A Test of the Expected Utility Model: Evidence from Earthquake Risks

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The purposes of this paper are twofold. The first is to demonstrate that the expected utility hypothesis is a reasonable description of behavior for consumers who face a low-probability, high-loss natural hazard event, given that they have adequate information. The second is to demonstrate that in California information on earthquake hazards was generated by a 1974 state law that created a market for safe housing that previously did not exist.

I. Introduction

In a recent survey article on expected utility theory, Schoemaker (1982) describes the theory as “the major paradigm in decision mak-

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ing since the Second World War.” But Schoemaker indicates that in field studies the theory has not been supported. In particular, people do not behave as if they are maximizing expected utility for low-probability, high-loss events such as natural disasters. This conclusion is drawn from the work by Robertson (1974), Kunreuther (1976), and others. For example, Kunreuther interviewed homeowners in flood plains and earthquake-prone areas and concluded that the expected utility model “provides relatively little insight into the individual choice process regarding the purchase of [flood and earthquake] insurance.”

The results in this paper are more encouraging for expected utility theory. An expected utility model of self-insurance that incorporates a hedonic price function is developed and applied to low-probability, high-loss earthquake hazards. Individuals can self-insure by purchasing houses in areas where the expected earthquake damage is relatively low. Our empirical results establish the existence of a hedonic price gradient for safety in the Los Angeles and San Francisco areas; *ceteris paribus*, individuals pay less for houses located in relatively hazardous areas. Moreover, the magnitude of the price gradient is consistent with our theoretical results when reasonable estimates of earthquake probabilities and potential damages are used, thereby lending support to the expected utility paradigm.¹

The existence of a safety price gradient implies that individuals in the Los Angeles and San Francisco areas possess information on the relative danger of different locations. Yet Kunreuther found that Californians residing in earthquake-prone areas did not purchase earthquake insurance, in spite of subjective values on probabilities and magnitudes of potential losses that suggest such insurance may have been desirable. Our empirics show that a 1974 law passed by the state of California provided information that has allowed individuals to self-insure. Essentially, the law’s passage created a market for safety that affected housing values.

The paper is organized as follows: In Section II, a simple theoretical model of self-insurance that includes a hedonic price function is developed. Empirical results on the existence of a safety price gradient and the source of safety information are presented in Section III. Section IV demonstrates the applicability of the expected utility model. A review of alternative evidence and qualifications to our analysis follows in Section V.

¹ Our approach can be likened to that of Gould (1969), who shows that the expected utility hypothesis cannot be rejected as a description of behavior for consumers purchasing auto insurance.

II. Theory

The theoretical model combines previous work on self-insurance in an expected utility framework with hedonic housing value analysis. Ehrlich and Becker (1972) discuss the acquisition of market insurance as a method of redistributing resources toward the less well-endowed states. They indicate that in lieu of market insurance, individuals may choose to perform a similar redistribution through self-insurance. The latter is therefore seen as a substitute for market-obtained insurance. Familiar examples of self-insurance include procuring a burglar alarm to thwart thieves or wearing a helmet while riding a bicycle. For earthquake hazards, self-insuring would entail, *inter alia*, locating one's residence in an area of relative safety.² If enough consumers possess information on where the relatively safer areas are located, one would expect to see higher housing values in these areas *ceteris paribus*. Location, with regard to safety, is a housing attribute much the same as other attributes including structural, neighborhood, and community characteristics. Thus, consumers choose a level of self-insurance through their locational choices with respect to earthquake safety.

In order to incorporate housing attributes into the self-insurance model, a hedonic price function similar to the type introduced by Rosen (1974) is utilized. Housing value studies using hedonic prices have proved fruitful for valuing public goods such as clean air (Anderson and Crocker 1971; Harrison and Rubinfeld 1978), social infrastructure (Cummings, Schulze, and Mehr 1978), and noise level (Nelson 1979), as well as estimating prices for more traditional attributes such as square footage, fireplaces, and swimming pools. The safety attribute is novel, however, in that it is random; it enters the consumer's utility function differently depending on the state of the world that prevails. It has a mitigating effect on damage if an earthquake occurs, whereas if there is no earthquake, there is no damage.

The existence of a hedonic price gradient for the safety attribute reveals that information about natural hazards is available and that

² Ehrlich and Becker (1972) distinguish between self-insurance and self-protection. The former reduces the loss in the event (e.g., earthquake) state whereas the latter reduces the probability that the loss will occur. It might be argued that location away from an earthquake hazard area accomplishes either or both of these objectives. However, reducing the loss in the case of an event rather than reducing the probability of the event and the associated loss seems more plausible. Therefore, we view the location decision as equivalent to the purchase of self-insurance. Although market insurance is available in some areas, few consumers purchase it. Only 4 percent of the structures in Los Angeles are covered by earthquake insurance (*Science*, May 1976).

consumers account for this information in their decision making. In our theoretical development, consumers are assumed to be informed about relatively safe and unsafe locations. The information may be attained by visual inspection, word of mouth, or a government program that delineates relatively unsafe housing locations for home buyers. The empirical results in Section III not only support the contention that information is available and considered in home purchase decisions, they shed light on the source of the information.

