake is the same as if the person is an uninsured, risk neutral person who utilizes equation (3) to make a decision on $r^*$.

Should premiums not reflect the reduction in expected losses from mitigation, then $z'(r) = z$ and the homeowner will want to set $r^* = 0$ and hence not engage in any loss reducing activity, since losses are fully covered by insurance. Of course, the homeowner may want to invest in mitigation measures for other reasons, such as reducing the chances of fatalities and serious injuries from an earthquake.

The presence of loading costs will not change the above result if this cost is independent of the magnitude of the loss. For example, there could be a fixed charge $C$ for processing a policy over and above the expected loss, so that $z(r) = C + pL(r)$. This is what often occurs in practice, given that loading costs are normally associated with marketing a policy (Doherty 1975).

The principal conclusion from this analysis is that a homeowner who maximizes expected utility will be less interested in adopting mitigation measures if they are required to purchase full insurance than if they are not protected at all. We now introduce a set of other
considerations based on empirical data that provide much more convincing evidence that few homeowners are likely to invest in mitigation measures unless they are required to do so, whether or not they are insured.

4. Consumer Decision Processes and LRM Adoption

Few homeowners voluntarily adopt mitigation measures against earthquake damage. One reason is that there is a basic asymmetry between the concept of costs and benefits when it comes to adoption of protective or loss reduction measures. The costs are known with certainty. You are told how much it costs to have air bags in your car; a developer or contractor provides a dollar figure on how much it will cost you to anchor the walls to the foundation of the house. The benefits, on the other hand, are highly uncertain. They depend on your estimate of the probability of the event occurring, the reduction in losses from adopting the mitigation measure, and the length of time that the mitigation measure will be useful.

A substantial body of empirical evidence suggests that individuals do not utilize models of choice such as expected utility theory but rely on simplified heuristics when determining whether to protect themselves against low probability high consequence (LP-HC) events. In their study of the purchase of flood and earthquake insurance, Kunreuther et. al. (1978) determined that the expected utility model was not an accurate characterization of behavior by individuals. Using individuals' own estimates of probabilities, consequences, and insurance premiums, they found that over 40 percent of the individuals who purchased earthquake insurance should not have done so if they maximized expected utility and almost 20 percent of the uninsured individuals should have purchased coverage.

The contingent weighting model proposed by Tversky, Sattath, and Slovic (1988) may be a more descriptive model of the choice process for LP-HC risks. According to this approach, individuals make tradeoffs between certain dimensions of alternatives, such as probability and utility. The weights put on each of these dimensions may vary depending on how they perceive the problem. For example, in many LP-HC events, people may perceive the probability to be the critical dimension. If their estimate of the probability (p) of an accident or disaster occurring is below a certain threshold level (p*) then they take no action to reduce the risk or its potential loss. If p > p*, then they decide to take action (Camerer and Kunreuther 1989).

Individuals' estimate of probability and how it affects their decision making is illustrated in the following examples:

1) The failure of individuals to wear seat belts voluntarily may be due to a perception on the part of the motorist that the chances of an accident are so small that "it won't happen to me."

2) The huge increase in demand for breast cancer examinations following the disclosure that some public figures (e.g., Betty Ford) had mastectomies may reflect the perception that "it can happen to me."

In other situations, a sequential model of choice may more appropriately characterize behavior. For example, if p < p*, then a person behaves as if he does not have to worry about the event occurring; if p > p*, then he determines how severe the consequences (L) will be should an accident occur without any protective measures undertaken. If L is below a critical
threshold ($L^*$), then no action would be taken. Otherwise the expected benefits of the LRM will be compared to its costs. Weinstein (1987) and Kunreuther et al. (1978) found that this model appeared to characterize subjects adoption of protective measures much more accurately than utilizing an expected utility model.

Simple rules like threshold models are easy to explain and justify to oneself and to communicate to others. For example, two principal reasons given for not adopting LRM’s for earthquakes by homeowners in California were that they were “too expensive” or “not necessary because there was not much likelihood of a disaster.” Interestingly enough, the most important reason given was procrastination, “never got around to it,” implying that the probability of an earthquake was not sufficiently high for the individual to worry about its consequences (Kunreuther et al. 1978).

Another reason why homeowners may choose to not adopt protective measures is that they focus on the relatively large up-front expenditure, not recognizing that the potential benefits will be reaped for as long as the house is occupied. If people only think about an LRM’s potential return over the next few years rather than over the life of the house, the investment is likely to be unattractive.

