THE LOMA PRIETA EARTHQUAKE: AN EVENT STUDY OF CHANGES IN RISK PERCEPTIONS AND THE HOUSING MARKET

prepared by

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I. INTRODUCTION

A. BACKGROUND

On October 17, 1989 at 5:04 PM the Loma Prieta earthquake, magnitude 7.1, struck the San Francisco Bay region. The earthquake occurred along the San Andreas fault and was centered in the Santa Cruz mountains. It was felt over an area of approximately 400,000 square miles, from Los Angeles (350 miles to the south) to the Oregon-California state line (north) to western Nevada (225 miles to the west).

The major impacts of the earthquake occurred in the bay area, home to approximately six million people. Confirmed impacts from the 15 seconds of shaking included: (1) in excess of 60 fatalities and 3700 injuries; (2) 12000 people left homeless; and (3) 1018 and 23408 homes destroyed and damaged, respectively resulting in over seven billion dollars in property damage. The pattern of damage was crazy-quilt (Washington Post, October 18, 1989) in that distance from the epicenter was less important than other factors such as soil type and structural engineering.

The Loma Prieta Earthquake of 17 October 1989 represents an exogenous shock to the markets in the San Francisco Bay area. As such, we would expect a set of short (transitory, lasting less than 6 months) and long (persistent, exceeding one year) term impacts to result (see Los Angeles Times December 18, 1989). These impacts are expected to be more significant in heavily damaged areas or areas that have similar characteristics to those heavily damaged.

Our expectations concerning market impacts are based on previous work on markets for consumer goods and services that were significantly affected by "events" outside the control of the economic agents that participated in the affected markets. The literature concerning the markets for financial instruments (stocks, bonds, etc.) is extensive in this regard (see Bowman, 1983 for a survey of this literature; see also Bondt and Thaler, 1987). In addition, it has been demonstrated that state and/or federal laws and statutes can (and have) impact(ed) residential housing prices and consequent development. Brookshire, et al (1985) found that the California Special Study Zone (SSZ) program designed to inform home buyers of potential earthquake hazard significantly affected housing prices. That is, enactment of the SSZ notification requirements negatively affected prices for homes located in special study zones, relative to those outside SSZs. In addition, Dale-Johnson (1988) and Bernknopf et al (1990) have observed significant housing value effects for coastal zoning regulations, and earthquake and volcano warnings, respectively. Therefore, it is well established that laws and regulations have effects on specific markets.

However, the relative effect of an actual physical event (e.g., natural hazard) has received little attention (one exception is Anderson and Weinrobe, 1986).

B. RESEARCH OBJECTIVES

The objective of the research reported herein is to assess the impacts of the Loma Prieta earthquake, to measure their initial magnitude and their propensity to persist into the future. We focus on two potential impacts: (1) the risk perceptions of citizens of the San Francisco Bay area; and (2) the housing market. Two types of data, subjective perceptions obtained from a survey of households and actual housing market transactions, are employed. The study area consists of the counties of Alameda, Contra Costa, San Mateo, Santa Clara, Marin, and San Francisco (areas both damaged and undamaged by the earthquake).

Our analysis of risk perception is based on subjective data and includes examination of two issues. First, we examine the roles played by government agency publications in forming perceptions. Second, we examine the relationship between risk perceptions and willingness to pay (or accept) to reduce (increase) earthquake risks.

The housing market analysis uses both subjective and objective data to investigate the relationship between location influences with varying degrees of associated risk and housing prices. That is, our analysis is designed to determine if risk, as measured by location influences such as soil type, is a significant determinant of housing price and the magnitude of any hedonic price gradient. In addition, we compare estimates based on subjective and objective data to determine the relationship between perception and actual market transactions.

The risk perception and housing market analyses are used to determine the value of risk attributes and hence the value of geologic information. Policy prescriptions are also offered.

C. RESEARCH METHODS

The empirical work related to risk perceptions and housing values is based on the theoretical construct in Brookshire, et al (1982). In this framework utility maximizing consumers allocate income between goods to the point that marginal willingness to pay for an additional unit of a good is exactly equal to the market price. A proposed change in the quantity of any good can then be determined by analyzing either willingness to pay information obtained from a survey (subjective) or market transactions data (objective). Given this theoretical construct we empirically test a set of hypotheses by utilizing both of these data sources. Empirical results based on the two data sets are also compared.

The subjective willingness to pay and associated risk perception data are obtained from a survey of homeowners in the San Francisco Bay area. The survey also includes questions pertaining to home attributes and perceived home value for comparison to the actual market transaction data. In order to heighten validity of the results a large sample of homeowners was surveyed. Several validation tests pertaining to possible survey biases are also conducted.

The housing market transaction data was obtained from Damar Corporation, a data clearinghouse in Los Angeles. This data service tracks all residential home sales in California. Our data set is for the period immediately before and after the Loma Prieta earthquake (January 1988 to November 1990). Thus, the housing data set is both large and of recent vintage, allowing accurate estimation of the relationship between risk and housing price and comparison to the survey estimates. Sensitivity analysis is also conducted.

D. SUMMARY OF RESEARCH RESULTS

Our research suggests that the Loma Prieta earthquake had a measurable impact on both risk perceptions and on housing prices. We expect that these effects will dissipate with time from the event. In addition, individuals attach a measurable monetary value to changes in risk. Improvements in soil type and/or location vis-a-vis earthquake special study zones are valuable to residents of the San Francisco Bay area. Exact monetary estimates, which are obtained from both the objective and subjective data, are provided for changes in these variables. Finally, available evidence suggests that estimates derived from market data is more certain.

Our research results suggest two policy recommendations. First, geologic information, which has monetary value to homeowners, should be provided wherever possible. Accurate information concerning expectations about earthquake location and magnitude or the relative performance characteristics of geologic variables will produce greater efficiency in the operation of markets. In addition, this information will enable individual decision makers to upgrade existing locations to better protect themselves from potential geologic hazards. Second, geologic information should be used by policy makers to determine (1) the appropriateness of building in a specific area and (2) the relevant building codes that should apply. That is, geologic information should be utilized in a location specific manner to affect building behavior and land-use planning.

E. ORGANIZATION OF REPORT

The remainder of the report is organized as follows. In the next chapter we present the theoretical basis for our analysis. The overall theoretical construct, as well as the frameworks for the individual studies on risk perceptions and the housing market are presented. The set of testable hypotheses that correspond to the theoretical model are also described. Chapter III is concerned with the survey analysis. Included in this chapter are discussions of the research methodology, the sample plan and response rates, and research results pertaining risk perceptions and the value of risk reductions. In chapter IV the housing market analysis is presented. Data specifics, estimation results, and conclusions concerning the value of risk attributes are presented. A comparison to the housing market analysis based on subjective data is also included in this chapter. Chapter V focuses on econometric analysis of the survey data. Four specific analyses are conducted: (1) subjective assessment of risk variables on housing prices; (2) estimated bid functions from contingent valuation data; (3) estimated utility functions; and (4) referendum contingent valuation method. We also conduct relative comparisons between the subjective and objective approaches. Comparisons of our results with other recent work are also included. Conclusions and policy implications are offered in the final chapter.

II. THEORETICAL BASIS AND TESTABLE HYPOTHESES

A. BACKGROUND

In the analysis reported herein we use the housing value and survey approaches to place an economic value on risk changes. These approaches are labelled the hedonic price method (HPM) and the contingent valuation method (CVM), respectively. Each of these approaches has received considerable theoretical scrutiny. The hedonic price method is based on the writings of Rosen (1974) and Freeman (1979). The survey approach has been modeled using standard concepts of consumers' surplus by Randall et al (1974), Bohm (1972), and Brookshire, Ives, and Schulze (1976), among others. Viscusi and Evans (1990) provide the latest theoretical treatment of the survey method. Brookshire et al (1982) in their seminal article develop a theoretical model that incorporates the HPM and the CVM.

In this report we utilize the Brookshire et al (1982) construct as our overall theoretical basis. Given this framework we also describe in detail the hedonic price method and the specific survey approach. In particular, the analysis of Viscusi and Evans (1990) is used to estimate the willingness to pay for risk reductions and to determine the welfare loss associated with any over-reaction to risk information (see also Foster and Just, 1990).

B. GENERAL THEORETICAL MODEL

The typical household is assumed to maximize a utility function

$$U = U(R, X) \qquad (1)$$

subject to the budget constraint

$$Y - KX - P(R, A) = 0, \qquad (2)$$

where R = the level of earthquake related risk; A = a vector of housing attributes other than earthquake risk; X = consumption of a composite commodity, exclusive of housing; K = unit cost or price of the composite commodity X; P = the periodic price of housing; Y = household income; and U(R, X) = household utility, a decreasing function of risk, $U_R < 0$, and an increasing function of consumption, $U_X > 0$. We also assume the existence of a continuous, differentiable price gradient P(R, A) and that lower prices will be paid for homes in areas more susceptible to earthquake damage ($P_R < 0$). Moreover, to simplify the analysis each house is assumed to have identical housing attributes (i.e., the vector A is constant across households)[1]

The first order conditions for choice of R and X imply that

$$K^*(U_R/U_X) = P_R, \qquad (3)$$

or that the marginal rate of substitution between risk R and the composite commodity X, valued at the cost of the composite commodity K, equals the slope of the housing price gradient at equilibrium location and consumption levels.

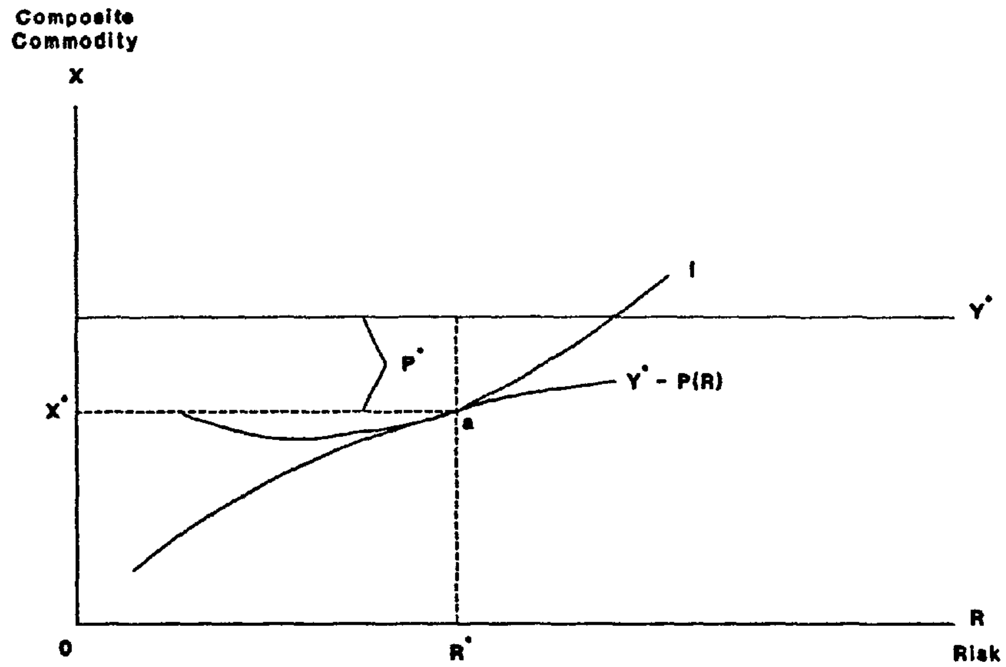
Figure 1 illustrates the solution graphically as a tangency between the housing price gradient and an indifference curve. The vertical axis measures the quantity of the composite commodity under the assumption that its price is equal to unity. Earthquake risk is measured on the horizontal axis. Given household income Y^0, the relevant budget constraint shown as Y^0 - P(R) is obtained by vertically subtracting the price gradient. Thus, the typical household, with preferences shown by the indifference curve I would maximize utility at point a, choosing to locate with risk R^0, consume X^0, and pay housing price P^0. Of course, both income and preferences over risk and consumption determine location decisions over risk levels; that is, households with greater income would likely consume more of the composite good and less risk, whereas those with strong risk aversion would trade off consumption of X for greater safety.

Our next task is to examine benefit estimation within this general framework. Benefits (damages) associated with an improvement (deterioration) in risk can be measured along either the housing price gradient or the individual indifference curve. Consider each of these important relationships in greater detail.

[1] Brookshire, et al (1982) have shown that relaxing this assumption does not alter the primary predictions of the model.

Figure 1

Utility Maximization



C. BENEFIT ESTIMATION: HOUSING MARKET ANALYSIS

The housing price gradient is estimated using the hedonic price approach, which is based on the theoretical writings of Rosen (1974) and Freeman (1979). The method allows the estimation of the benefits of both marginal and non-marginal changes in attributes that comprise the composite commodity housing. In the application under study the cost of housing in the San Francisco area market is assumed to be described by a hedonic price function. Let

$$P = P(R, A) \tag{4}$$

be the hedonic function which relates the price of a home to earthquake risk and a vector of structural, neighborhood, and environmental variables. The marginal cost or hedonic price of an additional unit of a particular characteristic is then determined as the partial derivative of P(R, A) with respect to that characteristic.

As indicated above the rational consumer will choose the optimal bundle of attributes by maximizing a utility function subject to an income constraint which depends on P. Thus, the individual locates such that his/her indifference curve is tangent to the price gradient. Individual willingness to pay for a marginal change in a characteristic is equal to the hedonic price---the right hand side of equation (3) above (Rosen, 1974). Thus, the estimation and partial differentiation of P(R, A) reveals the marginal willingness to pay for the various attributes of housing.

Each point on the estimated hedonic price gradient (market locus of opportunities) represents a utility maximizing position for some individual. Following Freeman and Rosen, this information can be used to estimate the benefits of a non-marginal change in an attribute using a multi-step procedure. The hedonic price obtained in an earlier step is related to a vector of individual characteristics to determine the individual's implicit demand curve for the characteristic.[2] The integral of the implicit demand curve over the proposed change in the attribute yields an estimate of the benefits of non-marginal changes in the attribute.

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[2] Under the assumption that individuals have identical utility functions then various locations (set of utility maximizing points) are chosen because individual characteristics vary across individuals. A relationship between hedonic prices for a particular attribute and a vector of individual characteristics (cross-sectional data base) yields an estimate of the implicit demand function for the attribute.

The Freeman-Rosen approach for determining the benefits of non-marginal changes in attributes has been subjected to extensive criticism. Especially problematical is the identification of the implicit demand curve (see Mendelsohn, 1985; Epple, 1987; Bartik, 1987). Therefore, we opt for an alternative approach.

Brookshire et al (1982) demonstrate that a housing value change along the hedonic price gradient (associated with a non-marginal improvement in an attribute) is an upper bound estimate of benefits. A similar result was proven by Kanemoto (1988) in a recent paper. In addition, Bartik (1988) has shown that this housing value change is an accurate indicator of benefits since the usual benefit measure (Freeman-Rosen) underestimates benefits because it ignores adjustments by housing demanders and suppliers. Therefore, even though housing value changes are an upper bound estimate (compared to the theoretically correct measure) they are reasonably close to true benefits since the usual measure underestimates benefits. Thus, in our analysis of risk attributes we use housing value changes along the hedonic price gradient as a measure of benefits. An improvement in risk from R^0 to R^1 in Figure 2 would then be valued at ΔX or $X^0 - X^1$.

Of particular interest are the studies by Brookshire et al (1985) and MacDonald et al (1987) who examined the notion of losses from a natural hazard as influencing home prices. Brookshire et al model the expected loss (s) as one of the characteristics of the home. Then, under an expected utility hypothesis with two states of the world (earthquake or no earthquake), the partial derivative of the hedonic price function with respect to the expected loss equals the consumers marginal valuation of safety. MacDonald et al also use a two-state utility function and the expected utility hypothesis. They model the problem in probability space, however. If p equals the probability of the good state, then they show that p becomes one of the characteristics of the home. The partial derivative of the hedonic price function with respect to p is the marginal "option price" or marginal valuation of increasing the probability of the good state. The two approaches are really similar, since the expected loss in the Brookshire et al paper is just (1-p) times the loss from the natural hazard occurring (the bad state in MacDonald et al). Therefore, we can think of p as the probability of loss. Moreover, in the Brookshire et al paper, to increase the probability of the good state, the consumer chooses to locate in an area with lower probability of damage.

The findings in both Brookshire et al and MacDonald et al support the use of the hedonic methodology to estimate consumers' marginal valuations of earthquake hazards. The model is simply modified to include earthquake risk variables (R). Hence, $P = P(S, N, R)$. The interpretation of the hedonic price of R depends on the type of measure used.

Below, we extend some of the results of Brookshire et al and MacDonald et al. We think of the earthquake variables as measuring the consumers' "perception of hazard". The actual hazard is the fact that some financial loss is possible (non-zero probability). This thought experiment is different than Brookshire et al and MacDonald et al, who assumed that the hazard was known. In our model, the hedonic price of the hazard perception ($\partial P/\partial R$) gives the marginal valuation of the hazard.

D. BENEFIT ESTIMATION: UTILITY FUNCTION ANALYSIS

An alternative approach for estimating benefits is to examine risk changes along the individual's indifference curve. In Figure 2 an improvement in risk would be worth $X^0 - W^1$ if one measured benefits directly along the individual's indifference curve since the individual maintains constant utility as the risk level changes. However, this approach is problematical since there exist no market data that can be used to estimate the individual's indifference curve (i.e., it is unobservable to the researcher). Survey approaches provide the relevant data.

The survey used in this study asked households to determine their maximum (minimum) willingness to pay (accept) to obtain an improvement (deterioration) in earthquake risk at their residential site. These survey responses are directly comparable to the value of risk changes obtained from the analysis of housing market data.

Directly comparing survey responses to housing market benefit estimates as suggested above presumes that there is no change in the utility function as the risk level changes. However, the utility function may be affected by a change in risk. This possibility requires a state-dependent utility function as in Arrow (1971),

$$EU = \sum s_j U_j(Y), \tag{5}$$

where EU is expected utility, s_j is the probability of event j, and U_j is the state-dependent utility function that obtains when event j occurs. The rational consumer is assumed to maximize (5) subject to the usual budget constraint. First order conditions imply a tangency between the locus of market opportunities (hedonic price gradient) and a constant expected utility locus. In Figure 1 the only relevant change is that indifference curve I is replaced by the constant expected utility locus.

This formulation seems to complicate matters since we now have two utility functions (event state and no event state) that appear to be unobservable. However, Viscusi and Evans (1990) illustrate how survey data can be used to estimate the parameters of these utility functions under specific conditions. Consider this approach in more detail.

In our survey we obtain information on: (1) the respondents' assessment of the damage potential given his/her current residential location; (2) the respondents' assessment of the damage potential given a change in a geological variable (either soil type or location vis-a-vis a special studies zone); (3) the purchase price of his/her home; (4) the compensation required for an increase in risk and/or the willingness to pay to obtain a risk improvement; and (5) the damage experienced dependent on geological characteristics.

Let U denote the utility of wealth (we use home price as a proxy) in the no event state and let V denote utility of wealth after the event. In addition, let R^0 equal the base risk and R^2 equal the increased risk after the change in the geological variable (see Figure 2). Finally, let d_j equal the damage in the base and post situations. This damage leaves r_j remaining wealth in the base and post states. Then the amount of compensation (C, a fraction of wealth) that equates expected utility after the change in the geological variable satisfies

$$(1 - R^0)*U(Y) + R^0*V(Y*r_1) = (1 - R^2)*U(Y*(1 + C))$$

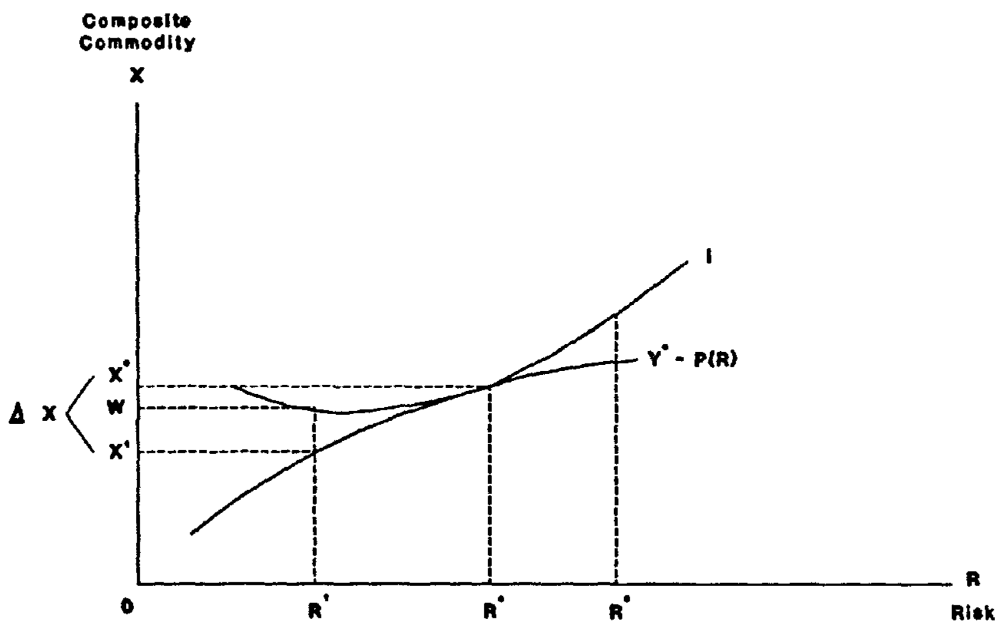
$$+ R^2*V(Y(1 + C)*r_2). \qquad (6)$$

Viscusi and Evans (1990) illustrate how equation (6) can be used to empirically estimate the parameters of the utility functions U and V. However, restrictions on functional form are required. For example, if one uses the Cobb-Douglas parameterization, then $U(Y) = Y^u$, $V(Y) = Y^v$, and equation (6) can be re-written as

$$(1 - R^0)*u*\log(Y) + R^0*v*\log(Y*r_1) = (1 - R^2)*u*\log(Y*(1 + C))$$
$$+ R^2*v*\log(Y(1 + C)*r_2). \qquad (7)$$

Figure 2

The Value of Changes in Risk



Equation (7) does not allow the independent estimation of the unknown parameters u and v. However, one can estimate their ratio a = u/v by solving equation (7) for C and using non-linear least squares (see Viscusi and Evans, 1990 for specification of equation actually estimated). Once the parameters of the utility functions are estimated then analysis of changes in risk levels can be directly evaluated and compared to the estimates obtained from the housing market analysis.

E. EMPIRICAL PROCEDURES AND TESTABLE HYPOTHESES

Our analysis of the value that individuals attach to changes in risk encompasses three interdependent studies. First, we obtain data from the housing market in the study area and estimate P(R, A), the hedonic price gradient. Differentiation of this function allows calculation of the change in price for a corresponding change in risk. Following Brookshire, et al (1982), Bartik (1988), and Kanemoto (1988) this price change is interpreted as the benefits (damages) of a risk improvement (deterioration). The important testable hypothesis in this analysis is:

Hypothesis 1: Geologic risk measures are not capitalized into housing values.

Alternative: Geologic risk measures are capitalized into housing values.

This hypothesis is also tested using data on home characteristics obtained from our survey sample. This latter analysis is labelled the subjective hedonic approach.

In the second study we utilize survey data to directly estimate willingness to pay and/or accept for various changes in geologic variables. These willingness to pay and/or accept values are directly compared to the house price differential obtained in the first study. The Brookshire et al (1982) paper suggests that for an improvement in risk the price differential will equal or exceed the willingness to pay value. On the other hand a risk deterioration will result in a willingness to accept value that equals or exceeds the price differential. This leads to our second hypothesis:

Hypothesis 2: For risk improvements the price differential will not equal or exceed willingness to pay.

Alternative: For risk improvements the price differential will equal or exceed willingness to pay.

The case of deterioration is also tested.

The final study also uses survey data. We follow Viscusi and Evans (1990) and use these data to estimate the parameters of the underlying utility function. This allows us to evaluate various risk changes and to compare the resulting values to the corresponding housing market values. This modeling effort leads to a number of testable hypotheses.

Hypothesis 3: $U(Y) < V(Y)$. The utility of income in the no event state $U(Y)$ is not greater than the utility of the event state $V(Y)$.

Alternative: $U(Y) > V(Y)$. The utility of income in the no event state $U(Y)$ is greater than the utility of the event state $V(Y)$.

Hypothesis 4: For risk improvements the price differential will not equal or exceed willingness to pay obtained from the estimated utility function.

Alternative: For risk improvements the price differential will equal or exceed willingness to pay obtained from the estimated utility function.

The case of deterioration is also tested.

III. SURVEY DESIGN AND SUMMARY RESULTS

A. INTRODUCTION

A significant portion of the empirical analysis conducted herein requires detailed data on risk perceptions, behavior adjustments to the Loma Prieta earthquake, and the value that individuals' attach to geologic information. However, actual transactions data from established markets are not available. Thus, we utilize survey procedures to obtain the necessary information. In this chapter the survey objectives, procedures, and summary results are discussed.

The chapter is organized as follows: The next section provides details of the survey objectives. Survey design and pre-testing are discussed in sections C and D, respectively. Sample selection and survey implementation follow. The final section provides summary results for a variety of issues.

B. OBJECTIVES OF SURVEY

The survey was designed to obtain three types of information: (1) individual risk perceptions; (2) housing and personal characteristics; and (3) willingness to pay/accept to obtain risk changes. The first major focus of the survey is risk perceptions. In particular we were interested in the formation of risk perceptions, the consistency of risk perceptions across risk types, and the change in risk perceptions associated with the Loma Prieta earthquake.

Risk perceptions pertaining to earthquakes are influenced by a variety of variables such as personal and related experience of other man-made or natural disasters, the amount of time spent in the California/Bay Area and previous experience with earthquake damage. In order to evaluate the precise impact of the Loma Prieta earthquake on risk perceptions these other potential determinants need to be evaluated.

The consistency of risk perceptions is examined by obtaining information on smoking behavior, seat belt use, traffic behavior history, and the utilization of smoke/burglar alarms. Information about various types of precautions undertaken by homeowners is also obtained to provide a comprehensive assessment of risk perception consistency. This information is also relevant for evaluating the degree of self-insurance (e.g.,gravitating to a safer location such as those outside special study zones) undertaken to protect against losses associated with earthquake risks.

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The final risk perception issue concerns the impact of events on risk perceptions. Data that allows evaluation of the degree to which the Loma Prieta earthquake may have heightened risk perceptions is obtained.

The second objective of the survey was to obtain information on housing characteristics; structural, neighborhood, and location. This information allow the estimation of a hedonic equation based on survey data. This subjective hedonic equation is compared to the objective equation generated from actual market transactions. The valuation of earthquake risk obtained from each study is also compared. In this context risk of a potential earthquake is defined by either the type of soil on which the home is situated or location in/out of a special study zone (SSZ). This comparison requires controlling for "other" factors which affect housing values besides earthquake risk, such as house characteristics and quality of the neighborhood. Consequently, the survey focuses on obtaining this type of information. In addition, we obtained information on the personal characteristics of respondents for use as control variables.

