Natural Hazard Research

THE LOCAL ECONOMIC EFFECTS OF NATURAL DISASTERS

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SUMMARY

A theoretical economic model, capable of considering both inter- and intra-city elements, was constructed in order to test the local economic effects of natural disasters. An important conclusion from the analyses performed is that in the context of economic models, the test for local economic effects should be based on deviations of the actual rate of disaster activity from the expected rate of activity. Previous analyses of the economic effects of natural disaster have not distinguished between anticipated and unanticipated disasters. This analysis also indicates that changes in the expected frequency of natural disasters can affect local economic activity in ways that are reflected in the land market.

The local economic effects of natural disasters were tested using a model suggested by theory in which housing markets react to the perceptions of the likelihood of natural disaster. The empirical tests required detailed data on the sales price and physical characteristics of owner-occupied housing in a cross-section of U.S. cities in different years. We used Annual Housing Survey Data (collected by the Census Bureau for HUD), for the years 1979, 1980, and 1983, in 70 SMSAs.

This study makes a number of contributions to the current understanding of local economic effects of natural disasters, including original data assembly, development of new theory, and new tests of the way disasters affect a local economy. Two earlier project publications provide details of the disaster incidence data that were collected and analyzed for this report.

PREFACE

This paper is one in a series on research in progress in the field of human adjustments to natural hazards. It is intended that these papers be used as working documents by those directly involved in hazard research, and as information papers by the larger circle of interested persons. The series was started with funds from the National Science Foundation to the University of Colorado and Clark University, but it is now on a self-supporting basis. Authorship of the papers is not necessarily confined to those working at these institutions.

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BACKGROUND

This paper presents the results of the recently completed research project, "The Local Economic Effects of Natural Disasters." The project was undertaken from September, 1985 through July, 1987, during which time two intermediate products were completed. The final project report was sent to the National Science Foundation in August, 1987. A description of the earlier products and details about their dissemination and utilization are covered later in this chapter.

The Proposed Project

In the initial problem statement, we noted that relatively little research in recent years has focused on the long-term economic recovery process after a major natural disaster. We proposed to measure the state of economic activity in a community by observing the conditions of its housing market. Further, we proposed to make a large number of observations in order to study changes in the price of housing services caused by disasters as well as those caused by postdisaster relief.

Using data on disasters that occurred from 1965 to 1985, we set out to measure the state of economic activity in a sizeable number of communities by observing their housing markets. A large number of observations enabled us to study changes in the price of housing services caused by disasters as well as those caused by postdisaster relief.

The results of this study were expected to provide specific information on the economic reaction of housing markets to different types of disasters, including those of a repetitive and nonrepetitive nature, and implications of effects on local economies. We planned to determine if the consumers and investors react so that higher probability, repeat natural disaster events (such as periodic floods) are reflected in existing housing market values while lower probability disaster events are not incorporated into market values.

Early in the study, while obtaining the disaster incidence data we needed for the economic analysis, we decided that our data on disaster incidence location and on the frequency of occurrence would be of interest and use to many other persons. We anticipated that we could perform a useful service by sharing that data with other researchers and also with persons with operational and mitigation planning responsibilities. Consequently, we prepared two secondary reports, each issued and distributed as soon as was feasible during the project year. We received a small add-on grant to support the additional tasks required to prepare the first report.

Since each of the two intermediate products are self-explanatory, this report focuses on the main mission of the project: the determination of the local economic impact of natural disasters. In particular, this report covers the economic theory, analysis, and results of the research effort.

Because large data sets we developed to perform the proposed work, we used many computer tapes and disks to store the data. For persons seriously interested in the details of our study, or for those who would like to use our data for special purposes of their own, the data tapes are available.

Project Products: Dissemination and Utilization

Much of the disaster incidence data we collected early in the project has been included in the two interim products: 1) Summary of Major Disaster Incidents in the U.S., 1965-85, which was issued as Special Publication #17 by the University of Colorado, Natural Hazards Research and Applications Information Center, September, 1986; and 2) Details on Frequency of Disaster Incidents for Federally-Declared Disasters, 1965-85, which was issued as an

Occasional Paper by the Graduate Program in Science, Technology and Public Policy at The George Washington University, March, 1987.

The Summary includes a series of statistical analyses of presidentially-declared disasters that occurred in the U.S. during the last two decades. For each of the major disaster agents, it reports loss of life, number of injuries, and estimated federal and private outlays. Details on Frequency of Disaster Incidents contains frequency data which we had planned to issue in summary form in the final report. Owing to the high interest of people who had seen some of our preliminary data, we provided more details on the frequency tables and prepared this special report prior to completing the research and prior to preparing this final report. We provided copies of the preliminary data to staff members in the national offices of FEMA and the Red Cross and to several university researchers. In addition, we have provided some researchers with our actual data files. Currently, a contractor to the American National Red Cross is using our data for a large project, and a contractor to FEMA is using the data for work on damage inventories. In addition, the city of Tulsa has used our disaster incidence data as justification for intensifying local flood hazard mitigation planning efforts.

THEORY OF THE LOCAL ECONOMIC EFFECTS OF NATURAL DISASTERS

The prerequisite for empirical testing of local economic effects of natural disasters is a theoretical model of the manner in which areas respond to disaster events. Such a model not only provides guidance about the relation between disasters and the economy but also helps to define what one might mean by an economic effect. Thus, this chapter begins by considering the economic meaning of the effects of natural disasters. Economic theory suggests that the effects of natural disasters depend on prior expectations concerning disasters which prevailed before the disaster occurred. Consequently, any test for the effects of disasters must be made within a context that considers disaster expectations. The second section reviews the theoretical literature on inter-city and intra-city effects of natural disasters. In the final section, these theoretical models are merged into a composite model capable of considering both inter- and intra-city elements. This composite model provides the basis for the empirical tests to be performed in this project, the results of which are reported here.

A Definition of Local Economic Effects of Disasters

A local economy consists of capital and labor which are allocated to production using the natural resources, including land, in a particular area. In the context of economic theory, a natural disaster is like a negative natural resource in that it has an effect on output and the production process and is not produced by humankind. It might seem that natural disasters are differentiated from natural resources because of the uncertainty with which disasters occur. Some natural resources, however, are also subject to considerable uncertainty; for example, the occurrence of minerals or petroleum in the earth or the quantities of rainfall and sunshine during a growing season can vary considerably. Indeed, rainfall, in extreme amounts, may cause a natural disaster.

Thus, natural disasters are not unique economic phenomena but rather can be treated within the general context of natural resource economics, i.e., as negative natural resources. The research problem can thus be redefined in terms of economic theory as the local economic effects of natural resources (or negative natural resources). Given the conventional assumptions made about production functions, greater amounts of natural resources tend to raise the productivity of capital and labor and hence to attract capital and labor to an area. Conversely, negative resources tend to repel these inputs. If all other things are held constant, a decrease in resources in an area should result in a decrease in the volume of economic activity in that area. Thus, an increase in natural disasters (if they are considered as negative resources) is equivalent to a decrease in resources and results in lower levels of labor and capital.

The uncertainty that accompanies some resources, particularly natural disasters, may be added to this model without difficulty. In a risk-neutral world, which is assumed in the analysis performed subsequently in this report, markets react to changes in the expected level of resources. This expectation is a statistical construct based on whatever models and data are available to predict the true levels of occurrence of uncertain resources. In the case of petroleum and valuable mineral resources, elaborate geological models have been developed to aid the forecast or expectation of resource availability. Similar efforts have been undertaken for disasters in the areas of earthquake and landslide prediction. If uncertainty were added to the model, the nature of the question, "What are the local economic effects of natural disasters?" becomes more complex. But so does any question about the effects of natural resources.

The markets allocating capital and labor respond to the expected occurrence of natural resources. Changes in this expectation of resource availability produce market responses. For example, an oil strike in a proven field attracts little attention, but a find in an area thought to have little potential may produce a wave of exploration. The market effects of additional data on resources depend on what that information implies for the current expectation of natural resource occurrence. If the additional data simply confirms current expectations, then no revision in expectations will occur, and there will be no observable market reaction. This is the case with the productive well in the proven field. Alternatively, recent observation of resource occurrence may not agree with expectations, causing a revision in expectations which generates a corresponding shift in market allocation of capital and labor.

