DATA COLLECTION AND ANALYSIS

Introduction

What is a disaster? A definition often used by social scientists is that

> disasters are accidental or uncontrollable events, actual or threatened, that are "concentrated in time and space, in which a society, or a relatively self-sufficient sub-division of a society, undergoes severe danger, and incurs such a loss to its members and physical appurtenances that the social structure is disrupted and the fulfillment of all or some of the essential functions of the society is prevented" (Fritz, 1961).

More practically, the federal government in its enabling legislation for the Federal Emergency Management Agency (FEMA), defines both a major emergency and a major disaster in terms of damage to the built environment and of deaths and injuries. According to the FEMA regulations [44 CFR Part 205],

> Major disasters are catastrophes which warrant assistance under the Act . . . to supplement the efforts and available resources of States, local governments, and disaster relief organizations in alleviating the damage, loss, hardship or suffering caused thereby.

In other words, for the federal government to declare a major disaster and to so state in a presidential declaration, that incident would, by definition, have overwhelmed the resources of the local and state governments involved. In an effort to study only major disasters, to have a sample that met at least certain minimal characteristics (those included in the criteria for a presidential declaration), and to readily acquire data on such disasters, we have limited our study sample to presidentially-declared disasters. Still, these constitute all of the largest disasters that occur in the U.S.

We created nine categories of natural disasters: 1) ice and snow events, 2) hurricanes/tropical storms, 3) earthquakes, 4) dam and levee failures, 5) rains, storms, and flooding (including land, mud, and debris flows and slides), 6) high winds and waves, 7) coastal storms and flooding, 8) tornadoes, and 9) drought/water shortages. These categories combine the largest categories that FEMA uses and were created to simplify the process of analysis and the presentation of our results. Two types of disasters--fires and volcanoes--were intentionally excluded.

As it turns out, the criteria and selection process for a declaration are not as clear-cut as one might hope or infer from the regulations. In fact, the General Accounting Office prepared a report in 1981, entitled Requests for Federal Disaster Assistance Need Better Evaluation (Comptroller General, 1981), in which the office was critical of FEMA for not adopting a more systematic decision-making process. Nevertheless, while the information about presidentially-declared disasters is not trouble free, it is superior to that available for disasters that did not receive such a declaration. (In the future, researchers would probably find several fruitful lines of study in comparing the relief and recovery efforts in undeclared and declared disasters. However, this will not be possible until arrangements are made to obtain data from FEMA on the latter category for many previous years; presently, data going back more than about two years are kept in an archive that is not accessible.)

As an initial source of information, we contacted FEMA's Office of Disaster Assistance Programs for copies of their Disaster Management Information System (DMIS) reports, which contain basic information about each declared disaster. For the study period (1965-85), staff provided us with DMIS Report 1.2, which covers the state, counties, date of incidence, FEMA contract number, date declared, and type of disaster agent, and also DMIS Report 2.4, which is titled "President's Fund: Actual and Project Obligations." This latter report enabled us to obtain data on the total federal outlays for the disasters listed in DMIS Report 1.2. Once we had that information, we prepared a coded master list of states and counties therein.

It should be noted that we were primarily concerned with disaster incidence data--particularly with frequency and recurrence. We did not attempt to collect or measure data regarding the amount of aid (federal and other) provided in response to the declared disaster, nor did we try to aggregate data on aid for disaster recovery.

Local Economic Data Used to Test Economic Effects of Disasters

The local economic effects of natural disasters were tested using a model suggested by the previously outlined theory in which housing markets react to the perceptions of the likelihood of natural disasters. The empirical tests required detailed data on the sales price and physical characteristics of owner-occupied housing units in a cross-section of U.S. cities in different years. It was also desirable to have comparable data on rental prices of housing units. While several alternative sources of housing data were considered, the final choice was the Annual Housing Survey conducted by the Bureau of the Census for the Department of Housing and Urban Development (see Abt, 1984). The specific years of data selected were 1979, 1980, and 1983.

The distinctive feature of the Annual Housing Survey is that since 1973, it has been based on a panel of some 75,000 housing units that was assembled as a national probability sample of the U.S. housing stock. The number of units in the sample has increased annually with the size of the housing stock. A concern about the representativeness of the data has arisen in recent years because this process of addition, along with deletions due to the demolition or combination of units, has altered the sample characteristics of the survey. Also, agency budget constraints led to the elimination of the survey in alternate years so that there was no 1982 survey. Beginning with the 1985 survey, which was renamed the American Housing Survey, a new sample of housing units was drawn so the initial panel terminated in 1983.

For each housing unit, the survey records very detailed information on the unit's physical characteristics--information collected through a combination of resident responses and enumerator observation. The use of enumerators ensures high quality of data. Structural data include the number of rooms of various types, the number of units per structure, type and quality of plumbing, electrical equipment, appliances, type of heating system, and age and tenure status (owner versus renter occupied) of the unit. In addition, there are detailed observations on physical flaws such as cracks, peeling paint, broken stairs, inadequate wiring, etc.

Comparing the annual information on units allows one to account for additions, improvements, and deterioration. House price data includes the owner-occupant's estimate of value and, for renters, detailed information on rental, utility, and fee payments. One obvious limitation in such data is that rents are not observed for the owner-occupied unit nor asset prices for the rental unit.

Based on examination of the areas in which disasters had occurred during the 1965-1983 period, and of the cities which were identified in the Annual Housing Survey data set, housing units located in several Standard Metropolitan Statistical Areas (SMSAs) were selected for inclusion in the sample (Table 1). This list of SMSAs includes almost all such areas located within the states of Alabama, Arizona, California, Florida, Illinois, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, Pennsylvania, Tennessee, Texas, Virginia, Washington, and West Virginia which were identified in the Annual Housing Survey.