The third focus of the survey was on determining individual willingness to pay and/or accept for changes in risk variables. Specific questions that required respondents to evaluate their willingness to pay/accept for risk changes were included in the survey.

C. SURVEY DESIGN

There is an extensive literature in Economics and Psychology which stresses two research findings. First, surveys should be designed in such a way that they are neutral and as bias free as possible. Specifically, the viewpoints of the designers of the survey regarding the topics of interest should not be reflected in the survey itself. A general discussion of these issues is available in Wallsten et al (1980). Second, survey questions should be simple and result in little cognitive overload if individuals are to respond effectively (Simon, 1978; Slovic and Lichenstein, 1968).

The survey was designed with these two issues in mind. The questions are worded in an objective, bias free manner. Almost all questions require either a yes/no response or a selection of desired values from a menu of options. A copy of the survey is presented in the Appendix.

The survey contains five major sections, each concerned with specific information category. The initial section is designed to obtain information about the respondent's experience with natural events (landslides, hurricanes, floods etc.) and man-made events (home burglary, auto theft, violent crime etc.). These personal experiences may influence a respondent's risk perception. This section also contains questions which probe deeper into risk preference behavior. Questions are asked about smoking behavior, seat belt use and burglar/smoke alarms usage. These questions assess whether the respondent is sensitive to other types of everyday risk. Finally, this section investigates the type of preparations respondents have made for a possible earthquake. These questions include whether they have read the U.S.G.S. brochure entitled "The Next Big Earthquake". Questions about purchase of earthquake insurance, changes in commuting patterns, and availability of emergency supplies are asked. The precautions taken in making the home earthquake proof are also assessed.

The second section is concerned with evaluating risk perceptions of earthquakes. Questions about actual and potential damage to the home set the stage for assessing risk perceptions. Respondents are asked to rank their risk perceptions of a possible earthquake relative to other natural and man-made events such as a flood, tornado, home fire, theft, plane crash, etc. The comparative evaluation is made using a risk-ladder where the higher the event on the ladder, the greater the chances of the event taking place. Past studies have shown that individuals are better able to assess risk in a relative sense. The presence of other risky events allows well known reference points to act as bench marks. The respondents are requested to evaluate the possibility of property damage from a future earthquake on this relative ladder-scale before and after the Loma Prieta earthquake.

The next portion of the survey obtains data on the value of geological information by assessing the subjective dollar value respondents place on two types of risk variables: (1) the type of soil on which the house is located; and (2) home location vis-a-vis the earthquake special study zone (SSZ). Or procedures can be illustrated through closer examination of the value respondents place on safer soil type.

First, respondents were requested to circle the type of soil on which their home is located: gravel, clay, unconsolidated sediment, volcanic rock, sandstone or granite rock. In the second step the respondent was asked to assess the relative safety of his/her home relative to other soil types, either safer or riskier. In the final step, the respondent was requested to provide the dollar value he/she would pay/accept to obtain an alternative level of safety.

Previous literature has shown that the willingness to pay measure for additional safety is generally much lower than the compensation demanded for additional risk undertaken (Harless, 1989). The willingness to pay measure is considered relatively more reliable whereas the compensation measure is considered unstable and upward biased.

Moreover, each of these measures of assessing the value of risk has methodological weaknesses (Mitchell and Carson, 1988). Thus, an alternative procedure for evaluating the value of risk soil-type is employed. This procedure involves attaching a specific dollar value to the valuation question and requesting a yes/no response. For instance, a particular respondent is asked whether he is willing to pay $X to have his/her home in a safer location. Each respondent is given a different dollar value with which to respond. In this way the yes/no responses are obtained for an entire distribution of dollar values. The dollar threshold at which the yes-responses convert to the no-responses can than be identified as the maximum bid for the additional level of safety. In a subsequent chapter these referendum responses are evaluated by a logit model to determine the subjective value respondents place on safer locations.

The procedures mentioned above are conducted for two risk variables; soil type and SSZ location. In each case the direct valuation procedure and the referendum method are employed to elicit subjective price for additional safety.

The third section of the survey gathers information about home and neighborhood characteristics. This information is necessary in order to control for factors (other than earthquake risk) that also influence the value of a typical home. Besides the time and purchase price of the home, other site specific information such as lot size, interior square footage, number of bedrooms/bathrooms, availability of a scenic view, pool, etc. is obtained. Variables capturing the quality of the neighborhood include air and school quality and the risk of crime in the vicinity. Distances from the home to work, ocean/bay and major fault lines are also obtained. The respondent is also asked the current perceived value of the home and perceived change in value corresponding to the Loma Prieta Earthquake.

The fourth section obtains information about the respondent and his family. These control variables are potentially important for subjective valuation of risk. Information about the respondents age, sex and education is obtained. Family characteristics include household size and family income.

The final portion of the survey encourages respondents to indicate whether any important issue has been omitted, as well as any other comments they may have. The survey concludes with a thank you and an offer to send respondents a summary of the results if desired.

D. SURVEY PRE-TEST: FOCUS GROUPS

A draft copy of the survey was pre-tested on two convenient sample groups: 89 upper-undergraduate students and 16 staff members of the San Diego State University. The survey was administered to these focus group participants. Upon completion of the survey an informal discussion was held with each focus group to identify potential ambiguities in the questions and to seek improvement in question design and sequencing. These focus group discussions were helpful in identifying several potential trouble spots in the survey. For instance, the focus groups alerted us to the need to clarify that the odds indicated on the risk-ladder represented nationwide averages. The names attached to various soil types were also clarified by dividing them into two groups: (1) unconsolidated soils/landfill and (2) consolidated soils/rock. The ordering of the questions was also altered on the basis of the feedback from the two pre-tests. Upon completion of the focus groups the final version of the survey was prepared.

E. SAMPLE SELECTION

In order to assess the impact of the Loma Prieta earthquake on risk perceptions and housing values in the San Francisco Bay area, data was obtained from six counties: Alameda, Contra Costa, Marin, San Francisco, San Mateo and Santa Clara. This broad geographical base ensured that areas which were heavily damaged by the earthquake, as well as areas which did not experience significant damage were included in the study.

An earthquake in the Bay area could potentially cause considerable damage to life and property and affect a broad spectrum of individuals. However, we could not survey all groups. Criteria were established for sample selection. First, we focused on those with relatively permanent ties to the area---property owners. Our second criteria for sample selection was the presence of a readily available data base. Damar Corporation, a data clearinghouse centered in Los Angeles, CA. keeps track of every single family home sale in California. Thus, we focused on single family home owners. Third, it was presumed that recent purchasers of homes in the bay area would be relatively more cognizant of earthquake risks. Thus, we focused on owners of homes purchased after January 1, 1988.

The data obtained from Damar Corporation consisted of individual names, addresses, and detailed structural characteristics of the home for every home sale in the study area from January 1988 to November 1990. Since the study focuses on the impact of the earthquake, it is important to have information before and after the event. The original sample had in excess of 50,000 observations. However, many of the observations were incomplete. For example, many of the observations were missing the census tract indicator, an important variable for matching neighborhood data to the structural information. Consequently, the original sample was reduced to approximately 10,000 complete data points. A random sample of 3,033 was selected from this reduced data set for the mail survey.

F. SURVEY IMPLEMENTATION AND RESPONSE RATE

Survey methods for obtaining primary data have improved significantly over the last decade. These improvements, as well as the desired procedure for conducting surveys is discussed in detail by Dillman (1978). The approach adopted for this homeowners survey closely adheres to the procedures recommended by Dillman.

The basic feature of the Dillman or Total Design Method (TDM) is to achieve a planned response rate by careful design and control of the implementation procedure. In order to stimulate interest and encourage responses, the entire procedure is personalized.

Following the TDM, each sample observation was sent a package that contained three components: (1) personalized cover letter; (2) self-addressed return envelope; and (3) the survey. All packages were sent in hand-stamped envelopes with an initial mailing date of March 18, 1991.

The cover letter was personally addressed and was individually signed. It was made clear in the cover letter that the respondent was selected in a scientific sample and that his/her contribution to the study was critical. Complete anonymity was ensured. A sample of the cover letter appears in the Appendix.

One week after sending the initial package, a personalized postcard reminder was mailed. For those who did not reply in three weeks, a second cover letter, with another copy of the survey and another self-addressed return envelope was sent on April 8, 1991. This second cover letter again emphasized the importance of returning the completed survey (see the Appendix). Although Dillman suggests further follow-up procedures such as a telephone call, this study did not pursue the matter after the second reminder. However, we did respond to approximately 40 phone calls from respondents who asked various clarifying questions.

Out of the 3,033 surveys mailed out, 93 were returned because of incorrect addresses. Consequently, the effective sample size was reduced to 2,940. The overall response rate turned out to be 37.13% (1,092 responses from the effective sample of 2,940). The daily cumulative response rate is plotted in Figure 3. We regard this level of response to be satisfactory.

Important factors that contributed to the level of response in the positive direction include the controversial nature of the topic, the heightened interest in risk issues after Loma Prieta, the personal stake of home owners, and the strict adherence to the personalized procedures of the TDM. However, the response rate was limited because homeowners were requested to fill out an eleven page questionnaire without any financial remuneration and some of the questions may have caused some undue concern. For example, questions concerning earthquake insurance and home alarms seemed to offend some potential respondents.

G. SURVEY RESULTS

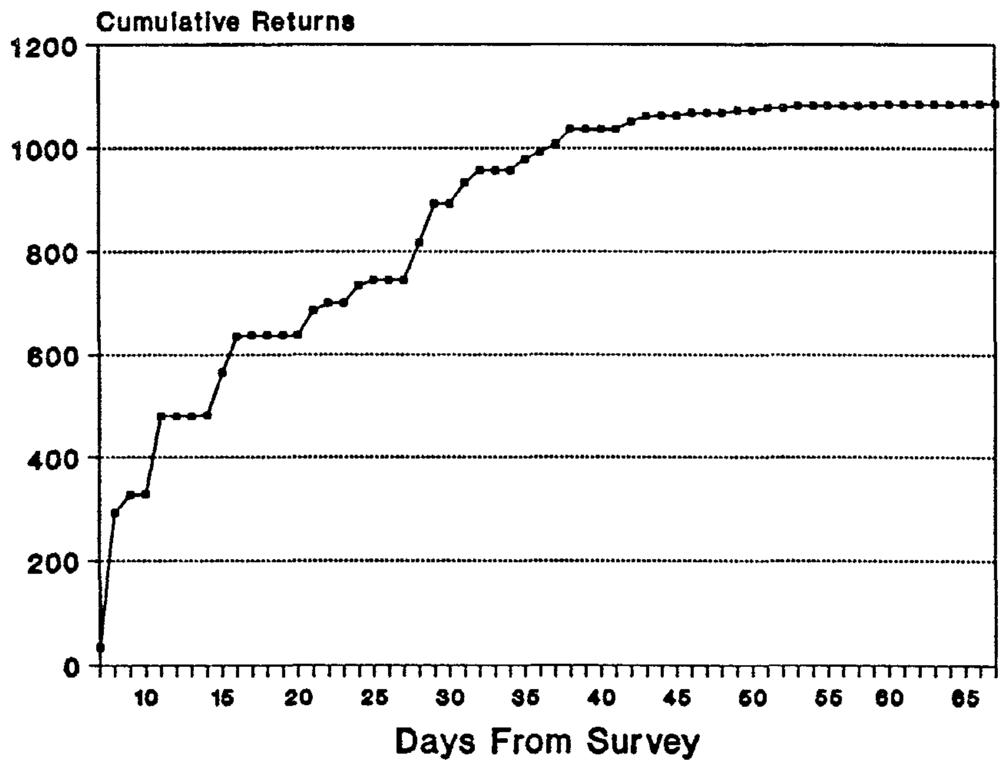
In this section brief results are provided for the following nine categories: (1) respondent socioeconomic characteristics; (2) the risk experience of respondents; (3) the role of information provided by the U.S. Geological Survey; (4) behavior modifications after Loma Prieta; (5) perceptions of earthquake risk; (6) home characteristics; (7) actual and potential damage assessment; and (8) the value of geological information. Consider each of these categories.

Respondent Characteristics

Since our survey focused on homeowners and the average home value in the study area is approximately $300,000 then one would expect survey respondents to be relatively more prosperous and well educated compared to the average state and/or national profile. The average income of the family in our homeowners sample is $81,742 compared to the state average per capita income of $18,753. The same pattern is borne out in educational attainment. In our sample 96.3 percent of the respondents have completed high school and 71 percent have completed some college work. The corresponding national numbers are 59.2 percent completing high school and 20.3 percent performing some college work. The educational achievements of our sample respondents are depicted in Figure 4.

Figure 3

Cumulative Surveys Returned vs Days From Survey



The average age of survey homeowners is 38 years compared to state average of 33.6 years. Again, this should not be surprising, given the need to build up savings before being able to purchase a home in the San Francisco area.

Risk Experience of Respondents

On the average the respondents have lived in California for 22.61 years. The average amount of time spent in the Bay area is 18.33 years. Given the average age of 38 years, this implies that approximately one-half of the lifetime of a representative individual has been spent in the Bay area. It is important to take into account the exposure of the respondents to different types of natural disasters, since these experiences could potentially shape their risk perceptions about future earthquakes.

Exposure is evaluated at two levels: (1) personal experience; and (2) knowledge of "others" having experienced natural disasters. It is not surprising that almost all respondents have had a personal (99.07%), as well as a related experience (98.50%) with earthquakes. Other common forms of disasters experienced (ranked in terms of frequency) are floods, hurricanes and tornados. The ordering of this frequency ranking is similar for personal as well as related experiences. Figure 5 provides a detailed composition of the experiences of respondents regarding natural disasters.

The Role of the USGS Brochure

After the Loma Prieta earthquake, the U.S. Geological Survey prepared and mailed out a very comprehensive brochure entitled The Next Big Earthquake. Relevant topics included evaluating of earthquake risks and undertaking different precautionary measures. In order to assess the impact of the brochure we included questions about it in the survey. From the sample data, it appears that roughly 38.2 percent of the respondents are familiar with the brochure. Fifty-two percent of this group have casually glimpsed through it whereas 21 percent have read it carefully and 39 percent have kept it for future reference. These statistics indicate that only about half the home-owners who received the brochure have bothered to glimpse through it, a somewhat surprising result.

Figure 4

Educational Achievements of Sample

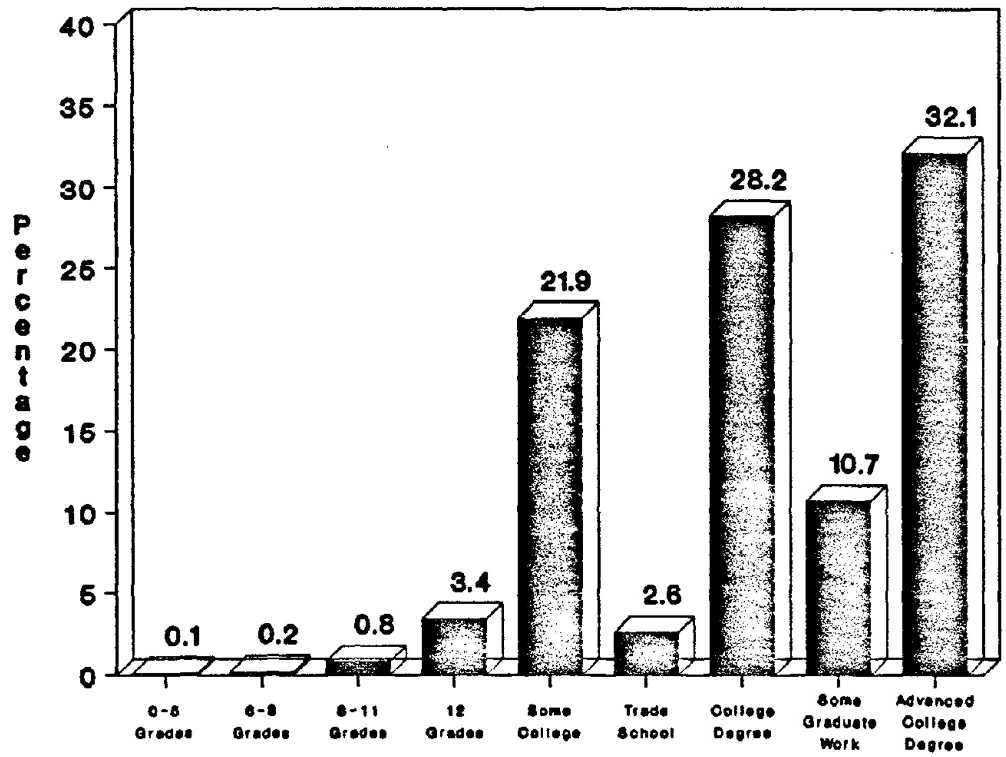
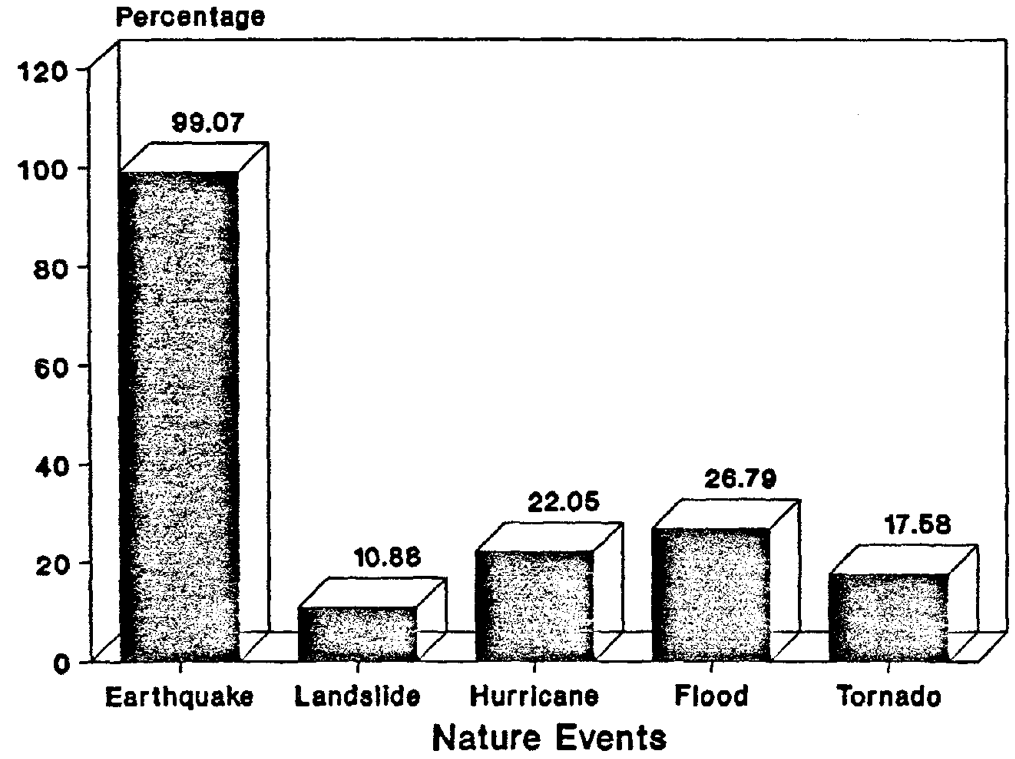


Figure 5

Personal Experience with Natural Events



Behavior Modifications

Since the Loma Prieta earthquake has the potential to be a significant psychological shock, one would expect some behavior modification after the event. This is indeed the case. Prior to the earthquake only 40.5 percent of the homeowners had purchased earthquake insurance when they bought their home. After the earthquake 54.2 percent of the individuals who bought their home also purchased earthquake insurance. This information implies that the earthquake made home owners more sensitive to earthquake risks, resulting in a 14 percent increase in earthquake insurance purchases.

Behavioral changes with regard to changes in commuting patterns after the earthquake were similar in that 14.33 percent of the respondents changed their commuting patterns after the earthquake.

The percentage of respondents that keep flashlights and other emergency material was approximately 95.8 percent. About 56 percent of those who indicated preparedness indicated a change in behavior after the earthquake. The proportion of respondents that store canned goods and/or water was relatively lower (60.4 percent). Again, approximately 64 percent of this category indicated that the earthquake changed the amount of cans/water stored.

One way to prepare for a possible earthquake is to make the home more resistant to tremors. It turns out that only 37 percent have made changes to their home. About 79 percent of those who made changes, indicated that the precautions taken were minor. Securing bookshelves and pictures was the most common adjustment.

Perception of Earthquake Risk

One of the basic objectives of this study is to determine how the Loma Prieta earthquake has affected risk perceptions concerning future earthquakes. Elsewhere in this investigation, we approach the issue systematically by econometric analysis. In this section, we examine the reported evidence without controlling for confounding variables. The homeowners in the survey were requested to indicate the chances of property damage in a future earthquake along a probability ladder. This ladder indicates the relative probabilities of different types of natural and man-made disasters, such as a plane crash, explosion, tornado, flood, home fire, theft etc. Based on his/her perceptions, the respondent is asked to indicate the relative chances of property damage from an earthquake. The probability scale ranges from

"A" to "R" (18 increments). The average response was the "Jth" increment (median was the "Kth" value). In relative terms, the average likelihood of property damage from a future earthquake is viewed as "three times more likely" than the possible damage from a tornado but "seven times less likely" than the potential damage from a flood.

The Loma Prieta earthquake had a significant effect on the perception concerning the potential damage from a future earthquake. Before the event, the chances of property damage from a possible earthquake were ranked between the "H" and "I" probability increments. To state it differently, before the Loma Prieta earthquake, respondents on the average considered the possibility of earthquake damage as five times less likely than the damage from a tornado. The actual event increased the perceived odds of damage from a future earthquake eight-fold. The Loma Prieta earthquake appears to have significantly heightened the risk perceptions concerning property damage from a future earthquake. Figures 6a and 6b compare the detailed shift in the odds-frequency distribution before and after the Loma Prieta earthquake, respectively.

Home Characteristics

As we indicated earlier, the average perceived price of a home is $341,000, whereas the median perceived price is $285,000. Since the mean price is heavily influenced by extreme values, the best estimate is somewhere in between the mean and median values: in the vicinity of three hundred thousand dollars. A frequency distribution of home values is provided in figure 7. The average living area is 1890 square feet, whereas the average lot size is 9,466 square feet. A typical home is about 33 years old. The mean, median and standard deviation for living area, lot size and age of the home are provided in Figures 8a, 8b, and 8c.

The respondents were requested to evaluate whether there had been a fall in the value of their home after the Loma Prieta earthquake and if so, to provide a dollar estimate of the decline in price. The sample data indicates that respondents who reported damages estimate the average fall in the value of the home to be $32,851 (median estimate $20,000). This converts to a 9.6 percent decline in the mean value of the home (7.01 percent decline in the median value). The question in the survey asks at what price the home would sell today if the earth quake had not occurred. Consequently, these numbers indicate that there is a significant drop in the perceived value of the home even seventeen months after the earthquake.