Extended to the case of natural disaster events, this reasoning implies that disasters that occur at a rate consistent with current expectations will have no significant allocation effects, because they do not cause forecasts of the rate of disaster occurrence to change significantly. Such situations can be termed "anticipated disasters." Alternatively, the rate of occurrence of disasters can be above or below expectations forcing a revision in disaster rates. Such unanticipated disaster effects will, in turn, provoke a market response.

Thus, the observed rate of disaster occurrence in an area will have positive, negative, or zero effects on the current level of economic activity based on whether that rate is smaller, larger, or identical to the expected disaster rate. This conclusion has a profound implication for the interpretation of the phrase "local economic effects of natural disasters." In the context of economic models, the test for local economic effects should be based on deviations of the actual rate of disaster activity from the expected rate of activity. The proper test in terms of theory is for the local economic effects of unanticipated natural disaster activity and should include both negative and positive deviations of the actual disaster rate from that expected.

While this analysis of theory is fairly straightforward, its empirical implementation is rather difficult. In order to measure the effects of unanticipated disaster activity, one should know the expected disaster rate and then compute the difference of the actual and expected rates. But the expected disaster rate, like other collective forecasts, is not observable, and some estimate of this expected rate must be formed. Most previous studies of local effects of disasters failed to differentiate between anticipated disasters, which should have no effects, and the unanticipated component of the disaster rate.

Perhaps the most imaginative approach to the problem of measuring the effects of revised disaster expectations is that found in the work of Brookshire et al. (1985). Emerging geological evidence improved scientists' ability to locate high-risk earthquake zones in California, and the California legislature therefore passed legislation requiring that the location of a residence in a Special Studies Zone (an area of seismic history, so designated under the Alquist-Priolo Act) must be disclosed to buyers. The hypothesis in the Brookshire study was that such disclosure would revise expectations of earthquake occurrence upward in the Special Studies Zones compared to surrounding areas. This was tested by estimating the partial effect, before and after the disclosure law was implemented, on sales prices of housing units located in Special Studies Zones.

The results suggest no significant discount before enactment of the law for locations in a higher risk area, but a significant discount subsequent to the law's passage. This seems to confirm that buyers responded to the disclosure of location in a Special Studies Zone by demanding a discount (or, alternatively, paying a premium for a location outside such areas) and that expectations of earthquake risk had been modified by the disclosure law. Thus, changes in expectations can produce observable changes in market outcomes.

This change in relative house prices inside and outside the Special Studies Zones, apparently due to revised expectations after disclosure was required, is essential to the empirical test because a host of neighborhood factors, other than earthquake expectations, can account for house price differentials across neighborhoods; but the change in size of the house price discount for units located in Special Studies Zones after the disclosure law is not likely to have been caused by other changes in neighborhood factors that just happened to match the Special Studies Zones.

The definition proposed here for local economic effects of natural disasters in terms of effects due to changes in anticipated disaster rates is very much in the spirit of the theoretical approach taken by Brookshire et al. (1985). Again, the definition focuses on the influence of recent actual disaster experience compared to historical disaster rates on which expectations should be based. Differences between expected and actual disaster frequency cause a revision in expectations. Thus, our approach deals directly with the influence of actual disasters on expectations rather than with problems created by inadequate disclosure of information on disaster predictions.

Literature on Inter- and Intra-City Effects of Disasters

The "inter-city" or "inter-area effect" refers to the way in which resource effects of disasters shift economic activity from one city to another. Inter-city effects change the levels of capital and labor which accumulate in a particular city. "Intra-city effects" arise when disasters shift the location of economic activity within a city. These are neighborhood effects which occur while the aggregate level of activity is held constant. The local economic effects of natural disasters include a combination of both types of effects.

Inter-city effects arise from the migration of capital and labor. The rule for capital migration is simple: capital must earn the same rate of return in all locations and hence it will move from areas where its return is low to areas with higher rates of return. Comparative rates of return depend on productivity of capital in different locations. Increases in expected disasters lower expected productivity of capital because they threaten survival of the capital stock. Labor migrates to areas where, given wages paid, living costs, and amenities, workers can secure the highest levels of satisfaction or utility. Increases in expected disasters raise living costs and lower expected amenities, reducing utility and prompting outmigration of labor.

The general form of inter-city effects is traced in a number of neoclassical models of regional economic development which follow the seminal work of Borts and Stein (1964). The inter-city effect has implications for capital and labor migration as noted above, but given existing data sources, migration of capital and labor is virtually impossible to measure, making direct tests or applications of the theory difficult. However, the theory has a number of implications for wages and, particularly, for land prices. Both differentials have been used frequently in indirect tests of inter-city effects. Rosen (1979) proposed a wage-based index of the quality of urban life and claims that variation in wages across areas can be used to measure the compensating differential in wages which workers require in order to live with environmental problems in certain cities. Goldfarb and Yezer (1979) proposed and implemented a wage-based index of efficient city size.

The inter-city effects of changes in the expected disaster rate are potentially significant. Tests of this effect require a model that considers the connections among the change in disaster expectations, effects on productivity and migration of capital and labor, and subsequent changes in something that can be observed directly and be used as the object of empirical econometric tests. Subsequent development of such an inter-urban model in this report demonstrates that wage-based measures of natural disaster effects are not appropriate. However, substantial support is found for the use of land or house price measures to reflect the economic effects of natural disasters.

The intra-city effects of natural disasters have been examined in important and creative work by Scawthorn et al. (1982). They argue that the rate of depreciation of real capital rises monotonically with the expected disaster rate. The expected productivity of capital invested in parts of the city more likely to have disasters is lowered relative to the safer neighborhoods. The net result is quite intuitive. The standard urban model predicts that the city will grow away from the highest disaster rate neighborhoods. The ratio of real property capital and labor inputs per acre will be lowered in the neighborhoods where expected disaster rates are highest.

The paper by Brookshire et al. (1985) discussed above, is based upon a similar model of intra-city effects. Households require discounts in the price of housing capital if they are to live in Special Studies Zones. This lower price of housing capital will induce capital outmigration from such neighborhoods, and result in lower density housing (i.e., lower capital/land ratio) than would ordinarily apply. However, the capital migration and housing density effects that are so difficult to measure at the inter-city level cannot be measured among neighborhoods; so Brookshire et al. rely instead on observation of a lower price of housing services in the zones, and from those observations they infer that the other effects follow. Their research implicitly assumes that inter-city effects are zero. For example, the publication of high-risk earthquake zones in Los Angeles and San Francisco could generally lower the desirability of location in these cities compared to other U.S. cities. Thus, the tests performed in Brookshire, et al. may ignore the most important effects of widespread publication of natural hazard risk data.

Local economic effects of natural disasters include both inter- and intra-city outcomes. While inter-city effects may be most important for policy purposes, it is important to have theoretical and empirical approaches which capture both effects. The inter-city effect is captured by a regional economic model in which the general level of economic activity varies with disaster expectations. The possibility that disasters may alter the spatial disposition of activity within a city is also considered.

The inter- and intra-city effects of changes in disaster expectations will be termed the general "level" and neighborhood "tilt" effects, respectively. The inter-city, or level, effects refer to the inverse relation between changes in expected disaster rates and the general level and intensity of economic activity averaged over the entire city. The intra-city, or tilt, effects arise because the distribution of economic activity by neighborhood is tilted away from areas with higher expected disaster rates. In specific neighborhoods these two effects may work in opposite directions, producing interesting outcomes. For example, an increase in expected disasters in one neighborhood will have a negative level effect throughout the city, but, in areas farthest removed from the neighborhoods with the raised disaster expectations, there will be a favorable tilt effect which may be larger than the level effect and result in a rise in economic activity. Thus a rise in expected disasters produces a net increase in economic activity in some neighborhoods. The possibility for such unusual results should be considered carefully when modeling local effects of disasters and when interpreting empirical results.

A Model of Intra- and Inter-City Effects of Disasters

The challenge put forward by the previous section is to formulate a model which can predict the likely local economic effects of natural disasters on aspects of cities which can be measured and used as the basis for empirical analysis. Such a model must consider both intra- and inter-city effects. These effects must be projected beyond the direct reaction of variables such as employment, output, investment, or migration because there are no adequate economic time series on these variables for U.S. cities to be used in empirical testing. The most promising variables for testing, based on the literature, are wages and the price of housing services. Thus, the model developed here is intended to generate economic consequences of disasters for wages and house prices.