Examination of disaster declarations during the 1965-1983 period indicated that the areas experiencing the greatest numbers of disasters were located in these states. An effort was made to sample as many different areas

TABLE 1

SMSAs INCLUDED IN THE EMPIRICAL ANALYSIS

Albany-Schenectady-Troy, New York
Allentown-Bethlehem-Easton, Pennsylvania-New York
Anaheim-Santa Ana-Garden Grove, California
Baltimore, Maryland
Birmingham, Alabama
Buffalo, New York
Chicago, Illinois
Cincinnati, Ohio-Kentucky-Indiana
Dallas, Texas
Detroit, Michigan
Fort Worth, Texas
Grand Rapids, Michigan
Houston, Texas
Kansas City, Missouri-Kansas
Los Angeles-Long Beach, California
Louisville, Kentucky-Indiana
Memphis, Tennessee
Miami, Florida
Minneapolis-Saint Paul, Minnesota
New Orleans, Louisiana
Newport News-Hampton, Virginia
Oklahoma City, Oklahoma
Omaha, Nebraska
Orlando, Florida
Philadelphia, Pennsylvania-New Jersey
Phoenix, Arizona
Pittsburgh, Pennsylvania
Rochester, New York
Sacramento, California
Saginaw, Michigan
Saint Louis, Missouri-Illinois
San Antonio, Texas
San Bernardino-Riverside-Ontario, California
San Diego, California
Seattle-Everett, Washington
Spokane, Washington
Tacoma, Washington
Washington, D.C.-Maryland-Virginia
Wichita, Kansas

as possible given the number of sites in the sample. The reasons for this limitation on number of states was the possibility that differences in the way in which states and regions organize responses to disasters could be a significant factor in determining local economic effects. By limiting the number of states in the sample, the variation in such public policy was reduced.

In order to perform the empirical analysis, it was necessary to construct measures of the rental price of owner-occupied units and the asset price of rental units. This is a classic problem in price index construction which is usually solved using hedonic price index techniques. The basic empirical technique was first employed by Stone (1956) and popularized by Griliches (1971). It has been used for a variety of purposes for constructing prices for complex goods such as housing. In papers by Anderson and Crocker (1971), Freeman (1979), and Maler (1977), and Nelson (1978) it was used directly to value the effects of environmental amenities as characteristics of housing units. Brookshire et al. (1985) have even used the threat of earthquake as an element of an hedonic regression using property value data from California.

Complex goods such as housing have a single purchase price but really consist of a collection of characteristics each of which is valued separately. The overall price of the housing unit, whether a renter or asset price, is a function of the amounts of these characteristics contained in the unit and of the individual hedonic prices attached to different characteristics. Thus the hedonic price function takes the following form:

(16) $$Ai \text{ or } Ri = F\,(c1i, c2i, c3i, \ldots cni)$$

where Ai and Ri are asset and rental prices of unit i and the cli . . . cni are measures of the first through the nth characteristic of housing unit i. In essence, this is an appraisal equation which expresses the sales price of a housing unit as a function of its physical characteristics. But the sales price is the product of the quantity of characteristics in the unit and the asset price of housing services. Thus, the asset price of housing services can be thought of as F(c1i,c2i,c3i, . . . cni)/G(c1i,c2i,c3i, . . . cni) where G(.) is a simple function of the ci's. Both theory and empirical evidence indicate that the asset price of housing services varies with geographic location. Thus, it is customary to include location among the characteristics inserted in the F(.). This practice was followed in the current study with individual dummy variables for the various SMSAs in the sample added to the hedonic equations. Similar arguments can be made for the rental price function. The exact form of the hedonic function F(.) is a matter of some controversy. A semi-logarithmic form, in which the natural logarithm of Ai or Ri is the dependent variable and F(i) is linear, was used in our research because it is most common in the literature. Specific housing characteristics used in the hedonic price function are listed in Table 2.

TABLE 2

HOUSING CHARACTERISTICS USED IN HEDONIC PRICE FUNCTIONS

ROOMS	=	Number of rooms in the unit
BATHS	=	Number of full bathrooms in the unit
AGE	=	Years since the structure was built
FLAWS	=	Ratio of physical flaws (broken glass, roof leaks, cracks in walls, peeling paint, and/or holes in floors) to rooms
GARAGE	=	Unity if unit has a garage and zero otherwise
BASEMENT	=	Unity if unit has a full basement and zero otherwise
HEAT	=	Unity if unit has central heating and zero otherwise
CCITY	=	Unity if unit located in central city and zero otherwise

TESTING AN EXPECTATIONS MODEL OF THE ECONOMIC EFFECTS OF DISASTERS

The empirical tests described in this chapter build on the theory of inter- and intra-city effects of natural disasters that, in turn, is based on the expectations hypothesis and simple general equilibrium model of urban spatial structure presented earlier. In this section, measures of the expected frequency of natural disasters are developed for cities. The divergence between observed disaster rates and prior expectations, called the unanticipated disaster rate, is then related to the rates of appreciation of housing prices. Changes in land values developed in the theory are shown to imply corresponding changes in house prices which can be measured. Statistical tests are implemented which relate the component of unanticipated disaster rates, based on the divergence between expectations and observations, to the rate of change in the price of housing services. Overall, the test results are consistent with expectations that the unanticipated component of recent disaster experience is negatively related to the rate of house price appreciation.