The consumer's problem is to maximize expected utility over two states of the world: the earthquake state and no earthquake state, which occur with probabilities ρ and $1 - \rho$, respectively. The consumer pays $p(a, s)$ for a house where $a = (a_1, \dots, a_n)$ is a vector of n attributes and s is the safety attribute. Specifically, s is the monetary loss that the consumer perceives would be sustained during an earthquake. The function $p(a, s)$ is assumed to be twice continuously differentiable in all arguments with first partial derivatives positive for $i = 1, \dots, n$. This implies that the n attributes are all desirable; if, for instance, neighborhood crime is considered, the attribute is the absence of crime. The partial derivative of the hedonic price equation with respect to the safety attribute is necessarily negative as shown below.

Expected utility is written as

$$V = \rho U[W(a) - p(a, s) - s] + (1 - \rho)U[W(a) - p(a, s)], \quad (1)$$

where U has continuous first and second partial derivatives. The function $W(a)$ is the wealth equivalent of the bundle of attributes the consumer has in the two states and is also assumed to be twice continuously differentiable. The safety attribute (or the amount of self-insurance) appears in both states as a reduction in the price of the house but appears again in the earthquake state as a damage loss.

The optimum choice of attributes is characterized by the following first-order conditions:

$$a_i: \rho U'_e(W_i - p_i) + (1 - \rho)U'(W_i - p_i) = 0, \quad i = 1, \dots, n; \quad (2)$$

$$s: -\frac{(1 - \rho)p_s}{\rho(1 + p_s)} = \frac{U'_e}{U'}; \quad (3)$$

where subscripts on W and p denote partial derivatives and the e subscript on U denotes evaluation in the earthquake state. Assuming nonsatiation ($U'_e, U' > 0$), condition (2) implies that the i th attribute is chosen where $W_i = p_i$, or its marginal value to the consumer equals its marginal cost in the market. Condition (3) indicates that at the optimum the ratio of marginal utilities in the two states must equal the price ratio of self-insurance where the prices are weighted by the state

of the world probabilities.³ Note also that $-1 < p_s < 0$, or an additional dollar spent on safety must decrease damages by more than a dollar.

Assuming second-order conditions are satisfied, optimum values of a and s solve conditions (2) and (3). Either risk neutrality or risk aversion is compatible with second-order sufficient conditions.⁴

Equation (3) forms the basis for testing the expected utility model. That is, given values for the unknown parameters in equation (3) one can determine whether or not individuals act in accordance with expected utility theory. The empirical analysis presented in the next section is directed at determining both the existence of a price gradient with respect to relative earthquake safety and the magnitude of any price differential (p_s). In addition, the source of this location information is examined. In Section IV the estimated price differential is combined with probability and expected damage estimates to analyze the expected utility model.

III. Empirical Analysis: Hedonic Housing Equations

In the theoretical model it was hypothesized that individuals, acting on hazard information and possessing varying levels of risk aversion, would locate along a hedonic price gradient, with relatively safer homes commanding higher prices, everything else equal. In this section, a methodology that enables this hypothesis to be tested is described. Empirical tests are conducted for both Los Angeles County and the San Francisco Bay Area counties—Alameda, Contra Costa, and San Mateo. Also included is a description of the data base and the test results.

Proximity to earthquake-related hazards is the important variable under study. Relatively hazardous areas have been delineated through research programs conducted by the U.S. Geological Survey and the California Division of Mines and Geology. The outcome of these efforts was the Alquist-Priolo Special Studies Zone Act passed by the California legislature in 1972 and amended in 1974, 1975, and 1976. This act represents an attempt to provide society with information concerning relative earthquake-associated risk.

Special Studies Zones (SSZs) are designated areas of elevated relative risk determined by potentially and recently active earthquake fault traces (surface displacement has occurred in Holocene time, i.e.,

³ See Ehrlich and Becker (1972) for graphical interpretations of a similar result.

⁴ One of the sufficient conditions for a maximum is that $V_{ss} = -\rho(U''_c p_s + U'_c p_{ss}) - (1 - \rho)(U''_s p_s + U'_s p_{ss}) < 0$. This is satisfied if the marginal cost of safety is increasing, $p_{ss} > 0$, and if either $U'' = 0$ or $U'' < 0$ for risk neutrality or risk aversion, respectively.

over the last 11,000 years). The evidence of faults may be directly observable (ruptured streets, crooked fences, etc.) or inferred (i.e., geomorphic shapes). The length of an SSZ coincides with the fault length whereas the width is generally one-eighth of a mile on each side of the fault.