To illustrate the impact of different time horizons on behavior, suppose that the cost of a particular loss reduction measure is $M$ and the annual discount rate is $d = .05$. If a homeowner expects to live in his house for the next $T$ years, the annual cost of the LRM is determined by finding $r$ (the value defined in our model above) so that:

$$\sum_{t=0}^{T} \frac{r}{(1+d)^t} = M.$$  

If $T = 5$ years and $M = $1,000, then $r = $231. Naturally, as $T$ increases and/or $d$ decreases, the annual cost of mitigation is reduced and LRM’s appear more attractive.

5. Benefit-Cost Analysis of Two LRM’s

Recent studies for the California Department of Insurance and the Federal Emergency Management Agency (FEMA) have examined the potential benefits of specific LRM’s to residential structures. In this section, we illustrate two different benefit-cost analyses for evaluating the relative attractiveness of LRM’s, using actual empirical data. The first analysis evaluates the potential benefits of a specific LRM (anchoring walls to a foundation) as measured by the reduction in direct property losses from a single earthquake. This is referred to as the Single Event Benefit-Cost Analysis.

The second analysis illustrates standard Expected Benefit/Cost Analysis. This requires one to include all possible events and calculate the potential reduction in damage should an LRM be adopted. The expected benefit from the LRM is then compared to its actual cost. By definition, this analysis incorporates additional earthquakes that are not part of the single event analysis. Any given LRM will be more desirable using this methodology than under the single-event analysis for the same structure in the same location. We will evaluate the impact of another LRM (strapping gas water heaters to the dwelling’s structural frame) using this approach.
Single Event Benefit-Cost Analysis

The California Department of Insurance concluded that over 25 percent of the dwellings built before 1940 moved from their foundations as a result of the 1983 Coalinga, California quake. A typical one-story house built prior to 1940 with a concrete foundation can be braced so it is prevented from going off its foundation at a cost of between $1000 and $2000, with savings of between $25,000 to $30,000 should an earthquake of the magnitude of the 1989 Loma Prieta earthquake in California occur (Gallagher Associates 1990). Table 1 presents the data for undertaking a single event benefit-cost analysis for this LRM under the assumption that a future earthquake will be identical to the 1989 Loma Prieta earthquake. The estimates for the cost of the LRM and its impact on damage reduction are the midpoints of the dollar ranges estimated by Gallagher Associates. Two homeowners' estimates of the annual probability of an earthquake are considered in evaluating whether or not the benefit/cost ratio exceeds 1. The annual discount rate used is 5 percent.

<table>
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<th>Table 1. Benefit-Cost Analysis of Loss Reduction Measures</th>
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![Bar chart showing benefit/cost ratio](image)

*Figure 1. Benefit/Cost Analysis of Earthquake Mitigation Measures*
Figure 1 graphically depicts four estimates of the benefit/cost ratio under the assumption that if a quake occurs it will be at the end of any given year. The first estimate is based on looking at the case where Homeowner A has a one-year time horizon in making his choice and hence only considers the benefits of mitigation for the next year. In this case, the benefit/cost ratio would be 0.35 and the LRM would not be cost-effective. On the other hand, Homeowner B, who has a much higher estimate of the probability of a quake will want to adopt the measure even under this short time horizon since his benefit/cost ratio is 1.7.

In contrast, suppose both homeowners plan to live in the house for the next five years and consider the benefits of the LRM over this entire time period. Then figure 1 shows that anchoring the walls to the foundation is attractive for both homeowners if they calculated benefits and costs according to the Single Event Analysis. Using a five-year time horizon, one can show that if a homeowner estimates the probability of a quake as low as 1 in 79, he will want to brace his house to its foundation given the estimates of benefits and costs depicted in table 1.

**Expected Benefit-Cost Analysis**

This analysis requires one to estimate the probability of earthquakes of different magnitudes and then determine the impact of this event on actual damage to the structure with and without the specific LRM. As part of a study for FEMA, a computer-based interactive mitigation model has been developed at the Wharton School for undertaking expected benefit-cost analysis for different LRMs (Danes and Moore 1990). The model evaluates the potential benefits and costs of alternative mitigation measures taking into account direct property losses as well as the potential savings from indirect losses (i.e., reduction in lives lost, business interruption, and temporary housing costs).

One relatively inexpensive LRM that promises to reduce losses from fire following earthquakes is strapping gas water heaters to the home’s structural frame. This LRM was analyzed with respect to residential structures in Seismic Zone 4, the most seismically active area in California. The life of the property was assumed to be 80 years and the damage to the structure was based on a Modified Mercalli Intensity Scale which relates the intensity of the quake to the percent of the building value damaged. The costs of different mitigation measures were based upon technical evidence and expert judgement of structural engineers.