Previous analysis of the economic effects of natural disasters has not distinguished between anticipated and unanticipated disasters. Implicitly such studies treat all disasters as unanticipated or they assume disaster expectations are the same in all locations. Because of the sharp differences between the empirical analysis performed here and that found in other studies, this section begins with a review of the alternative results. Then, tests analogous to the empirical tests found in the literature are undertaken using the data assembled for this study. Because they neglect differences in initial disaster expectations, these previous tests yield results which are seriously flawed. The empirical results in which prior approaches, particularly the work of Wright et al. (1979), are reproduced validate the theoretical expectation that meaningless results are obtained when testing is not consistent with theory. The possibility of faulty interpretation of statistical results in previous work is demonstrated using the data on housing prices from this study. This refutation of previous results, which show no long-term economic effects of disasters, is important because opposing conclusions are reached when tests are reformulated based on the expectations hypothesis and comprehensive urban model developed here.

Following this analysis, we develop a rationale for the formation of anticipated disaster rates for cities and for measuring the deviation of actual disasters from those expectations. This formulation is most important because, again, it is necessary to measure the unanticipated component of disaster rates to determine housing market effects. A specific analysis of the manner in which expectations of house price changes affect housing markets is also provided. Next, tests for the market effects of natural disasters are developed. In the final section, the results of estimates of the housing market effects of a variety of factors including unanticipated disaster rates are presented. These tests of the expectations hypothesis indicate that unanticipated disaster rates have the expected inverse relation to rates of house price increase.

Previous Literature That Ignores Disaster Expectations

In a recent book, May (1985) has provided a brief but cogent review of evidence regarding the longer term economic effects of disasters. All the studies reviewed fail to distinguish the differential effects of anticipated and unanticipated disasters. The tests provide very mixed evidence on economic effects of disasters as demonstrated by the exchange in Wright and Rossi (1981). The differences in the literature appear to match an extensive list of case studies on large disaster incidents by Cochrane (1975), Erikson

(1976), Friesema et al. (1979), Haas et al. (1977), Barton (1969), and Dacy and Kunreuther (1969) against an econometric estimate of long-run effects on housing markets by Wright et al. (1979) and survey evidence of local officials, such as that provided by Rossi et al. (1982).

Case studies of large disaster events provide great detail and document the importance of individual area responses. However, they often seem to show that the event interrupts economic trends and that it is followed by an acceleration of the economic decline or advance that was occurring before the disaster. In some cases, substantial changes in the growth and/or path of the local economy occur in the wake of a major disaster. Dacy and Kunreuther (1969) argue, based on the aftermath of the great Alaskan earthquake of 1964, that the rush of aid in response to a major disaster gives a community a chance to reverse a previous pattern of long-term decline. The opportunity to rebuild on a massive scale, which rationalizes the provision of public services to introduce the latest technology, could open a local economy to production possibilities which might otherwise locate elsewhere. While most case studies have shown significant long-term effects--both positive and negative--the record also contains observations of little or no effect (see Friesema et al., 1977). Overall, the case studies provide mixed evidence at best regarding local economic changes following disasters.

A major econometric study of a large national cross-section of disaster events occurring between 1960 and 1970, conducted by Wright et al. (1979), found no long-term effects on population or housing trends. While this study has been criticized for using only population and housing units as indicators, the theoretical analysis presented in this paper suggests that population and housing changes could be appropriate indicators of local effects of disasters if the proper tests are performed. The same authors provide additional support for the no effect results by conducting opinion surveys reported in Rossi et al. (1982). They report results indicating that natural disaster concerns are not particularly important among public officials, many of whom might be charged with dealing with disaster consequences. Of course, recent occurrence of a disaster can elevate the priority of hazard/disaster concerns temporarily, but, on the whole, these issues were far down the list of priorities for most officials in the survey.

Finally, the evidence of sensitive housing market reaction to the announcement of earthquake risk found by Brookshire et al. (1985) contrasts sharply with the lack of long-term effects reported by Wright et al. (1979).

Because of the similarity between the study by Wright et al. and our research, the former is examined here in some detail. The "test" for long-term effects of natural disasters performed by Wright et al. generally involved estimation of a multiple regression equation. The dependent variable was either the level of population or housing reported in the 1970 census for a particular area or the percentage change between 1960 and 1970. Independent regressors included the 1960 census level of the dependent variable, 0-1 dummy variables for the region in which the area was located, other area characteristics, and 0-1 dummy variables indicating the occurrence of different types of natural disasters in the area during the decade of the 1960s. The hypothesis that the rate of change in the dependent variable during the decade was negatively related to the disaster occurrence dummy variables was not confirmed. Indeed, the estimated coefficients of the disaster dummies were often positive and larger than their standard errors. Such results should indicate that something very unusual is happening and prompt more detailed examination of the tests performed.

Major problems with the tests used by Wright et al. are evident from the theory developed earlier in this paper. Their approach ignores the expectations hypothesis about market effects and has no model of land market responses to disaster events or other forces determining development. Local economic activity should already embody an adjustment for the expected frequency of disaster occurrence.

The expectations hypothesis regarding market responses to disasters implies that, if the frequency of disasters in each city during the 1960s were identical to prior expectations, then the observed disaster rate in each city would have no effect on economic activity. Unanticipated disasters are equal to zero in this case. If actual disaster experience were significantly higher (lower) than expectations, the expectations hypothesis suggests that disaster expectations would rise and the consequent negative (positive) effects on employment, housing, and land rents discussed above would be observed. For example, the occurrence of three floods during the 1960s in an area expected to have 1 (3) [5] floods per decade should have a negative (neutral) [positive] effect on expectations of flood danger and a corresponding positive (neutral) [negative] effect on the local economy. In an area expected to flood three times per decade, the danger of flooding has already been discounted at that frequency and is reflected in both land values and levels of employment and population. As unanticipated disasters rise from -2 to 0 to +2, the local economy experiences increasing negative effects.