The theoretical model of intra- and inter-city effects of natural disasters is based on the work of Stull (1974) on the economics of zoning. With moderate levels of modification, this model can be applied to a variety of problems and economic questions. For purposes of exposition, the city will be given the simple linear geometry shown in Figure 1, in which C is an urban center and z is an index of distance along a radius from that center. For reasons that will be made clear, land use follows a pattern in which firms

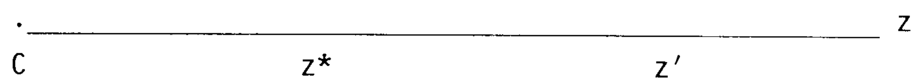

FIGURE 1

GEOMETRIC MODEL FOR ANALYSIS OF URBAN EFFECTS

locate on the interval (C,z*) and households reside on (z*,z′). There is agricultural activity located outside z′. The division of economic activity over space is determined by the ability or willingness of the three activities--production, residences, and agriculture--to pay for space. Agriculture is willing to pay a uniform reservation price, r_A, which is equal to the rent at the edge of the urbanized area, $r(z') = r_A$.

The city functions by attracting capital and labor to be used in producing output in industries located on the (C,z*) interval. The markets for capital and labor are perfectly competitive so that the city must pay a sufficient wage and rate of return to attract these inputs. This limits the total expansion of the city to z′ and the division of space between firms and housing at z*.

For convenience, assume that all households contain a single identical worker with the following concave utility function:

$$u = U(x,q,L(|z-z\#|,f)) = U(x,q,L) \tag{1}$$

where x is the quantity of a non-housing commodity purchased, q is the quantity of land purchased for housing, $|z-z\#|$ is the distance from the household's residential location at z to the location of a potential natural disaster at z#, and f is the frequency or rate at which the disaster is expected to occur. Thus $L(|z-z\#|,f)$ is the expected loss rate from disasters with the first partial derivatives $L_{|z-z\#|}<0$ and $L_f>0$. The consumer is assumed to be risk-neutral, and hence utility depends only on the expected frequency with which disasters occur. The signs of the marginal utilities are, $U_x>0$, $U_q>0$, and $U_L<0$. Thus $U_{|z-z\#|}>0$ and $U_f<0$. Second derivatives are all negative, $U_{xx}<0$, $U_{qq}<0$, and $U_{LL}<0$.

Households try to maximize utility subject to a budget constraint of the form:

(2) $$y = px + r(z)q + tz$$

where y is the annual urban wage in the city, p is the price of the composite good x, r is the annual rent per unit land, t is the annual commuting cost per unit distance. A number of assumptions about the city are made here in order to simplify the mathematics. First, annual commuting cost, tz, only depends on distance from the city center, and not on distance from z*, the edge of the area dominated by firms. Second, the price of the composite commodity, x, does not vary with z; indeed it is constant across cities. Implicitly x is assumed to be easily transportable across cities. Third, there is one worker per household, so the labor supply is equal to the number of households. Fourth, durable capital inputs are ignored in order to produce a framework in which comparative static analysis is fully justified. Finally, all urban land used for housing is divided into plots of uniform size, q*, which are then rented by consumers and used to produce housing services. The annual rental payment, r, may be turned into an equivalent purchase price simply by capitalizing the expected future rental payments by the appropriate discount factor. These assumptions are not necessary, but they produce great simplifications in the mathematics.

In addition to these permanent assumptions, it is convenient to make the temporary assumption that the point in the city most threatened by a natural disaster is at the center, C, or $z\# = 0$. All measures of distance from $z\#$ can be made in terms of z.

It is now possible to model the residential portion of the city and to trace implications for the size of the urban labor force. Households move to the city which yields the highest levels of utility. Thus, in equilibrium, all cities must yield a common level of utility which will be set equal to u^*. If any city has a higher (lower) level of utility, workers will migrate to (from) that city until wages in the city fall (rise) so that utility in the city returns to u^*. Note that it is not possible for all, or even a majority, of the urban population to consider inter-city migration for this equalization of utility to occur. A modest percentage of workers, moving among cities and sensitive to small differences in the living standard achieved in alternate locations, is sufficient to generate equilibrium. The fact that gross migration flows among U.S. cities are so large compared to net flows indicates that U.S. cities are close to such an equilibrium in which utilities are equated to a common u^*. The consequence of this assumption for any particular city is that:

(3) $$u^* = U(x,q^*,L)$$

Of course, utility of households within the city must be equal at all locations or workers would migrate within the city. Thus households in the city all maximize utility at a given value u^*, and what really varies within the city is the number of households that can arrive before the utility is driven below u^* by falling wages. Put another way, the attraction of a city depends on the wages paid, y, and the living cost as embodied in the land rent, r. Rents charged by landlords are equal to the largest values which consumers earning the urban wage can pay and still achieve the standard utility level, u. From the budget constraint (3), it is possible to express the rent-paying ability of households as:

(4) $$r(z) = [y - px - tz]/q^*$$

The land market functions so that landlords can get the maximum possible r from workers subject only to the constraint that the workers must achieve the standard level of utility u*, or:

(5) $$r(z) = \text{MAX}\ \{\ [y - px - tz]/q^* + V[u^* - U(x,q^*,L)]\ \}$$

where V is an undetermined multiplier. Using equation (5), it is possible to derive expressions for the bid rent curve r(z) which indicates the maximum rent which will be collected by landlords from consumers provided the urban wage is y.

The basic form of the bid rent function, r(z), is easily determined. Differentiating (5) with respect to z gives an expression for the slope of this function across the city:

(6) $$r_Z = -t/q^* - V\ U_L\ L_Z = -t/q^* - V\ U_Z$$

It can be shown that V<0 and by arguments made above $U_Z>0$ if z# = 0 so that the second term of equation (6) is positive while the first term is negative. It may appear that the sign of r_Z is indeterminate, but we know that if the city is to have a limit, eventually the urban land rent must fall to the agricultural reservation price at r(z′). Thus, while r_Z may be positive for small z, it must become negative as the household bid rent curve slopes down toward the edge of the city at z′. This will be called Result 1.

The effects of other variables which shift r(z) may be determined by similar method. Differentiating (5) with respect to y gives:

(7) $$r_y = y/q^* > 0$$

Thus, increasing the urban wage raises the bid rent curve of households. This will be termed Result 2.

Increasing the expected frequency of disasters, f, shifts the bid rent curve down as can be seen by differentiating (5) with respect to f:

(8) $$r_f = -V\ U_L\ L_f = -V\ U_f < 0$$

Again noting that $V<0$, it follows that $r_f<0$, and raising the expected frequency of natural disasters shifts the bid rent curve down, an effect that will be termed Result 3.

Finally, decreasing the distance to the disaster by raising z# also lowers the bid rent curve as can be shown by similar method.

Taken together, these results allow us to write the bid rent curve of workers as r(z;y,z#,f) where $r_y>0$ and $r_{z\#}<0$, $r_f<0$, and $r_z<0$ throughout most, if not all, of the city. In addition, we know that total labor supply to the city is equal to the number of households (one worker per household) so that $L_s = (z'-z^*)/q^*$. But it also follows that $dz'/dr>0$ and $dz^*/dr<0$ because the area occupied by households expands in both directions as rents bid by households rise. Hence anything that raises r, also raises L_s and, conversely, what lowers r will lower L_s. Using Results 2 and 3, this immediately implies Result 4 for labor supply to the city, which can be written as:

(9) $$L_s = L_S(y,z\#,f)$$

where $L_y>0$, $L_f<0$ and $L_{z\#}<0$. The intuition behind such results is quite simple. Labor supply increases with the wage, i.e., the labor supply curve to the city has a positive slope, and labor supply decreases as the expected frequency or proximity of disasters increases.