Three cases were considered in analyzing this LRM in order to determine how sensitive the Expected Benefit/Cost ratio is to different assumptions. Case 1 assumed that the damage was only to property and made a conservative assumption of an 8 percent discount rate. Case 2 assumed that the damage was to property and affected lives (each life was valued at $300,000) with a discount rate of 3 percent. Case 3 took into account property losses, lives lost (each life was now valued at $1 million) as well as business interruption losses, unemployment, and temporary housing costs. The discount rate for Case 3 is 0 percent.

If the expected benefit/cost ratio exceeds 1 under the very conservative assumptions of Case 1, then this LRM should be viewed as very attractive, since the expected benefit estimates are very conservative. At the other extreme, if the B/C ratio is less than 1 under Case 3 then the measure should never be recommended given that the assumptions regarding benefits are most generous.

Figure 2 presents the resulting benefit/cost ratios for strapping gas water heaters to the home’s structural framing. This mitigation measure is very important in decreasing losses
from fire following earthquakes. The ratios range from 1.3 to 8.1. The cost of this measure is estimated to be only .2% of replacement value (e.g., $200 for a $100,000 house) so budget constraints should play less of a role here than for the decision on whether to anchor a home’s walls to its foundation.

6. Policy Implications

The evidence presented above suggests that some loss reduction measures will provide substantial benefits to homeowners by reducing the potential damage to property, lowering the risk of injury and death, and reducing disaster relief expenditures for temporary housing, business interruption, and other losses induced by a catastrophic loss.

Yet the evidence on the tradeoffs between insurance and mitigation, as well as the nature of consumer decision processes, suggests that there will be limited interest by homeowners in voluntarily adopting these measures. Specifically, if full insurance is required as a condition for a mortgage, then LRM's will be less attractive than if the person is uninsured, even if premium discounts are provided for adopting a specific measure. Furthermore, most homeowners appear to use simple heuristics which enable them to avoid even considering the benefits and costs of a particular LRM. For example, when homeowners indicate that they have procrastinated on adopting mitigation measures because they never got around to thinking about them, then it is hard to imagine that they will undertake a benefit/cost analysis and then decide to adopt an LRM.

Building Codes

For these reasons, it may be desirable to require that certain LRM's be incorporated into
the building codes for new structures. Cohen and Noll (1981) have pointed out the desirability of having building codes under certain circumstances. They note that the primary economic justification for seismic building codes is that the structural soundness of a building is a social value that is not likely to be taken into account by its owners, even if they accurately evaluate the benefits and costs to themselves.

When a building collapses, the owner suffers an economic loss that may be considerably less than the full social cost, due to the secondary losses discussed above. This implies that the level of mitigation that minimizes private costs will be too small to minimize social costs. The desirability of a building code, then, is determined by whether the reduction in social costs from having a safer building outweighs the increase in private cost needed to meet such a code.

One way to view this tradeoff is to determine the increase in taxes that each citizen will have to pay to cover these social costs following the next earthquake. If a building code were to reduce this amount substantially without imposing an undue burden on affected building owners, then it may be appropriate to implement such standards.

Incentive Systems

With respect to existing structures, one could consider developing some type of incentive system for both builders and occupants to adopt attractive LRMIs. Insurance premium reductions for investment in mitigation are one way to encourage such action, but as we have suggested, they may be of limited value given the actual decision processes of homeowners. A more attractive option may be offering homeowners subsidized loans. The economic rationale for such a provision would be the savings in disaster relief payments should a catastrophic earthquake occur.

Today there is renewed interest in California in utilizing earthquake insurance and financial incentives to encourage mitigation. On August 31, 1990, the California State legislature instituted a law creating the California Residential Recovery Fund which is designed to provide homeowners with basic $15,000 earthquake protection and to encourage homeowners to adopt mitigation measures. Each of the 6.5 million residential insurance policies and 500,000 mobile home policies will have a surcharge of between $12 and $60 imposed to cover possible damage of up to $15,000 to the structure from a future earthquake. These surcharges are put in a State Fund and will be the principal source of relief should there be a large earthquake. If the amount in the fund is insufficient, a pro rata distribution will be made to the claimants. Mitigation will be encouraged through low interest state loans as the Fund grows and by reduced surcharges to properties that are retrofitted to withstand earthquake damage (Roth 1990).

These steps to encourage and/or require mitigation measures coupled with insurance are essential if we are to avoid large scale federal disaster relief following the next severe earthquake. There is sufficient evidence from previous catastrophic disasters indicating that liberal relief is likely to be forthcoming should individuals be unprotected and suffer severe losses, which is another reason why individuals may prefer not to invest their own funds in adopting protective measures.

The issue as to whether or not to require mitigation measures on residential structures in earthquake prone areas in the United States has assumed particular importance as the U.S. Congress is now seriously considering a joint private-Federal earthquake insurance program.
for residential structures, in which all homeowners would be required to purchase coverage if they have a mortgage issued or reinsured by a federal agency or by a federally insured financial institution.