Deviations of actual disaster experience from expectations can generate windfall gains or losses and cause consequent reassessment of the allocation of capital and labor. Hence it is not surprising that Wright et al. fail to observe systematic negative market responses in areas that have more disasters. Cities that have more disasters are generally located where more disasters are expected. To the extent that the larger number of disasters is anticipated, the lack of economic effect is not surprising. Such results prove nothing about the effect of unanticipated disaster rates on local economic activity.

Another problem with the empirical approach adopted by Wright et al. involves the measures of population and housing units within a given area. A fall in the density of population or housing in a census tract may not be an indication of economic decline. Rising income generates increased demand for living space which is met through construction of larger housing units and/or rehabilitation of older small units in a fashion that lowers the density of housing. The theory section showed that changes in the total housing or employment in a city might be used as an indicator of changes in land rent or social surplus generated by the city. This argument cannot be extended to individual neighborhoods or census tracts where density may fall due to rising wages rather than falling economic activity.

It is possible to design a test similar to the one used by Wright et al., that does not have the deficiencies of their tests. Such a test would follow the general literature described earlier on using housing hedonic models to evaluate environmental conditions. The hedonic equation simply relates the asset price of the house to the physical characteristics, surrounding environment, and location of the housing unit. The estimated coefficients are interpreted as so called "reduced form" hedonic price effects that reflect influences from both the supply and demand sides of the housing market that cause the asset price of a house to vary depending on its characteristics and location. The basic form of the estimated equation would be:

$$\ln A_i = b_j C_{ij} + c_k L_{ik} + dD_i + v_i \qquad (17)$$

where A_i is the asset price of the i^{th} housing unit, C_{ij} is a matrix of physical housing characteristics, L_{ik} is a matrix of locational characteristics, D_i indicates recent disaster experience in the area where the unit is located, v_i is an identically and independently distributed random normal variate, and b_j, c_k, and d are vectors of parameters to be estimated.

The restated version of the Wright et al. test for local economic effects of natural disasters reduces to the hypothesis that the estimated coefficient of d is negative. Formulated in this fashion, the revised test appears similar to others which have appeared in the literature on the evaluation of environmental quality.

Results for the restated hypothesis, obtained by estimating equation (17) using ordinary least squares techniques, are displayed in Table 3. The data are taken from the Annual Housing Survey for 1979 and the dependent variable is the natural logarithm of the owners estimate of the current asset price of the housing unit. The housing units are located in the cross-section of U.S. SMSAs previously presented. Physical characteristics of the housing units included in the regression are standard variables found in the literature including: ROOMS, number of rooms; BATHS, number of bathrooms; AGE, age of the unit in years; FLAWS, an indicator of inferior physical condition based on the quotient of the number of different types of flaws found in the unit and the number of rooms; GARAGE, a dummy variable equal to 1 if there is a garage and 0 otherwise; HEAT, a dummy variable equal to 1 if there is central heating and 0 otherwise; and BASEMENT, a dummy variable equal to 1 for units with a basement and 0 otherwise. The vector of location dummy variables is very long and hence is not reported in the table. There is one dummy variable for each state and one dummy variable indicating location in the central city of the SMSA.

The variable reflecting recent disaster experience is PASTD which equals the quotient of the number of presidential disaster declarations in the SMSA

TABLE 3

RELATION BETWEEN ASSET PRICE OF HOUSING AND DISASTERS:
A MODIFIED VERSION OF THE TEST USED BY WRIGHT ET AL.

OLS Estimation Results for 1979 and 1983

Variable	1979	1983
Intercept	9.733**	9.821**
	(356.)	(363.)
ROOMS	0.088**	0.086**
	(29.3)	(28.8)
BATHS	0.219**	0.233**
	(30.8)	(33.0)
AGE	-0.0062**	-0.0063**
	(-27.2)	(-26.7)
FLAWS	-0.507**	-0.492**
	(-7.84)	(-6.76)
GARAGE	0.192**	0.202**
	(19.4)	(20.5)
HEAT	0.185**	0.150**
	(14.0)	(11.5)
BASEMENT	0.079**	0.087**
	(6.92)	(7.82)
CCITY	-0.091**	-0.088**
	(-9.15)	(-8.80)
PASTD	0.153**	0.261**
	(3.18)	(4.79)
NOB	13,103	13,103
R^2	0.52	0.55
F(61,13,032)	236.**	255.**

Notes:

t-ratios are in parentheses

*statistical significance at 10% level, two-tailed test

**statistical significance at 1% level, two-tailed test

A vector of location dummy variable for states and SMSAs was included in the regression, but the estimated coefficients are not reported here in order to focus on important results.

during the 1964-1978 period and 15--the number of years in the period. Thus, PASTD may be interpreted as a recent disaster rate experienced for a period of 15 years, which is longer than the ten years in the Wright et al. study.

The estimated coefficients from this semi-logarithmic functional form, which was used because of its popularity in the literature, may be interpreted as the partial effect of the regressor on the percentage change in the price of housing services in the area. Overall, the estimation results are similar to those in other work. The estimated coefficients generally have the expected sign and significance. However, the coefficient of PASTD is positive (0.153) and would be statistically significant if a two-tailed test were used. Taken literally, this implies that a rise in the past disaster rate of one disaster per year (a very large rise) would raise the asset price of housing in the city by 15.3%.

The restated test yields results which are similar to those reported in Wright et al., and quite counter to intuition. It is also a rather silly result if interpreted as suggesting that rising disaster frequencies could result in a rapid increase in the asset price of housing services. The flaw lies in the specification of the initial test equation. The expected rate of natural disaster occurrence should have an effect on the price of land and hence on the price of housing services produced with that land as a major input. However, it is difficult to observe the expected frequency of disaster occurrence. The actual rate of recent occurrence is certainly not an adequate measure of the expected rate.