Next we turn to firm location on the interval from C to z*. All firms produce a single output, W, according to an identical production function:

(10) $$W = F(L,Q)$$

where L is the number of workers employed annually, Q is the land input, and W is units of output per year. Assume $F_L>0$, $F_{LL}<0$, $F_Q>0$, and $F_{QQ}<0$ as is usual. Assume that natural disasters affect the firm by interrupting the flow of output for a period of time and that the extent of this effect is reduced as distance from the disaster site to the firm increases. Then the firm will have a disaster interruption function of the form $I(|z-z\#|,f)$ which is similar to the household loss function in that $I_{|z-z\#|}<0$ and $I_f>0$. Here we consider temporarily the special case of $z\#=0$. The expected amount of output produced by a firm with expected disaster interruption losses of $I(|z-z\#|,f)$ will be $F(L,Q)[1-I(|z-z\#|,f)]$.

If firms sell the output in a central marketing point at C for a price equal to w, pay annual land rent of R(z), and incur transportation costs of Tz (where z is the location of the firm and T is a transportation rate per mile on output), then annual firm profit at z, P(z), may be written as:

(11) $$P(z) = (w-Tz)\ W\ [1-I(|z-z\#|,f)]\ -yL\ -R(z)Q$$
$$= (w-Tz)\ F(L,Q)[1-I(|z-z\#|,f)]\ -yL\ -RQ$$

From (11) it is possible to develop usual results. For example, first order conditions for a maximum of P(z) imply that:

(12) $$P_L = (w-Tz)F_L[1-I(|z-z\#|,f)]-y = 0$$

or that the annual wage of labor, y, equals the expected value of its marginal revenue product net of transportation cost and expected damage, $(w-Tz)F_L[1-I(|z-z^*|,f)]$.

Assuming, for notational convenience, that each firm uses Q* of land in its production process, and that firms operate in a perfectly competitive market so that P(z)=0 everywhere within the city and also in other cities, then maximum rent which landlords can induce firms to pay for land may be written as:

(13) $$R(z) = (w-Tz)\ \{F(L,Q^*)[1-I(|z-z\#|,f)]/Q^*\}\ -\ y(L/Q^*)$$

Taken together, conditions (11) and (12) imply that one can write for the firm a bid rent function of the following form:

$$R = R(z;\ y,\ f,\ |z-z\#|) \tag{14}$$

where $R_y<0$, $R_f<0$, $R_{|z-z\#|}>0$ and R_z is generally <0. This may be termed Result 5. It is justified by differentiation of equation (13). For example, $R_y = -L/Q^*<0$, or $R_f = -(w-Tz)F(L,Q^*)I_f/Q^*<0$ given that $I_f>0$. The slope of the bid rent curve is given by: $R_z = -\{T[1-I]+(w-Tz)I_z\}F(L,Q^*)/Q^*$. Given that $I_z<0$, R_z may be positive particularly near C where I_z could be numerically large. But as z rises, I_z should become less significant and R_z will have a negative slope.

Similarly there is a labor demand by firms located at z which may be written in general form as $L = L(z;y,T,|z-z\#|,f)$ with $L_y<0$, $L_T<0$, $L_{|z-z\#|}>0$, and $L_f<0$. This will be termed Result 7, and it follows from total differentiation of equations (12) and (13). For example, the differentiation produces: $L_y = 1/\{F_{LL}(w-Tz)[1-I(|z-z\#|,f)]\}$. This is the usual result that labor demand varies inversely with the wage rate.

The total labor demanded by all firms in the city is given by:

$$L_D = (1/Q^*) \int_0^{z^*} L(z;y,T,|z-z\#|,f)\ dz = L_D(y;T,f) \tag{15}$$

It follows easily that aggregate labor demand in the city, L_D also varies inversely with the wage, y. Similarly, it is easy to show that for aggregate labor demand that $L_T<0$, $L_f<0$. Now it is possible to combine the demand for and supply of labor to examine the factors that influence labor market equilibrium. Recall that equation (9) gave labor supply as $L_S = L_S(y;z\#,f)$ with $L_y>0$, $L_{z\#}<0$ and $L_f<0$ while labor demand is given by equation (15). Consider what happens if y rises. Labor demand falls and supply rises, tending to create excess supply.

Now consider an increase in f. Labor demand and supply both decrease in that, at a given wage, less labor is desired by firms and less is supplied by workers. Hence employment in the city should fall. This may result in an increase, decrease, or constant level of wages, but this is a very important result. It demonstrates that wage-based tests for the effects of a change in the expected frequency in natural disasters on a local economy are not appropriate. Changes in f, which may have important employment effects do not have corresponding wage effects. Indeed, an increase in f, which has unusually large labor supply effects, could even raise wages. Clearly, theory is demonstrating how tricky it may be to test for the local economic effects of natural disasters.

One answer to the problems posed by a wage-based index of the effects of changes in expectations of natural disasters might be to use the employment effects which are unambiguous and negative. There are two problems with such a measure--one raised by the theory and the other a measurement problem. First, the theoretical analysis does not relate the fall in employment to a welfare loss. The fall in employment is accomplished by migration of workers to other cities where they still receive the u* level of utility and firms continue to earn zero economic profits in the city as well as in other areas. Thus the fall in employment is not obviously related to any loss in social welfare of workers or firm owners. Second, there are practical measurement problems in dealing with total employment changes. Both the choice of employment by place of residence versus place of work and the lack of precise time series data on urban employment create problems. In addition, labor is heterogenous, and workers may be employed for more or less than 40 hours per week. These and other measurement problems have significantly limited the use of employment data in empirical tests of the effects of various phenomena on urban economic development.

Fortunately, the model developed here is based on the simultaneous equilibrium of the urban land and labor markets, and hence the land market provides a second opportunity for measuring the local economic effects of natural disasters. Consider the increase in wages which was postulated to produce excess supply of labor in the earlier example; the situation in which wages arbitrarily rise above their equilibrium, or market-clearing level, is illustrated in Figures 2a and 2b. Land market equilibrium requires that the bid rent of firms equal that of households at z* or that $R(z^*;y,f,|z^*-z\#|)$ from equation (14) equal $r(z^*,y,f,|z^*-z\#|)$ analyzed in equations (7) and (8). Given that $R_y<0$ and $r_y>0$, a rise in y tends to shift the bid rents down for firms and up for households. This decreases z* as the radius of firms contracts and the residential area expands toward C and z′ grows also. Again, the effects of an increase in wages above their equilibrium level on the labor and land markets are illustrated in Figure 2. As wages rise from y_0 to y_1, the bid rent function of firms falls and that of households rises. Thus, the excess supply of labor is reflected in the land market by an increase in the ratio of residential to commercial land uses.

The effects of an increase in expected frequency of natural disasters in the land market may be analyzed by similar method. The labor market effects developed above include a decrease in both the supply of and demand for labor and an ambiguous change in the urban wage. Land market effects are based on prior results in which R_f and r_f were both shown to be negative. Thus both bid rent curves fall. It might be thought that this would simply maintain the urban area but reduce land rents. However, the agricultural reservation price, r(z′), is not reduced and the residential area will shrink as the household bid price falls. This is really the land market reflection of the fall in labor supply. There will be a corresponding fall in z* as the radius of firms shrinks. The final position of the bid rent curve as well as the labor market effects of the rise in f are illustrated in Figures 3a and 3b.