Figure 6a

Risk Perception of Earthquake Relative to Other Events before Loma Prieta

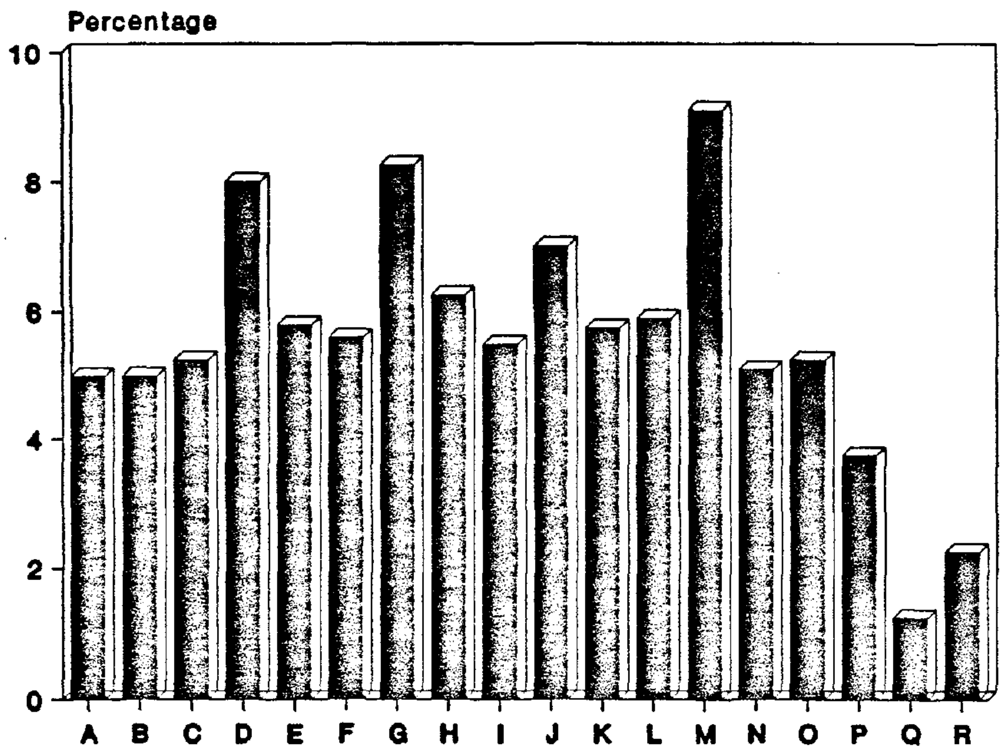


Figure 6b

Risk Perception of Earthquake Relative to Other Events after Loma Prieta

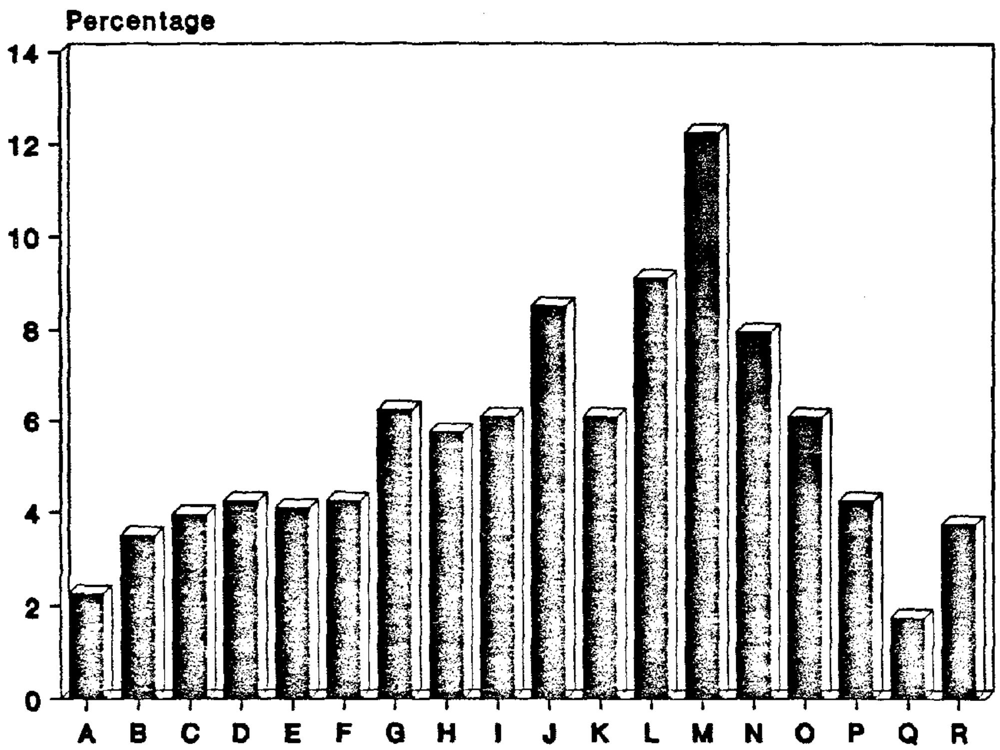


Figure 7

Distribution of Home Values of Sample

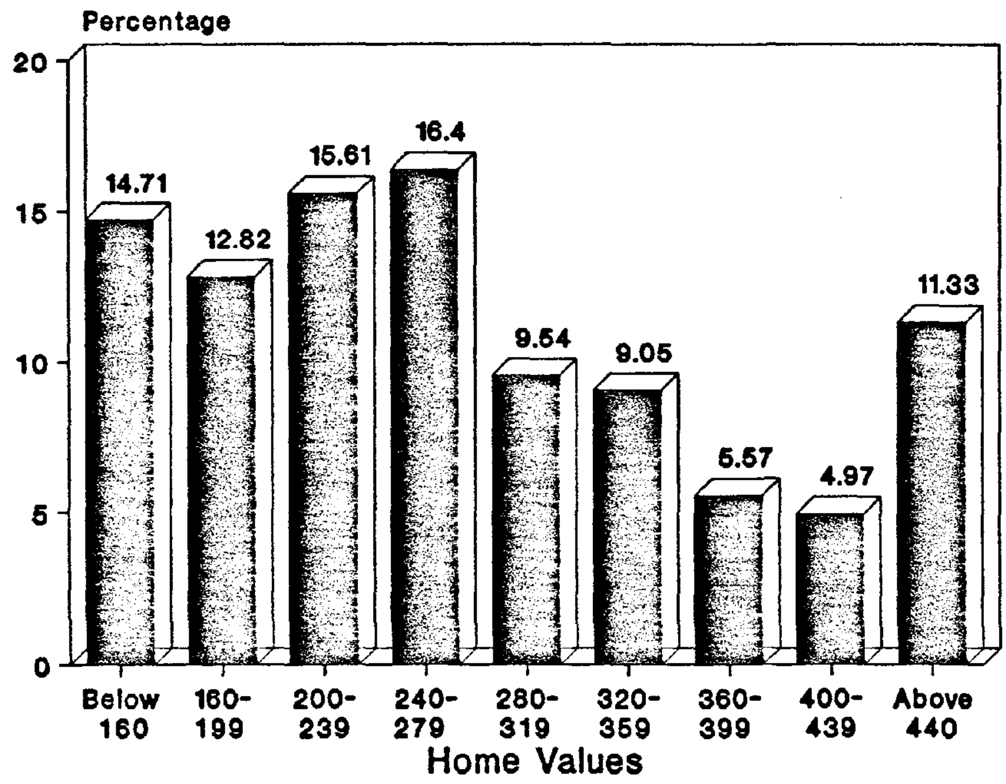


Figure 8a

Home Characteristics - Living Area

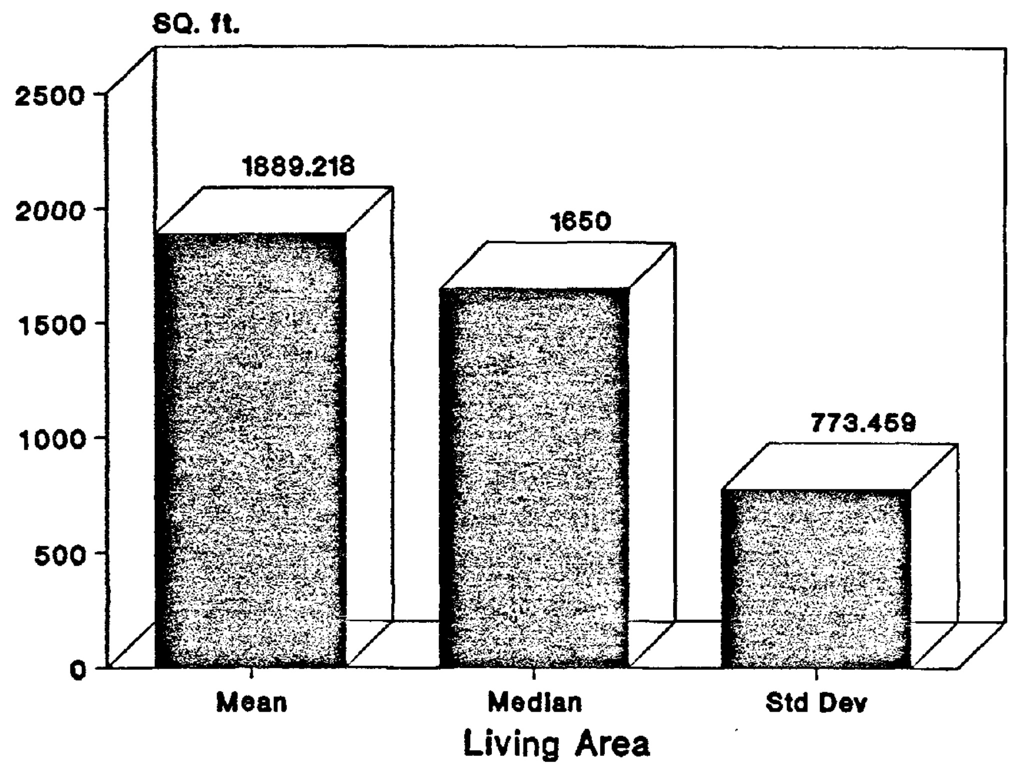


Figure 8b

Home Characteristics - Lot Size

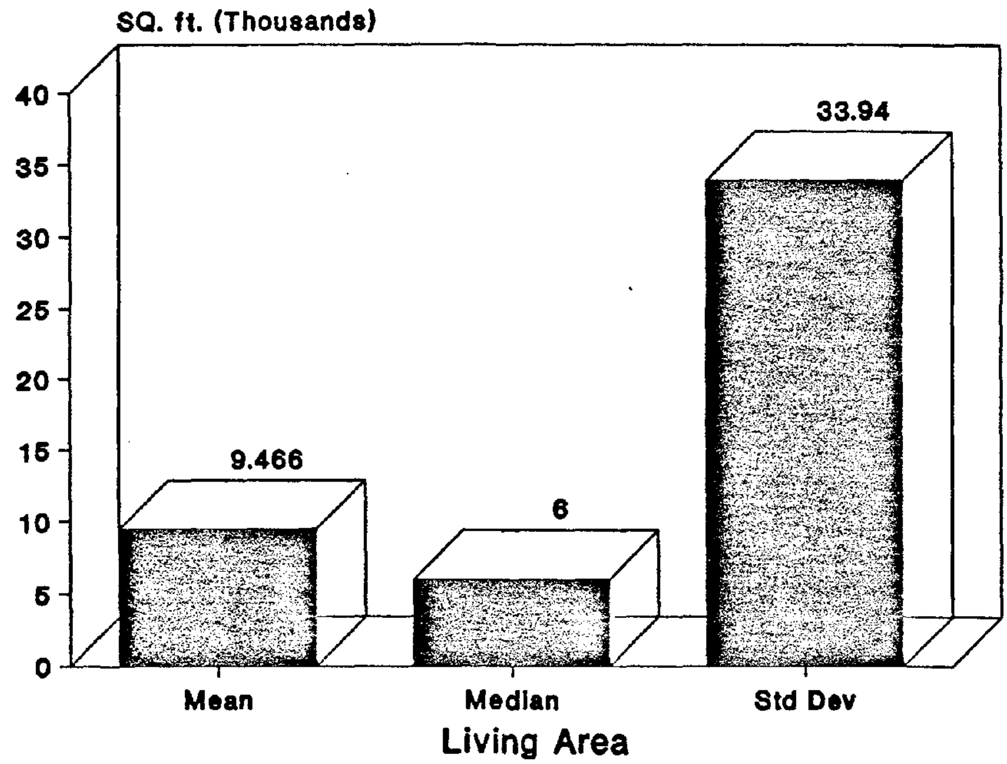


Figure 8c

Home Characteristics - Age of House

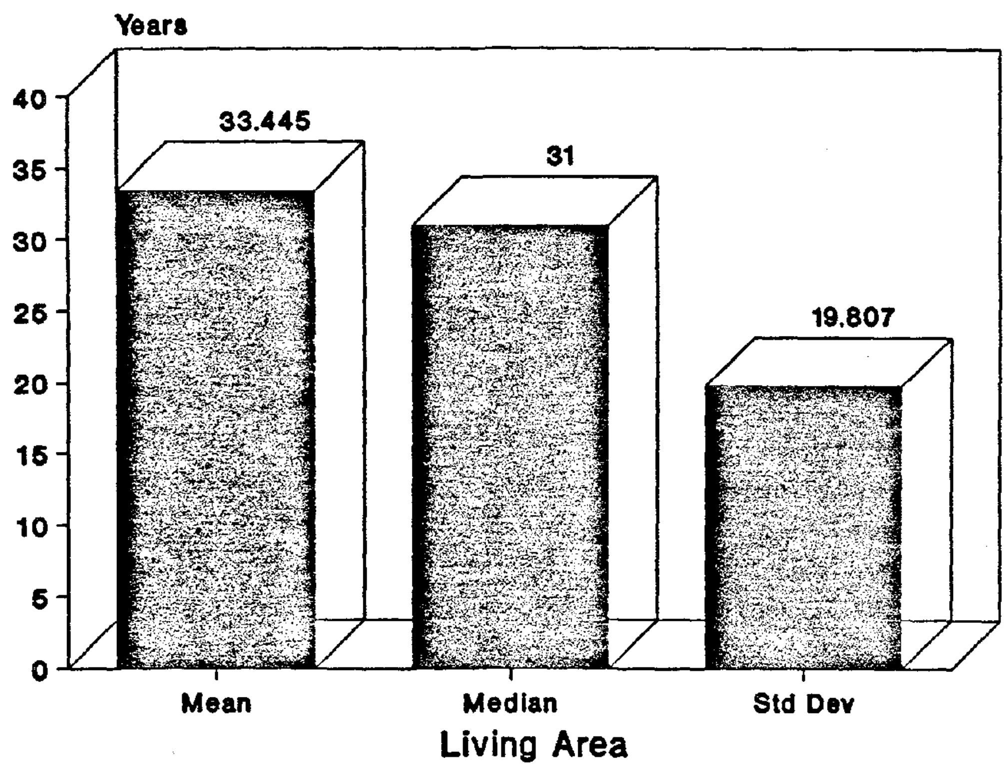


Figure 9a

Home Value after Loma Prieta Earthquake

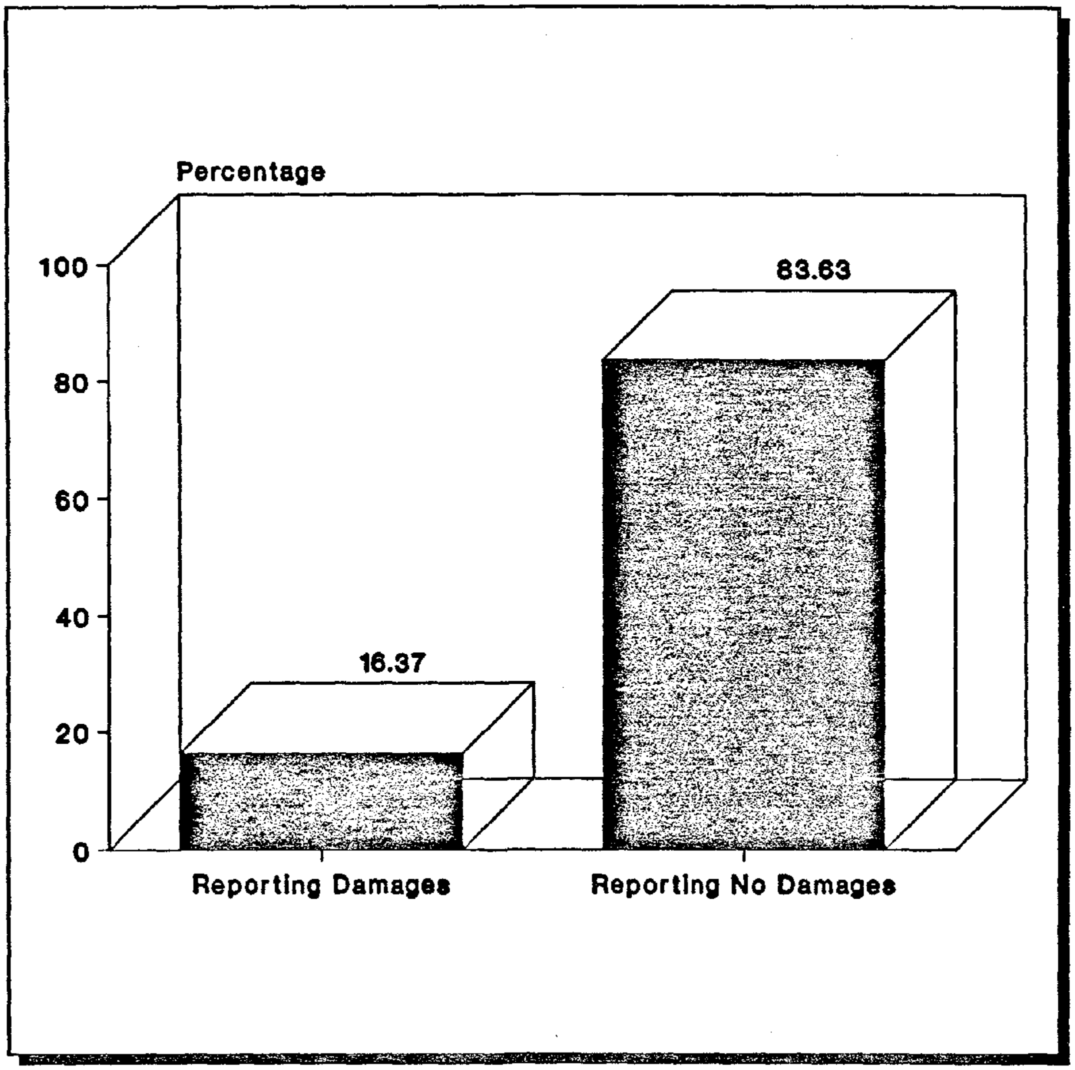
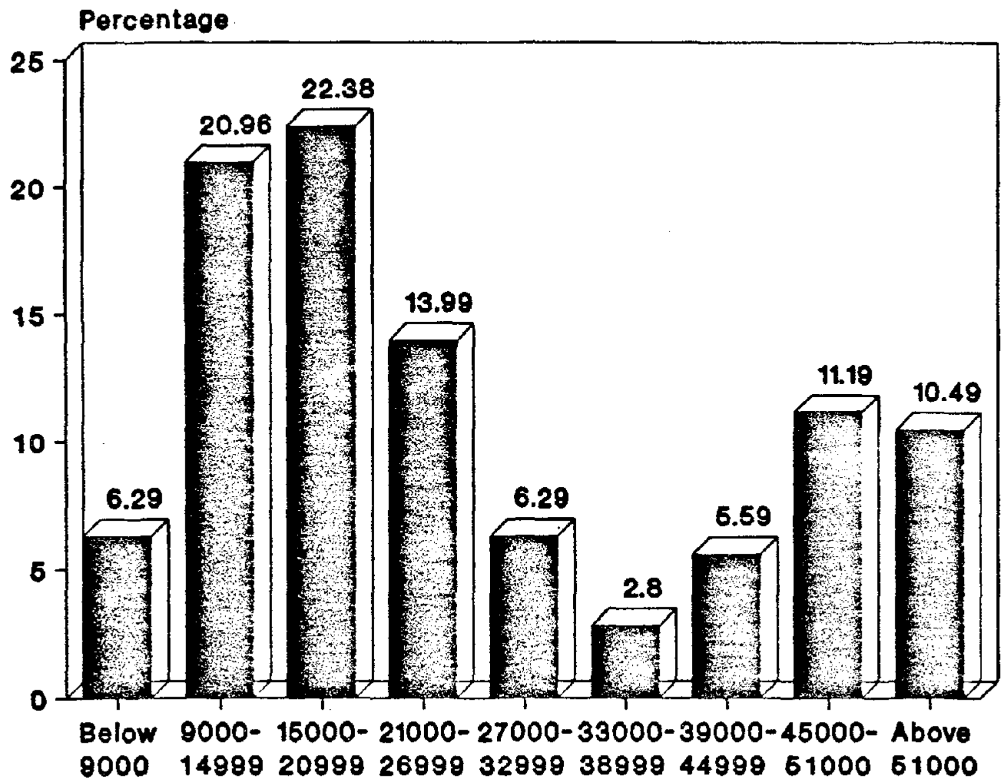


Figure 9b

Perceived Fall in Home Value after Loma Prieta Earthquake



A frequency distribution of the different estimates of the perceived fall in value is provided in Figures 9a and 9b.

Damage Assessment

The assessment of damage is made along two lines: actual damage sustained and expectations about future damage. One quarter of the homeowners surveyed reported actual damage due to the Loma Prieta earthquake. A majority of this group (56.8 percent) indicated that the damage was slight. The average dollar cost of the damage was $2,504 (median value equaled $425) for those reporting damages. As one would expect, the average estimate is heavily influenced by some occurrences of considerable or extensive damage (only 7.14 percent incidence out of total damages reported).

It is interesting to note that the incidence and cost of "expected" damage is relatively higher. As one would expect, the Loma Prieta earthquake heightened perceptions about the possibility of future damage. Approximately 55 percent of the respondents indicated that they expected damage from a future earthquake. This is more than twice the amount of respondents who sustained actual damage. Correspondingly, the average dollar value of expected damage for those reporting damages is also higher: $20,198. The average expected damage works out to be eight times higher than the average actual damage. This magnification gives some sense of the extent to which the earthquake heightened perceptions about future damage.

In Figures 10a and 10b, the incidence and distribution of actual and expected damage is contrasted by two sets of histograms. It is also interesting to note that the eight-fold increase in the expected damage relative to actual damage correspond with the eight fold increase in the odds of property damage discussed above. In each case, the Loma Prieta earthquake has magnified the perceived impact of a future earthquake.

Value of Geological Information

The survey analyses two types of geological information: the soil-type on which the home is situated and whether it is located within a special study zone (SSZ). In each instance, we are interested in determining the dollar value homeowners place on a safer attribute: homes located on firmer soil or outside the SSZ. There are two alternative methods of directly eliciting these values. The first is to ask how much an

Figure 10a

Actual Damage to Home Owners

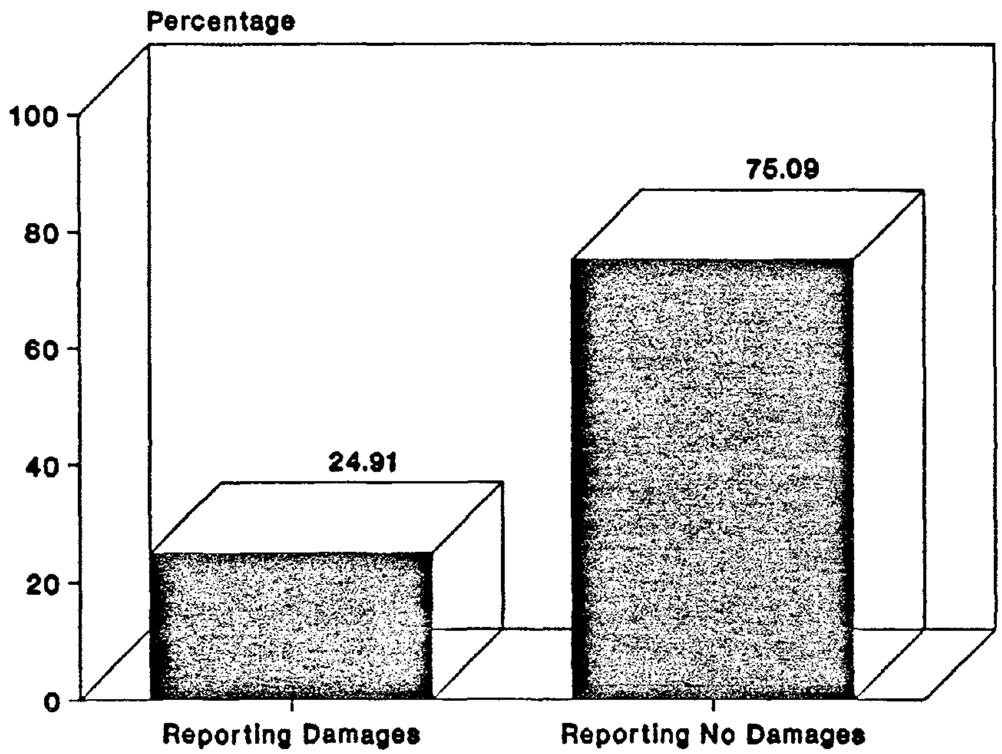


Figure 10b

Actual Damage to Home Owners for those Reporting Damages

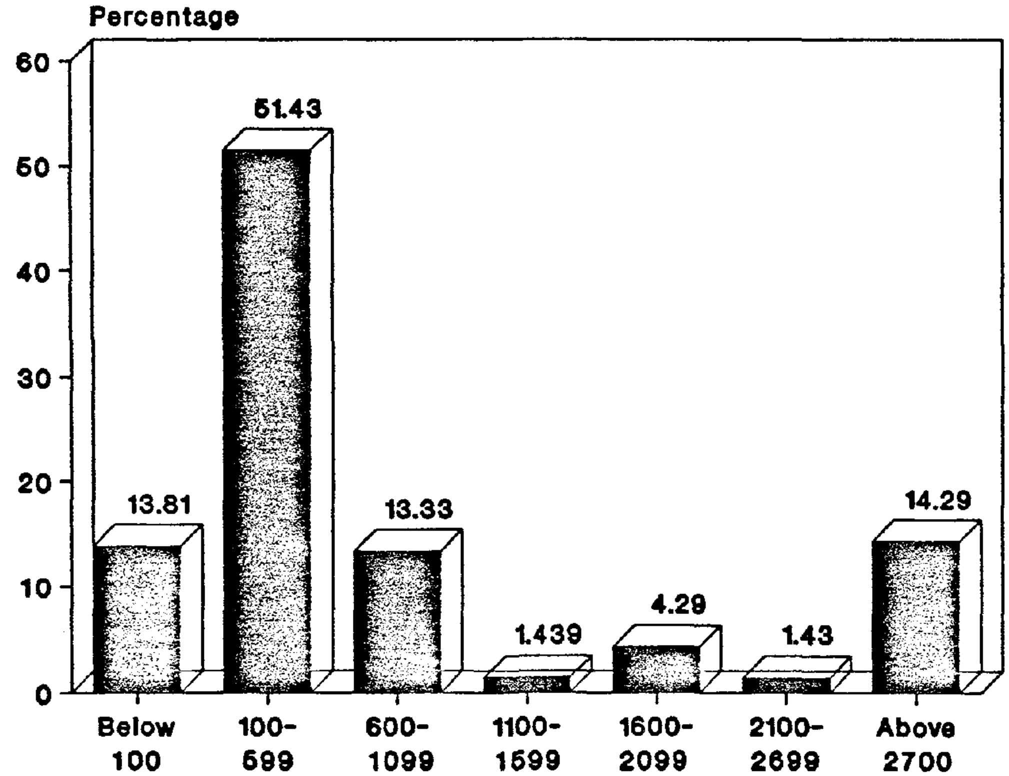


Figure 11a

Expected Damages to Home Owners

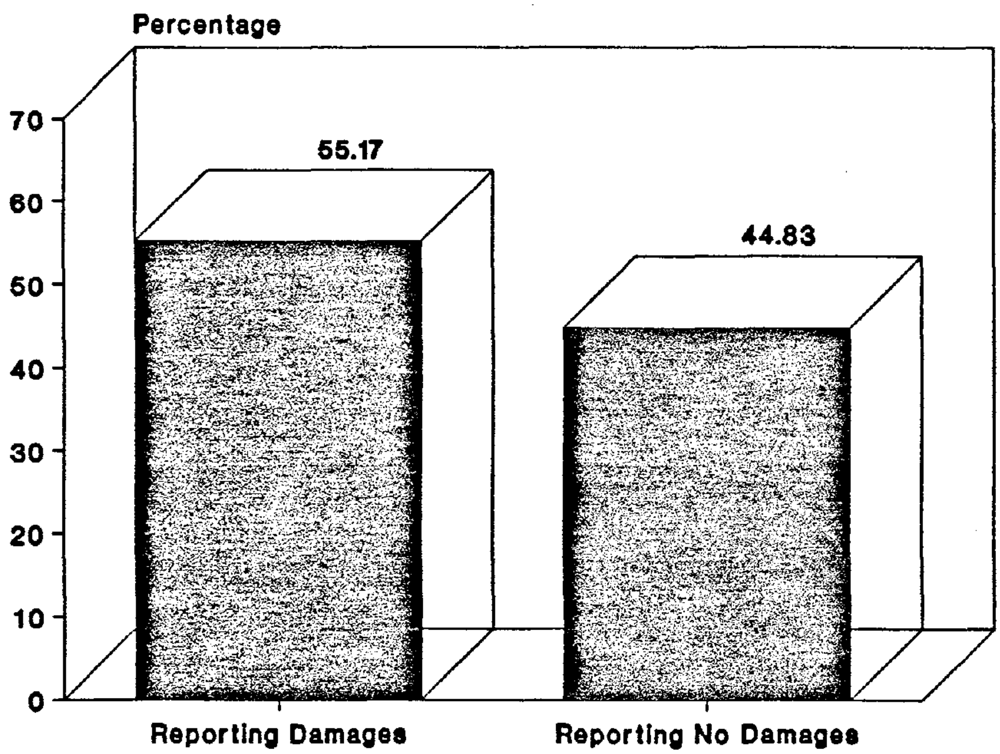
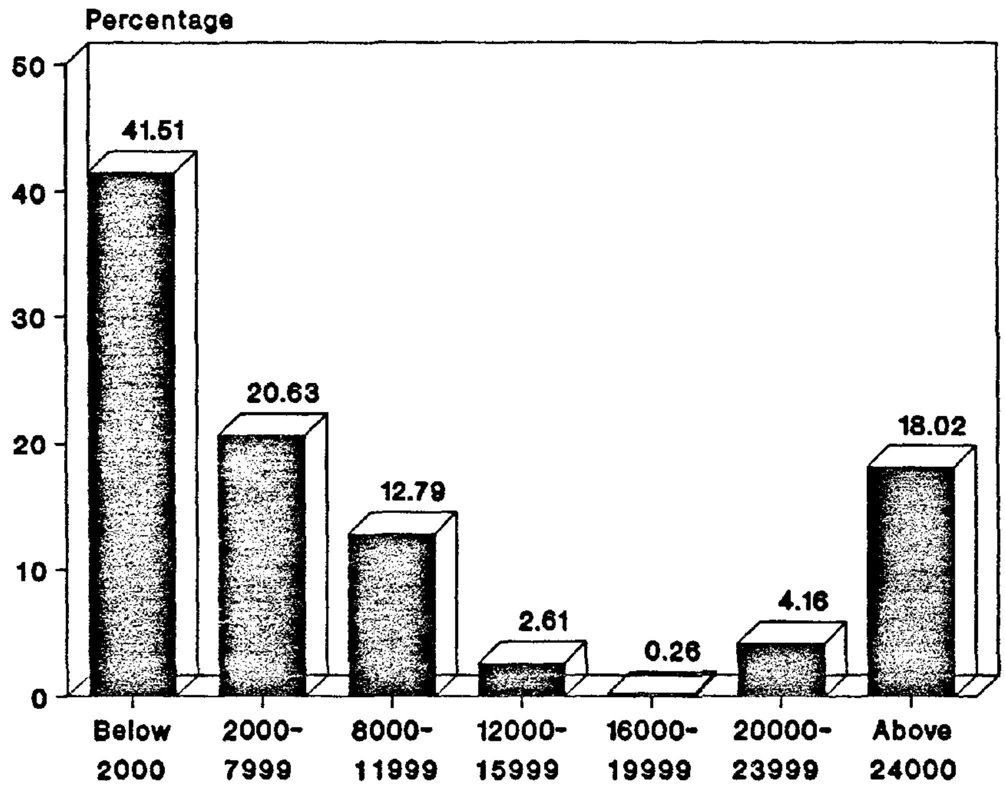


Figure 11b

Expected Damages to Home Owners for those Reporting Damages



individual is willing to pay to locate his home on safer soil or outside the SSZ. The alternative is to ask how much compensation an individual would require to locate his home on riskier soil-type or inside the SSZ. As indicated earlier, previous literature reveals that the "willingness to pay" measure is more reliable than the "compensation demanded" measure. The estimate for the latter is generally many times higher than the estimate for the former. The results for soil-type and SSZ are discussed individually.