Within California, the total number of SSZs designated through January 1979 was 251. There are two important ways in which consumers become aware of these. First, when an SSZ is designated, property owners in the zone are notified. Second, consumers selling property in an SSZ are required to notify prospective buyers that the property is in a zone (Alquist-Priolo Special Studies Zones Act 1974). This latter requirement has been implemented by the Department of Real Estate by having agents disclose the information via an addendum to the purchase contract. The buyer is then granted a period to collect additional information or to cancel the sale.

The potential effects of the Alquist-Priolo Act form the basis of a testable hypothesis. The null hypothesis is that consumers respond to the awareness of hazards associated with SSZs with the alternative being that they do not.

Data Specifics

The study areas are Los Angeles County and the San Francisco Bay Area counties, and observations are confined to single family residences. Thus, we do not consider the impact of hazard location on other structures (multiple family dwellings, mobile homes, commercial, etc.) or other ownership types (rental, leasing, etc.). Therefore, within our sample, this research asks if Los Angeles and San Francisco Bay Area households will pay a premium in the form of higher housing values for homes located outside an SSZ and what is the magnitude of that willingness to pay.

The data base was constructed so that hypotheses concerning the impact of SSZ location differences on housing sale price could be tested. The dependent variable in the entire analysis is the sale price of owner-occupied single family residences.⁵ The independent variable set consists of variables that correspond to three levels of aggregation: house, neighborhood, and community. The Appendix describes further the data employed in the study.

The housing characteristic data, obtained from the Market Data Center (a computerized appraisal service centered in Los Angeles),

⁵ Note that sale price or the discounted present value of the flow of rents rather than actual rent is used as the dependent variable. The two are interchangeable given the appropriate discount rate.

pertain to houses sold in 1978 and contain information on nearly every important structural and/or quality attribute. The Appendix provides summary statistics for the housing, neighborhood, and community characteristics used in the hedonic analysis. It should be emphasized that housing data of such quality (e.g., micro level of detail) are rarely available for studies of this nature. Usually outdated data that are overly aggregate (for instance, census tract averages) are employed. These data yield functions relevant for the "census tract" household but are only marginally relevant at the household (micro) level.

The Market Data Center provided computer data tapes listing all houses sold in Los Angeles County and the San Francisco Bay Area counties during the period specified. The number of entries was unmanageably large, so the data set was reduced as follows. First, a data set was constructed that contained houses within SSZs.⁶ This was accomplished by first searching the tape for all houses located in census tracts that were wholly or partly in an SSZ. This list was further reduced through a random number matching system. The addresses of the remaining entries were then checked against a detailed map to select those clearly within an SSZ. The numbers of valid Los Angeles County and the San Francisco Bay Area SSZ data points were 292 and 745, respectively.

Second, data sets were constructed that included houses not located in hazard areas. After deletion of incomplete data entries, a random number matching system was utilized to choose sample sizes of approximately five thousand observations in each study area. The safety variable is then represented by a dummy variable that takes on the value one for houses in an SSZ and zero otherwise.

In addition to the immediate characteristics of a home, other variables that could significantly affect its sale price are those that reflect the condition of the neighborhood and community in which it is located. That is, school quality, ethnic composition, proximity to employment centers (and in Los Angeles County, distance to the beach), and measures of the ambient air quality have a substantial effect on sale price. In order to capture these impacts and to isolate the independent influence of location vis-à-vis the SSZs, these variables were included in the econometric modeling.

The data base assembled for the housing value study is appropriate to test the hypotheses outlined above for two reasons. First, the housing characteristic data are extremely detailed at the household level of aggregation and extensive in that a relatively large number of observations are considered. Second, a variety of neighborhood and com-

⁶ See Hart (1977) for the location of SSZs.

TABLE 1
ESTIMATED HEDONIC EQUATIONS FOR LOS ANGELES COUNTY AND BAY AREA COUNTIES

Variables	Los Angeles County	Bay Area Counties
Site-specific characteristics:		
Sale date	.002 (17.92)	.008 (8.17)
Age of home	-.002 (-11.37)	.0005 (2.37)
Square feet of living area	.0003 (36.85)	.00005 (14.85)
Number of bathrooms	.098 (11.58)	.260 (40.12)
Number of fireplaces	.124 (17.90)	.188 (27.86)
Pool	.093 (8.66)	.067 (4.83)
View	.143 (11.56)	.128 (12.68)
SSZ location	-.056 (-3.76)	-.033 (-3.39)
Community characteristics:		
School quality	.020 (20.72)	.012 (12.85)
Home density	-.00004 (-7.72)	-.00002 (-14.15)
Percent black	-.006 (-33.55)	-.006 (-29.91)
Percent greater than 62 years old	.003 (6.35)	.009 (18.22)
Air pollution	-.001 (-5.01)	-.004 (-9.76)
Location characteristics:		
Distance to employment	-2.313 (-2.04)	-.401 (-.17)
Distance to beach	-.016 (-22.44)	N.A.
Alameda County	N.A.*	-.158 (-15.78)
Contra Costa County	N.A.	-.27 (-21.20)
Constant	5.003 (60.59)	5.335 (77.17)
R^2	.79	.69
Residual sum square	281.02	302.570
Number of observations	4,865	5,438

NOTE.—Dependent variable = $\ln(\text{home sale price in 1978 \$100s})$; t -statistics in parentheses.
*N.A. = not applicable.

munity variables that make it possible to isolate the SSZs' location influence on housing values have been included.