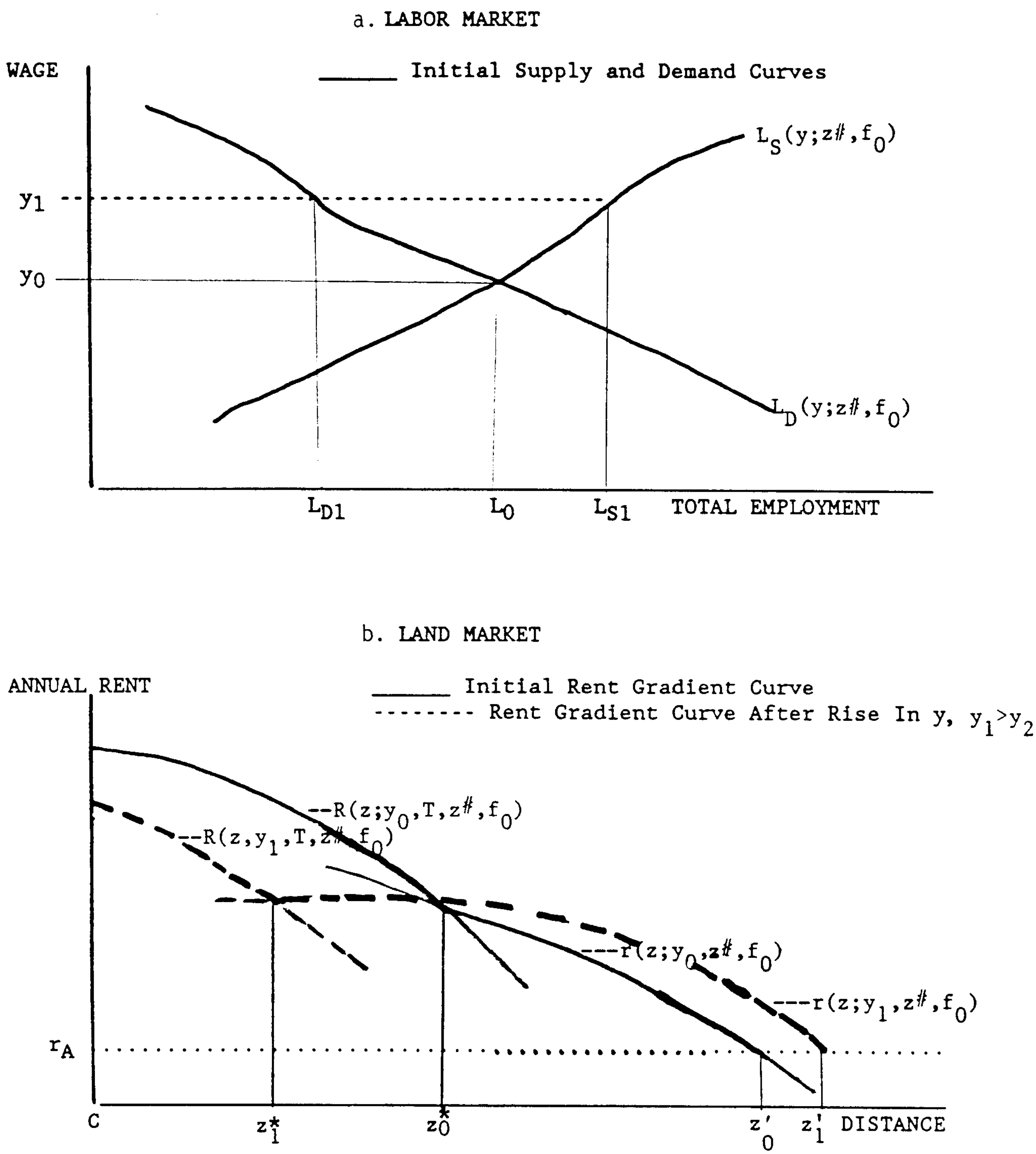

FIGURE 2

RESPONSE OF LABOR AND LAND MARKETS TO EXOGENOUS RISE IN THE URBAN WAGE

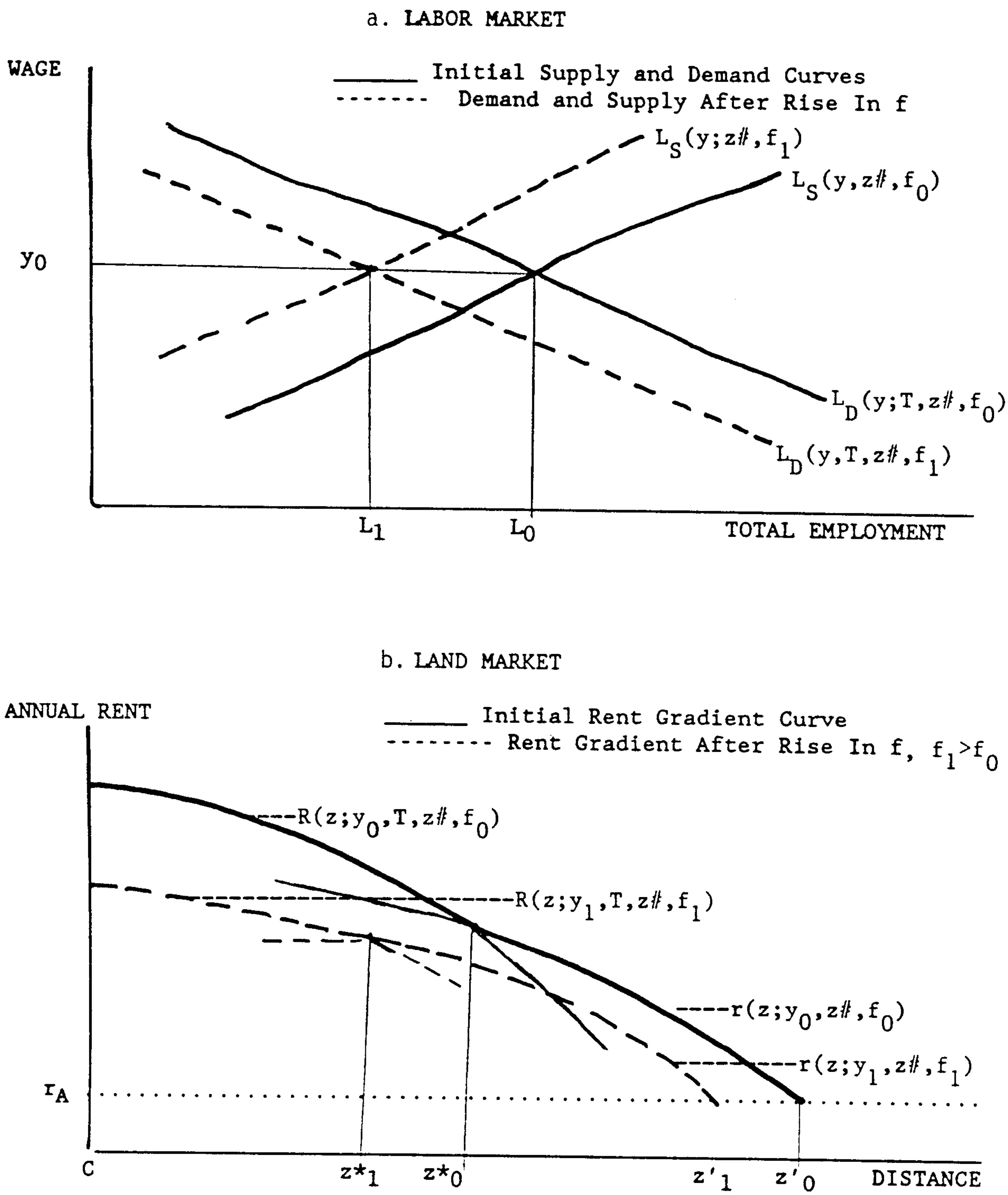

FIGURE 3

REPONSE OF LABOR AND LAND MARKETS TO A RISE IN EXPECTED DISASTER RATE, f

Theory suggests that land markets react dramatically to the change in f. The negative effect on total land values as well as rents at each radius, r(z), within the urbanized area is unambiguous. This is the inter-city effect in which resources migrate out of the city and the average intensity of economic activity falls. Figure 3 illustrates why the inter-city effect is also referred to as a "level effect"; the general level of the urban rent gradient falls.

The land market also provides a social welfare interpretation of the economic effects of the rise in f. While outmigration of labor does not lower its utility, and movement of firms does not change economics profits, the rental payments to landlords are substantially lowered by the rise in f. But this is a direct reflection of the loss in social welfare from the increased risk of natural disaster. Rental payments are a reflection of social surplus generated by the city after labor has been paid sufficiently to reach world utility levels and firms have earned normal profits. The reduction in area under the urban rent gradient due to level can be used as a direct measure of the fall in social welfare due to the increased expectation of natural disasters.

As Figure 3 illustrates, the level effect is not expected to be uniform across the city because the effects of the increase in f are attenuated as $|z-z\#|$ increases. It is possible to imagine situations in which this non-uniformity would be more extreme. If the disaster only affected business, then the land and labor market reactions would be different because neither labor supply nor household bid rent curves would shift. Thus the fall in labor demand would initially lower wages and the fall in firm bid rent curves would lower the rent gradient near the city center and reduce z^*. In response to the fall in wages, the household bid rent curve falls, reducing the size of the city as z' falls, lessening the reduction in z*, and distributing the fall in the level of the rent gradient throughout the city.