Value of Safer Soil

In this category, unconsolidated soils/landfill are classified as relatively unsafe soil-types whereas consolidated soil/rock are regarded as safe soil-types. On the average, a respondent is willing to pay $7,527 to locate his home on safer soil type. Alternatively, an individual is willing to locate his home on a riskier soil type for an average compensation of $188,539.

There are several reasons why the "compensation demanded" measure much more higher than the "willingness to pay" measure. First, the traditional reasons for the upward bias of the compensation measure are the income effect and unfamiliarity with the compensation demanded format. In this study there is an additional reason for the discrepancy; self-insurance. That is, homeowners who value safety more gravitate to a relatively safer location and pay the resultant market premium. Naturally, when these homeowners are requested to specify the dollar amount of compensation for a riskier location, they will specify a relatively higher amount since they value safety more than others. There is a self-selection bias at work. One could say that the same logic applies in the alternative direction: persons who are living on riskier locations and have been compensated by a relatively lower buying price are also "self-selected" to a degree. There is however one difference, the individuals who bought safety actually paid out of their pockets, implying that they valued safety. On the other hand homeowners on a riskier location may simply care less about safety. Since the relationship is not symmetric, the self-selection bias is their case is expected to be less pronounced.

Value of Locating Outside the SSZ

The same methodology is employed to elicit the value respondents place on locating their home outside an SSZ. On the average, a homeowner is willing to pay $12,371 to locate his home outside a SSZ. Alternatively, he is willing to shift his home within a SSZ if he is compensated on the average by $29,486. Again, the compensation demanded measure is relatively higher than the willingness to pay value, but the extent of the divergence is relatively less compared to the valuation for soil types.

IV. MARKET HEDONIC PRICE FUNCTION ESTIMATION

A. DATA SOURCES

The data set used to estimate the hedonic price functions was assembled from four primary sources: real estate sales transactions, U.S Census data, community data, and geologic hazard data. The data set was limited to measures of the numerous attributes thought to influence the selling price of single family detached owner-occupied homes. Rental units, multifamily apartment complexes, office/retail space, and condominium units were excluded.

As described in Chapter II, equilibrium in the housing market implies a locus of points which is described by the hedonic price function. The price of particular home depends on its characteristics, which we categorized into site characteristics, neighborhood characteristics, and risk (earthquake hazard) characteristics; hence, P = P(S, N, R).

B. DATA SPECIFICS

Site Characteristics

The site characteristics were purchased from DAMAR Real Estate Information Service in Los Angeles, California. We requested information on the sales transactions for homes in the San Francisco Bay Area from January 1, 1988 through September 30, 1990. Each record contained 124 variables pertaining to sales transactions. Table 1 displays the descriptions of the variables obtained from DAMAR. In addition to the negotiated selling price, practically every imaginable site attribute is measured. Our decisions to include or exclude a particular site characteristic variable in the estimation of the hedonic price function were based predominately on our familiarity with the literature, although several different specifications (described below) were tested.

The original DAMAR file contained over 50,000 records with data from six counties and 84 cities. For our purposes, however, the number of usable records was about 10,000. That is, after filtering the data to exclude condominiums, rental units (nonowner-occupied), and records with incomplete location descriptors, there were 9,457 records.

Table 1

Variable Descriptions of the DAMAR Real Estate Information Services Data

No.	Descriptor
1	Assessor's Parcel Number
2	State Code
3	County
4	Thomas Bros. Map Reference
5	Situs Sheet
6	Situs City and Zip
7	Situs Zip
8	Situs Carrier Route
9	Sales Transaction Recording Date
10	Land Use Descriptor (e.g. Single Family Unit)
11	Data Identifier -- Owner
12	Owner Name
13	Second Owner Name
14	Vesting Code
15	Mailing Street
16	Mailing City and Zip
17	Mailing Zip
18	(Reserved)
19	Owner Phone
20	Data Identifier -- Sale
21	Document Number
22	Document Type
23	Sale Price
24	Sale Code
25	Seller Name
26	% Ownership Transferred
27	Transfer Type
28	Title Company
29	Multi APN Flag
30	Prior Document Number
31	Prior Document Type
32	Prior Recording Date
33	Prior Sale Price
34	Prior Sale Code
35	Prior Trust Deed
36	Prior Trust Deed Code
37	Gross Income
38	Net Income
39	Type Income
40	Expenses
41	Number Vacant
42	Data Identifier -- Loan

Table 1 (cont.)

Variable Descriptions of the DAMAR Real Estate Information Services Data

No.	Descriptor
43	First Trust Deed
44	First Trust Deed Code
45	Lender Name
46	Lender Type
47	Cash Down
48	First Trust Deed Interest
49	First Trust Deed Years
50	Seller Points
51	Association Dues
52	Junior Trust Deed
53	Junior Trust Deed Code
54	Data Identifier -- Tax
55	Assessment Year
56	Land Value
57	Improvement Value
58	Total Value
59	Improvement Ratio
60	Homeowner Exception
61	Absentee Owner Flag
62	Tax Code Area
63	Tax Amount
64	Year Delinquent
65	County Use
66	Data Identifier -- Legal
67	Census Tract
68	Legal Description
69	Flood Zone
70	Zoning
71	Data Identifier -- PCR
72	Total Rooms
73	Bedrooms
74	Full Bath
75	Half Bath
76	Fireplaces
77	Style
78	Pool
79	Lot Size
80	Lot Area
81	Building Area
82	Number of Units
83	Number of Stories

Table 1 (cont.)

Variable Descriptions of the DAMAR Real Estate Information Services Data

No.	Descriptor
84	Parking Spaces
85	Location Influence (e.g. View, Bay, etc.)
86	Type Construction
87	Foundation
88	Year Built
89	Effective Year Built
90	Comments
91	Data Identifier -- PCR2
92	Quality
93	Condition
94	Air Condition
95	Heating
96	Ground Lease
97	Parking Type
98	Basement Area
99	Roof Type
100	Roof Cover
101	Frame
102	Exterior Walls
103	Garage Carport Area
104	Utilities
105	Sprinklers
106	Paved Parking
107	Elevator
108	Office Square Feet
109	Canopy Square Feet
110	Rent Area
111	Truck Door
112	Number of Buildings
113	Building Class
114	Water
115	Sewer
116	Other Rooms
117	Other Improvements
118	Amenities
119	Basement Finish
120	Basement Rooms
121	Functional Utility
122	Equipment
123	Remodeled
124	Type Improvement

Each observation required complete location descriptors for two reasons. First, in order to match the other data (neighborhood and earthquake risk) to the site data, we required a location key. The census and community data were matched by census tract, while the earthquake risk data were matched by the Thomas Bros Maps grid identifier. Second, the design of the survey required that survey respondents be a subset of the owners from the sales transactions data. This constraint dictated that only the records with complete mailing addresses be used from the DAMAR data.

We had some concern that our sample selection criteria would bias the results of both the survey and the market hedonic price function estimation. However, a simple analysis of the frequency distributions of the raw data, presented below, suggests that most areas in the Bay area are adequately represented by our sample selection.

Neighborhood Characteristics

Numerous variables were employed to measure the neighborhood characteristics of a particular piece of property. These variables are based on three different levels of aggregation: census track, city, and county. The census track variables were obtained from the 1980 U.S. Census. The variables are acres, population, percentage of the tract population that is white, percentage of the population that is over the age of 62, and the average commute time to work. With over 1000 census tracts in the study area, variation in these data are substantial. Taken as a group, the census tract data can be thought of as proxy variables for the density (people per acre), age distribution, racial make-up, and location vis-a-vis major employment areas. While certainly other census information is available and we could probably develop other proxy variables our previous experience in estimating hedonic price functions indicates that other data adds little to the quality of the analysis.

There are 84 communities in the study area. Data pertaining to the school quality in the communities were obtained from California education authorities. The data reflect the average achievement scores in 1988 on a standardized exam battery for eighth and twelfth grade reading and math and eighth grade science. The average achievement scores are not the only measures of school quality. However, they do provide readily accessible proxy measures which are hypothesized to be important in defining the relationship of home prices to school quality.

Crime data by community were obtained from the FBI annual survey on crime rates. We used the composite measure of the seven major crimes in 1988 and divided this by the community population to create a crime rate measure.

The local air quality has been shown to be a significant influence to property values in numerous studies. We obtained measures for ozone, particulate matter, and total suspended particulates from the California Air Resources Board (CARB). By plotting the CARB observations on maps, we were able to assign air pollution levels to each community.

It is possible that some differences in housing prices can be attributable to counties. The study area includes Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara counties. We constructed six dummy (0 or 1) variables to test for the effects of county on house price.

Earthquake Risk Characteristics

The risk of earthquake damage for each location in the study area was measured by data from the U.S. Geological Survey. They produce maps which detail the geologic characteristics and fault locations. They also provide maps with more specific information about earthquake risks; e.g., shaking intensity and potential damage from a specific type and location of an earthquake. Moreover, California has designated Special Study Zones (SSZs) which pertain to recent (10,000 years) surface movements. A home buyer must be notified if the property falls within a SSZ. We used the USGS maps, the SSZ locations, and the Thomas Bros Maps grid system to create new "maps" (computer files) which could be merged to the site characteristics and selling price of homes. In the study area, there are just over 20,000 grids. Moreover, the varied terrain in the Bay area leads to substantial variation in these measures.

Earthquake Hazard Variables

We are particularly interested in the earthquake risk variables. Four index measures (GEOGRADE, PODAMAGE, SOILTYPE, and SHAKING) are presented in Table 2. A more detailed description of these variables is also presented in terms of the associated dummy variables. The other measure, FAULTREG, denotes location in a SSZ. Thirty-four percent of the sample lie in an SSZ. We expect that the SSZ location distinction negatively impacts on house value, holding all other influences

Table 2

Variable Descriptions and Summary Statistics for the variables used to Estimate Hedonic price functions

Variable	Description	Mean	Std. Dev.	Min	Max
PRICE	Sales Price ($1000)	291.138	175.463	38	2584.5
TROOMS	Total Rooms	6.447	1.553	3	17
BROOMS	Bedrooms	3.119	0.82	1	10
BATH	Bathrooms	1.912	0.787	1	8.5
FIRE	Fireplaces	0.69	0.602	0	5
LOTAREA	Lot Area (100 square feet)	85.044	83.509	25.01	1090.68
LIVAREA	Living Area (100 square feet)	15.948	6.328	1.3	83.3
STORIES	Number of stories	1.231	0.52	0	4
PARKING	Number of parking spaces	1.706	0.667	0	6
AGE	Age of home	35.39	20.167	1	91
POOL	1 if pool, 0 otherwise	0.125	0.33	0	1
VIEW	1 if view influence, 0 otherwise	0.133	0.34	0	1
BAY	1 if bay influence, 0 otherwise	0.015	0.12	0	1
WOODED	1 if wooded influence, 0 otherwise	0.026	0.158	0	1
OTHERL	1 if other influence (canal, etc.), 0 otherwise	0.008	0.086	0	1
AVQ	1 if average condition, 0 otherwise	0.644	0.479	0	1
ABOVEQ	1 if above average condition, 0 otherwise	0.347	0.476	0	1
SMONTH	Month of sale	17.635	8.717	1	32
CTDENS	Population per acre in the census tract	8.345	6.993	0.007	116.367
CTWPOP	Percentage of the population white in CT	82.362	18.971	0.11	99.74
CTTTW	Average travel time to work in CT	25.496	4.221	11	39
CTO62	Percentage of the population older than 62	17.723	10.316	1.36	85.86
CMCRIME	FBI crimes per person in the city	4.89	2.475	1.295	15.35
CMOZ1	Average hourly ozone (ppm)	1.981	0.362	1.4	2.9
CMPM	Average particulate matter (ppm)	28.515	5.592	21.7	39.2
CMR12	Average reading score in twelfth grade	271.961	29.154	150.5	376
CMM8	Average math score in eighth grade	293.808	29.077	231	412.75
ALAMEDA	1 if Alameda county, 0 otherwise	0.217	0.412	0	1
CONTRA	1 if Contra Costa county, 0 otherwise	0.184	0.388	0	1
MARIN	1 if Marin county, 0 otherwise	0.167	0.373	0	1
SANTAC	1 if Santa Clara county, 0 otherwise	0.208	0.406	0	1
SANFRAN	1 if San Francisco county, 0 otherwise	0.052	0.221	0	1
SANMAT	1 if San Mateo county, 0 otherwise	0.173	0.378	0	1
GEOGRADE	Susceptability to ground shaking	4.943	1.343	1	8
GEO1	1 if APII less than -1.0, 0 otherwise	0.002	0.045	0	1
GEO2	1 if APII from -1.0 to -0.6, 0 otherwise	0.016	0.125	0	1
GEO3	1 if APII from -0.5 to -0.1, 0 otherwise	0.134	0.341	0	1
GEO4	1 if APII from 0 to 0.4, 0 otherwise	0.191	0.393	0	1
GEO5	1 if APII from 0.5 to 0.9, 0 otherwise	0.403	0.491	0	1
GEO6	1 if APII from 1.0 to 1.4, 0 otherwise	0.069	0.254	0	1
GEO7	1 if APII from 1.5 to 1.9, 0 otherwise	0.166	0.372	0	1
GEO8	1 if APII greater than 2.0, 0 otherwise	0.019	0.136	0	1
PODAMAGE	Cummulative damage to wood frame dwellings	2.024	0.965	1	5
POD1	1 if potential damage 0 to 0.2%, 0 otherwise	0.326	0.469	0	1
POD2	1 if potential damage 0.3% to 1.0%, 0 otherwise	0.424	0.494	0	1
POD3	1 if potential damage 1.1% to 2.0%, 0 otherwise	0.18	0.384	0	1
POD4	1 if potential damage 2.1% to 3.0%, 0 otherwise	0.041	0.199	0	1
POD5	1 if potential damage 3.1% to 4.1%, 0 otherwise	0.029	0.168	0	1
SOILTYPE	Soil type classification	2.789	1.469	1	8
SOI1	1 if mud, 0 otherwise	0.069	0.253	0	1
SOI2	1 if unconsolidated sediments, 0 otherwise	0.606	0.489	0	1
SOI3	1 if moderate to well consolidated, 0 otherwise	0.091	0.288	0	1
SOI4	1 if volcanic rocks, 0 otherwise	0.002	0.042	0	1
SOI5	1 if sandstone, shale, metamorphic rocks, sheared rocks, or volcanic rocks, 0 otherwise	0.192	0.394	0	1
SOI6	1 if sandstone, shale, and conglomerate; locally in oldest part of basaltic volcanic rock, 0 otherwise	0.024	0.153	0	1
SOI7	1 if serpentine and peuodotite, 0 otherwise	0.009	0.095	0	1
SOI8	1 if granite rock, 0 otherwise	0.008	0.086	0	1
SHAKING	Modified Mercalli scale of ground shaking	6.425	0.619	6	9
SHA6	1 if felt by all, 0 otherwise	0.632	0.482	0	1
SHA7	1 if difficult to stand, 0 otherwise	0.322	0.467	0	1
SHA8	1 if people frightened, 0 otherwise	0.034	0.18	0	1
SHA9	1 if general panic, 0 otherwise	0.012	0.109	0	1
FAULTREG	1 if in a special studies zone, 0 otherwise	0.344	0.475	0	1
POST	1 if sale date after 10/19/89, 0 otherwise	0.341	0.474	0	1

constant. This would seemingly be true regardless of the actual hazard from being in a SSZ, since hazard perception is probably affected.

The first geologic measure of earthquake hazard is GEOGRADE. GEOGRADE is an index from 1 to 8 that measures susceptibility to ground shaking. The underlying scale is based on a geologic measure called "average predicted intensity increment" (APII). As the index increases, so does the APII. However, there is no clear functional connection between the APII and damage, meaning that a set of dummy variables might be the best way to represent GEOGRADE in the hedonic price function. Approximately 72% of the homes in the sample fall in either GEOGRADE equal to 3, 4, or 5. Approximately 25% fall in categories above 5, while only 2% are in categories 1 and 2.

The second earthquake hazard variable is PODAMAGE. This variable is a index from 1 to 5 that reflects increasing damage to wood frame homes from an earthquake of specific magnitude. The index considers the geologic factors, such as type of ground and susceptibility to ground shaking, that cause an earthquake to damage homes. In some ways, therefore, it is a composite measure of the other variables. Of the available variables, PODAMAGE is probably the best single measure of the likely damage from an earthquake. Consequently, it is likely to be the most influential in the hedonic price function.

The scale for PODAMAGE is evident from the dummy variable definitions. As displayed, the measure is not a truly continuous variable. For example, when PODAMAGE takes on a value of 4, the potential damage ranges from 2.1% to 3.0%. Rather than enter PODAMAGE into the hedonic equation, we can enter a set of dummy (0 or 1) variables to reveal the discontinuous nature of the PODAMAGE measure. POD1 through POD5 are the dummy variables which measure PODAMAGE. Approximately 74% of the cases fall in categories 1 and 2, with 18% in category 3 and the remaining falling evenly in categories 4 and 5. Thus, the vast majority of the homes in the sample are "moderately low" or lower potential damage categories.

The third earthquake hazard variable is SOILTYPE. SOILTYPE is also an index (1-8) variable. The higher numbers reflect less hazard from an earthquake, all else equal. In addition to the index measure, we also constructed the dummy variables SOI1 - SOI8. The dummies probably are more appropriate for SOILTYPE than for PODAMAGE, since there is no underlying scale to the SOILTYPE index; i.e., the soil types are pure classification schemes. About 60% of the homes in the sample fall in the soil type 2 classification (unconsolidated sediments). Very few homes (.2%) fall in type 4, but about 20% fall in type 5. Since we do not know how risky category 5 is, it is a little more difficult, when compared to (say) PODAMAGE, to summarize the risk of the majority of homes by the SOILTYPE variable.

The last earthquake hazard variable is based on shaking intensity. SHAKING is scaled according to the Modified Mercalli scale. The variable takes on the values of 6, 7, 8, or 9. There is little variation in this variable. Over 90% of the homes in the sample fall were assigned a 6 or 7 for SHAKING. Evidently, the scale is too crude to facilitate more variation in the Bay area.

Variable Descriptions and Summary Statistics

After matching the 9,457 records on site characteristics to the 1054 census tract records, the 20,706 grids with earthquake hazard data, and the data from the 84 communities, we had a file of about 8500 records. This file was further analyzed to identify missing values (e.g., the selling price coded as zero or the square feet of living area coded as zero), leaving a final data set with 7102 records.

A brief description of the variables and summary statistics for this data set are presented in Table 2. The average home in the sample sells for about $290000, is 34 years old and has about 1600 square feet of living area, 3 bedrooms and 2 bathrooms. The lot size is about 7800 square feet (approximately one fifth of an acre) and the home is a one-story with parking for 1 or 2 cars.

In order to analyze the extent of non-random stratification due to our sample selection process, a simple frequency by city was tabulated. This is presented in Table 3. As can be seen, homes fall in practically every city. The most common is San Francisco, which is also the largest in terms of population. The sample does not represent the general population, however. For example, about 14% of the more than 5 million residents of the Bay area counties live in San Francisco. Yet, only 9% of the homes in our data set are located in this city. The largest single city category in our data is the "unincorporated" areas of Alameda, Contra Costa, Marin, Santa Clara, and San Mateo counties. This category, in total, accounted for about 40% of the sample. Only about 10% of the population live in these areas. These figures are intuitively appealing. The fraction of people who live in multifamily dwellings and rental units is larger in the city than in outlying suburban areas. Since we have only included single family owner-occupied units, our sample will not represent the population.

Table 3

Number of Cases By City

Name	Freq	Name	Freq
Alameda	35	Sausalito	25
Albany	37	Tiburon	44
Berkeley	57	Unincorporated	398
Dublin	62	Campbell	38
Emeryville	25	Cupertino	14
Fremont	262	Gilroy	10
Hayward	133	Los Altos	34
Livermore	105	Los Altos Hills	5
Newark	19	Las Gatos	21
Oakland	210	Milpitas	3
Piedmont	46	Monte Sereno	6
Pleasanton	55	Morgan Hill	6
San Leandro	92	Mountain View	2
Union City	26	San Jose	19
Unincorporated	303	Santa Clara	25
Antioch	3	Saratoga	11
Clayton	12	Sunnyvale	51
Concord	87	Unincorporated	1162
Danville	3	San Francisco	350
El Cerrito	44	Atherton	61
Hercules	7	Belmont	79
Lafayette	21	Brisbane	16
Martinez	2	Burlingame	42
Moraga	3	Colma	60
Pinole	38	Daly City	46
Pittsburg	20	Foster City	13
Pleasant Hill	98	Half Moon Bay	39
Richmond	71	Hillsborough	32
San Pablo	38	Menlo Park	57
San Ramon	8	Millbrae	60
Walnut Creek	45	Pacifica	142
Unincorporated	747	Portola Valley	4
Corte Madera	20	Redwood City	8
Fairfax	45	San Bruno	38
Larkspur	42	San Carlos	55
Mill Valley	74	San Mateo	106
Novato	240	South San Franc.	23
Ross	27	Woodside	4
San Anselmo	95	Unincorporated	282
San Rafael	121		

Not surprisingly, when we compute a simple Chi-square statistic for comparing our sample distribution of homes sold to the distribution of people living in the Bay area, the statistic indicates rejection of a hypothesis that the two distributions are from the same population; i.e., our sample represents single family homeowners, rather than all of the people.

C. BENCHMARK ESTIMATES OF HEDONIC PRICE FUNCTIONS

As described above, the estimation of hedonic price functions have become a common statistical technique for estimating the marginal valuation of "goods" which are not explicitly traded in markets. (The same can not be said about estimating non-marginal valuations.) However, numerous empirical problems make the actual estimation of a hedonic price function a difficult exercise. The concerns which are most relevant to our work are specification of the characteristics, empirical functional form of the hedonic price function, multicollinearity, and errors in variables. To analyze the impact of these issues on the hedonic price of earthquake related risks, we first present a set of benchmark equations. The results from the benchmark equations are then compared to others in order to measure the sensitivity of the results to the various estimation issues.

Four benchmark regressions are presented in Table 4. The functions vary only by their hazard variables. They are each the "semilog" form. Using standard econometric notation, the semilog form is

$$\ln(Y) = X\beta + \varepsilon, \tag{8}$$

where Y is the selling price of homes X is a matrix of independent variables, and ε is a normally distributed error term with constant variance and zero mean. For the semilog form, the estimated hedonic price of an attribute x_i is

$$\partial Y/\partial x_i = \exp(X\beta)\cdot\beta_i. \tag{9}$$

By practically any standard, the benchmark equations represent good fits for the Bay area data.