There are important problems of omitted variables bias in the hedonic estimation. A variety of factors may influence the price of housing services. Often these are difficult to measure, and, generally, they are omitted from the estimating equation. Some environmental factors that are related to natural disasters, such as proximity to water and steep terrain, are also significant influences on the desirability of a residential location. It may be that natural features which are associated with increased disaster frequency also increase attractiveness for residential location.

The scenic hilltop with its expansive views and desirable microclimate may be at risk from a major landslide hazard. Similarly, a waterfront location may provide superior access to outdoor recreation and pleasant breezes, but it may be highly vulnerable to coastal storms and flooding. The positive coefficients of factors such as number of floods may simply reflect the additional value of housing units located near attractive waterfronts. Unfortunately, there does not appear to be an appropriate way to adjust for the bias from omitted variables. Problems that arise because locational factors associated with proximity to hazards also aid in the production of housing services should be investigated further. The tendency to find positive coefficients for disaster rate variables in hedonic equations reported here or in population and housing growth equations, such as those in Wright et al. (1979), suggests that proximity to hazards may be associated with compensating factors that are desired by households.

This report takes an alternative approach to testing for the local economic effects of natural disasters--one which is suggested by theory and is not so susceptible to biased estimates. In the remainder of this section, these tests are explained and their results presented using the Annual Housing Survey data. In contrast to the results from earlier studies, the estimates clearly indicate that deviations of actual disasters from expected disaster frequency--i.e., unanticipated disasters--result in significant local economic effects. The simplistic hedonic estimates reported implicitly assume that anticipated disaster rates are equal everywhere. The silly results obtained with this simplistic approach demonstrate problems with the testing techniques in which actual disaster occurrence is related to subsequent economic change.

Importance of Anticipated and Unanticipated Disaster Effects

Land and housing markets in a city incorporate an adjustment to the prevailing expectation of natural disaster frequency. The expectations hypothesis implies that, if actual disaster rates equal expectations, there should be no significant response in the city housing market because unanticipated disasters are equal to zero. Thus there is a need to develop an anticipated disaster frequency measure in order to determine if actual disasters are more (less) frequent than expectations, i.e., to measure unanticipated disasters. This question of expectation formation and measurement of those expectations is essential to the research.

The theory previously presented developed the relation between changes in the expected frequency of disaster events, usually from f_0 to f_1, and local economic responses of the labor and land markets. Empirical testing requires a specific stochastic specification of the process which households use in formulating expected disaster rates and the way it is altered by actual disaster experience. Essentially, households assume that the underlying stochastic process generating disasters is stable over time. They use information on recent disasters to "update" their expectations concerning the "true" disaster rate.

The specific expectation process adopted here assumes that disaster events follow a Poisson process, which has a probability density function fe^{-fT} and a cumulative density function $F(T) = 1-e^{-fT}$. The expected value is $E(T) = 1/f$ where T is the time between disaster events. Thus if the expected disaster rate or frequency is 0.5 then the expected time between events is $1/f = 1/0.5 = 2$ years. The variance is $Var(T) = 1/(f^2)$. This expected time interval is constant as long as f is unchanged. The probability that a flood will occur between t and t+h is independent of what occurred prior to t. The general applicability of the Poisson process to explaining disaster frequencies is discussed in Cox and Lewis (1966) and its specific applicability to flood hazards is proposed by Brown (1972) among others.

Because the Poisson distribution is a function of the single parameter f, sources of changes in expectations as households "update" their information can be summarized in terms of changes in this single parameter. First assume that economic actors recognize that disasters are determined by a Poisson process and that there is a true value of f which can only be estimated based on past observation of past T's. The economic actor observes past disaster intervals, T_1, T_2, T_3, . . . and assumes that these are generated by a Poisson process that can be described by a negative exponential = fe^{-fT}. It is important to note the implicit assumption that f depends only on past values of T in the particular area in question.

Raiffa and Schlaifer (1961) suggest that a two parameter "gamma-1" distribution can describe the probability density function of agents' beliefs about f. There is an easy intuitive explanation of the two parameters provided by Brown (1972). The probability density function takes the following form:

(18) $$G(f|a,b) = [e^{-fb}(f^b)^{(a-1)}\ b]/[a-1]!$$

The mean of f is E(f) = a/b and the variance is Var(f) = a/b_2. The expected interval between disasters will be E(T) = b/(a-1). Brown (1972) notes that the parameter "a" can be interpreted as the number of disasters observed and t as the time period over which the disasters were monitored. Thus the economic actor would form the conditional expectation of the rate of disasters by finding the sample mean of the disaster frequency for the city in question.

The expected disaster rate conditional on the city having experienced a_0 disasters in the past b_0 years is affected by the observation of a_1 disasters in the succeeding b_1 years. The expected disaster frequency conditional on the initial experience is $E(f_0) = a_0/b_0$ and the new frequency expectation will be $E(f_1) = (a_0+a_1)/(b_0+b_1)$ or the new and updated disaster frequency will rise (fall) if a_1/b_1 is greater (less) than a_0/b_0. In cases where the intervals b_0 and b_1 are constant, the change in disaster expectations will vary directly with the difference of recent disaster experience less the past rate $[(a_1/b_1)-(a_0/b_0)]$. This difference is used as the measure of the change in disaster expectations in the empirical analysis performed here. The deviation between recent disaster rates and previous disaster rates is used as the measure of the change in expected disaster frequency. This is equivalent to a conditional or Bayesian expectation of the disaster frequency under the prior assumption that the underlying stochastic process generating disasters is Poisson with stable but unknown f.