Figure 4 illustrates the shift in the labor and land markets due to the rise in f from f_0 to f_1 when households are unaffected by disasters. An important result is illustrated by this case. Although the natural disasters can only damage firms, the land market responds with a level effect that extends throughout the city. Thus, testing for changes in the level of residential land rents can detect local economic effects of natural disasters even when the damage is confined to the commercial sections of the city. The converse results could also be proved for disaster effects which only affect households.

Each case, in which inter-city effects were generated by an increase in f, also evidenced a measure of intra-city tilt in the land rent gradient. The tilt occurs because the effects of a rise in f for disasters expected to occur at z# are understandably concentrated there and attenuated significantly as distance from z# increases.

The theoretical analysis presented here indicates that changes in the expected frequency of natural disasters can affect local economic activity in ways that are reflected in the land market. Indeed, these rental effects could provide a measure of the welfare losses or gains from changes in f, the expected frequency of disasters. The empirical challenge is to provide measures that can monitor the level effect and relate it to changes in the expectation of problems from disasters.

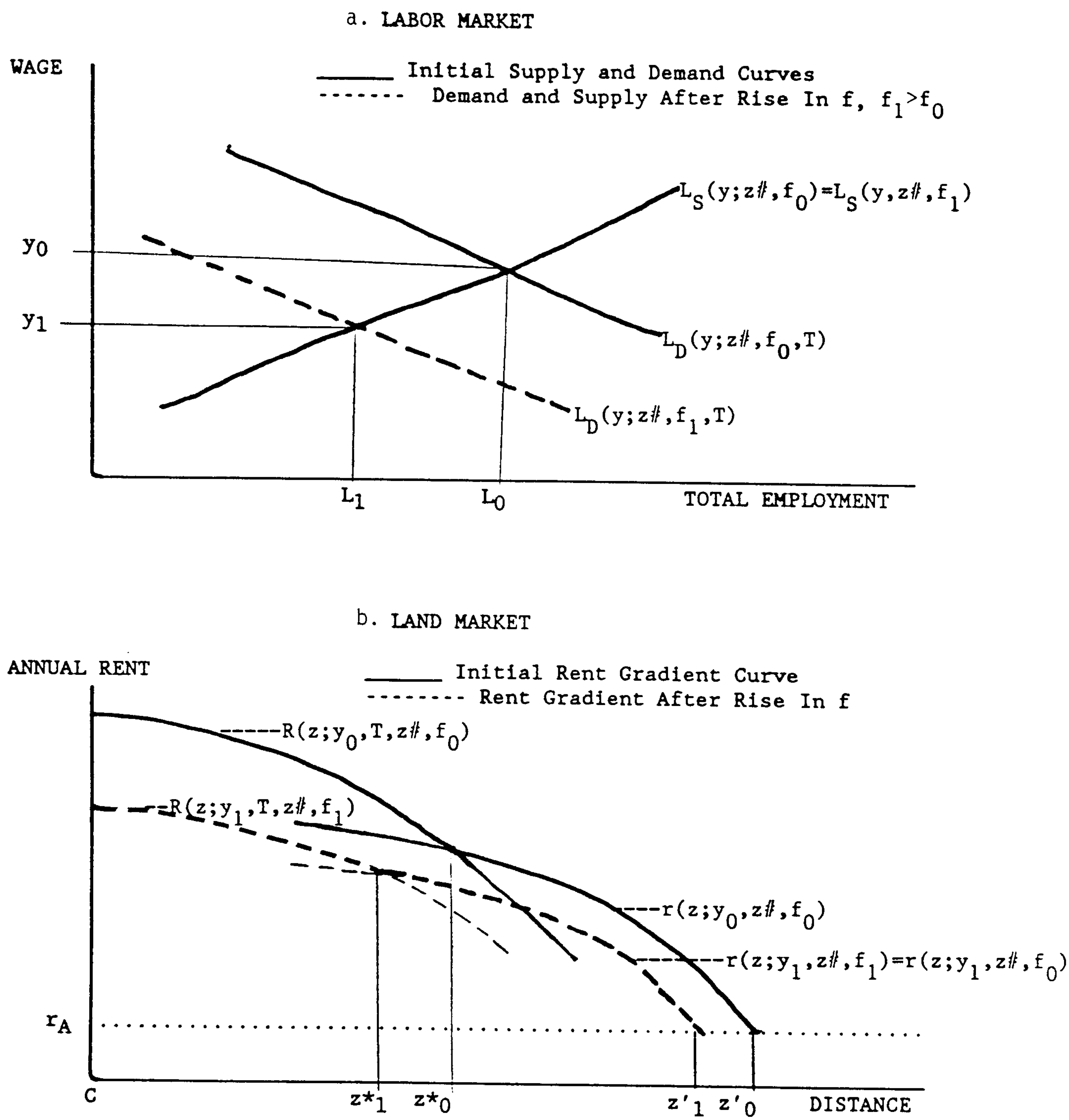

FIGURE 4

RESPONSE OF LABOR AND LAND MARKETS TO A RISE IN EXPECTED DISASTER RATE, f, WHEN DISASTERS AFFECT FIRMS BUT DO NOT DIRECTLY AFFECT HOUSEHOLDS

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:

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

where Ai and Ri are asset and rental prices of unit i and the c1i . . . 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 $F(T) = 1\text{-}e^{-fT}$. 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) $$G(f|a,b) = [e^{-fb}(fb)^{(a-1)}\ b]/[a-1]!$$

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 multi-variate 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:

(19) $$h = H(L,N)$$

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:

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

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**	0.305**
	(5.88)	(5.45)
ROOMS	-0.00057	-0.0088*
	(-1.37)	(-2.06)
BATHS	0.0010	-0.0073
	(0.11)	(-0.80)
AGE	0.0033	0.00054*
	(1.25)	(1.94)
FLAWS	-0.321**	-0.287**
	(-4.71)	(-4.16)
CHANGFLAW	-0.339**	-0.337**
	(-7.88)	(-7.84)
GARAGE	0.186*	0.0034
	(2.00)	(0.32)
HEAT	-0.206	-0.020
	(-1.56)	(-1.53)
BASEMENT	0.012	0.0043
	(1.10)	(0.40)
ERENTVALU		-21.58**
		(-3.10)
ERENT	0.0005*	0.00079**
	(4.37)	(5.35)
EVALUE	-0.0000023**	-0.0000035**
	(5.85)	(-6.38)
PASTD	0.565**	0.598**
	(2.42)	(2.56)
$PASTD^2$	-1.237**	-1.354**
	(-2.48)	(-2.71)
CHANGD	-0.0796*	-0.0896*
	(2.188)	(-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** (6.20)	0.110** (3.63)
ROOMS	0.00061 (0.266)	-0.00012 (-0.051)
BATHS	-0.00093 (-0.195)	-0.0028 (-0.54)
AGE	0.00017 (1.18)	0.00022 (1.46)
FLAWS	-0.0329 (-0.649)	-0.0272 (-0.53)
CHANGFLAW	-0.148** (-3.30)	-0.146** (-3.29)
GARAGE	0.00040 (0.079)	-0.0022 (-0.38)
HEAT	-0.0113 (-1.51)	-0.012 (-1.59)
BASEMENT	-0.0040 (-0.726)	-0.0048 (-0.83)
ERENTVALU		-3.523 (-0.96)
ERENT	-0.00014* (-2.217)	-0.00008 (-1.03)
EVALUE	0.000000048** (2.36)	0.000000029 (1.05)
PASTD	0.154* (2.05)	0.177* (2.12)
$PASTD^2$	-0.195* (-1.99)	-0.214 (-1.60)
DISTD	-0.0289** (-2.75)	-0.0359** (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.

SUMMARY AND CONCLUSIONS

This study makes a number of contributions to the current understanding of local economic effects of natural disasters: original data assembly, development of new theory, new tests of the way disasters affect a local economy, and evaluation of public policy implications. For many readers, the arguments made here will appear to be a significant break with understanding based on previous literature. Therefore, in this section we consider carefully how the current research differs from previous literature which has often focused on direct damage measures rather than on indirect effects on the local economy generally. Finally, we draw from these results some of the many implications for public policy and decision making.