Some variables were dropped from the benchmark specifications. In particular, we found that TROOMS, BROOMS, and BATH were highly correlated, so we just present the results with BATH. We also found high correlation between the school quality measures. A specification with just two measures, rather than

Table 4

Estimated Coefficients of the Benchmark Hedonic Price Function Specification Semilog Form

Variable	(1)	(2)	(3)	(4)
CONSTANT	3.7804	3.7552	3.6885	3.4144
SMONTH	0.0173	0.0173	0.0172	0.0174
AGE	0.0007	0.0007	0.0006	0.0006
LIVAREA	0.0377	0.0378	0.0377	0.0375
LOTAREA	0.0005	0.0005	0.0005	0.0005
BATH	0.0091 *	0.0088 *	0.0090 *	0.0083 *
FIRE	0.0241	0.0242	0.0236	0.0242
STORIES	-0.0265	-0.0264	-0.0283	-0.0277
PARKING	0.0327	0.0325	0.0321	0.0325
POOL	0.0552	0.0553	0.0576	0.0561
VIEW	0.0614	0.0625	0.0471	0.0640
BAY	0.1641	0.1664	0.1495	0.1617
WOODED	0.0853	0.0860	0.0637	0.0916
OTHERL	0.0886	0.0936	0.0847	0.0920
AVQ	0.0601	0.0609	0.0630	0.0622
ABOVEQ	0.1594	0.1604	0.1616	0.1589
CTDENS	0.0030	0.0029	0.0032	0.0023
CTWPOP	0.0065	0.0065	0.0064	0.0063
CTO62	0.0025	0.0026	0.0025	0.0024
CTTTW	-0.0064	-0.0061	-0.0069	-0.0058
CMM8	0.0010	0.0010	0.0012	0.0009
CMR12	0.0013	0.0012	0.0011	0.0013
CMCRIME	0.0042	0.0042	0.0057	0.0018
CMOZ1	-0.0521	-0.0513	-0.0417	-0.0406
CMPM	0.0059 *	0.0062 *	0.0044 *	0.0087 *
ALAMEDA	-0.5272	-0.5263	-0.4959	-0.5585
CONTRA	-0.7410	-0.7375	-0.7015	-0.7563
MARIN	-0.5319	-0.5277	-0.5201	-0.5373
SANTAC	-0.4344	-0.4407	-0.3820	-0.5509
SANMAT	-0.2529	-0.2526	-0.2387	-0.3025
POSTQ	-0.1016	-0.1014	-0.1015	-0.1026
FAULTREG	-0.0317	-0.0303	-0.0377	-0.0178
GEOGRADE	-0.0071			
PODAMAGE		-0.0105		
SOILTYPE			0.0253	
SHAKING				0.0524
R-SQUARE	0.7777	0.7778	0.7815	0.7793

* Indicates that the coefficient is not significant at the .05 level.

all five seemed to be the best representation of the relationship. A similar situation was noted with respect to the air pollutants. Nonsensical results were obtained with all of the measures in one equation. Hence, we just look at the two most common. Interestingly, and something we investigate in detail below, the earthquake hazard variables and FAULTREG remained very robust with respect to the addition/subtraction of other variables. The exception is SHAKING which is significant but exhibits the wrong sign. As discussed further below, this appears to be caused by significant collinearity with the county dummies.

As shown in equation 9, the hedonic prices from the semilog form are nonlinear. This means that the prices themselves depend on the other characteristics. To gauge the magnitude of the hedonic prices we can evaluate the function at the mean values of other independent variables. Since a regression line goes through the mean the calculation is relatively easy. The estimated hedonic prices are $1819, $2644, $6497, and -$13600 for GEOGRADE, PODAMAGE, SOILTYPE, and SHAKING. These hedonic prices give the marginal willingness to pay for a unit improvement from the average hazard level. The hedonic price for SHAKING is negative because an improvement reduces home price.

The October 1989 earthquake appears to have significantly decreased home values; that is, the coefficient estimate on POST is negative and significant. The POST variable just captures the general shift of the hedonic equation due to the earthquake. The estimated impact ranges from approximately $25500 to 26500. We investigate below, the extent of correlation with this variable with SMONTH, a time tend variable.

D. INFLUENCES ON BENCHMARK HEDONIC EQUATIONS

Functional Form

Discrepancies in estimated hedonic prices due to functional form are quite common in the literature (Graves, et al, 1988 and Halvorsen and Pollakowski, 1981). Since we want to compare the estimate from the market based hedonic price function to estimates based on the survey data, it is important to check the sensitivity of our benchmark estimates to alternative functional forms. We consider the loglinear, linear, and a semilog with some quadratic terms.

The loglinear form is

$$\ln(Y)=\ln(X)\beta + \varepsilon \tag{10}$$

and the hedonic price of x_i is

$$\partial Y/\partial x_i = \exp(\ln(X)\beta)\beta_i/x_i = \hat{Y}\beta_i/x_i \tag{11}$$

where only the X variables without zero in their range would be transformed.

The hedonic price function in linear form and the corresponding estimate of the hedonic price is

$$Y = X\beta + \varepsilon \tag{12}$$

and

$$\partial Y/\partial x_i = \beta_i, \tag{13}$$

respectively.

Estimates of the loglinear model are presented in Table 5. Using the mean values for the independent variables and taking logs where appropriate, the hedonic prices of GEOGRADE, PODAMAGE, SOILTYPE, and SHAKING are respectively \$986, \$2115, \$7958, and -\$21764. We see that the loglinear predicts a somewhat higher value for SOILTYPE and lower for the others. FAULTREG is somewhat lower, while POST falls substantially, suggesting a nonlinear relationship that is explored below.

The linear form is a standard regression model. The hedonic prices from a linear model are constant and equal to the estimated coefficient. Thus, comparisons to the linear form can be made directly. The estimates are given in Table 6. The hedonic prices of the four hazard variables are -\$1297 (insignificant), \$2579, \$5421, and -\$25176. We can see that with the hedonic prices are quite robust with respect to functional form for PODAMAGE and SOILTYPE.

Numerous other specifications are candidates for a hedonic model. We estimated quadratic models (square terms for the continuous variables) and examined the hedonic prices of hazard variables. While some of the quadratic terms were significant, the addition of these terms did not appreciably change the hedonic prices of interest. We, therefore, decided to keep the basic semilog form, with one exception. The POST and SMONTH variables are measuring almost the same effect on prices. If the rate of appreciation, which is captured by SMONTH, changed over the sample period, this change would be reflected in the

Table 5

Estimated Coefficients of the Benchmark Hedonic Price Function Specification Loglinear Form

Variable		(1)		(2)		(3)		(4)	
CONSTANT		-0.5505		-0.5322		-0.6431		-0.8295	
SMONTH	+	0.1596		0.1596		0.1590		0.1603	
AGE		0.0013		0.0013		0.0012		0.0011	
LIVAREA	+	0.6534		0.6534		0.6476		0.6446	
LOTAREA	+	0.1856		0.1850		0.1868		0.1886	
BATH		0.0112		0.0111		0.0121		0.0104	
FIRE		0.0216		0.0216		0.0207		0.0209	
STORIES		-0.0091	*	-0.0090	*	-0.0105	*	-0.0105	*
PARKING		0.0275		0.0274		0.0267		0.0269	
POOL		0.0534		0.0535		0.0555		0.0538	
VIEW		0.0472		0.0475		0.0301		0.0487	
BAY		0.1480		0.1490		0.1305		0.1423	
WOODED		0.0678		0.0674		0.0413		0.0728	
OTHERL		0.0976		0.1016		0.0951		0.1061	
AVQ		0.0253	*	0.0257	*	0.0284	*	0.0282	*
ABOVEQ		0.1177		0.1182		0.1197		0.1164	
CTDENS	+	0.0145		0.0144		0.0161		0.0133	
CTWPOP	+	0.1315		0.1314		0.1285		0.1265	
CTO62		0.0044		0.0044		0.0042		0.0041	
CTTTW	+	-0.2151		-0.2131		-0.2379		-0.1999	
CMM8	+	0.1824		0.1827		0.2468		0.1143	
CMR12	+	0.4388		0.4326		0.3913		0.4548	
CMCRIME	+	-0.0265		-0.0266		-0.0113		-0.0391	
CMOZ1	+	-0.1224		-0.1209		-0.1013		-0.0670	
CMPM		0.0041	*	0.0044	*	0.0021	*	0.0080	*
ALAMEDA		-0.5716		-0.5713		-0.5417		-0.6112	
CONTRA		-0.7938		-0.7927		-0.7587		-0.8193	
MARIN		-0.5623		-0.5603		-0.5548		-0.5634	
SANTAC		-0.4959		-0.5017		-0.4356		-0.6617	
SANMAT		-0.2875		-0.2885		-0.2798		-0.3580	
POSTQ		-0.0020		-0.0019		-0.0024		-0.0029	
FAULTREG		-0.0305		-0.0300		-0.0372		-0.0131	
GEOGRADE		-0.0034	*						
PODAMAGE				-0.0073					
SOILTYPE						0.0274			
SHAKING								0.0752	
R-SQUARE		0.7703		0.7704		0.7750		0.7742	

\+ Variable entered in natural logarithmic form.
* Indicates that the coefficient is not significant at the .05 level.

Table 6

Estimated Coefficients of the Benchmark Hedonic Price Function Specification Linear Form

Variable	(1)	(2)	(3)	(4)
CONSTANT	-278.454	-262.476	-277.581	-419.98
SMONTH	4.9598	4.9565	4.944	4.9938
AGE	0.704	0.6991	0.6805	0.6477
LIVAREA	15.7752	15.7478	15.7244	15.6093
LOTAREA	0.3956	0.3936	0.395	0.3968
BATH	7.5297	7.6875	7.7282	7.5318
FIRE	6.9288	6.7801	6.6447	6.7068
STORIES	-14.6893	-14.641	-15.0487	-15.2187
PARKING	5.0298	5.0104	4.919	4.9686
POOL	11.4378	11.326	11.8248	11.6826
VIEW	7.5904	6.728	3.4853 *	7.0998
BAY	71.8972	71.0518	67.4651	68.5539
WOODED	23.2893	21.6339	16.981	23.5018
OTHERL	24.2883	26.4854	24.3481	27.4371
AVQ	-32.7255	-32.6371	-32.1866	-31.8915
ABOVEQ	-10.1049 *	-10.1281 *	-9.888 *	-10.7359 *
CTDENS	0.5191	0.5669	0.6338	0.3033
CTWPOP	1.2112	1.1959	1.1747	1.0934
CTO62	0.929	0.9097	0.8889	0.8407
CTTTW	-3.4049	-3.572	-3.7352	-3.4674
CMM8	0.5681	0.5569	0.5886	0.4734
CMR12	0.2495	0.2596	0.2353	0.2842
CMCRIME	4.4301	4.5154	4.8214	3.3847
CMOZ1	7.3129 *	8.1284 *	10.1172 *	13.7948
CMPM	0.5091 *	0.5971 *	0.1948 *	1.8544 *
ALAMEDA	-151.788	-152.55	-146.001	-168.349
CONTRA	-205.168	-207.509	-199.676	-217.496
MARIN	-141.02	-141.914	-140.283	-146.625
SANTAC	-118.053	-121.659	-108.743	-177.192
SANMAT	-62.4744	-65.3285	-62.1326	-90.821
POSTQ	-29.9473	-29.9973	-30.0171	-30.5777
FAULTREG	-9.4394	-9.8607	-11.4275	-3.9153
GEOGRADE	1.2974 *			
PODAMAGE		-2.579		
SOILTYPE			5.4205	
SHAKING				25.176
R-SQUARE	0.7373	0.7374	0.7386	0.7405

* Indicates that the coefficient is not significant at the .05 level.

coefficient on POST. We might incorrectly assign an economic trend (changing market conditions) to the earthquake. This scenario appears to be the case. With SMONTH2 (sales month squared) in the model the coefficient on POST falls dramatically-- from about .10 to .02. The effect remains significant, however. Additionally, the coefficient on SMONTH2 is also significant. Another model was used to test the stability of the POST coefficient. A new variable was constructed by Multiplying POST by the number of months since the earthquake. The estimates on this new variable suggested that the POST coefficient was stable.

We feel that the model with SMONTH and SMONTH2 best represents the economic conditions and the impact of the earthquake. The impact is estimated to be about $5000 on the average house, rather than the previous estimate of approximately $26000. In Table 7, we present the new benchmark specifications. The only difference is the addition of the SMONTH2 term.

Multicollinearity

The data used to estimate the hedonic price functions are not collected from a controlled experiment. Economists often refer to the data generation process as a "social" experiment. In contrast to a controlled experiment, society's experimental design may not facilitate statistically important variation in all of the characteristics. When this happens, our ability to precisely identify the relationship of each characteristic with price is lowered. Some covariation in the set of independent variables is not harmful. With hedonic price function estimation, however, several of the independent variables should be expected to exhibit significant multicollinearity.

If the earthquake hazard variables are highly collinear with other geographic measures; i.e., the existence of a view or certain neighborhoods and communities, the relationship between the hazard variables and price may be difficult to interpret. Moreover, the statistics that are relevant for testing the relationship can be biased. It is, therefore, important to properly diagnose multicollinearity and take steps to reduce its impact on the regression findings. If severe multicollinearity is detected, precise estimates of the affected measures is difficult without additional information. In the context of the study here, additional information may be available from the survey instrument. On the other hand, if we fail to detect multicollinearity in the measures of interest (earthquake hazard measures) this gives us much more confidence in inferences drawn about them.

Table 7

Estimated Coefficients of the Benchmark Hedonic Price Function Specification Semilog Form

Variable	(1)		(2)		(3)		(4)	
CONSTANT	3.6835		3.6591		3.595		3.3285	
SMONTH	0.0317		0.0317		0.0315		0.0316	
SMONTH2	-5e-04		-5e-04		-5e-04		-5e-04	
AGE	0.0008		0.0008		0.0007		0.0007	
LIVAREA	0.0376		0.0377		0.0375		0.0374	
LOTAREA	0.0005		0.0005		0.0005		0.0006	
BATH	0.0091	*	0.0088	*	0.0091	*	0.0084	*
FIRE	0.0281		0.0283		0.0275		0.0282	
STORIES	-0.026		-0.025		-0.027		-0.027	
PARKING	0.032		0.0319		0.0315		0.0319	
POOL	0.0553		0.0553		0.0576		0.0562	
VIEW	0.0619		0.063		0.0478		0.0645	
BAY	0.1637		0.166		0.1493		0.1614	
WOODED	0.0874		0.088		0.066		0.0935	
OTHERL	0.097		0.1019		0.093		0.1002	
AVQ	0.0609		0.0616		0.0638		0.0629	
ABOVEQ	0.1604		0.1614		0.1626		0.16	
CTDENS	0.0028		0.0028		0.0031		0.0022	
CTWPOP	0.0065		0.0065		0.0064		0.0063	
CTO62	0.0025		0.0025		0.0024		0.0024	
CTTTW	-0.006		-0.006		-0.007		-0.006	
CMM8	0.001		0.001		0.0011		0.0008	
CMR12	0.0013		0.0013		0.0012		0.0013	
CMCRIME	0.004		0.0039		0.0054		0.0016	*
CMOZ1	-0.051		-0.05		-0.041		-0.04	
CMPM	0.0067	*	0.0071	*	0.0053	*	0.0094	*
ALAMEDA	-0.532		-0.532		-0.502		-0.563	
CONTRA	-0.746		-0.742		-0.707		-0.761	
MARIN	-0.537		-0.532		-0.525		-0.542	
SANTAC	-0.453		-0.459		-0.401		-0.566	
SANMAT	-0.259		-0.259		-0.245		-0.307	
POSTQ	-0.02		-0.02		-0.021		-0.022	
FAULTREG	-0.031		-0.03		-0.037		-0.018	
GEOGRADE	-0.007							
PODAMAGE			-0.01					
SOILTYPE					0.0249			
SHAKING							0.051	
R-SQUARE	0.7814		0.7815		0.7851		0.7829	

* Indicates that the coefficient is not significant at the .05 level.

Numerous detection methodologies have been suggested in the econometric literature (see Judge et al, 1985, Ch. 22, Belsley, et al, 1980, Ch. 3). Here, we consider two of the more promising methods; (i) an examination of the "variance inflation factors" (VIF) and (ii) an examination of "condition indices" constructed from the eigenvalues of the independent variables crossproducts matrix and the associated "variance decomposition" of the coefficients estimated variance. The first method was proposed by Chatterjee and Price (1977), while the second was proposed by Belsley et al (1980). In reviewing the literature, Judge et al (1988, Ch. 21) suggest that the Belsley et al method represents the current state of the art of detecting multicollinearity. Thus, we rely more heavily on their method in this section.

The VIF_i corresponds to the R-squared (R_i) that would be obtained by running a regression with x_i as a dependent variable and the remaining x's as independent variables (called an auxiliary regression). Formally,

$$VIF_i = \frac{1}{1-R_i} \tag{14}$$

As the R_i approaches one, the VIF_i takes on greater values, indicating a "good fit" between a set of independent variables. A value for the VIF of 5 or more is sometimes used as a rule-of-thumb to indicate a near linear dependency. That the VIF will detect multicollinearity is obvious. If the data contained an exact linear dependency, the R_i would equal one and the VIF_i would equal infinity. Belsley et al (1980, page 93) argue that the VIF is insufficient because it does not provide any guidance on finding the variables involved in the near linear dependency.

The procedure developed by Belsley et al is based on the eigenvalues of the X'X matrix. From matrix algebra, we know that the OLS regression coefficients are the solution to the following system of equations ("normal equations"):

$$(X'X)\beta = X'Y. \tag{15}$$

To successfully solve for β, X'X must be inverted; i.e., X'X must be nonsingular. If X'X is singular (there is one or more linear dependency in the X matrix), it will have one or more zero eigenvalues. Moreover, when X'X becomes almost singular it will have one or more relatively small eigenvalues. And, the number of relatively small eigenvalues is the number of problematic near linear dependencies.

The significance of the Belsley et al work is that they give meaning to the phrase "relatively small". When the condition index, which is the ratio of the square root of the largest eigenvalue to the square root of the individual eigenvalues (if there are 10 independent variables, there are 10 eigenvalues), exceeds 30, harmful near linear dependencies probably exist in the data. Harmful means that the relationship and associated statistics are difficult to understand. A different critical value for the condition indices gives more or less confidence in the procedure. Certainly very high condition indices (100 or 1000), indicate a problem.

When a high condition index is found, Belsley et al show that the variables involved in the relationship can be identified by examining the decomposition of the estimated coefficient variation. If <u>two or more</u> decompositions are greater than .5, then these variables are involved and inferences using the OLS coefficients on these variables will be difficult. This identification procedure must be modified when the X matrix contains numerous high condition indices of the same magnitude. In this case, the proper procedure is to add the variance proportions and check to see if the sum is greater than .5.

The necessary information to perform the Belsley et al procedure can be estimated using an option on the SAS REG procedure. The output is voluminous. Some of the relevant data in exhibited in Table 8 along with the VIFs. None of the VIFs indicate a problem. The nine condition indices displayed is somewhat arbitrary. We could have picked a cutoff of 30 or 15, but the nature of our problem would not change. The table suggests that there are nine possible near linear dependencies, three of which are clearly serious. The primary question is the extent that the hazard variables are involved in one or more of the dependencies. We can see that only for SHAKING is there any evidence of multicollinearity causing a problem. Since SHAKING is probably our worst indicator of earthquake hazard (recall that there was little variation in this variable), this is strong testimony to the robustness of the hazard variable results vis-a-vis the inclusion/exclusion of independent variables. We noted above, that the coefficient estimates did not change much when alternative independent variable sets were tried. The results here confirm this informal observation.

In tracing the problem with respect to SHAKING, the collinearity diagnostics seem to point to a relationship with the county dummies. This makes sense given the low variation in the SHAKING variable. Probably, a large percentage of the homes coded (say) SHAKING = 6 is in one county.

Table 8

Condition Indices[1] and Variance Semipositions of the Earthquake Hazard Variables

(Variance Inflation Factors in parentheses)

Condition Index	Faultreg (1.421)	Geograde (1.242)	Podamage (1.0957)	Soiltype (1.4414)	Shaking (2.3405)
37.9526	0.0103	0.0141	0.0040	0.0301	0.0008
42.4063	0.0028	0.0653	0.0147	0.0060	0.0090
46.2854	0.0026	0.0001	0.0011	0.0022	0.0186
64.9677	0.0032	0.0125	0.0004	0.0002	0.7463
105.0110	0.0026	0.0017	0.0002	0.0026	0.0189
140.5290	0.0012	0.0351	0.0094	0.0081	0.2048

[1] Based on Belsley et al (1980). Estimates from the New Benchmark specification.

The results in this section also support our findings with respect to functional form. Graves et al (1988) noted that the influence of functional form was magnified when the variables of interest were collinear. Since we have very little collinearity, we should not expect the estimated hedonic prices for hazard to change dramatically over alternative functional forms.

Measurement Error

Several characteristics that theoretically belong in the hedonic price function are observed with error. School quality, for example, is difficult to measure. Academic performance is one dimension of school quality; experience is another dimension, making exposure to the arts, debate, and sports meaningful attributes of school quality. Another example is neighborhood quality, which is imperfectly measured by CTO62, CTWPOP, CMCRIME, and the county dummies is our data set. Whenever a characteristic is measured by a "proxy" variable, the characteristic can be modeled as measured with error.

Let R (or HAZARD, empirically) be the theoretical earthquake hazard characteristic which differentiates homes in the Bay area. GEOGRADE, PODAMAGE, SOILTYPE, SHAKING, and, perhaps, FAULTREG are the proxy variables or indicators of it. R is often called a latent variable (Bollen, 1989). Since a primary goal of this research is to estimate the hedonic price of R, we are faced with determining the properties of our estimates given that R is unobserved and that other characteristics in our specification are also unobserved or measured with error. Econometric theory indicates that the OLS coefficients in a model with measurement error are biased and inconsistent. This property is very damaging from an accuracy point-of-view so we want to make every attempt to minimize the bias.

The bias results from two sources. The first stems from the measurement error in the R characteristic. When a variable is observed imperfectly, the OLS estimates on its indicators are biased. Not surprisingly, the bias depends on the strength of the relationship between the indicators and the true measure. There is little that can be done to reduce the bias here besides adding additional information to reduce the measurement error.

The second source of bias is the measurement error in the other characteristics. This source is disturbing, since it implies that even if R was measured perfectly, the estimated coefficients on R might still be biased. The magnitude of the bias from this source depends on the collinearity of the variable of interest (R) and the other variables (Bollen, 1989, chapter 5). When the collinearity is small, the bias is small.

Fortunately, our analysis of multicollinearity showed little evidence of collinearity between the indicators of R and the other independent variables. Therefore, we concentrate on minimizing the first source of bias.

Bollen (page 306) suggests that a latent variable model may reduce the size of the bias. The basic idea is to impose a linear structure on the relationship between the indicators and the latent variable. This is called confirmatory factor analysis (CFA). CFA stands in contrast to exploratory factor analysis, wherein the relationship is not defined a priori. The methodology in CFA is the same as regression analysis, since the functional form, error distribution, and causality are all given before estimation. As in regression, the model can only be rejected.

We assume that the relationship between R and the indicators is as follows:

$$\text{GEOGRADE} = \lambda_1 R + \gamma_1$$
$$\text{PODAMAGE} = \lambda_2 R + \gamma_2$$
$$\text{SOILTYPE} = \lambda_3 R + \gamma_3$$
$$\text{SHAKING} = \lambda_4 R + \gamma_4.$$

In matrix notation this system is

$$Z = \lambda R + \gamma, \qquad (16)$$

where Z, λ, and γ are 5 by 1 matrices. This structure holds for each observation (house) so there is an implied observational subscript on Z and R. We assume that the expected value of γ is zero, that the covariance between R and γ is zero, and that the covariance between γ_i and γ_j is zero for i not equal to j. The estimated λ are often called "factor loadings", although in econometrics it more common to simply refer to them as unknown parameters.

Bollen shows that the covariance matrix of the Z can be written in terms of the variances of γ and R and the λ parameters. The model contains 11 unknowns; i.e., the variances of R and γ and the λ parameter. However, we have the sample covariance matrix of the Z. This contains 15 values, making the model over identified. (In general, a model with one latent variable is identified if there are at least three indicators.) We can estimate the parameters using a maximum likelihood or some other technique. We use the maximum likelihood method.

Once the parameters are estimated, we can solve for R to get estimates of the latent variable (sometimes called factor scores). We refer to these estimates as HAZARD. Unfortunately, HAZARD is not a perfect measure for R, meaning that a model with HAZARD does not totally eliminate the bias. The idea is that bias is reduced as long as the hypothetical structure (16) reflects reality.

The maximum likelihood estimates of λ_i are, respectively, .97, .61, -.47, and .11. Thus, it appears that the latent variable really does reflect earthquake risk. The predicted variable (HAZARD) should be negative in the hedonic price function. The latent variable model seems to be a good fit of the observed indicators. The likelihood ratio test of the hypothesis that the λ are jointly equal to zero is rejected at the .00001 level. In terms of magnitudes, the most important indicator in the model can be determined by looking at standardized coefficients. This points to GEOGRADE, followed by PODAMAGE, SOILTYPE, and SHAKING.

The hedonic price function with HAZARD entered as an independent variable is presented in Table 9. The scale of the HAZARD variable closely resembles the scale of GEOGRADE (λ_1 = .97). Hence, the interpretation of the variable is similar to the interpretation on GEOGRADE; i.e., an index from 1 - 8. The specification given in Table 9 represents our best single equation estimate of the hedonic price function.

E. CONCLUDING REMARKS

Our investigation of the housing market in the San Francisco area indicates that homeowners are willing to pay for information concerning geologic risk variables. This willingness to pay translates into a measurable hedonic price gradient. Thus, homes with relatively risky attributes sell for less than those with a safer combination of attributes. In the following chapter these market based hedonic price estimates are compared to estimates derived from survey data.

Table 9

Regression Results with the Estimate for the Latent Variable, Earthquake Hazard, as an Independent Variable

Variable	Coefficient	T-ratio
CONSTANT	3.6835	22.2863
SMONTH	0.0317	21.8082
SMONTH2	-0.0005	-10.6473
AGE	0.0008	4.675
LIVAREA	0.0376	48.996
LOTAREA	0.0005	13.4439
BATH	0.0091	1.6425
FIRE	0.0281	5.6086
STORIES	-0.0255	-4.0068
PARKING	0.032	6.3638
POOL	0.0553	6.2395
VIEW	0.0619	6.9033
BAY	0.1637	6.9868
WOODED	0.0874	4.8157
OTHERL	0.097	3.0149
AVQ	0.0609	2.0961
ABOVEQ	0.1604	5.4624
CTDENS	0.0028	4.9192
CTWPOP	0.0065	34.6667
CTO62	0.0025	7.1399
CTTTW	-0.0064	-7.0296
CMM8	0.001	5.1067
CMR12	0.0013	6.5231
CMCRIME	0.004	1.9566
CMOZ1	-0.051	-3.5315
CMPM	0.0067	0.9909
ALAMEDA	-0.5324	-15.8598
CONTRA	-0.7458	-23.4059
MARIN	-0.5365	-12.6599
SANTAC	-0.4529	-3.7453
SANMAT	-0.2588	-8.3396
POSTQ	-0.0202	-1.6501
FAULTREG	-0.0311	-4.6245
HAZARD	-0.0069	-3.0109
R-SQUARE	0.7814	

V. ECONOMETRIC ANALYSIS OF SURVEY DATA

A. BACKGROUND

In this chapter we undertake a more detailed analysis of the data obtained via the survey. Four specific analyses are conducted. The results of each analysis are compared to those obtained from the survey summary and the market data hedonic approach detailed in the previous two chapters.