For each city, the number of presidential disaster declarations during a 15-year period (1965-1979) is used to form the prior expectation of disaster frequency, PASTD = a_0/b_0. For types of disasters that have low periodicity, 15 years is a very short estimation period. Nevertheless, data limitations explained previously force such an approximation. The change in disaster expectation is based on the difference between the initial expectation and the rate of presidential disaster declarations for the city during the subsequent year (1979-80) or four-year (1979-1983) period. Thus the initial disaster frequency is f_{65-79} and the change in expectations is based on the difference of f_{79-80} or f_{79-83} and f_{65-79}.

It is possible to formulate alternative views of the process in which disaster expectations are formed and hence of the manner in which actual disaster experience during a given period would alter expectations. One alternative approach to that taken here would be to estimate a general multivariate model of the determinants of disaster rates in cities as a function of both lagged values of disaster frequency and lagged values of other characteristics of the city which might be related to disaster probabilities. In order to do this, it would be necessary to construct times series data for each city. Then the relation between current disaster frequency and lagged values of both disaster rates and other characteristics could be estimated using vector autoregressive techniques.

This approach was not taken here for a variety of reasons. First, most of the city characteristics which would explain disaster frequency would be constants over the relevant period. Second, the underlying stochastic process generating disasters should be quite stable over fairly long periods. Third, the Poisson process presented above provides a superior a priori explanation for the formation of disaster expectations. Finally, the data and estimation requirements for vector autoregression estimation on over 70 U.S. cities would involve vast amounts of work.

In addition to disaster expectations, the study performed here considers measures of the prior expectation of change in the asset price of housing services in the city. Theory provides an indirect measure of the expected rate of house price appreciation in a housing market. The yield from housing consists of a rental return, equal to the ratio of rent to asset price, and the expected appreciation in the asset price. If housing markets are efficient, then the yield on housing assets should be equated across housing units. This implies that the rental return and appreciation return should vary inversely in a system of efficient housing markets. Rental return is the ratio of the implicit rental income, net of costs, to the asset price of the housing unit. The rental return can be constructed statistically gross of housing production costs. Appreciation return is based on the expected rate of housing price appreciation, which cannot be observed. But the inverse relation between rental return and appreciation return allows the opportunity to use statistically constructed rental return to measure appreciation return. This second technique for measuring the unobservable appreciation return is used in the empirical testing reported here.

Testing Economic Effects of Unanticipated Natural Disasters

Building on the theory and data set forth earlier, this section rationalizes and presents tests of the expectations hypothesis that there are significant local economic effects of unanticipated natural disasters. Such effects, if they exist, can be seen in the reaction of the urban land market to an unanticipated increase or decrease in the frequency of disaster occurrence. While there are no time series data on urban land prices, data on the asset prices of urban housing can be used as an indicator of land price movements. The tests reported here relate the rate of house price appreciation over one- and four-year intervals to, among other things, the divergence of actual disaster rates from the expected rate based on past disaster frequencies for the area. The argument proceeds in a number of stages beginning with the relation between land prices and housing prices and continuing through the final specification of the test equation.

Muth (1969) initiated a vast literature on the relation between the urban land market and the price of urban housing services. As a major input into the production of housing, and particularly as the major component whose price varies spatially, land price differentials are crucial to spatial differences in the asset price of housing services. It is common to find empirical studies of house price variation used to measure environmental factors which affect the underlying price of urban land, see, for example, Blomquist and Worley (1981) and Linneman (1981). The recent papers by Brookshire et al. (1985) and Shilling, Sirmans, and Benjamin (1984) use estimates of the proximity to potential disaster sites in hedonic house price equations to estimate the effects of disasters which originate in the land market.

Urban housing uses land as a major input. Housing services, h, are produced using land, L, and non-land, N, inputs according to a housing services production function of the form:

$$h = H(L,N) \tag{19}$$

where $H_L>0$, $H_N>0$, $H_{LL}<0$ and $H_{NN}<0$. Land is the input that varies most in cost spatially. Indeed, the price of the non-land input, P_N, is often assumed to be spatially invariant. Therefore the output price of housing services will reflect the underlying variation in the rental price of land, r. If the ratio of land cost to asset price of the housing is 0.2, then the variation in the price of housing services will be approximately 20% of the variation in the underlying rental prices. Thus the price of housing services reflects underlying spatial differences in land rents but land rent variations are substantially larger, perhaps by a factor of five or ten, than the consequent house price variations which they generate.

Because tests must be performed using house price changes, these price changes understate by a sizable multiple the underlying land rent differences where theory suggests the effects of disaster differentials appear in the long run. Of course, in the short run, housing investment is substantially fixed, and thus it assumes some of the locationally permanent characteristics of land. Over short periods of one or two years, it is probably safe to regard housing investment as fixed and hence the prices of these fixed non-land inputs should vary substantially in the short run also. As the time period over which impacts are measured lengthens, non-land inputs become variable, and land alone begins to bear the full effect of changes in disaster expectations. Thus, tests of local economic effects of disasters using house price data will be more sensitive in the short than in the long run.

The empirical test for local economic effects implemented here uses detailed data on housing units in the cross-section of U.S. SMSAs which are identified in the Annual Housing Survey. Changes in the asset prices of housing units over two time periods, 1979-80 and 1979-83, are considered. Given that the same housing units are visited in each iteration of the Annual Housing Survey, data records for successive surveys could be linked and changes in the unit observed in detail. The change in asset price, based on the owner's estimate of value, can be computed easily. It is possible to observe any changes in the physical characteristics of the unit over the period. Finally, the rental prices of owner-occupied housing units can be estimated because the Annual Housing Survey also contains data on rents for the rental housing stock. Hedonic techniques can be used to estimate the rental price of housing services and the estimated rents then used to construct an implicit rent for owner-occupied units whose appreciation is being estimated in the main empirical test.