In this study, local economic effects are evaluated net of the current structure of government disaster aid. Public disaster assistance programs, which address the direct effects or physical damage done by a disaster, act to attenuate the market reaction to changed disaster expectations. Such compensation for direct effects, if sufficiently generous, could produce net economic reactions which are small or totally insignificant even when the gross economic effects are large. Thus the effect of compensation programs is to attenuate both direct and indirect local economic effects of disasters and make detection of local effects more difficult.

The results of this study are different from other studies in that the tests performed here indicate that the main body of economic theory can be applied by treating disasters as negative natural resources whose effects can be analyzed using an expectations hypothesis. This is a major difference, because the economic theory of natural resources has a rich variety of implications for the local economic effects of disasters. Some of these implications are developed in this section, with particular attention given to estimation of the potential economic effects of changes in the expected rate of natural disasters, which can be extremely large in real dollars, and to the estimation of returns from hazard mitigation.

Original Data Assembly

To determine the local economic effects of natural disasters, it was first necessary to estimate the expected probability of disaster occurrence in particular locations. We used an expectations model in which past frequency of disasters was noted to estimate expectations of future disaster rates. It was necessary to construct such estimates for a significant number of areas so that significant variation in disaster expectations and subsequent outcomes could be observed. Because no adequate time series on disaster experiences for a large cross-section of areas were available, we developed the needed data series for this project.

We constructed time series data on the disaster experience of individual counties for 1965-1985 from information supplied by the Federal Emergency Management Agency on presidential disaster declarations. Then, the counties were combined to form Standard Metropolitan Statistical Areas (SMSAs) for which data on local economic effects were available. The expected rate of natural disasters was based on the frequency with which presidential disaster declarations had occurred in an area during the 15 years between 1965 and 1980.*

Clearly, the use of presidential disaster declarations may result in an understatement of the rate at which disasters occur in some areas. There is some evidence that the declarations are not based on a consistent set of

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*For a detailed discussion of the data, see the report, Summary of Major Disaster Incidents in the U.S. (1965-85), by Rubin, Yezer, Hussain, and Webb (1986).

standards for degree of damage or threat posed. Nevertheless, the information about large disasters available because of federal record keeping regarding declared disasters is better than any alternative. Concentrating the analysis on cities means that significant hazard events occurring in an area are likely to cause sufficient damage, due to the density of economic activity in cities, to warrant a disaster declaration. If rural areas had been analyzed, the chance that a significant disaster event could occur without causing sufficient damage to warrant a disaster declaration would be significant. Again, however, in cities disaster events cause large enough losses to make declaration a virtual certainty.

Development of New Theory

This research effort centered on the development and testing of a theoretical model that treats natural disasters as a negative natural resource whose effects on the local economy are uncertain because firms and households do not know when a disaster will occur. The indirect effects of disaster experiences arise because of the connection between past events and future expectations. Firms and households do recognize that disaster events follow a probability distribution and have expectations about this distribution, based on past rates of disaster events. This gives rise to an expectations model of indirect economic effects in which local economic activity is altered when a change in the rate of occurrence of disasters modifies expectations for the future. A number of other researchers, including Brown (1972), Brookshire et al. (1985), and Ellson et al. (1984) also have analyzed economic effects of disaster events through an examination of the effects of disasters (or of disaster predictions) on expectations. Thus the expectations hypothesis has been applied to the analysis of disasters in a number of alternative contexts.*

The most important result of the application of an expectations model to indirect economic effects of disasters is the conclusion that the unanticipated component of disaster experience leads to economic change, while the anticipated component of disaster experience does not result in indirect economic effects. Thus, if an area is expected to have a flood every three years and there is one flood during the next three years, then the actual disaster rate is equal to the expected rate, and there should be no change in disaster expectations or in the local economy. If, however, there were no disaster events during the three-year period, then actual disasters would be below expectations. In other words, there would be -1 unanticipated disasters during the period. To the extent that disaster expectations were lowered during this period, economic activity would be stimulated in the area. Conversely, two disaster events in three years produces +1 unanticipated disasters which will raise expectations and tend to depress economic activity.

The expectations hypothesis also implies that the indirect local economic effects of a given disaster rate depend on the previous disaster rate and the expectations associated with that experience. One flood during three years may increase disaster expectations in an area where floods seldom occur and lower expectations in areas that ordinarily flood every year. In the former area, the single flood in three years would depress economic activity because it was unanticipated, while in the latter, a single flood event in three years would provide an economic stimulus, there being -2 unanticipated floods in the area. In order to know whether recent disaster rates have had a positive or

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*Expectations models have been used by economists to analyze problems other than disasters. The most common applications have been to examine effects of expectations on asset prices of financial instruments. Indeed, the Securities and Exchange Commission uses changes in securities prices to detect changes in expectations which may indicate the presence of insider trading.

negative effect on a local economy, one must determine the expectations for that area based on past experience.

In order to construct estimates of prior disaster expectations and to observe subsequent disaster experience so that anticipated and unanticipated components of actual disaster experience can be distinguished, we developed time series data on natural disaster experience of metropolitan areas for events that received a presidential disaster declaration. The 20-year histories of presidential declarations, disaggregated by disaster agent and county for this research, are a substantial addition to data on disaster experience. Longer time series and information on disasters not receiving a declaration would be useful both to test the expectations hypothesis further and to aid policy formulation or administration. Future research on and policy applications of the expectations approach to disaster effects would be greatly aided by an expanded data set giving the disaster history of individual cities over longer periods of time.

A theoretical model of a local economy capable of demonstrating the manner in which expectations of disasters change observable economic phenomena was needed to formulate a test of the expectations hypothesis. This is a significant departure from other studies in which no normal model of the way in which the disaster rate experienced in one city might influence the development of that city vis-a-vis other cities in a region. The theoretical model is a simple general equilibrium model of a city with housing and firms occupying the land. This type of model has been used by economists to analyze various urban development issues, and it was specially modified to relate disaster expectations to the local economy. Natural disasters affect the local economy by damaging output of firms and lowering welfare of workers who experience both damage to their homes and losses through personal injury.

The local economy model relates changes in disaster expectations to a variety of local economic variables including output, population, wages, profits, land area, land values, numbers and value of housing units, etc. This information on indirect economic effects of changes in disaster expectations on various variables was used to select variables to be used in the empirical test of disaster effects. The ideal test variable should move in an unambiguous fashion when disaster expectations change, or when the actual disaster rate differs from the expected rate producing an unanticipated component of the disaster rate. Finding such an ideal test variable was not easy because the local economy model demonstrated that many local economic indicator variables did not change in an unambiguous fashion when disasters changed. For example, a rise in disaster expectations can certainly change local wages, but the change can be either positive or negative. Similarly, the effects on the total amount of housing or population are not clear. Even where effects of changes in disaster expectations are unambiguously positive or negative, it is desirable that the changes have further economic significance. The local economy model suggested that land values and house prices were the most promising test variables.

As an indicator of disaster effects, land values have the special advantage of measuring the change in economic welfare associated with the change in natural disaster rate expectations. Thus, the change in land values can be used as a measure of the welfare effects of disaster mitigation efforts, insofar as such efforts succeed in lowering expected disaster rates.

The theoretical model was used principally to identify a particular test for local effects of natural disasters. Nevertheless, the model is quite rich and capable of elaboration by adding capital stock and investment considerations. Given the success of empirical tests in verifying conclusions of the model, some elaboration should be seriously considered by researchers in the future.

Statistical Tests of the Expectations Model

The theoretical land market effects are formulated in a specific statistical test by using hedonic housing price techniques which rely on the translation of land values into asset values of housing. Thus movements in land values result in corresponding movements in asset prices of housing. A final theoretical issue concerned the exact manner in which current disaster experience changes disaster expectation. A model of the relation between recent experience and expectations based on past disaster rates was developed and used as the basis for estimating the unanticipated component of disaster experience. The occurrence, or non-occurrence, of a disaster in a given year will raise or lower previous disaster expectations as the public updates its expectation of disaster probabilities. Current disasters have a local economic effect through the changes they cause in the expected future disaster rate. Thus, it is not the direct measure of damage done but an indirect measure of the effects of that damage on expectations for future economic productivity of the city which should be used to measure local economic effects. For example, over a given time interval a city may experience direct damage from flooding measured in terms of replacement or repair cost of property damaged, but if the flood damage is below prior expectations, the indirect effect will be positive. Conversely, another city with less direct flood damage could have a large negative indirect effect if prior expectations for the possibility of flooding had been very low. In sum, direct property damage during a given time interval is a poor indicator of the indirect local economic effects of disasters.