Empirical Results

The underlying structure of the hypothesis test is a single-equation empirical model that attempts to explain the variation in sale prices of houses located in Los Angeles County and the San Francisco counties.⁷ The estimated coefficients of these hedonic equations specify the effect a change in a particular independent variable has on sale price. In reference to the SSZ location variable, this procedure allows one to focus on its significance while separating out the influence of other extraneous variables. Therefore, this analysis yields two outputs concerning the relationship of hazard location differentials to housing price. First, the relative significance of location variations is determined and, second, the estimated coefficient pertaining to location implicitly measures its monetary value.

The estimated Los Angeles and San Francisco hedonic gradients that provide the best fit of the data are presented in table 1.⁸ A number of aspects of the equations are worth noting. First, as measured by R^2 , the nonlinear form is a significant improvement over linear specifications. In addition, a comparison of the log of the likelihood values (semilog to the linear) indicated that the semilog form was a significant improvement at the 1 percent level (see Judge et al. 1980). As Rosen (1974) pointed out, this is to be expected since consumers cannot always arbitrage by dividing and repackaging bundles of housing attributes. Thus, on both theoretical and empirical grounds the semilog specification proved to be a better functional form.

Second, in the semilog equations all coefficients have the expected sign and are significantly different from zero at the 1 percent level. The SSZ dichotomous location variable has the a priori expected relationship to home sale price and is significant at the 1 percent level. This result is invariant with respect to various sample sizes, model formulations (various independent variable sets were tested), and estimated functional form.⁹ These results indicate that individuals are

⁷ See Freeman (1979) and Mäler (1977) for a review of estimates of hedonic housing equations.

⁸ The main difference between the Los Angeles and Bay Area analyses is the locational variables. In the Bay Area distance to beach (ocean) is unimportant due to the presence of the bay. In addition, the three Bay Area counties were assigned dichotomous variables to account for county differences. San Mateo County is the excluded group and therefore is included in the constant term.

⁹ Since the SSZ location variable is a zero-one variable then our choice set over functional forms was essentially restricted to the linear and semilog forms. Thus, possi-

acting on hazard information when making locational choices, and this action is translated into a measurable hedonic gradient.

Regarding the monetary impact on housing sale price, the non-linear specification does not allow straightforward interpretation since the effect of any independent variable depends on the level of all other variables. However, the Los Angeles County (Bay Area) results indicate that if all other variables are assigned their mean values, then living outside of an SSZ causes an increase in home value of approximately \$4,650 (\$2,490) over an identical home located in an SSZ. In relative terms the magnitude has approximately one-half the impact of a swimming pool or one-third the value of a view.

In the next section, these monetary figures are used to test the expected utility model. But before proceeding to this analysis, we can confirm the source of the hazard information used by home buyers. As indicated above, the Alquist-Priolo Act was enacted in 1974. Therefore, a pre-1974 analysis of the housing market would yield insight concerning the importance of the act in providing consumers relative risk information.

Housing data for the 1972 time period are used in the test of the Alquist-Priolo Act. Successful enhancement of consumers' awareness by the Alquist-Priolo disclosure provisions would require a change in the hedonic rent gradient over time. This change could take one of two forms: (i) an SSZ location would be an insignificant housing characteristic in 1972 yet significant in 1978; or (ii) the location variable would be significant in both years but its relative magnitude would increase over time. The first type of change could be considered a strong test of the impact of the Alquist-Priolo Act since the act would have filled an existing information void. Thus evidence of a direct market effect would be available. The magnitude change of the SSZ variable would imply a weaker response since it would be evident that consumers had hazard location information from some other source and were already acting on it before passage of the Alquist-Priolo Act.

The relative impact of hazard information independent of the Alquist-Priolo Act is also tested using the pre- and postdata sets; that is, if SSZ location remains a stable (no relative magnitude change), significant determinant of housing price, then consumers are acting on some available information although their preferences have not been enhanced or changed by the public disclosure program.

ble forms such as quadratic, log, inverse semilog, exponential, semilog exponential, and the Box-Cox transformation of the SSZ location variable are not available since they inevitably reduce to zero-one or cannot be estimated (e.g., log of zero). Further, a Box-Cox transformation of the dependent variable that is not equivalent to linear or semilog yields difficult to interpret results. Finally, the translog transformation is not available because the objective is to determine the separate influence of SSZ locations.