Results of a Test for Local Economic Effects of Disasters

The test for local economic effects of natural disasters examines sources of changes in the asset price of housing services for individual housing units in a cross-section of SMSAs. As explained above, the sample of SMSAs was selected based on data available in the Annual Housing Survey and on the number of presidential disaster declarations in the SMSA. The number of disasters measured is based on these declarations, and hence these are large disaster events. However, it could be argued that, due to the density of population in these SMSAs significant natural hazard events would be likely to produce enough damage to justify a presidential declaration.

The estimates of local economic effect should be regarded as reflecting changes in expectations of loss net of any government compensation. Presidentially declared disasters are likely to be accompanied by significant aid from local, state, and national agencies. If such aid were sufficient so that economic agents believed that all future losses from disasters would be offset by compensation, then unanticipated disasters would have no net local economic effects. In terms of our theory, the initial losses that prompt the land and labor market adjustments would be completely negated by positive transfers, leaving no local economic reaction to anticipated or unanticipated disaster incidents. Thus, the empirical results obtained here have implications for effects net of compensation. A finding that unanticipated disasters had no statistically significant effects on the rate of change of housing or land prices would not imply that such effects would be zero in the absence of government compensation programs. Rather, it would imply that compensation was sufficient to offset expected future losses. If compensation were more than adequate to cover losses, then unanticipated disaster events would actually be positively related to the measures of price appreciation used here.

The actual percentage change is related to a vector of location dummy variables; rent, asset price, and the rent-to-asset price ratio at the start of the period; specific characteristics of the units; past disaster rates; and the deviation of the disaster rate during the period from past trends. The specific form of the equation which was estimated by ordinary least squares techniques is:

$$(20) \quad \%CHANGEP_i = a_0+a_1ROOMS+a_2BATHS_i+a_3AGE_i+a_4FLAWS_i+a_5CHANGFLAW_i$$
$$+a_6GARAGE_i+a_7BASEMENT_i+a_8ERENTVALU_i+a_9ERENT_i+a_{10}EVALUE_i$$
$$+SUM_jb_jLOCATION_{ij}+c_1PASTD_i+c_2(PASTD_i)^2+c_3CHANGD_i+e_i$$

where i indexes observations of a vector of 1,2, . . . i, . . . I housing units, and most regressors have been discussed earlier. New variables include CHANGFLAW, the change in the measure of flaws over the observation period. It is possible for other physical characteristics of the unit to change during the period also, but changes in number of rooms, baths, or presence of a garage were so infrequent that these few observations were simply deleted. Variables beginning with "E" and including ERENTVALU, rent/value ratio; ERENT, rent; and EVALUE, sales price, are all statistical constructs using hedonic equations describing the condition of the housing unit at the beginning of the observation period. The location dummy variables are indexed by j.

To allow specifically for the possibility that there was some non-linearity in the relationship between past disaster rates and house price change, PASTD was entered as a quadratic form. Finally, CHANGD is the deviation of the disaster rate during the observation period from PASTD or a representation of $(a_1/b_1)-(a_0/b_0)$ as presented above. The expectations hypothesis concerning the local economic effects of natural disasters is that $C_3<0$, i.e., that the rate of increase in house prices varies inversely with the difference of the actual and the expected disaster rates. There is no particular relation anticipated between PASTD and the rate of house price appreciation. This contrasts with the tests based on PASTD which were used by Wright et al. (1979).

Table 4 presents the results from the estimation of equation (20) for effects of disasters during the 1979-1983 period using ordinary least squares. Two specifications are reported, one with ERENTVALU, the estimated rent-to-

TABLE 4

DETERMINANTS OF PERCENTAGE INCREASE IN HOUSE PRICES, 1979-83

Variable	Equation A	Equation B
Intercept	0.151** (5.88)	0.305** (5.45)
ROOMS	-0.00057 (-1.37)	-0.0088* (-2.06)
BATHS	0.0010 (0.11)	-0.0073 (-0.80)
AGE	0.0033 (1.25)	0.00054* (1.94)
FLAWS	-0.321** (-4.71)	-0.287** (-4.16)
CHANGFLAW	-0.339** (-7.88)	-0.337** (-7.84)
GARAGE	0.186* (2.00)	0.0034 (0.32)
HEAT	-0.206 (-1.56)	-0.020 (-1.53)
BASEMENT	0.012 (1.10)	0.0043 (0.40)
ERENTVALU		-21.58** (-3.10)
ERENT	0.0005* (4.37)	0.00079** (5.35)
EVALUE	-0.0000023** (5.85)	-0.0000035** (-6.38)
PASTD	0.565** (2.42)	0.598** (2.56)
$PASTD^2$	-1.237** (-2.48)	-1.354** (-2.71)
CHANGD	-0.0796* (2.188)	-0.0896* (-2.45)
NOB	11,603	11,603
R^2	0.055	0.56
F(65,11,578)	10.4**	10.4**

Notes:
t-ratios are in parentheses
*statistical significance at 5% level, two-tailed test
**statistical significance at 1% level, two-tailed test
A vector of location dummy variable for states and SMSAs was included in the regression, but the estimated coefficients are not reported here in order to focus on important results.

value ratio, noted "Equation B," and the other without it. The null hypothesis of no significant effect of the unanticipated component of disaster rates is rejected at the 5% level in both equations using a two-tailed t-ratio test.

The estimated coefficient of CHANGD, c_3, is negative and significant, indicating that the rate of house price appreciation varies inversely with the unanticipated increases in natural disaster rates. The mean of CHANGD is -0.053, and the minimum and maximum are -0.666 and 0.917 respectively. Given that the mean of the rate of appreciation is 0.20 and that c_3 equals approximately 0.085, this implies that, over the range of CHANGD, the effect of unanticipated disaster rates on appreciation is about 0.13 (-0.06 to +0.07), which is a considerable proportion of the mean appreciation rate.