One controversial issue is whether those homeowners who are required to purchase insurance should also be forced to adopt cost-effective LRMs on their structure. The above analysis suggests that it may be highly desirable to recommend this course of action, but that it may be necessary to provide low interest loans for those measures which are relatively expensive and hence may be strongly resisted by homeowners due to budget constraints.

We are becoming increasingly aware of the large potential costs to society of letting individuals decide on their own how they want to protect themselves against low probability high consequence events. The above analysis suggests that improved building codes and mitigation requirements are essential to reduce both the private and social costs from future earthquakes in the United States.

Notes

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1. The 1906 earthquake registered 8.3 on the Richter scale, which implies that it would be more than 30 times as powerful as the Loma Prieta earthquake. A change of one point on the Richter scale represents a difference of about 30 in energy release. The insurance industry estimates that the insured losses if such an earthquake occurred would be about $40 billion. These figures do not include any uninsured losses, such as damage to public buildings, which are likely to be quite significant (Doherty et al. 1991).

2. The more risk-averse utility function can be represented by a concave transformation (k) of U such that the new utility function, \( V \), is defined as \( V = k(U) \), with \( dV/dU > 0, d^2V/d^2U < 0 \). See Dionne and Eckhardt (1982).

3. The full insurance assumption is made in this analysis because it provides a clear contrast with the case where a homeowner is uninsured. The analysis of partial insurance is considerably more complex but requires a similar type of tradeoff as in this comparison. We are assuming that all damage from the quake will be replaced by insurance and that there is no additional sentimental value attached to specific parts of the house which are uninsured.

4. If no mitigation measure was cost-effective then \( z'(0) > -1 \) so that \( r^* = 0 \).

5. On the other hand, if \( z(r) = pL + C + CL(r) \) then \( z'(r) = (p + C)U'(r) \), and (4) implies a higher level of mitigation than if premiums were actuarially fair.

6. In a 1974 survey of 1000 California homeowners in earthquake prone areas, 12 percent adopted protective measures against earthquake damage (Kneueth et al. 1978). In a 1989 survey of 3500 homeowners in four California counties subject to earthquake damage, the percentages were even lower, ranging from 5 to 9 percent (Palm et al. 1990).

7. This analysis assumes that the value of the property remains the same as prior to the adoption of an LRM. If the value increases by $1000 and this affects both property taxes and the amount of full insurance, then this would raise the cost of mitigation above \( M = 1000 \). This calculation is also based on the assumption that there will be no quake over the 5 year period or that if there were a quake the mitigation measure would be intact so that the $1000 cost would not have to be incurred when the house was repaired.

8. For this statement to be correct, one must assume that the estimated probability and damage reduction from the earthquake considered in the single-event model is the same as in the expected benefit cost analysis.

9. The Loma Prieta earthquake occurred on California's San Andreas Fault and registered 7.1 on the Richter scale. It occurred approximately 70 miles southeast of San Francisco. It damaged more than 100,000 buildings and caused more than $8 billion in damage to buildings, roadways, vehicles, and other property (Ballen 1990).

10. See Dames and Moore (1990, Appendix C) for the specific assumptions that were used for computing the benefits from a reduction in indirect losses.
11. The value of life used for different studies has varied greatly. Estimates are as high as $6.2 million (Moore and Viscusi 1990). Had we used a figure higher than $1 million then any particular LRM would have been more desirable than in the current analysis.

12. Some LRMs will reduce the premiums for earthquake insurance policies, while other measures would impact on other coverage (e.g., life, homeowners'). For example, if a homeowner anchored walls to the foundation, the reduction in damage relates directly to the shaking from the quake itself so that it can be reflected in premium reductions on an earthquake policy. Strapping gas water heaters to the dwelling's structural framing reduces fire losses following a quake. The insurance industry would have to reflect these potential benefits by reducing the premium on the family's homeowners policy (which covers fire losses) rather than focusing on earthquake premiums.

13. A deductible of between $1000 and $3500 is imposed on this policy depending on the value of the house. There is no coverage for contents under this program.

References


Bea, Keith, and James E. Mielke. 1990. “Earthquake and Disaster Relief Policies: San Francisco Bay Area Earthquake.” Congressional Research Service (June 8).


Palm, Risa, Michael Hudson, R. Denise Blanchard, and Donald Lyons. 1990. Earthquake Insurance
Testimony Before the Subcommittee on Policy Research and Insurance of the Committee on
Testimony Before the Subcommittee on Policy Research and Insurance of the Committee on
Tversky, Amos, Shmuel Sattath, and Paul Slovic. 1988. "Contingent Weighting in Judgement and
havior." In Taking Care: Understanding and Encouraging Self-Protective Behavior, edited by N.