The 1972 time period results are presented in table 2. The semilog functional form provides the best fit of the data, and all coefficients, with the exception of SSZ location, are significant at the 1 percent level and related to home sale price as expected. However, the most noteworthy aspect of the equations is that the SSZ location variable does not demonstrate significance in 1972, even at the 10 percent level. The combined 1972 and 1978 results indicate that the Alquist-Priolo Act *has* caused a structural change in the hedonic gradient over time. This is evidenced both by the significant monetary impact change over time and by the change in significance. Therefore, in the study areas the Alquist-Priolo Act does pass a strong test of effectiveness, suggesting that the act provided information that consumers used in their market decisions.

IV. Empirical Results: Expected Utility Model

If consumers behave as if they maximize expected utility, then first-order condition (3) must necessarily be satisfied. The terms in condition (3) include the probability of an earthquake, marginal utilities of income, marginal damage to a house, and the marginal change in the house price. Our approach is to solve equation (3) for this latter term by substituting in reasonable values of all the former terms for the Los Angeles region. This provides an analytical solution for the price difference between houses in and out of SSZs. This price difference is then compared to the observed difference in housing prices estimated in the previous section. The two differences are shown to be close, thereby supporting the expected utility paradigm.

In the empirical work, houses were described as either in or out of unsafe areas so that the safety attribute was discrete. In equation (3) the attribute is continuous. Therefore, the partial derivative p_s in (3) is approximated as $\Delta p / \Delta s$, where Δp is the total price difference between safe and unsafe houses, and Δs is the total damage in dollars resulting from an earthquake. Equation (3) can then be rewritten as

$$\Delta p \cong \frac{U'_c}{U'} \left\{ \frac{-\rho \Delta s}{1 - \rho[1 - (U'_d/U')]} \right\} < 0. \quad (4)$$

The hedonic housing equation provides an estimate of Δp of $-\$4,650$ for an average house worth $\$83,153$. On an annual basis using the prevailing home mortgage interest rate in 1978 (9.5 percent), this implies a home outside of an SSZ would cost $\$442$ more per year in mortgage payments than one in an SSZ. One possible assumption is that this is the perceived annual cost of living outside of an SSZ to home buyers, which may be plausible given a home turnover rate of once every 3–4 years in 1978. However, if home buyers properly

TABLE 2
ESTIMATED HEDONIC EQUATIONS FOR LOS ANGELES COUNTY AND BAY AREA COUNTIES

Variables	Los Angeles County	Bay Area Counties
Site-specific characteristics:		
Sale date	.004 (5.20)	.004 (6.96)
Age of home	-.005 (-19.52)	-.002 (-15.17)
Square feet of living area	.0003 (41.71)	.0002 (47.42)
Number of bathrooms	.133 (19.51)	.084 (15.35)
Number of fireplaces	.091 (18.10)	.103 (20.52)
Pool	.131 (14.73)	.105 (9.57)
View	.130 (10.36)	.080 (10.20)
SSZ location	.0002 (.0174)	-.022 (-1.44)
Community characteristics:		
School quality	.0098 (12.44)	.003 (7.34)
Home density	-.000017 (-3.88)	-.00001 (-8.83)
Percent black	-.0029 (-22.64)	-.002 (-15.147)
Percent greater than 62 years old	.002 (4.83)	.004 (13.25)
Air pollution	-.0018 (-6.33)	-.004 (-13.18)
Location characteristics:		
Distance to employment	-7.64 (-8.40)	-8.113 (-4.74)
Distance to beach	-.0095 (-16.74)	N.A.*
Alameda County	N.A.	1.020 (-135.04)
Contra Costa County	N.A.	-.233 (-25.34)
Constant	5.54 (82.05)	6.126 (170.53)
R^2	.80	.91
Residual sum square	169.44	150.700
Number of observations	4,927	5,460

NOTE.—Dependent variable = $\ln(\text{home sale price in 1972 } \$100\text{s})$; t -statistics in parentheses.
*N.A. = not applicable.

perceive the role of inflation and keep their homes for a longer period, then use of the real rate of interest would be more appropriate in calculating the true cost differential for living outside of an SSZ. From the early 1950s up until 1978 the real rate of interest on home mortgages averaged around 3 percent. If we use this rate of interest, we obtain a real cost differential of \$140 per year. These figures provide a range for comparison to Δp from equation (4) after substituting in values for ρ , Δs , and U'_e/U' .