The estimated coefficients of PASTD and $PASTD^2$ are statistically significant and opposite in sign. The net effect on the rate of appreciation in house prices is just balanced at zero when PASTD = 0.24 which is close to the mean of PASTD at 0.20. Thus areas with unusually high rates of past disasters are expected to have lower rates of future appreciation. There is no theoretical justification for such effects, just as there was no a priori reason for past disaster rates to be positively related to the level of house prices in the results reported in Table 3.

Because the validity of a particular coefficient test is judged, in part, on the overall agreement between the estimation results and theory, some attention to the general results reported in Table 4 is necessary. First, consider the variables reflecting physical characteristics of the housing unit. Clearly the negative and significant effect of CHANGFLAW is expected because units with increasing flaws should have lower rates of price appreciation. Other physical characteristics generally have nonsignificant estimated coefficients. This is generally consistent with theory. In an efficient housing market, there is a presumption that rates of price change should not be different for one physical characteristic than they are for other characteristics. Age of the unit is expected to have a positive and significant coefficient because depreciation rates are highest in the early years after construction. In Equation A, however, AGE is non-significant while it is positive and significant in Equation B.

ERENTVALU, the ratio of estimated rent to estimated value, is a measure of the gross rental return to the unit. In the equilibrium of an efficient housing market, the sum of the rental return and appreciation rate should be equal, indicating equality of the total rate of return across units. Thus the proxy variable for gross rental return should vary inversely with rates of house price change, and the negative and significant coefficient indicates that this is true. Estimated rent and value, ERENT and EVALUE, are inserted into the equation to allow for the possibility that rates of house price appreciation may vary with the quantity of housing services delivered by the unit. Filtering models of the housing market, such as that developed by Struyk and deLeeuw (1976), allow for such differential effects in certain types of housing markets.

The four-year period for house price appreciation was selected to construct the estimation results in Table 4 because of the desire to observe a period during which a significant alternative disaster rate could be constructed. It should not be necessary to wait very long, however, to observe a reaction of the asset price of housing services to changes in expected disaster rates. Table 5 reconstructs the estimates of equation (20), using the change in asset price of housing services over the 1979-1980 period. Given the one-year observation period, the observed disaster rate is reduced to a dummy variable, DISTD, which is equal to 1 if a disaster occurred during the

TABLE 5

DETERMINANTS OF PERCENTAGE INCREASE IN HOUSE PRICES, 1979-80

Variable	Equation A	Equation B
Intercept	0.0868**	0.110**
	(6.20)	(3.63)
ROOMS	0.00061	-0.00012
	(0.266)	(-0.051)
BATHS	-0.00093	-0.0028
	(-0.195)	(-0.54)
AGE	0.00017	0.00022
	(1.18)	(1.46)
FLAWS	-0.0329	-0.0272
	(-0.649)	(-0.53)
CHANGFLAW	-0.148**	-0.146**
	(-3.30)	(-3.29)
GARAGE	0.00040	-0.0022
	(0.079)	(-0.38)
HEAT	-0.0113	-0.012
	(-1.51)	(-1.59)
BASEMENT	-0.0040	-0.0048
	(-0.726)	(-0.83)
ERENTVALU		-3.523
		(-0.96)
ERENT	-0.00014*	-0.00008
	(-2.217)	(-1.03)
EVALUE	0.000000048**	0.000000029
	(2.36)	(1.05)
PASTD	0.154*	0.177*
	(2.05)	(2.12)
$PASTD^2$	-0.195*	-0.214
	(-1.99)	(-1.60)
DISTD	-0.0289**	-0.0359**
	(-2.75)	(3.09)
NOB	9,949	9,949
R^2	0.042	0.042
F(64,9885)	6.75**	6.60**

Notes:
t-ratios are in parentheses
*statistical significance at 5% level, two-tailed test
**statistical significance at 1% level, two-tailed test
A vector of location dummy variable for states and SMSAs was included in the regression, but the estimated coefficients are not reported here in order to focus on important coefficients.

1979-1980 period and 0 otherwise. DISTD can be interpreted as a simple indicator of actual disaster rate in excess of expectations. The estimated coefficient of DISTD is negative and significant at the 1% level. Its magnitude is numerically smaller than in the previous specification where changes over a four-year period were being explained. Thus the general negative effect of actual disaster rates in excess of expectations is documented here as in earlier results.

Very high rates of PASTD have a negative effect on appreciation rates. This time the level of PASTD at which there is no effect on house price change is about 0.40.

Overall, the one-year time interval is so short that few of the non-disaster variables which were often significant in estimates of price change over four years are not significant over one year. The major exception is CHANGFLAW whose significance level is quite high and understandable. Increasing the number of flaws in a unit should depress its asset price.

Thus both the one- and four-year house price change equations provide strong support for the expectations hypothesis of the effects of natural disasters on local economies. The strong inverse relation between unanticipated disasters during a time interval and city land market values is consequential by itself. This confirms the hypothesis that markets are reacting to unanticipated disasters and that the magnitude of the reaction is significant. Additional analysis of the size of these market effects will be presented in the next section.

Perhaps even more important than the direct estimates of market effects, the confirmation of the expectations hypothesis suggests that a variety of related results which can be obtained through the application of the urban development theory and applied natural resources economics can be used to evaluate natural hazards. Such applications can be very important in analysis of policy issues involving the local economic effects of disasters. Such applications might include analysis of the likely effects of alternative insurance arrangements or compensation for victims of disasters. Indeed, the expectations hypothesis suggests a re-examination of the definition of loss from hazard in terms of unanticipated disasters which could cause a fall in property values. Some of these potential applications are reviewed in the concluding section.