Statistical tests of the relation between rates of appreciation in the asset price of housing and disaster rates found the expected negative effect of the difference between the recent disaster rate and past rates on appreciation rates. This is consistent with the expectations hypothesis that recent disasters affect local economic activity to the extent that they diverge from expected rates based on past disaster experience. The empirical results also indicate that the rate of disasters is already incorporated into economic decision making so that, if recent disaster rates are the same as past rates, there is little or no local economic effect. Indeed, simple tests of the relation between asset prices of housing and the past rate of disasters actually indicate positive effects. Again, this result indirectly confirms the need to formulate economic effects in terms of an expectations process in order to obtain sensible and valid estimates of the change in a local economy due to its disaster experience during a given period.

The test for local economic effects of natural disasters includes the influence of aid from the local, state, and national governments. Such aid was forthcoming for the disasters included in our data set because these were all situations receiving a presidential disaster declaration and hence national assistance. If disaster relief efforts provided full compensation for damage, or led to the expectation that future disasters would be fully compensated, then disasters would have no local economic effect whether they were anticipated or unanticipated. The calculations of total economic effects of changed disaster reactions performed in the next section will indicate why negative net effects of unanticipated disasters were observed. Basically, the local economic effects occurring in areas that have a significant component of unanticipated disaster experience are of sufficient magnitude to dwarf available governmental and insurance compensation which is directed mainly at dealing with direct effects.

Policy Implications of the Research Results

The empirical results are consistent with the implications of the expectations hypothesis and the urban economic model which were used to develop the tests. These tests also demonstrated that failure to separate anticipated and unanticipated disaster effects results in biased statistical estimates of economic effects. Thus, there is strong evidence that local economic effects of disasters can be understood within the framework of expectations models and neoclassical urban development theory. This theory can be used to produce a variety of implications for the role of natural hazards in regional economic development, some of which are noted here. Greatest attention is given to the calculation of overall economic effects of disasters net of compensation payments.

The theoretical model of local economic responses to natural disasters presented earlier has implications far beyond those that were tested empirically. They include positive economic results regarding the way in which development in an urban area may be altered by a particular natural hazard or by changes in the expectation that disasters will occur. In addition, the model can be used to develop normative economic results about the way in which disasters affect social welfare. Specifically, the change in social welfare, as measured by value of output lost and changed real compensation required by workers, is fully reflected in the change in land rents and house prices. This change in social welfare is appropriate for use as a measure of benefits in economic benefit/cost analysis and has been used as such in the other literature on economic effects of natural disasters reviewed earlier. The intuitive reason for measuring social welfare changes through land and housing market effects is that capital and labor are mobile and may move away from areas where disaster expectations increase. Indeed the rate of return to capital and the real wage of labor must be equated across regions. Only land prices vary in a fashion which reflects differences in disaster expectations.

Given the potential importance of measuring the decline in total land values within an urban area associated with an increase in disaster expectations caused by disaster experience during a given period, such calculations are reported here based on the empirical results previously presented. Great care in interpretation and use of these results is necessary. First, the results are net of current government disaster aid programs. Second, there is substantial uncertainty about the point estimates used to perform the calculations given the large standard errors accompanying the coefficient estimates in Tables 4 and 5. These limitations should be considered when referring to the estimates of net economic effect made below.

The effect of unanticipated disasters on asset prices of housing in a city can be estimated as follows. If disaster expectations had been 0 in 1979 and actual disaster experience during the subsequent period had included a single disaster episode, the disaster rate during the four-year observation period would have been 0.25 and hence CHANGD would be 0.25-0.00 = 0.25. Given that the estimated coefficient of CHANGD in Table 4 is approximately -0.08 or -8%, this implies that the percentage increase in the asset price of housing would be 0.25(-8%) = -2%, i.e., 2% lower due to the effect of the disaster on expectations. The average appreciation in asset prices of housing during the period was 36%. The effect of the disaster would be to reduce the expected appreciation to 34% at the mean of the sample.

While this point estimate of percentage effect may appear small, the total dollar effect is computed by attributing it to the entire land market. Consider only the residential component of that market. The mean asset price of housing in the sample was $64,000 in 1979. For a city with 250,000 housing units, the 2% fall in asset price implies a decline of over $300 million in the aggregate asset prices of housing units due to the effects of a single unanticipated disaster in a city where disaster expectations had been nil. A loss of 2% in housing asset price implies a fall of approximately 8% in the underlying land values. If this fall were extended to all values of developed land throughout the city, the economic effects would be far larger than the $300 million estimated above. However, it is difficult to acquire data on urban land values, and such extended estimates could perhaps be estimated best by applying the losses on residential land to all developed land in the city.

For a city in which disaster experience had been more frequent, so that prior disaster expectations were 0.50, observation of a single disaster event during the four-year period would actually produce negative values of CHANGD. Specifically CHANGD would equal 0.25-0.50 = -0.25, and the negative unanticipated disaster rate would result in a 2% increase in asset values. Finally, occurrence of exactly two disasters during the observation period in this city with expectations of 0.50 would result in CHANGD = 0.50 and not change the rate of housing asset price appreciation.

From a public policy viewpoint, the expectations approach to measuring local economic effects of disasters creates a number of problems and opportunities. For example, the calculations above illustrate that a single disaster event, occurring where prior disaster experience had been infrequent, will be largely unanticipated and hence can have substantial negative local economic effects. However, the same experience, in an area with a history of frequent disasters and many natural hazards, will be viewed by the market as a negative net unanticipated disaster, producing a fall in disaster expectations and a positive local economic effect. This is not to say that the area benefits from the disaster, but merely that, over the period in question, experiencing fewer actual disasters than expected will produce a positive local economic response.

The economic model provides a context for understanding economic effects, and implications for public action will depend on policy goals. If the major goal of policy is to provide compensation for unanticipated losses, the implication is that aid to areas with high disaster expectations should not be large unless recent disaster experience is unusually high. Thus, "safe" areas which experience a single unanticipated disaster should receive more compensation than high-risk areas which have more than one disaster, _if_ public policy relates compensation to local economic effect.

Undoubtedly, basing compensation on the local economic effects associated with an expectations approach is counterintuitive to many observers. The reason for this non-intuitive result is clear if one examines the theory put forward at the outset of this paper. Residents of areas where disaster expectations are high are compensated for differences in disaster probability by the higher real wages which they receive compared to individuals living and working in areas perceived as being free of natural hazards. Paying equal compensation for disasters without regard to the prior expectations in the area essentially provides double compensation for living in high disaster areas. Put another way, real wages are higher in Alaska than in the lower 48 states. This is compensation for the harsh Alaskan winter and the higher cost of living. To pay extra compensation to Alaskan residents every time there is a heavy snowfall or long period of sub-zero weather would be redundant, given the real wage differential already in force.

The expectations hypothesis presents an alternative approach to measuring the benefits of hazard mitigation. Theory suggests that these benefits are reflected in land values and that estimates of benefit can be constructed by determining what land prices would be after a mitigation effort is completed. Presumably estimates of the value of this change could be gained by observing changes in land values in other locations where mitigation efforts had successfully lowered disaster rates. Comparisons should be made between cases in which sufficient experience with the effects of mitigation had been accumulated so that expectations had actually changed.

The potential applications of the expectations hypothesis and urban development model to public policy issues regarding natural disasters go far beyond the thoughts developed here. Indeed, this approach suggests different ways of viewing natural hazard policy problems. There is an important interaction between the models which we use to understand the local economic effects of natural disasters and the public policy questions which we choose to ask. The project team involved in this research has tried to make a contribution to both the measurement of local economic effects of disasters and to the conceptual framework within which policy issues related to those effects are viewed.

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