First, consider a range of values for U'_e/U' . As a lower bound, and to be consistent with second-order maximization conditions, we use risk neutrality where $U'_e/U' = 1$. For risk aversion, however, $1 < U'_e/U' < \infty$. To establish an upper bound we appeal to recent work that employs cross-sectional data on household assets to establish properties of household utility functions. In particular, Cohn et al. (1975) found evidence that the coefficient of relative risk aversion is slightly decreasing in wealth. Friend and Blume (1975) found that "if there is any tendency for increasing or decreasing proportional risk aversion, the tendency is so slight that for many purposes the assumption of constant proportional risk aversion is not a bad first approximation" (p. 915). More recently, Morin and Suarez (1983) found the coefficient to be slightly decreasing for wealth levels up to \$100,000, after which it becomes approximately constant. Furthermore, Friend and Blume estimated the market price of risk to determine a value for the coefficient, which they argue is greater than one and may be as high as two. Since we are interested in the ratio of marginal utilities and not the coefficient of relative risk aversion, we cannot use these results directly; but we can explore the implications suggested by this work.

To determine an upper bound, one approach is to examine U'_e/U' for various utility functions that exhibit the properties cited above. The largest upper bound is associated with a utility function exhibiting constant relative risk aversion equal to two; thus, we use $U(A) = -A^{-1}$, where A is total wealth. The denominator of U'_e/U' is evaluated at total wealth, while the numerator is evaluated at total wealth minus the dollar value of earthquake damage. Again, to determine the largest upper bound, we assume the maximum expected damage of about \$20,000 developed below. To obtain total wealth we note from Friend and Blume's data (table 3, p. 908) that over their entire sample the market value of a house as a percentage of total wealth averaged 16 percent.¹⁰ Since the average market value of houses in

¹⁰ The use of 16 percent as the ratio of market value of houses to total wealth may seem small until one realizes that Friend and Blume (1975) define wealth to include human wealth. The authors regard this as the most appropriate definition; consequently, we use it here.

our sample is \$83,153, we use as an estimate of total wealth $A = \$83,153/.16 = \$519,706$. Finally, using $U(A) = -A^{-1}$, we obtain $U'_e/U' = 519,706^2/499,706^2 = 1.08$ for the largest upper bound.

Another approach for estimating U'_e/U' is to use a linear approximation (first-order Taylor series expansion) for describing changes in U' . Thus, we assume $U'(A) \cong U'(A_0) + U''(A_0)(A - A_0)$, where the Taylor series expansion takes place around the level of wealth A_0 . Since the coefficient of relative risk aversion is defined as $c = |U''(A_0)A_0/U'(A_0)|$ we can then rewrite our approximation for $U'(A)$ as

$$U'(A) \cong U'(A_0) \cdot \left[1 - c \left(\frac{A - A_0}{A_0} \right) \right].^{11}$$

If we let A_0 equal the level of wealth before the earthquake and let A equal the level of wealth after the earthquake, dividing the expression above by $U'(A_0)$ gives

$$\frac{U'_e}{U'} \cong 1 - c \left(\frac{A - A_0}{A_0} \right)$$

as an approximation of the ratio of marginal utilities in the two states of the world. This expression does not depend on use of a particular utility function, but rather will be a good approximation for utility functions that have small higher order terms for U''' and beyond. Using the highest estimated value for c of 2 and the highest estimate of damages of about \$20,000 we obtain

$$\frac{U'_e}{U'} \cong 1 - 2 \left(\frac{499,706 - 519,706}{519,706} \right) = 1.08.$$

This second approach gives an identical estimate to the first developed above and suggests that risk aversion plays a surprisingly small role in our analysis apparently due to the relatively small changes in lifetime wealth involved.

To estimate the odds of an event in the Los Angeles area, we use two sources. First, Kunreuther et al. (1978) report results of a survey question among California residents on the subjective beliefs concerning the odds of an earthquake. The average perceived odds of an event from that survey are about 2 percent per year.¹² To obtain a more objective estimate of the risk of an event we turn to a report

¹¹ Note that $U''A/U'$ will be a negative number for risk-averse individuals. Thus, we replace $U''A/U'$ by $-c$ in developing this formula.

¹² The average of the perceived odds used here was obtained from fig. 5.7 on p. 96 of Kunreuther et al. (1978) by taking the average of the end point risk of each risk category and multiplying by the reported frequency of occurrence.

issued by the Federal Emergency Management Agency (FEMA 1980), which estimated the odds of a large earthquake to be from 2 percent to 5 percent per year for the Los Angeles area. The upper bound of that range, 5 percent, resulted from scientific concerns over the Palmdale bulge, a temporary uplifting of the desert floor north of Los Angeles that occurred in the late 1970s. The lower bound estimate, which was widely publicized prior to the FEMA report, is based on the historical pattern of large earthquakes that have occurred in the Los Angeles area (Sieh 1978). For the relevant time period for our study, 1972–78, and for the Los Angeles area, there exists a remarkable coincidence between subjective and objective measures of risk of an earthquake. The FEMA lower bound estimate, which is appropriate prior to the occurrence of the Palmdale bulge, and the Kunreuther et al. estimate both imply $\rho = .02$ for estimating Δp in equation (4).