First, we examine the respondents' subjective assessment of the earthquake impact on housing prices. The hedonic price method is utilized on the survey data. Estimates of the economic impact of the earthquake and various location indicators are obtained. Second, we estimate bid functions that describe the relationship between an individual's willingness to pay or accept to a set of explanatory variables. Third, we estimate individual utility functions using the approach suggested by Viscusi and Evans (1990). These functions are used to examine the effect of changes in the geologic variables soil type and SSZ location. Finally, we provide estimates of willingness to pay and accept from a referendum style contingent valuation experiment.

The remainder of the chapter is organized as follows. Sections B through E are devoted to the issues defined above. In the final section (F) we examine the relative performance characteristics of objective data (market transactions) versus the subjective data (survey).

B. SUBJECTIVE HEDONIC PRICE APPROACH

In the previous chapter we described the effect of the earthquake and several geologic measures on actual sales prices of single family homes. The econometric results suggested that the earthquake event and the location indicators (soil type and special studies zone (SSZ) location) significantly affected home prices. In this section we examine respondents subjective assessments of these same factors. We apply the hedonic price method to data on home and neighborhood characteristics and estimated home values obtained from the survey. Our results are generally consistent with those obtained from the market data, implying that home owners accurately assess house price determinants and changes in prices due to exogenous events.

The remainder of this section is organized as follows. The next sub-section contains a detailed description of the data used in the study. The empirical results are presented in the following sub-section. Concluding remarks are offered in the final sub-section.

Data Specifics

The original data set included 869 observations obtained from the survey instrument. However, several observations were incomplete. Elimination of the data points left an operable sample of 643 observations. The dependent variable is the home sale price of owner-occupied single family dwellings. The independent data set includes variables that correspond to four types of attributes: house, neighborhood and community, access, and hazard location and timing. Variable descriptions are listed in Table 10. Descriptive statistics are provided in Table 11. These summary statistics are generally consistent with those provided in the previous chapter.

House size or quantity is described through such variables as square footage of living space and number of bathrooms. House quality is depicted by house age and zero-one dichotomous variables for the presence of fireplaces, view, and pool. The quality of the surrounding community is measured by air, school, and neighborhood quality, which are subjective assessments by the individual respondents. Access is measured by distance to work and the nearest major water body (ocean or bay). The important hazard variables are soil type, location vis-a-vis an SSZ and the earthquake event. We also include several time related variables to determine relative trends of house values over time.

There exist two sources of uncertainty concerning the independent variable set: (1) inclusion or exclusion; and (2) the sign of the variable's coefficient. Consider each of these.
The hedonic theory as presented above does not provide the researcher with any guidelines concerning which variables to include as a part of the independent variable set. Atkinson and Crocker (1987) and Graves et al (1988) have empirically examined the impact of various independent variable sets on hedonic price estimates. Their research indicates that variable selection can significantly affect these estimates. Moreover, the relative importance of variable selection varies by variable type (structural, neighborhood, access).

Table 10

Variable Descriptions

Variable	Definition	Units
Dependent:		
Home Value	Home value of single family residence	$
Independent-Housing:		
Square Footage	Total square feet of living space	Sq ft
Bath	Sum of full and half baths	Number
Age	Age of home	Years
Pool	1 if in/above ground pool, 0 if not	0/1
Fireplace	1 if one or more fireplaces, 0 if not	0/1
View	1 if view, 0 if no view	0/1
Sale Month	Month home was purchased (1/89 to 10/90)	1-32
Independent-Neighborhood, Community:		
School Quality	Subjective evaluation (1 = poor, 5 = excellent)	1-5
Air Quality	Subjective evaluation (1 = poor, 5 = excellent)	1-5
Neighborhood Quality	Subjective evaluation (1 = poor, 5 = excellent)	1-5
Distance to Work	Distance to work	Miles
Distance to Water	Distance to nearest water	Miles
Independent-Location:		
Special Studies Zone	1 if in SSZ, 0 if not	0/1
Soil Type	Type of soil beneath home (gravel to granite)	1-6

Table 11

Descriptive Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Home Attributes:				
Home Value	304573	174881	35000	1700000
Age	33.84	20.91	0.00	106.00
Square Footage	1822.7	720.4	900.00	6000.00
Number of Baths	2.098	.79	1.00	8.00
Fireplace (1=yes, 0=no)	0.88	0.32	0.00	1.00
Pool (1=yes, 0=no)	0.28	0.45	0.00	1.00
View	.40	.49	0.00	1.00
Sale Month			1.00	32.00
Neighborhood and Community Variables:				
School Quality	3.84	.88	1.00	5.00
Air Quality	4.06	.83	1.00	5.00
Neighborhood Quality	4.33	.91	1.00	5.00
Distance to Work	18.43	23.19	0.00	400.00
Distance to Water	19.71	13.78	0.00	112.00
Location Variables:				
Special Studies Zone	.278	.49	0.00	1.00
Soil Type	3.46	1.70	1.00	6.00

Structural variables (e.g., living area, bath, pool) have been found to be relatively insensitive to the inclusion or exclusion of independent variables. However, previous research indicates that hedonic price estimates for the neighborhood and access variables are highly sensitive to variable selection due to collinearity between these variables. The approach used herein is to select a benchmark independent variable set that contains variables representative of the structural, neighborhood, community, and access attributes and is consistent with the equations estimated using market data.

As in the case of variable selection there is no explicit theory to provide a priori predictions concerning the relationship between independent variables and house price. Thus, our expectations concerning the sign of the coefficients on the independent variables are taken from earlier literature. The structural variables square footage, bathrooms, pool, and fireplace are expected to be positively related to house price. We attach no a priori expectation concerning age of home. Air, school, and neighborhood quality should be positive influences on house price. The effect of the policy variables (SSZ location, soil type, and the earthquake event) are the subject of the empirical work below.

The importance of individual observations was tested using the procedures suggested by Belsley, Kuh, and Welsch (1980). Observations are considered influential or outliers if they alter the parameter estimates by a significant amount. The procedure essentially entails estimating the benchmark equations without each observation and then testing for significant differences. Several criteria have been suggested for identifying outliers.

In our analysis we defined an observation to be an outlier if the absolute value of the studentized residual exceeded two in absolute value and if the change in the parameter estimate of our policy variables exceeded the recommended size-adjusted cutoff (Belsey, Kuh, and Welsch, 1980). Given these criteria we identified 19 observations that could be considered outliers. These observations were eliminated from further consideration.

Empirical Results

A representative hedonic housing value equation estimated for the San Francisco area is presented in Table 12. A number of aspects of the equation are worth noting. First, most of the estimated coefficients are significantly different from zero at the five percent level and have the expected relationship to home sale price. The exceptions in the structural and neighborhood categories are view, and distance to work and air quality, respectively.

Second, approximately 67 percent of the variation in home sale price is explained by the variation in the independent variable set. Third, the estimated functional form is semi-log making the equation quite amenable to interpretation. Regarding the monetary impact on housing value of a change in an independent variable it is evident that a fireplace, a pool, and one less mile to water are worth approximately $19030, $32349, and $1880, respectively.

The most important aspects of the equation from the perspective of this study concern the hazard information variables. The coefficient on SSZ location is not significantly different from zero. This result is stable with respect to various functional forms, sample sizes and

Table 12

Estimated Subjective Hedonic Equation
Semi-Log Functional Form
Dependent Variable = Estimated Home Value

	Coefficient	t-statistic
Housing Structure Variables:		
Square footage	.0002	8.38
Number of baths	.153	7.17
Age of house	.0036	6.16
Fireplace	.071	2.14
View	.029	1.24
Pool	.12	4.73
Sale Month	.011	5.92
Neighborhood and Community Variables:		
School quality	.070	5.42
Air Quality	-.0008	-.06
Neighborhood Quality	.086	6.67
Distance to work	-.0003	-.47
Distance to Water	-.007	-8.14
Hazard Variables:		
Soil Type	.022	3.29
SSZ Location	-.01	-.44
Earthquake Event	-.069	-1.96
Constant:	10.83	127.37
Number of Observations	643	
R-Square	.67	

other experiments we conducted. This may reflect the uncertainty that many respondents' have concerning their location. We received numerous telephone calls from respondents indicating that they did not know the definition of a special studies zone. This apparent confusion is illustrated in the empirical results.

The soil type variable is significantly different from zero and possesses the expected relationship to home sale price. This result indicates that individuals are acting upon soil type information when making location choices and this action translates into a measurable hedonic price gradient. Moving from one soil type category to the next best category is worth approximately $5920. In addition, the earthquake event causes a 6.9 percent decrease in home value. This coefficient is also significantly different from zero.

The estimated equation presented in Table 12 serves as a benchmark against which it is possible to test the importance of variable selection and functional form. Each of these possible influences is considered in detail below.

To test the relative sensitivity of the benchmark equations to our selection of independent variables two experiments were conducted. The first experiment was to include other structural attributes. Number of bedrooms and presence of garage and/or other parking facilities have been used in previous studies. Our data set included information on the former. We re-estimated the benchmark equations with bedrooms being an additional regressor. The inclusion of bedrooms had no measurable effect on any of the policy variable coefficients. It seems that our benchmark equations are relatively insensitive to the inclusion of additional structural attributes. This is consistent with Atkinson and Crocker (1987) and Graves et al (1988).

The second experiment was to examine various trend variables. As in the previous chapter we included sales month squared. This caused the earthquake event impact to be reduced by approximately one-half. However, this additional trend variable was not significantly different from zero so was excluded from further consideration. Our second experiment involving trend variables is presented in Table 13. In this estimated form we include trend variables (post month, post month squared) that begin after the earthquake event. This formulation represents an attempt to measure the magnitude of any recovery from the event. As is illustrated the earthquake seems to have a larger immediate impact than in the benchmark equation. However, recovery begins immediately and within six months home values return to the before event levels. Finally, in a third stage, prices decline with economic conditions.

There has been extensive discussion in the literature concerning the importance of the estimated functional form of the hedonic price equation. Bender et al (1980), Halvorsen and Pollakowski (1981), and Graves et al (1988) conducted detailed investigations of functional form and found that the predicted hedonic prices vary significantly across various functional forms. Thus, the hedonic prices must be examined to determine their relative stability with respect to functional form.

The approach utilized in this study was to examine various commonly used functional forms to determine relative estimation properties and to test the stability of the hedonic prices. The estimated linear equation is presented in Table 14. As is evident the performance characteristics of linear specification are quite similar to the semi-log form.

Concluding Remarks

Our investigation of respondents' subjective assessments indicates that individuals are willing to pay higher home prices to locate in geologically preferred areas and that the earthquake event had a strong negative impact on house values. In addition, it seems that the impact of the earthquake dissipated within six months. Moreover, the subjective assessments are generally consistent with the analysis of market data. There are two significant exceptions. First, SSZ location is insignificant in the subjective assessment. This is likely a result of confusion concerning the actual definition of SSZ location. Second, the magnitude of the impact of the earthquake is somewhat larger in the subjective analysis.

C. ESTIMATED BID EQUATIONS

In chapter 2 we presented the raw averages for homeowners willingness to pay and willingness to accept for changes in soil type and SSZ location. These values were determined by asking homeowners direct questions. Respondents with homes located on risky soil or inside the SSZ were asked to specify the dollar amount they would be "willing to pay" (WTP) to locate their home on (1)

Table 13

Estimated Subjective Hedonic Equation
Semi-Log Functional Form
Dependent Variable = Estimated Home Value

Housing Structure Variables:	Coefficient	t-statistic
Square footage	.0002	8.35
Number of Baths	.152	7.11
Age of House	.0035	6.02
Fireplace	.071	2.14
View	.03	1.28
Pool	.12	4.86
Sale Month	.012	5.92
Neighborhood and Community Variables:		
School quality	.070	5.41
Air Quality	-.0004	-.03
Neighborhood Quality	.088	6.73
Distance to work	-.0003	-.46
Distance to Water	-.007	-8.24
Hazard Variables:		
Soil Type	.022	3.26
SSZ Location	-.01	-.43
Earthquake Event	-.144	-1.93
Post Month	.043	1.46
Post Month Squared	-.0044	-1.73
Constant	10.83	127.26
Number of Observations	643	
R-Square	.67	

Table 14

Estimated Subjective Hedonic Equation
Linear Functional Form
Dependent Variable = Estimated Home Value

<u>Housing Structure Variables:</u>	**Coefficient**	**t-statistic**
Square footage	79.53	8.35
Number of Baths	77975	9.28
Age of House	1780	7.70
Fireplace	13201	1.016
View	11561	1.24
Pool	29776	2.98
Sale Month	3298	4.14
<u>Neighborhood and Community Variables:</u>		
School quality	21585	4.26
Air Quality	-4025	-.73
Neighborhood Quality	17859	3.49
Distance to work	-414.8	-1.75
Distance to Water	-2124	-6.27
<u>Hazard Variables:</u>		
Soil Type	6819	2.55
SSZ Location	-6025	-.66
Earthquake Event	-59231	-2.00
Post Month	25679	2.22
Post Month Squared	-2344	-2.291
<u>Constant</u>	-262364	-7.84
Number of Observations	643	
R-Square	.65	

safer soil type (consolidated soils/rock) or (2) outside a special study zone, respectively. Respondents indicated a willingness to pay $7,527 for safer soil and $12,371 to locate outside an SSZ. Alternatively, residents with homes located on safe soil or outside an SSZ were asked the dollar amount they would be "willing to accept" (WTA) to locate their home on (1) riskier soil type (unconsolidated soils/landfill) or (2) inside a special study zone. Average willingness to accept ranged from $29,486 for location in an SSZ to $188,539 for location with relatively unsafe soil type.

In this sub-section we present estimated bid equations which attempt to explain the survey willingness to pay/accept responses in terms of respondent's characteristics. In effect, we are controlling for confounding factors that might account for variations in the raw averages.

Data Specifics

As indicated above there are four categories of home owners sampled by our survey questionnaire. The descriptive data specifics of these four categories of home owners are specified in Tables 15 (soil type) and 16 (special study zone). A definition and description of each variable is provided, along with its mean and standard deviation. A number of general points need to be made about the data.

First, the personal characteristics of the respondents are fairly uniform across the four categories. The average age of respondents ranges from 36.5 to 38.6 years across the sub-samples. Average size of the household varies from 2.84 to 3.11. Gross family income ranges from 57,000 to 60,224.

Second, there is considerable variation in purchase price of homes (HPRICE) across the sub-samples. As expected, the average price of homes located on risky soil type ($243,528) is relatively lower than that of homes on safer soil ($318,786). However, in the case of special study zones, the average purchase price of homes in SSZs ($299,304) is relatively higher than average price of homes that are not is SSZs ($271,030). Since these are home price averages without specific control factors, this price differential may be due to other confounding factors such as better view, community variables etc. Moreover, the high degree of variability in home prices, reflected in the standard deviations, implies that the difference in the mean values is not statistically significant. Third, there is a high degree of variability in the bid values indicated by respondents. The ratio of the standard deviation relative to the mean ranges from 2.42 to 5.72 across the four sub-samples.

Table 15

Data Specifics for Soil Type

WTP for Soil Type: 208 Observations

Variable Name	Description	Mean	Standard Deviation
WTPS	Willingness to pay for improved soil	5,384	22,447.9
DL	Difference in risk ladder between safe and risky soil	1.67	2.55
AGE	Age of respondent	36.55	7.81
SEX	Sex of respondent	0.73	0.44
HSIZE	Number in household	2.84	1.22
INCOME	Gross income of family[1]	57,000	16,847
HPRICE	Home purchase price	243,528	127,778
YSF	Years lived in San Francisco Bay area	19.40	12.38

WTA for Soil Type: 116 Observations

Variable Name	Description	Mean	Standard Deviation
WTAS	Willingness to accept for riskier soil	162,431	928,317
DL	Difference in ladder between risky and safe soil	3.06	2.9
AGE	Age of respondent	37.88	8.89
SEX	Sex of respondents	0.77	0.42
HSIZE	Number of household	2.85	1.47
INCOME	Gross income of family	60,740	1,504
Home Price	Home purchase price	318,786	189,624
YSF	Years lived in San Francisco Bay area	15.93	11.44

[1] Approximated from frequency distribution

Table 16

Data Specifics for SSZ ZONE

WTP for SSZ ZONE: 81 Observations

Variable Name	Description	Mean	Standard Deviation
WTP2	Willingness to pay for home outside SSZ	8,530	39,985
DL	Difference in ladder probability between homes in and out of SSZ	1.75	2.77
AGE	Age of respondent	38.65	8.65
SEX	Sex of respondent	0.74	0.44
HSIZE	Numbers in household	3.11	1.36
INCOME	Gross income of family[1]	60,062	1,727
YSF	Years lived in San Francisco Bay area	28.86	12.91
HPRICE	Purchase price of home	299,304	201,886

WTA for SSZ ZONE: 223 Observations

Variable Name	Description	Mean	Standard Deviation
WTA2	Willingness to accept for living in an SSZ	24,768	60,063
DL	Difference in ladder probability for home in and outside SSZ	1.20	2.14
AGE	Age of respondents	36.60	7.36
SEX	Sex of respondents	0.76	0.43
HSIZE	Number in the household	2.90	1.32
INCOME	Gross income of family	60,224	1,631
YSF	Years lived in San Francisco Bay area	16.81	11.11
HPRICE	Purchase price of home	271,030	138,914

[1] Approximated from frequency distribution

Fourth, the dollar amounts indicated for WTA are generally much higher than the corresponding amounts for WTP. We will address the issue of a potential bias in these estimates after an analysis of the data.

Empirical Results

The benchmark empirical equations are presented in Tables 17 and 18. A few general statements apply to all the equations. First, the coefficient of determination is relatively low in all the equations, ranging from 0.04 to 0.24 in different specifications. As indicated earlier, the bid values have a high degree of volatility. Coupled with the low explanatory power of the independent variables, the low R-squares are not surprising. This is generally common with individual level data. Second, all equations are reported after White's (1980) heteroscedastic correction. Third, the results are not altered significantly when an alternative specification for household wealth is employed in each sub-sample. Fourth, for each specification, two additional pieces of information is provided: the average predicted value of the bids (evaluated at the means of the explanatory variables) and the net change in the mean predicted bid value attributed to the change in perceived risk (DL). Next, consider each sub-sample.

Willingness to Pay for Safer Soil

The results for the first sub-sample are presented in Table 17. This group consists of respondents whose homes are located on a relatively riskier soil type, such as gravel, clay or unconsolidated sediment. The respondents were asked how much they would be willing to pay for the same home to be located on a safer soil type. Their perceived increase in earthquake risk is indicated by the letter they circle on the ladder probability scale (for details refer to the survey instrument provided in the Appendix). This positive difference in their "perceived risk" is captured by the DL variable.

Two control variables for household wealth are employed: gross household income or purchase price of the home. Model 1 controls for household wealth by employing income, whereas model 2 employs home purchase price. Since these two variables are generally correlated (correlation coefficients ranging from 0.34 to 0.52 across sub-samples) each variable is employed separately. The results are not altered significantly when both income and home price are included. We also control

Table 17

Regression Results for Soil Type

Model Type	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Dependent Variable	**WTP**	**WTP**	**WTA**	**WTA**
CONSTANT	-4,831.19	-1,698.64	-73,853.98	60,679.44
	(-.985)	(-.34)	(-.30)	(0.37)
DL	2,581.57	2,593.95	10,695.63	11,996.59
	(2.15)	(2.16)	(1.18)	(1.35)
AGE	-155.25	-200.20	7,578.24	7,920.41
	(-.60)	(-.77)	(1.28)	(1.07)
SEX	4,395.31	4,594.84	-427,666.42	-398,001.23
	(2.09)	(2.22)	(-.99)	(-1.00)
HSIZE	904.71	978.88	69,297.54	66,292.50
	(.79)	(.91)	(1.03)	(0.92)
INCOME	769.30	—	15,013.22	-
	(1.76)		(0.84)	
HPRICE	—	0.018	—	-0.13
		(2.13)		(-0.35)
YSF	-7.56	-30.82	-5,061.74	-4,822.26
	(-.09)	(-.43)	(-.99)	(-0.96)
R^2	0.10	0.11	0.05	0.04
Number of Observations	208	213	116	119
Average Predicted Value for WTP	5,403.04	5,234.6	160,388.5	160,343.29
Average Predicted Value for RISKY SOIL	4,311.24	4,330.31	32,728.66	36,709.56
(Significance Level)	(5%)	(5%)	(24%)	(18%)

NOTES: (1) All equations are reported after White's (1980) heteroscedastic correction.
(2) t-values are in parentheses.

Table 18

Regression Results for Special Study Zone

Model Type	Model 1	Model 2	Model 3	Model 4
Dependent Variable	**WTP**	**WTP**	**WTA**	**WTA**
CONSTANT	33,088.9	19,720.99	-63,263.49	-27,751.32
	(1.24)	(1.04)	(-1.81)	(-1.10)
DL	4,920.07	4,520.95	12,556.28	11,942.15
	(1.36)	(1.31)	(4.49)	(4.42)
AGE	-734.59	-713.33	858.92	548.08
	(-.93)	(-1.02)	(1.55)	(1.11)
SEX	11,456.79	9,193.52	13,059.68	317.49
	(1.29)	(1.26)	(2.20)	(0.03)
HSIZE	51.57	-74.28	1,491.36	1,026.63
	(.03)	(-.04)	(.68)	(0.51)
INCOME	-1,430.29	—	3,671.48	-
	(-1.17)		(1.55)	
HPRICE	—	0.012	—	0.08
		(1.44)		(1.62)
YSF	-91.29	-100.22	-170.04	-225.91
	(-.50)	(-.62)	(-.68)	(-0.951)
R^2	0.15	0.13	0.24	0.21
Number of Observations	81	85	223	231
Average Predicted Mean Value for WTP	8,522.02	7,512.93	24,766.39	24,978.60
Average Predicted Value for SSZ RISK	8,624.90	7,911.66	15,033.64	14,330.58
(Significant level)	(19%)	(19%)	(1%)	(1%)

Notes: (1) All equations are reported after White's (1980) heteroscedastic correction.
(2) t-values are in parentheses.

for various individual-specific attributes such as age, sex, household size, and years lived in the bay area.

As expected a higher value of perceived risk is associated with a higher dollar amount of WTP (significant at the 5% level for both specifications). The only other variable significant at the 5% level is sex, indicating that males are willing to pay relatively higher amounts than women. The average predicted value (evaluated at the mean) for willingness to pay is $5,403 for model 1 and $5,234 for model 2. The average amount respondents are willing to pay for a decline in mean perceived risk due to safer soil type is $4,311 in model 1 and $4,330 in model 2.

Willingness to Accept for Riskier Soil

In models 3 and 4 we analyze the respondents who have homes located on safer soil. These respondents were asked the dollar amount they would be willing to accept to have their home located on riskier soil. Note that in this sub-sample the variation in the WTA values is relatively higher, with the standard deviation being more than five times greater than the mean.

None of the independent variables are significantly different from zero in models 3 and 4. The average dollar amount respondents are willing to accept for the increase in perceived risk is $32,728 in model 3 and $36,710 in model 4. These estimates should be viewed with caution since they are statistically significant only at the 24% and 18% level respectively.

Willingness to Pay for Location Outside an SSZ

In Table 18 (models 1 and 2) estimates of respondents' valuation of reduction in perceived risk when the home is re-located outside an SSZ are provided. The set of control variables identified above is utilized. In this case, the variability in the willingness to pay values is also relatively high. The standard deviation is 4.7 times higher than the mean value. The average predicted WTP value for locating the home outside an SSZ is $8,624 in model 1 and $7,911 in model 2. Both coefficients are statistically significant only at the 19% level.

Willingness to Accept for Location Inside an SSZ

Models 3 and 4 in Table 18 relate to the amount of compensation demanded for the increase in perceived risk associated with re-location of the home inside a SSZ. The variability of the bid values in this sub-sample is relatively lower. The standard deviation is 2.42 times higher than the mean values. The coefficient for estimating the change in perceived risk is statistically significant at the 1% level in both models 3 and 4. The average compensation demanded for a perceived increase in risk is $15,033 in model 3 and $14,330 in model 4.

Concluding Remarks

In general, the estimated bid equations yield estimates for the value of soil type and SSZ location that are consistent with the market and subjective hedonic analyses (Chapter 4). The WTA and WTP values bracket the hedonic estimates exactly as predicted by economic theory. In addition, the WTP estimates perform relatively better than the WTA versions.

However, these results need to be interpreted carefully due to a number of problems. First, only the WTP coefficient estimates for soil type and the WTA estimates for SSZs are statistically significant. This result is not surprising given the fact that (1) the volatility of the subjective bid values is relatively lower in these two sub-samples and (2) these are the only two groups which have more than 200 respondents.

Second, there is a general tendency for the WTA values to be significantly higher than the WTP estimates. For soil type the average WTA estimate is approximately thirty times higher than the average WTP value. In the case of SSZs, the mean WTA estimate is roughly two times greater than the average WTP estimate. Besides differences due to an income effect, this discrepancy between the WTA and WTP estimates could be caused by two factors.

First, laboratory studies have indicated that there is an "endowment effect" at work which results in WTA values being relatively higher (Thaler, 1980). Basically, respondents find it painful to part with an out of pocket expenditure (WTP elicitation) and discount cash transfers made to them (WTA procedure). This discrepancy may be reduced in a learning environment (Coursey et al 1987). However, in a mail survey there limited opportunity for learning.

Second. past studies and this investigation show that there is a self-insurance market for risk; that is, risk takers gravitate to relatively inexpensive homes located on risky soil type or inside an SSZ whereas risk averse individuals prefer a safer home and pay the additional market premium (Brookshire et al 1982). Given that this self-selection has already taken place, then respondents who reside in a risky location place a relatively low WTP value on reductions in risk. Conversely, respondents who reside in relatively safe locations place a relatively high WTA on risk increases because they are risk averse. Consequently, this self-selection bias may skew the results.

Although each of these factors may potentially cause relatively higher (lower) values of WTA (WTP), it is difficult to assess the magnitude of their joint or individual effect on our sample estimates. Consequently, these valuation estimates of perceived changes in risk need to be interpreted with caution, particularly when the level of significance is also low.

D. UTILITY FUNCTION ANALYSIS

In the previous sub-section an individual's willingness to pay or accept was related to a set of explanatory variables. An alternative use of the same basic data is to estimate directly the individual's utility function using a procedure suggested by Viscusi and Evans (1990). The resultant utility function can then be utilized to determine the value that individuals attach to changes in risk associated with changes in soil type and/or SSZ location.