Finally, we need to develop an estimate of earthquake losses or damages associated with residing in an SSZ as opposed to residing outside of an SSZ, defined as Δs in equation (4). Again, we can obtain a subjective estimate of about \$20,000 from Kunreuther et al. (1978) for the average total damage people expect to occur to their homes if an earthquake occurs.¹³ As an alternative measure, engineering studies suggest that the *average* damage to a single-story frame house should a great earthquake occur near Los Angeles would be about 5 percent of the home's value (NOAA 1973). This implies a level of damage for the average house in our property value sample (worth \$83,153) of \$4,158. However, homes in areas of maximum ground shaking, such as would occur in an SSZ if the local fault ruptured, would suffer damage equal to about 25 percent of the home's value (NOAA 1973). For the average house in our sample, this implies damages of \$20,788 (for a home in an area of maximum ground shaking). These figures obviously span the Kunreuther et al. estimate, with the upper bound figure quite close, suggesting that households answering the Kunreuther survey may have perceived the question to imply that their home would be located in an area of maximum damage. Note, however, that Δs represents the difference in damages an individual would expect from living in versus outside of an SSZ should an earthquake occur. Thus, as an absolute upper bound, we will use a value of Δs of \$20,000 consistent with a subjective assessment that homes outside of an SSZ will suffer no damage. As a lower bound we will take the difference in the objective engineering assess-

¹³ Again, this average was obtained by weighting expected damage by frequency of occurrence among the survey respondents from fig. 5.6, p. 94, of Kunreuther et al. (1978).

ments (\$20,788 minus \$4,158) of \$16,630. Thus, the lower bound assumes homes in an SSZ will suffer the maximum level of ground shaking and homes outside an SSZ will suffer average levels of ground shaking.

To obtain an upper bound estimate for the annual value of living outside of an SSZ to an expected-utility-maximizing household, we substitute values of $U''/U' = 1.08$, $\rho = .02$, and $\Delta s = \$20,000$ into equation (4). These figures are consistent with the highest observed coefficient of relative risk aversion of 2 and the subjective evidence obtained by Kunreuther et al. on earthquake risk and damages. To obtain a lower bound estimate we assume risk neutrality so $U''/U' = 1$ and use scientific-engineering evidence for $\rho = .02$ and $\Delta s = \$16,630$. These assumptions yield a range for Δp of from \$333 to \$431 per year. In contrast, from the estimated property value equation, the perceived annual cost of living outside of an SSZ ranges from \$140 to \$440 depending on use of real or nominal interest rates. This evidence suggests that the estimated property value equation for Los Angeles is consistent with utility-maximizing behavior with respect to earthquake risks.

V. Conclusion

Schoemaker (1982, p. 552) summarizes the problems of expected utility theory as follows: "As a descriptive model seeking insight into how decisions are made, EU [expected utility] theory fails on at least three counts. First, people do not structure problems as holistically and comprehensively as EU theory suggests. Second they do not process information, especially probabilities, according to the EU rule. Finally, EU theory, as an 'as if' model, poorly predicts choice behavior in laboratory situations. Hence, it is doubtful that the EU theory should or could serve as a general descriptive model." Our analysis provides only indirect evidence with respect to Schoemaker's first point. However, having demonstrated consistency between our property value market results and the expected utility model for Los Angeles, we can strengthen the argument considerably by briefly considering the San Francisco case.

For San Francisco, home sale prices, damage to homes should an earthquake occur, and, presumably, risk preferences are all similar to the Los Angeles case analyzed in the previous section. However, the probability of a damaging earthquake is considerably less according to available scientific evidence. For example, the FEMA report (1980, p. 3) states: "the current estimated probability . . . is smaller [than for Los Angeles] but significant," and later gives annual odds for a great earthquake on the San Andreas fault near San Francisco as 1 percent.

These are half the odds given for a great earthquake in the Los Angeles area in the same report. Thus, from equation (4) of the previous section one would predict, on the basis of expected utility theory, that the property value differential for houses in SSZs in the Bay Area should be about half that observed in Los Angeles. From the two property value studies the differentials are \$2,490 and \$4,650, respectively. This successful "prediction" suggests both that individual households process probability information in a reasonably rational and accurate way and that, at least in a market situation with a well-defined institutional mechanism, the expected utility model may perform well in predicting behavior. It should be pointed out that through the decade of the 1970s, the media in California carried an average of two stories per week relating to local earthquake events, actual or possible damages, and probabilities (see, e.g., *Los Angeles Times*, April 7, 1975; April 4, 1976; April 22, 1978). Possible earthquake events are a topic of considerable interest within the state, and the level of awareness among state residents is very high (Turner et al. 1979). The scientific evidence summarized in the 1980 FEMA study used in our calculations was widely publicized throughout the 1970s and may well be responsible for the similarity between the Kunreuther et al. (1978) subjective probability estimates of earthquake risk and more objective scientific assessments.