The underlying theory for this approach is outlined in Chapter 2 (see equation 7). We estimate the following equation using non-linear least squares.

$$C = \exp((K_1 - K_2)/((1 - R^2)*a + R^2)) - 1 + e \qquad (17)$$

where:

$K_1 = (1 - R^0)*a*\log(Y) + R^0*\log(Y);$

$K_2 = (1 - R^2)*a*\log(Y) + R^2*\log(Y);$

C = willingness to accept given increase in risk as percentage of wealth;

R^0 = risk level in the safe location;

R^2 = risk level in the unsafe location;

Y = household wealth;

a = u/v, parameters of the Cobb-Douglas Utility Function; a is assumed to depend on the respondents' socioeconomic characteristics;

e = random error term.

We also estimate a similar equation for the willingness to pay. The primary hypothesis is that $a > 1$, indicating that both the level of utility and the marginal utility of income are higher in the relatively safer location.

Data Specifics

There are four groups of respondents that are the subject of the utility function analysis. We examine both willingness to pay and willingness to accept for a change in either soil type or SSZ location. The summary statistics for each of these samples are provided in Table 19.

As is illustrated each of the samples has comparable socioeconomic characteristics. It should also be noted that these statistics differ from those of the previous sub-section since a slightly different set of regressors are utilized. Thus, the number of *complete* observations depends upon the set of regressors used since some respondents answered some questions but excluded others. In addition, several outliers were eliminated from consideration on the basis of the Belsley, Kuh, and Welsch (1980) criteria. A final note concerns the baseline and subsequent risk values. These were calculated for each group by: (1) converting the ladder from letter values to exact probabilities; and (2) calculating the risk differential (subsequent level minus baseline level) by applying the ladder differential estimated for each group.

Empirical Results

The non-linear least squares estimates for each of the four groups are presented in Table 20. A number of aspects of the estimated equations are noteworthy. First, the particular functional form utilized performs poorly in terms of goodness of fit. The only exception is the model of willingness to accept for SSZ location. Second, the socioeconomic characteristics generally perform poorly as measured by t-statistics. Third, the estimated a values all exceed one implying: (1) the absolute level

Table 19

Descriptive Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Willingness to Pay for Soil: 153 Observations				
Education	7.20	1.49	3.0	9.0
Years in San Francisco	20.84	12.23	1.5	48.0
Sex	.69	.46	0.0	1.0
Age	37.55	8.15	24.0	72.0
Household Size	2.95	1.35	1.0	8.0
Baseline Risk	.157			
Subsequent Risk	.0075			
Willingness to Accept for Soil: 70 Observations				
Education	7.55	1.5	4.0	9.0
Years in San Francisco	14.58	10.15	2.0	41.0
Sex	.73	.45	0.0	1.0
Age	36.33	7.69	24.0	57.0
Household Size	2.87	1.56	1.0	9.0
Baseline Risk	.00167			
Sussequent Risk	.053			
Willingness to Pay for SSZ: 85 Observations				
Education	7.22	1.52	3.0	9.0
Years in San Francisco	20.41	12.58	1.5	48.0
Sex	.67	.47	0.0	1.0
Age	38.85	8.62	26.0	72.0
Household Size	3.02	1.42	1.0	8.0
Baseline Risk	.1901			
Sussequent Risk	.0091			
Willingness to Accept for SSZ: 201 Observations				
Education	7.39	1.46	3.0	9.0
Years in San Francisco	16.59	10.97	1.0	46.0
Sex	.74	.44	0.0	1.0
Age	36.25	7.18	24.0	62.0
Household Size	2.85	1.30	1.0	9.0
Baseline Risk	.0031			
Sussequent Risk	.031			

of utility is higher in the relatively safe location; and (2) the marginal utility of income associated with the safe location exceeds the marginal utility of income in the unsafe location.

The estimated "a" values can be used to evaluate changes in risk levels associated with changes in soil type or SSZ location. Equation (8) is the basis for this type of evaluation since all variables in (8) are known, once "a" is estimated. For the risk changes described in Table 19 the estimated values for willingness to pay and willingness to accept for soil type are $6192 and $8350, respectively. The corresponding values for SSZ location are $5200 (willingness to pay) and $13638 (willingness to accept).

The soil type values are significantly below comparable values obtained from the hedonic analysis (market and subjective) and the raw survey averages. The SSZ values are in accord with the market analysis. However, these values are highly unstable, as small changes in probabilities cause large changes in corresponding values.

Concluding Remarks

In this sub-section we reported on an attempt to estimate directly individuals' utility functions using survey data and several restrictions on functional form. The results for our data set are generally not encouraging. The overall significance level of the estimated equations and the individual coefficients was low. In addition, the predictions from the models are extremely unstable in that small changes in risk levels cause large changes in predicted values. This is obviously an area for further research.

E. VALUATION OF EARTHQUAKE RISK BY REFERENDUM DATA

In this section the value that individuals place on earthquake risk is evaluated using a different methodology. As indicated in our survey design chapter, we asked a sub-sample of home owners referendum type questions. The procedure involves asking homeowners whether they are willing to accept (pay) a specific dollar amount for an increase (decrease) in earthquake risk. Homeowners are only required to provide a "yes" or "no" response. The specific dollar amount (bid value) is varied over a range of values (10, 50, 75, 100, 250, 500, 1000). Although each individual is asked only one question with a specific dollar value, an entire distribution of values and yes/no responses are

Table 20

Nonlinear Least-Squares Estimates*

Variable	WTP-Soil Equation	WTA-Soil Equation	WTP-SSZ Equation	WTA-SSZ Equation
Intercept	.87	1.05	1.22	1.58
	(9.14)	(5.27)	(0.84)	(3.63)
Education	.0038	-.028	.0003	-.108
	(.60)	(-.72)	(.004)	(-2.84)
Years in San Francisco	.002	.0006	.002	-.012
	(1.56)	(.22)	(.31)	(-2.28)
Sex	.034	-.08	.09	-.305
	(1.02)	(-1.02)	(.44)	(-2.85)
Age	.001	.005	-.007	.03
	(.99)	(.70)	(-.35)	(2.66)
Household Size	-.001	.05	-.02	-.02
	(-.19)	(1.60)	(-.14)	(-.59)
Predicted "a" Value	1.062	1.105	1.014	1.425
Number of Observations	153	70	85	201

* t-statistics in parentheses

available for the entire sample. This distribution of yes/no responses can be utilized to identify the value of additional safety. This methodology of gleaning the underlying subjective valuation places less computational burden on the respondents and is relatively simple and straightforward. Earthquake risk is evaluated across two dimensions: soil type and special study zones.

Empirical Results

A number of general points can be made about the results. First, two specifications are employed: a linear probability model and a logit functional form. The linear probability model may predict outside the (0,1) range and is more susceptible to extreme values. Consequently, a logit model is employed as an alternative specification. Cameron (1988) discussed in detail how the logit formulation can be employed to predict the mean bid values. The logit model is estimated by the SYSTAT statistical package, which is subsequently utilized to predict a range of bid values at different probability levels (the percentage in the sub-sample who would say yes). Second, the responses are estimated after controlling for personal characteristics such as age, income, education, sex, household size, years lived in the bay area, and perceived changes in risk. However, these personal attributes do not play a significant role in predicting the response of homeowners. This is reflected by the relatively low t-values and R-square values. Third, the results indicate that the valuation of earthquake risk due to different soil types is statistically more significant than risk differences associated with special study zones, within the context of explaining changes in bid responses. Consequently, the former results are discussed in greater detail.

Compensation Demanded for Additional Risk (Soil Type)

In this sub-sample, respondents whose homes are located on consolidated sediment/rock are asked whether they are willing to accept a specific dollar amount for the same home located on riskier soil type (unconsolidated sediment/landfill). The results are reported in Table 21.

The estimates from the linear probability and the logit model indicate that the amount specified in the bid is statistically significant at the 7% level in explaining bid responses. The linear probability model is employed to predict the mean bid value by substituting the mean probability of bid responses and the mean values of the other explanatory variables in the regression equation. The mean monthly dollar value ($222.03) converted into an approximate capitalized value (at 10% discount rate) yields a final lump sum amount of $26,644. The corresponding value for the logit specification is $25,872. These two estimates are quite close to each other, in spite of differences in sample size and explanatory variables (the logit formulation does not have income as an independent variable).

In the second half of Table 21, the predicted bid values at different probability levels are reported. As expected, if a larger proportion of the sample is required to respond positively to the bid value, the compensation demanded by them is relatively higher. For 50 percent of the respondents to agree to the bid, the required monthly value is predicted to be $1201.18.

Willingness to Pay for a Reduction in Risk (Soil Type)

In this section, we analyze the case in which homes on risky soil were asked to reveal their bid responses to locate their home on safer soil. The procedure and specification of the linear probability and logit model (see Table 22) are similar to those discussed in the previous section. In this case, the bid value is significant at the 1% level for both specifications.

The predicted bid value capitalized at the discount rate of 10% works out to be $24,950 for the linear probability model and $16,862 for the logit model. The deviation in the predicted values can be attributed to the differences in the sample size, set of explanatory variables and the estimation method.

As expected, the amount respondents are willing to pay declines as a larger proportion of the sample is required to react positively to the bid. In order to require fifty percent of the respondents to say "yes" to the bid, a small amount ($9.80) has to be paid to the respondents for obtaining a reduction in risk. This can be (partly) attributed to the fact that respondents switch their bid response from "yes" to "no" at very early levels of the bid values (only 11.6 percent bid positively in the entire sub-sample). Consequently, when a larger amount are required to say yes, the predicted bid value drops quite rapidly.

Willingness to Accept and Pay for SSZs

In the willingness to accept sub-sample individuals were asked to answer yes/no to a specific dollar amount to locate their home inside the special study zone. The bid value as an explanatory variable is

Table 21

WTA for Soil Type

MODEL TYPE	LINEAR PROBABILITY MODEL (160 obs)	LOGIT MODEL (142 obs)	PREDICTIONS OF LOGIT MODEL FOR DIFFERENT PROBABILITIES	
Dependent Variable	Bid (Yes = 1) (No = 0)	Bid	Probability of Saying "Yes" to Bid (Percentages)	Estimated Bid dollar value
Constant	0.16 (0.59)	-2.27 (-1.50)		
Bid Value	0.00023 (1.82)	0.0013 (1.93)	5	-999.63
Age	0.0012 (0.337)	0.01 (0.45)	10	-441.13
Education	-0.0078 (-0.32)	-0.04 (-0.27)	15	-95.34
Income	-0.0036 (-0.16)	- -	20	164.99
Sex	-0.032 (-0.41)	-0.21 (-0.41)	21.12 (Average Probability of Sample)	215.60
Household Size	0.017 (0.68)	0.14 (0.93)	25	380.02
Years in Bay Area	-0.0005 (-0.19)	0.003 (0.16)	40	898.11
Difference in Ladder Probability	0.01 (0.99)	0.07 (1.04)	50	1,201.18
R^2	0.04			
Predicted Bid at Mean Probability Level	$222.03	$215.60		

Note: t-values in parentheses.

statistically insignificant in both the linear probability and the logit model (Table 23). Although, the low t-values do not warrant confidence in the results, the predicted bid values at the means of the sample data are reported at the bottom of Table 23. The predicted mean capitalized value for compensation demanded ranges from \$37,993 (logit) to \$26,530 (linear probability).

The results for the linear probability model for the willingness to pay measure (locate outside the SSZ) is more encouraging with t-value of 2.01 for the bid value coefficient. The corresponding numbers for the willingness to pay are \$24,059 (linear) and
-\$42.78 (logit). Note that the negative predicted value for the logit model does not make sense since buying safety should not be associated with a below zero cost. However, since the bid value coefficient is not statistically significant, the result is not pursued further.

Concluding Remarks

A number of inferences can be drawn from these results. Generally, the results for the valuation of risk associated with soil type are relatively more reliable in terms of statistical significance. The results obtained for the valuation of risk entailed by living in the SSZs are not significant, and should be viewed with caution, particularly the estimates for willingness to pay. Note that these estimates are also subject to the three biases discussed earlier: self-insurance bias, endowment bias and inertia or status-quo bias. Consequently the predicted values should be regarded as tentative estimates, even when they are statistically significant.

F. OBJECTIVE VERSUS SUBJECTIVE ESTIMATES

One of the major strengths of this investigation is that we attempt to obtain estimates of risk valuation from objective market data, as well as from subjective survey responses. Generally, economists regard market data as more reliable because it is the outcome of actual choices made by market participants when actual money is at stake. However, survey data is useful when investigating the value homeowners place on different types of earthquake risk because such values are not directly observable with market data. A remaining issue concerns the relative reliability of the subjective data compared to the objective data.

Table 22

WTP for Soil Type

MODEL TYPE	LINEAR PROBABILITY MODEL (259 obs)	LOGIT MODEL (240 obs)	PREDICTIONS OF LOGIT MODEL FOR DIFFERENT PROBABILITIES	
Dependent Variable	Bid (Yes = 1) (No = 0)	Bid (Yes = 1) (No = 0)	Probability of Saying "Yes" to Bid Value (in Percentages)	Estimated dollar Bid value
Constant	0.005	-3.73	5	208.05
	(0.032)	(-1.88)		
Bid Value	-0.00024	-0.01		
	(-3.03)	(-2.51)	10	152.76
Age	0.0014	0.0058		
	(0.63)	(0.20)	11.60 (Average probability of sample)	140.52
Education	0.013	0.18		
	(0.92)	(1.03)	15	118.53
Income	-0.0042	-		
	(-0.35)	-	20	92.76
Sex	0.03	0.91		
	(0.59)	(1.22)	25	71.48
Household Size	-0.0025	0.06		
	(-0.163)	(0.32)	40	20.19
Years in Bay Area	-0.0011	-0.009		
	(0.70)	(-0.48)	50	-9.80
Differences in Ladder Probabilities	0.035 (4.56)	0.32 (4.18)		
R^2	0.13	-		
Predicted Bid at Mean Probability Level	$207.92	$140.52		

Table 23

WTA and WTP for Special Studies Zones

	WTA		WTP	
MODEL TYPE	LINEAR PROBABILITY MODEL (241 obs)	LOGIT MODEL (228 obs)	LINEAR PROBABILITY MODEL (114 obs)	LOGIT MODEL (106 obs)
Dependent Variable	Bid (Yes = 1) (No = 0)	Bid	Bid	Bid
Constant	0.29 (1.36)	-1.74 (-1.26)	-0.48 (-1.76)	-6.29 (-1.99)
Bid Value	0.000022 (0.23)	0.0004 (0.62)	-0.00029 (-2.01)	-0.0040 (-1.42)
Age	-0.0028 (-0.89)	-0.013 (-0.57)	0.004 (1.19)	-0.03 (-0.65)
Education	-0.011 (-0.64)	-0.0078 (-0.06)	0.07 (2.73)	1.00 (2.90)
Sex	0.06 (0.97)	0.57 (1.06)	-0.09 (-1.14)	-1.34 (-1.59)
Household Size	-0.002 (-0.09)	-0.05 (-0.30)	-0.013 (-0.61)	-0.16 (-0.54)
Years in Bay Area	-0.0005 (-0.25)	-0.006 (-0.3)	-0.0025 (-1.03)	-0.02 (-0.85)
Difference in Ladder Probability	0.05 (4.61)	0.28 (4.11)	0.018 (1.72)	0.10 (1.30)
Income	-0.0009 (-0.05)	-	-	-
R^2	0.095	-	0.19	-
Predicted Bid Values at Mean Probability Level	$221.09	$316.61	$200.49	- $42.78

The relative evaluation of the objective and subjective data sets is admittedly difficult. However, we have estimates of risk values from hedonic price equations based on both objective and subjective data (see Chapter 4 and section B above). The *Lens Model* framework can be used to test the relative performance of these data sets. This framework is well established in clinical psychology (Brunswick, 1956; Beach, 1967; Singh, 1990). Basically, the model attempts to provide a relative evaluation of subjective and objective estimates based on the same information constraints.

In the next sub-section, the Lens model is discussed in the context of this investigation. In the following sub-section, various estimates of the Lens Model are provided. The final sub-section present some conclusions regarding the Lens Model.

The Lens Model

In this investigation, one basic focus is to determine the precise effect of earthquake risk on home prices. In order to control for confounding factors which influence home prices, we employ various proxies for home, community, and neighborhood attributes in the regression equation. The hedonic equation is written as:

$$OHP = P(R, A) \tag{18}$$

where, OHP is the objective home price, R is a vector of risk variables, and A is a vector of structural, community, and neighborhood attributes. Note that equation (18) is estimated with a random error term (Ut). A more detailed explanation of the variables can be found in the Chapter 4, which reports on the market hedonic price function.

On the basis of equation (18) the market home price (POHP) can be predicted given knowledge of the home's attributes. Similarly, we can capture the subjective perceptions by a second equation:

$$SHP = P(R, A) \tag{19}$$

Where SHP is perceived home price. From equation (19), which is estimated with random error Et, we can obtain predicted subjective values (PSHP). Note that the set of explanatory variables influencing home prices are the same in equations (18) and (19). This is necessary because reliability of the objective and the perceived home price values should be evaluated on the basis of the same information structure.

Given equations (1) and (2) we can establish the Lens model identity as follows:

$$Ra = Rs\ Re\ G + C\sqrt{(1-Re)}\sqrt{(1-Rs)} \tag{20}$$

where

Ra = Corr(OHP, SHP)
Rs = Corr(SHP, PSHP)
Re = Corr(OHP, POHP)
G = Corr(POHP, PSHP)
C = Corr(Ut, Et).

A brief explanation of each component of this identity is in order (for a detailed explanation see Singh, 1990). Ra is termed the "ex post symmetry" between the objective market price and the perceived subjective price. Note one reason for differences between OHP and SHP is the fact that the data is sampled at different points of time. Consequently, Ra should be interpreted with caution. However, the time trend variables control for this difference so that the other components of the Lens model can be interpreted without a significant problem. Rs is termed "cognitive consistency," the degree to which respondents can systematically filter the information provided by the explanatory variables. If individuals are rational about their subjective estimates, they should be able to successfully glean the systematic information and ignore the random variation from the explanatory cues. Re measures "statistical reliability," the extent to which the objective market price can be predicted from various explanatory attributes. G indicates the degree of "environmental compatibility," between the subjective and objective environment. Finally, C measures the variation between P and SHP which is not captured by the explanatory variables. In general, a high positive C estimate may indicate correct nonlinear utilization of the explanatory variables or missing explanatory variables. In the next section, the Lens model is estimated across different sub-samples to provide insight about the reliability of the subjective estimates relative to objective market data.

Lens Model Results

Since various details of the specifications of the objective (market) and subjective (survey) hedonic gradients are provided elsewhere in the report, in this section, the focus is on the correlation components of the Lens model. The Lens model results are not sensitive to the specific set of explanatory cues employed. The results of seven Lens model specifications are provided in Table 24. The first model employs all the available survey (and corresponding market data) observation points. The results indicate that cognitive consistency (Rs) is low relative to statistical reliability (Re). In contrast, environmental compatibility is relatively high (G). To some extent a high value of G is built into the Lens model because the same explanatory variables are employed for POHP and PSHP. The relatively low value of Rs implies that at least some respondents providing the subjective estimates are not making optimal use of the explanatory variables. A sizable positive value of C indicates some successful use of non-linear cues or possibility of omitted explanatory variables.

Given the indication that cognitive consistency is relatively low, the next question is whether this result holds up at different levels of actual and perceived risk. Checking the lens model estimates for perceived and actual risk will also indicate whether the pattern of results are similar across the objective\subjective dimension. Consider, first the perceived risk levels. The sample is stratified into a low perceived risk group (respondents who indicated ladder probability scale of "J" or less for survey question regarding chances of property damage) and high perceived risk group (ladder probability of "K" and greater). A comparison of these models (rows 2 and 3 of Table 24) indicates that the cognitive consistency is marginally lower in the high perceived risk group (0.755 vs. 0.797). Values of Re and G are also marginally lower for this group.

Actual risk of earthquake is analyzed across two dimensions: soil type and SSZs. Respondents are classified as follows: low risk for homes located on consolidated sediment\rock (row 4, Table 24) and high risk for homes on unconsolidated soil types (row 5, Table 24). The significance pattern of the results are similar to those in the perceived risk classification. When the sample is stratified on the basis of whether the home is located outside a SSZ (row 6) or inside a SSZ (row 7) a similar pattern is observed; that is, cognitive consistency is relatively lower for the high risk group. Note that for the SSZ classification, the decrease in cognitive consistency (high risk category) is more perceptible (approximately 4.3 percent).

Table 24

Lens Model Results

TYPE OF MODEL	OBS	Ra	Rs	Re	G	C
Entire Sample	837	.897	.768	.813	.978	.766
Low Perceived Risk	383	.893	.797	.833	.983	.712
High Perceived Risk	441	.905	.755	.813	.961	.822
Low Actual Risk (Soil)	305	.891	.773	.832	.974	.744
High Actual Risk (Soil)	456	.897	.767	.789	.970	.784
Low Actual Risk (SSZ)	475	.896	.788	.838	.974	.744
High Actual Risk (SSZ)	195	.861	.754	.801	.963	.720

Notes:
1. Ra: Ex post symmetry; Rs: Cognitive consistency; Re: Statistical reliability; G: Environmental Compatibility; C: Unexplained variation.
2. All values are Pearson Correlation Coefficients.

Conclusions From Lens Model

A number of broad conclusions can be drawn from the Lens model results. First, cognitive consistency is relatively lower than statistical reliability and environmental compatibility for all estimated specifications. This indicates some degree of sub-optimal response among the home owners surveyed. Note that the precise extent of suboptimal response is difficult to assess. However, judging from the relative levels of Rs, it appears to be small. One inference from this result is that the subjective values elicited by the survey are relatively less reliable than the objective (market) data. This result is not surprising, given the fact that survey information has some inherent limitations (Brookshire et al. 1987).

Second, a supplementary piece of evidence that also points to a similar conclusion is that the estimates of various components of the Lens Model display the same pattern for respondents stratified by either perceived or actual earthquake risk. This implies that the discrepancy between perceived and actual risk values is not the cause of this divergence.

Third, it appears that cognitive consistency is marginally lower for respondents who are exposed to higher "perceived" risk. This result also holds for respondents exposed to higher "actual" risk, although the differences in Rs are smaller. This result seems to indicate that respondents who are exposed to higher earthquake risks may not be fully cognizant of the risks involved.

Two caveats are in order. First, these conclusions are based solely on the objective\subjective home price information and may not necessarily apply to other components of the survey. Second, the lens model (by analyzing correlation coefficients) is only equipped to evaluate the "efficiency," not the "bias" statistical property between the objective and subjective home values. Hence, the conclusions should be viewed with caution.

VI. CONCLUSION

A. INTRODUCTION

The primary objective of the research reported herein was to assess the impacts associated with the Loma Prieta earthquake. We were concerned with both the magnitude of any initial impact and the propensity of any impact to persist in the future. Our research focused on changes in individual risk perceptions and the market prices of homes in the San Francisco Bay area. Two types of data, subjective perceptions obtained from a survey of households, and actual housing market transactions, were employed.

Our basic conclusions are summarized in the following four sections. In the first section, we describe the immediate impact of this exogenous shock to the housing market and risk perceptions and evaluate the propensity of these impacts to persist over time. The second section summarizes the range of estimates (of the dollar valuation of home risk) that can be attributed to either soil type or special study zones. The estimates are derived from alternative methodologies and are discussed in detail in the preceding chapters. In the third section, we discuss various policy implications that flow from these results. In the final section, suggestions are made for future research.

B. THE IMPACT OF THE LOMA PRIETA EARTHQUAKE

Our research suggests that the Loma Prieta earthquake had a measurable impact on both risk perceptions and on housing prices. These effects are expected to dissipate with time from the event. In addition, individuals attach a measurable monetary value to changes in risk. Improvements in soil type and/or location vis-a-vis earthquake special study zones are valuable to residents of the San Francisco Bay area. Exact monetary estimates, which are obtained from both the objective and subjective data, are provided for changes in these variables. Finally, available evidence suggests that estimates derived from market data is more certain. Some of these effects are summarized below.

Our subjective survey indicated that home owners perceived an average fall of $32,851 in the value of home because of Loma Prieta. This converts to about 10% of the mean home value. When the subjective estimates are analyzed in the regression framework and other confounding factors are controlled for, this value is adjusted downward to approximately 6.9%. Regression estimates based on market data range from $6600 to $23912, the lower estimate being derived after controlling for concomitant changes in the general economy which should be factored out. Consequently, we believe that the perceived estimates gleaned from the survey are somewhat exaggerated.

One other interesting immediate effect of the earthquake was the heightened perceptions about expected damage in the future. Actual damage was not very extensive, averaging approximately \$2,500. The median value of \$425 indicated that the mean estimate is skewed significantly by extreme values. The corresponding estimate for "expected" damage was relatively higher (mean= \$20198). The expected damage worked out to be eight times higher than actual damage sustained. We believe that this ratio is also somewhat exaggerated because of heightened perceptions after the earthquake.

Indirect evidence supporting this latter view is obtained by examining actual behavioral modifications undertaken by respondents after the event. For instance, only 37 percent of home owners surveyed made changes to their home. About 80 percent of these changes were minor, such as securing book shelves. In addition, only 14 percent changed their commuting patterns after the event, whereas 56 percent indicated a change in preparedness (such as keeping emergency provisions) after the earthquake. One significant impact was the increase in earthquake insurance purchases. Before the event only 40.5 percent of home buyers purchased earthquake insurance. After the earthquake this value increased to 54.2 percent of home buyers.

The pertinent question which arises is how much of these changes are transitory? We do not have a precise answer to this question because the sample survey was only conducted at one point of time. However, our regression analysis of survey data employing time trend variables indicates that most of the impact is dissipated within the first six months. Similar results were obtained from our analysis of market data.

C. DOLLAR ESTIMATES OF EARTHQUAKE RELATED RISKS

As indicated previously, we evaluated earthquake related risks defined by location vis-a-vis soil types and special study zones. Various analytical methodologies were utilized. The results are summarized in Table 25. A number of general points can be made about the summary results. First, note that the estimates vary considerably based on the different methodologies. The reasons for the variation include the inherent upward biases in WTA estimates relative to WTP estimates, the volatility of survey data, the lack of or differences in the control variables, and the different baseline assumptions inherent to the various methodologies.

Since the results are sensitive to different methodologies, overt reliance should not be placed on estimates based on a single procedure. Thus, our "best educated estimate" for dollar value placed on changes in soil type is approximately $8,000. Note that this estimate is close to the values provided by the market hedonic approach.

The results for Special Study Zones are relatively less consistent across different methodologies and statistically insignificant in some cases. For instance, in the subjective hedonic regressions the SSZ variable is statistically insignificant, probably because of a lack of consistent knowledge about these zones on the part of home owners. Previous studies have found that home owners are not fully cognizant of SSZs (Palm, 1981). We also obtained numerous phone call from respondents after the survey indicating their lack of precise knowledge about these zones.

In contrast, the market hedonic regressions indicate a statistically significant effect on home prices attributable to the SSZ classification. We believe that the "best educated estimate" for the risk premium of living in a SSZ is obtained from the objective hedonic estimates, approximately $10,000 or 3 percent of home sale price. This value is very close to the 3.3 percent of home price obtained in an earlier study of Special Study Zones in the San Francisco area (Brookshire, et al 1985). However, this estimate is inconsistent with current work being conducted by Cochrane et al (1992).

One reason for this difference in the results (between market and subjective hedonic equations) could be because the objective price in the market is set by marginal prospective homeowners making bids for the safety premium, consequently all the home owners need not be fully informed or rational. However, in the survey data we end up with an "average" bid which fully incorporates responses of all home owners, some of whom may not be knowledgeable about the relative premium on additional safety.

Table 25

Estimated Values for Increases in Earthquake Risks

DOLLAR ESTIMATE	METHOD OF ESTIMATION	COMMENTS
	Soil Type	
4,311	WTP Bid-Regression	5% significance
7,527	Mean WTP for survey	Without controls
7,305*	Market Hedonic (Table 5)	1% significance
16,862	WTP Referendum Logit	1% significance
17,760	Subjective Hedonic	1% significance
25,872	WTA Referendum Logit	5% significance
32,728	WTA Bid-Regression	24% significance
188,539	Mean WTA for Survey	Without controls Skewed by extreme values.
	Special Study Zones	
8,625	WTP Bid-Regression	19% significance
9,439*	Market Hedonic (Table 6)	5% significance
12,371	Mean WTP for Survey	Without controls
15,034	WTA Bid-Regression	1% significance
24,059	WTP Referendum linear	5% significance
29,486	Mean WTA for survey	Without controls

NOTES:

1. The dollar values estimated for soil type are for an average change of soil type 2 (Clay) to 5 (sandstone).

2. Estimates marked with an * are obtained from market data. All other estimates are obtained from survey data and tend to be relatively volatile.

3. Estimates mentioned under each methodology are representative values. There may be considerable variation in estimates for each specific methodology. For details see relevant chapters.

D. POLICY IMPLICATIONS

Besides providing information about the impact of the Loma Prieta earthquake and estimates of the dollar premium for additional safety, this investigation points to the following policy implications. First, there is a perceptible market premium for additional safety both with reference to soil and SSZ risk. This suggests an implicit self-insurance market; that is, prospective home owners who are risk averse may opt to pay the additional premium for a safer location instead of buying earthquake insurance. Given the magnitude of objective earthquake risk faced by home owners in the San Francisco Bay area, it has been difficult to explain why only about 40% of the home owners actually purchase earthquake insurance. One implication of this study is that a significant proportion of the home owners may prefer to self-insure.

The significant market gradient for risk suggests a second policy implication. We have pointed out previously that one potential reason why WTA estimates are significantly higher than WTP estimates is that risk averse homeowners have gravitated to relatively safe areas and the homeowners who have low regard for risk prefer the low price which accompanies a risky location. Given that this self-selection has already taken place, any public policy which encourages relocation to relatively safe areas, could entail significant costs. The implication for land utilization is that policies for encouraging safer home location should be carried out ex-ante rather than ex-post; that is, prior to any self-selection that concentrates home owners who are not risk averse in risky locations.

Third, our survey results indicate that knowledge about the SSZs is not very consistent across respondents, whereas they are relatively more informed about the risk involved with soil-types. The results of the Lens Model analysis indicate that home owners exposed to higher earthquake risk may not be making fully optimal decisions, particularly those located in SSZs. In this context, providing objective information about different dimensions of earthquake risk is highly desirable. The survey also showed that USGS informative brochure about earthquake risk entitled "The Next Big Earthquake" did perform a useful role, since 52 percent of those who received it glanced through it and 39 percent have kept it for future reference. However, only 38 percent of the respondents were familiar with the brochure. This type of objective information needs to be provided more comprehensively and frequently. Although some information about SSZs was provided in this brochure on page 11, a more comprehensive information drive will be useful so that home owners can more effectively match their risk tastes with the safety premiums. In addition, this information will enable home owners to undertake more responsible precautions.

E. FUTURE RESEARCH DIRECTIONS

Most of the research effort expended on this project has been directed at obtaining the requisite data and producing preliminary estimates of the effects of the Loma Prieta earthquake. We feel that this effort has been successful in that it has produced results that have policy relevance. However, so much more analysis could be conducted on the existing objective and subjective data sets. For instance, we have not considered multi-equation models in our analysis of the objective housing market transaction data. Moreover, our analysis of individual utility functions using the survey data are quite preliminary in that it is limited to a single functional form. Thus, further research must be conducted in order to ensure that our results are robust with respect to various influences.

We recommend that the following research tasks be completed. First, the analysis of the housing market data should include a detailed investigation of multi-equation models and the underlying structure of risk perceptions. The latter analysis would utilize the latent variable models suggested in Chapter 4. Second, further examinations of the survey data should include: (1) the consistency of risk perceptions across risk types; (2) survey response self-selection; and (3) various estimated functional forms for the utility function analysis. Finally, more detailed comparisons should be made between (1) survey responses to the willingness to pay and/or accept questions obtained from open-ended and referendum questions; (2) subjective and objective hedonic price estimates; and (3) various estimates of willingness to pay and/or accept for geologic variables. Each of these research tasks would provide project specific value in that the robustness of our preliminary results would be improved. In addition, more general benefits concerning the manner in which individuals process information from market transactions and respond to survey questions would be derived from further research.

Additional research tasks could include the following. First, relatively new multi-equation techniques could be employed to analyze the survey data jointly with an investigation of the effect of "response biases." These techniques are able to adjust the survey estimates appropriately for differences which may arise because certain category of homeowners are more likely to return the survey questionnaire.

The adjusted estimates will be more representative of the entire population. Second, we could investigate more fully the linkage between self-insurance of home owners (those who pay a market premium for safety) and the option of purchasing earthquake insurance. We would investigate specific circumstances and scenarios when the self-insurance option would be preferable to the earthquake insurance option. Finally, we could investigate more extensively the potential reasons for the upward bias in the WTA estimates relative to the WTP estimates. We have pointed out some possibilities, but detailed analysis needs to be performed to pin down the causes and the extent of these biases.

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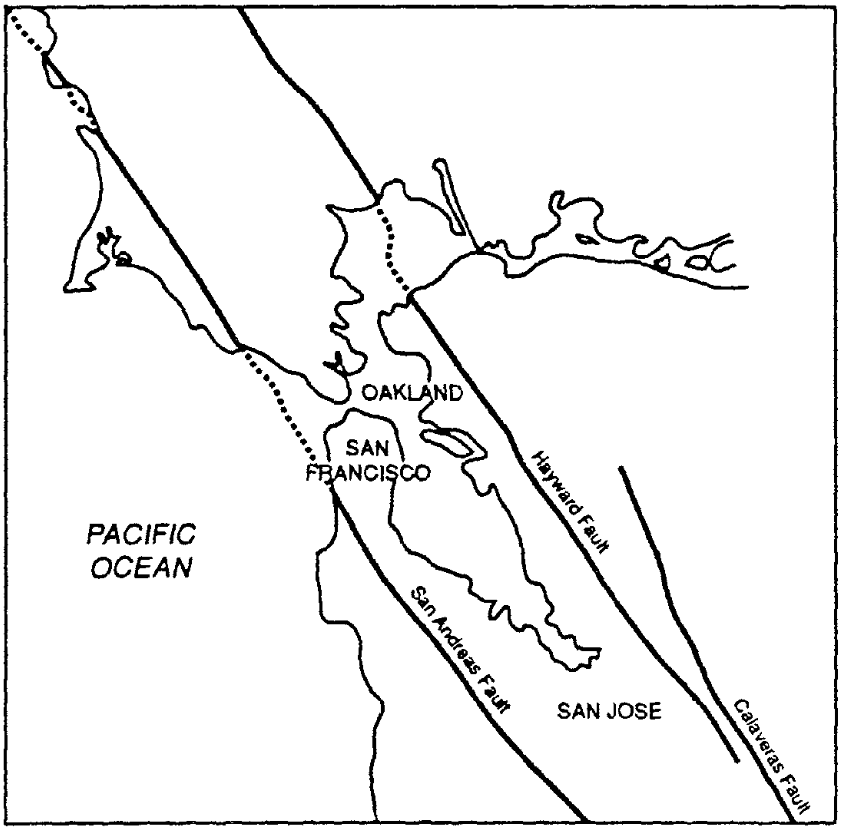
APPENDIX

EARTHQUAKES IN THE BAY AREA: A SURVEY OF HOMEOWNERS



Department of Economics
San Diego State University
San Diego, California 92182

This Survey should be completed by an adult member of your household.

NATURAL AND MAN-MADE EVENTS: YOUR EXPERIENCE

1. How many years have you lived in California? ______ YEARS

2. How many years have you lived in the San Francisco Bay area?

   ______ YEARS

3. Have you ever (anytime, anywhere) personally experienced the following natural events? (Circle the Letter)

EARTHQUAKE	A. YES	B. NO
LANDSLIDE	A. YES	B. NO
HURRICANE	A. YES	B. NO
FLOOD	A. YES	B. NO
TORNADO	A. YES	B. NO

4. Do you know others who have experienced the following natural events? (Circle the Letter)

EARTHQUAKE	A. YES	B. NO
LANDSLIDE	A. YES	B. NO
HURRICANE	A. YES	B. NO
FLOOD	A. YES	B. NO
TORNADO	A. YES	B. NO

5. Have you ever (anytime, anywhere) personally experienced the following man-made events? (Circle the Letter)

HOME BURGLARY	A. YES	B. NO
AUTO THEFT	A. YES	B. NO
VIOLENT CRIME	A. YES	B. NO
AUTO ACCIDENT	A. YES	B. NO

   → If YES, how many accidents have you been involved in, in which you were the driver?

   ______ NUMBER

   When did the accident(s) occur? (Circle the years)

   81 82 83 84 85 86 87 88 89 90

6. Do you know others who have experienced the following man-made events? (Circle the Letter)

HOME BURGLARY	A. YES	B. NO
AUTO THEFT	A. YES	B. NO
VIOLENT CRIME	A. YES	B. NO
AUTO ACCIDENT	A. YES	B. NO

7. Please rank the following man-made events as to the likelihood that they will occur to you in the next year.

	NOT LIKELY				CERTAIN
AUTO ACCIDENT	A	B	C	D	E
HOME BURGLARY	A	B	C	D	E
AUTO THEFT	A	B	C	D	E
VIOLENT CRIME	A	B	C	D	E

8. Do you smoke cigarettes on a regular basis? (Circle the Letter)

A. YES → If YES, how many cigarettes a day?
B. NO

_____ CIGARETTES/DAY

9. Do you have a burglar alarm for your home and/or car? (Circle the Letter)

HOME	A. YES	B. NO
AUTOMOBILE	A. YES	B. NO

10. Do you have a smoke alarm in your home? (Circle the Letter)

A. YES
B. NO

11. Do you wear a seat belt when in an automobile? (Circle the Letter)

A. YES, ALL THE TIME → If YES, how long have you worn a seat belt?
B. YES, SOME OF THE TIME
C. YES, BUT RARELY
D. NO

_____ YEARS

Did the California State Law alter your behavior concerning seat belt use? (Circle the Letter)

A. YES
B. NO

12. Have you received a traffic citation for a moving violation in the past three years? (Circle the Letter)

A. YES →
B. NO

If YES, please specify the nature of the citation. (Circle the Letter for each traffic citation)

	SPEEDING	RED LIGHT	STOP SIGN	RECKLESS DRIVING	OTHER
CITATION 1	A	B	C	D	E
CITATION 2	A	B	C	D	E
CITATION 3	A	B	C	D	E
CITATION 4	A	B	C	D	E

13. Are you familiar with the U.S. Geological Survey publication entitled "The Next Big Earthquake?"

A. YES ———→ If YES, have you
B. NO

A. Casually glimpsed through it?
B. Read it carefully?
C. Kept it for future reference?

14. Do you have earthquake insurance on your home? (Circle the Letter)

A. YES ———→ If YES, please specify when the insurance was first purchased.
B. NO

_____ YEAR

15. Have you altered your commuting pattern since the October 17, 1989 earthquake? (Circle the Letter)

A. YES
B. NO

16. Do keep a flashlight or other material available for emergencies? (Circle the Letter)

A. YES ———→ If YES, did the October 17, 1989 earthquake alter your emergency preparedness activities? (Circle the Letter)
B. NO

A. YES
B. NO

17. Do you store canned goods and/or water supplies in case of an emergency? (Circle the Letter)

A. YES ———→ If YES, did the October 17, 1989 earthquake change the amount of food and/or water you stored? (Circle the Letter)
B. NO

A. YES
B. NO

18. Have you in any way changed your home to make it more earthquake proof since the October 17, 1989 earthquake? (Circle the Letter)

A. YES ———→ If YES, please specify the nature of the changes.
B. NO

A. MINOR—secured bookshelves, pictures, etc.
B. MAJOR—secured fireplace, stabilized foundation, etc.

RISK OF PROPERTY DAMAGE

1. Was your home damaged in the October 17, 1989 earthquake?

   A. YES ⟶ If YES, please specify the dollar value of damages experienced.

   B. NO

   ______ DOLLAR VALUE

   Also, please specify the nature of the damages. (Circle the Letter that corresponds to your experience)

   A. SLIGHT DAMAGE:
   Dishes/glassware broken. Books fell off shelves/pictures fell off walls.

   B. MODERATE DAMAGE:
   Minor cracks in walls. Furniture broken.

   C. CONSIDERABLE DAMAGE:
   Major cracks in masonry/stucco. Cracks on wet grounds/steep slopes.

   D. EXTENSIVE DAMAGE:
   Collapse of structures. Damage to foundations.

2. Do you <u>expect</u> your home to be damaged in a future earthquake? (Circle the Letter)

   A. YES ⟶ If YES, please specify the dollar value of damages you expect to occur.

   B. NO

   ______ DOLLAR VALUE

   Also, please specify the nature of the damages you expect to occur. (Circle the Letter that corresponds to your experience)

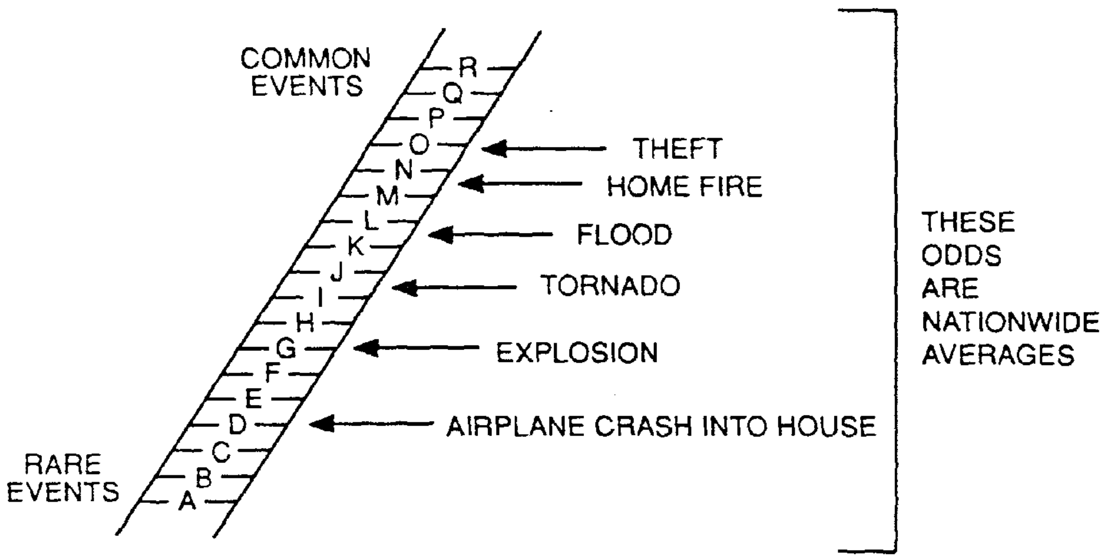
   A. SLIGHT DAMAGE:
   Dishes/glassware broken. Books off shelves/pictures off walls.

   B. MODERATE DAMAGE:
   Minor cracks in walls. Furniture broken.

   C. CONSIDERABLE DAMAGE:
   Major cracks in masonry/stucco. Cracks on wet grounds/steep slopes.

   D. EXTENSIVE DAMAGE:
   Collapse of structures. Damage to foundations.

Next, we would like to obtain more detailed information concerning your impressions about the chances that a future earthquake will cause damage to your property. The figure below represents the odds of damage to your property from various causes. The figure is in the form of a ladder where the higher you climb on the ladder, the higher the chances (or odds) of property damage. Each step (or letter) on this ladder increases the odds of damage by five. For instance, the likelihood of an average home being damaged by flood is about ten times greater than being damaged by a tornado.



3. Referring to the ladder above, choose the letter below that you think most closely represents the chances of property damage by a future earthquake. (Circle the Letter)

PROPERTY DAMAGE
FROM EARTHQUAKE a b c d e f g h i j k l m n o p q r

4. We would next like to determine if your feelings concerning the risk level have changed over time. Again, referring to the ladder above, please choose the letter below which you thought most closely represented the chances of property damage <u>before</u> the October 17, 1989 earthquake.

PROPERTY DAMAGE FROM
EARTHQUAKE BEFORE
OCTOBER 17, 1989 a b c d e f g h i j k l m n o p q r

The actual property damage you experience in an earthquake depends on a number of factors such as the location (or epicenter) of the earthquake, the magnitude of the earthquake, the type of construction, and the type of soil underneath your home.

5. What type of soil is your home built on? (Circle the Letter)

UNCONSOLIDATED SOILS/LANDFILL

A. GRAVEL
B. CLAY
C. UNCONSOLIDATED SEDIMENT

(If you picked A, B, or C)

6. Do you feel that damage from an earthquake would be less if your home was located on volcanic rock, sandstone, or granite rock? (Circle the Letter)

A. YES
B. NO

{IF NO, PROCEED TO NEXT PAGE}

7. Using the Ladder on the previous page choose the Letter that most closely represents the chances of your home being damaged by a future earthquake if it were located on volcanic rock, sandstone, or granite rock.

a b c d e f g h i j k l m n o p q r

8. Would your home be worth more if it were located on volcanic rock, sandstone, or granite rock? (Circle the Letter)

A. YES
B. NO

9. How much more would you be willing to pay for your home (exactly as it is) if it were located on volcanic rock, sandstone, or granite rock?

______ DOLLARS

CONSOLIDATED SOILS/ROCK

D. VOLCANIC ROCK
E. SANDSTONE
F. GRANITE ROCK

(If you picked D, E, or F)

6. Do you feel that damage from an earthquake would be more if your home was located on gravel, clay, or unconsolidated sediment? (Circle the Letter)

A. YES
B. NO

{IF NO, PROCEED TO NEXT PAGE}

7. Using the Ladder on the previous page choose the Letter that most closely represents the chances of your home being damaged by a future earthquake if it were located on gravel, clay, or unconsolidated sediment.

a b c d e f g h i j k l m n o p q r

8. Would your home be worth less if it were located on gravel, clay, or unconsolidated sediment. (Circle the Letter)

A. YES
B. NO

9. How much would you have to be compensated to have your home (exactly as it is) located on gravel, clay, or unconsolidated sediment.

______ DOLLARS

10. Is your home located in an Earthquake Special Studies Zone? (Circle the Letter)

A. YES

(If you picked A)

11. Do you feel that damage from an earthquake would be <u>less</u> if your home was not located in a special studies zone? (Circle the Letter)

A. YES
B. NO

(IF NO, PROCEED TO NEXT PAGE)

12. Using the Ladder on the previous page choose the Letter that most closely represents the chances of your home being damaged by a future earthquake if it were not located in a special studies zone.

a b c d e f g h i j k l m n o p q r

13. Would your home be worth more if it were not located in a special studies zone? (Circle the Letter)

A. YES
B. NO

14. How much <u>more</u> would you be willing to pay for your home (exactly as it is) if it were located outside the special studies zone?

______ DOLLARS

B. NO

(If you picked B)

11. Do you feel that damage from an earthquake would be <u>more</u> if your home was located in a special studies zone? (Circle the Letter)

A. YES
B. NO

(IF NO, PROCEED TO NEXT PAGE)

12. Using the Ladder on the previous page choose the Letter that most closely represents the chances of your home being damaged by a future earthquake if it were located in a special studies zone.

a b c d e f g h i j k l m n o p q r

13. Would your home be worth less if it were located in a special studies zone? (Circle the Letter)

A. YES
B. NO

14. How much would you have to be compensated to have your home (exactly as it is) located in a special studies zone?

______ DOLLARS

ABOUT YOUR PROPERTY AND NEIGHBORHOOD

1. What month and year did you purchase your home?

   ______ MONTH ______ YEAR

2. At the time you purchased your home did you know that there was a possibility of damaging earthquake activity in the San Francisco Bay Area? (Circle the Letter)

   A. YES
   B. NO

3. What was the purchase price of your home?

   ______ DOLLARS

4. What interest rate were you able to obtain on your mortgage?

   ______ PERCENT

5. Is the interest rate a fixed rate or a variable rate? (Circle the Letter)

   A. FIXED
   B. VARIABLE

6. How many years is your mortgage? ______ YEARS

7. What is the interior square footage of your home?

   ______ SQUARE FEET

8. About what is the size of your lot? ______ SQUARE FEET

9. Do you have a scenic view? (Circle the Letter)

   A. YES
   B. NO

10. Do you have a pool, hot tub, or spa? (Circle the Letter)

    A. YES
    B. NO

11. Do you have one or more fireplaces? (Circle the Letter)

    A. YES
    B. NO

12. How many bathrooms does your home have? ______ BATHROOMS

13. How many bedrooms does your home have? ______ BEDROOMS

14. When was your home originally built? ______ YEAR

15. How much do you think your property, that is house and lot, would sell for on today's market?

_____ DOLLARS

16. Do you think your property, that is house and lot, would sell for a different amount on today's market if the October 17, 1989 earthquake had not occurred? (Circle the Letter)

A. YES → If YES, how much do you think your property would sell for on today's market if the October 17, 1989 earthquake had not occurred?
B. NO

_____ DOLLARS

17. How would you rate the quality of schools in your area? (Circle the Letter corresponding to description)

	EXCELLENT	GOOD	AVERAGE	BELOW AVERAGE	POOR
NURSERY SCHOOLS	A	B	C	D	E
ELEMENTARY SCHOOLS	A	B	C	D	E
SECONDARY SCHOOLS	A	B	C	D	E

18. How would you rate the air quality in your immediate neighborhood? (Circle the Letter corresponding to description)

A. EXCELLENT
B. GOOD
C. AVERAGE
D. BELOW AVERAGE
E. POOR

19. Compared to crime rates in other Bay Area neighborhoods do you feel that your neighborhood is: (Circle the Letter)

A. SAFER
B. SOMEWHAT SAFER
C. AVERAGE
D. SOMEWHAT RISKIER
E. MUCH RISKIER

20. How many miles away from your home are the following places? (Enter Number in blank spaces)

A. WORK _____ MILES
B. OCEAN _____ MILES
C. BAY _____ MILES
D. DOWNTOWN SAN FRANCISCO _____ MILES
E. NEAREST EARTHQUAKE FAULT LINE _____ MILES
F. SAN ANDREAS FAULT LINE _____ MILES

ABOUT YOU AND YOUR FAMILY

1. What is your age? ______ YEARS

2. What is your sex? (Circle the Letter)

   A. MALE
   B. FEMALE

3. Including yourself, how many people live in your home?

   ______ NUMBER

4. Of this number, how many are under the age of 18?

   ______ NUMBER

5. How much formal education have you completed? (Circle the Letter)

   A. 0 - 5 GRADES
   B. 6 - 8 GRADES; FINISHED GRADE SCHOOL
   C. 8 - 11 GRADES; SOME HIGH SCHOOL
   D. 12 GRADES; FINISHED HIGH SCHOOL
   E. TRADE SCHOOL
   F. SOME COLLEGE
   G. COLLEGE DEGREE; B.A. OR B.S.
   H. SOME GRADUATE WORK
   I. ADVANCED COLLEGE DEGREE OR PROFESSIONAL DEGREE

6. What was your family's <u>gross</u> annual income (before taxes and deductions) in 1990? (Circle the Letter)

   A. LESS THAN $4,999
   B. $ 5,000 - $ 9,999
   C. $10,000 - $19,999
   D. $20,000 - $29,999
   E. $30,000 - $39,999
   F. $40,000 - $49,999
   G. $50,000 - $59,999
   H. $60,000 - $79,999
   I. $80,000 - $99,999
   J. OVER $100,000

Is there anything we have overlooked? Please use this space for any additional comments you would like to make about natural hazards in the San Francisco area.

Your contribution to this effort is greatly appreciated. If you would like a summary of results, please print your name and address on the back of the return envelope (not on this questionnaire). We will see that you receive it.

DEPARTMENT OF ECONOMICS
COLLEGE OF ARTS AND LETTERS
SAN DIEGO STATE UNIVERSITY
SAN DIEGO CA 92182-0379

March 18, 1991

There has been much discussion in the popular media concerning the October 1989 earthquake in the San Francisco area. However, no one really knows how the property owners of this area feel about the possible risks and consequences of such events.

Your household is one of a small number in which people are being asked to give their opinion on these matters. Your name was drawn from a scientific sample of all property owners in the San Francisco area. In order that the results truly represent the thinking of these property owners, it is important that each questionnaire be completed and returned.

You are assured of complete confidentiality. The questionnaire has an identification number for mailing purposes only. This is so that we may check your name off the mailing list when your questionnaire is returned. Your name will never be placed on the questionnaire. In addition, specific answers will never be attributed to individuals; all information will be reported only in statistical sums.

The results of this research will be made available to officials and representatives of our state and federal governments, and all interested citizens. You may receive a summary of results by writing "Copy of Results Requested" on the back of the return envelope and printing your name and address below it. Please <u>do not</u> put this information on the questionnaire itself.

I would be most happy to answer any questions you might have. Please write or call. My telephone numbers are (619) 594-1675 (office) or (619) 588-2361 (home). Thank you for your assistance.

Sincerely,

Mark Thayer
Project Director

March 25, 1991

Last week a questionnaire was mailed to you seeking information which is important in evaluating individuals' feelings concerning the possible risks and consequences of natural hazards in the San Francisco area.

If you have already completed and returned the questionnaire, accept our sincere thanks. If not, please do so today. Your household was drawn in a scientific sample of property owners. The questionnaire was sent to only a small, but representative, sample of people. Therefore, it is extremely important that your answers are included in the study.

If by some chance you did not receive the questionnaire, please call me collect at (619) 594-1675 or (619) 588-2361 and I will send another one in the mail immediately.

Sincerely,

Mark Thayer
Project Director