In summary, the property value studies make a strong case for self-insuring behavior consistent with maximization of expected utility. Further support of this result can be found by comparing the property value studies with surveys (Brookshire et al. 1982). In our survey of homeowners located in SSZs in Los Angeles (Brookshire et al. 1980), when asked how much more they would pay to purchase the same home outside of an SSZ, only 26 percent of respondents were willing to pay anything more. However, the average of all responses (including zero bids) was \$5,920, very close to the average sale price differential of \$4,650 from the Los Angeles property value study.¹⁴

Efficient prices should convey information to consumers. We have shown that the property value markets for both Los Angeles and San Francisco convey hedonic price differentials to consumers that correspond closely to expected earthquake damages for particular homes located in SSZs. Although the information provided by the SSZ program is by no means perfect, our results suggest that programs to provide consumers with hazard information may well be effective.

¹⁴ Interestingly, when homeowners located outside of an SSZ were asked how much less expensive their house would have to be to get them to relocate in an SSZ, the average response was \$28,250 (see Brookshire et al. 1980). This asymmetry between willingness to accept and willingness to pay measures of value has been demonstrated in a number of studies (see, e.g., Hovis, Coursey, and Schulze 1983).

Appendix

TABLE A1
VARIABLES USED IN ANALYSIS OF HOUSING MARKET

Variable	Definition (Expected Effect on Housing Sale Price)	Units	Source
Dependent			
Sale price	Sale price of owner-occupied single family residences	\$100	Market data center
Independent—housing:			
Sale date	Month home was sold (positive)	January 1972 = 1 December 1972 = 12 January 1978 = 1 December 1978 = 12	Market data center
Age	Age of home (negative)	Years	Market data center
Bathrooms	Number of bathrooms (positive)	Number	Market data center
Living area	Square feet of living area (positive)	Square feet	Market data center
Pool	1 if pool, 0 if no pool (positive)	0 = no pool 1 = pool	Market data center
Air conditioning	1 if air conditioned, 0 if not (positive)	0 = no air conditioning 1 = air conditioned	Market data center
Fireplaces	Number of fireplaces (positive)	Number	Market data center
Independent—neighborhood:			
Distance to beach	Miles to nearest beach (negative)	Miles	Calculated
Age composition	Percent greater than 62 in census tract (positive)	Percent	1970 census
Ethnic composition	Percent black in census tract	Percent	1970 census
Distance to employment	Weighted distance to 10 employment centers (negative)	Miles	Calculated
SSZ location	1 if in SSZ, 0 if not (negative)	1 = SSZ 0 = not in SSZ	Fault hazard zones in California (E. W. Hart)
Independent—community:			
School quality	Community's twelfth-grade reading score (positive)	Percent	California Assessment Program (1979)
Housing density	Homes per square mile in surrounding community (negative)	Houses/square mile	1970 census, Southern California Association of Governments, Bay Area Association of Governments California Air Resource Board
Air pollution (TSP)	Total suspended particulates (negative)		

TABLE A2
MEANS AND STANDARD DEVIATIONS (in Parentheses) FOR THE VARIABLES USED IN THE HEDONIC HOUSING EQUATIONS

VARIABLE	LOS ANGELES COUNTY		BAY AREA COUNTIES	
	1978	1972	1978	1972
Sale price (1978 dollars)	83,153 (55,938)	64,075 (35,213)	75,650 (37,581)	58,959 (36,881)
Sale date	5.382 (2.86)	6.61 (3.25)	6.33 (3.22)	6.141 (3.40)
Age of home	27.57 (17.09)	24.43 (12.91)	25.00 (17.69)	20.159 (15.64)
Square feet of living area	1,442 (642.3)	1,439 (626.8)	1,430.714 (994.19)	1,494.796 (531.89)
Number of bathrooms	1.690 (.71)	1.62 (.66)	1.670 (.62)	1.724 (.61)
Number of fireplaces	.663 (.62)	.63 (.61)	.825 (.52)	.897 (.50)
Pool	.130 (.33)	.12 (.32)	.059 (.23)	.045 (.20)
View	.095 (.29)	.05 (.22)	.126 (.33)	.098 (.29)
SSZ location	.060 (.24)	.049 (.22)	.137 (.34)	.022 (.14)
School quality	60.83 (3.70)	69.67 (3.70)	63.544 (4.19)	69.810 (6.41)
Home density	2,213.5 (731.96)	2,262 (697.9)	2,476 (2,152)	2,431 (2,018)
Percent black	5.47 (18.00)	9.91 (24.5)	6.636 (16.37)	4.603 (13.17)
Percent greater than 62 years old	10.94 (7.01)	11.69 (7.84)	9.802 (7.37)	10.113 (7.75)
Air pollution	107.7 (14.16)	106.12 (13.93)	52.319 (11.91)	51.585 (11.92)
Distance to employment	.0183 (.004)	.0183 (.004)	.007 (.002)	.007 (.002)
Distance to beach	12.41 (7.69)	11.48 (7.48)		
Number of observations	4,865	4,927	5,438	5,460

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