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

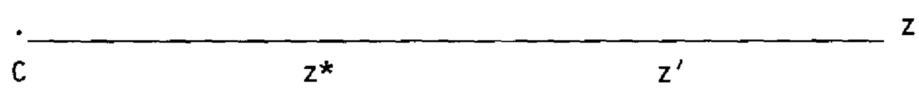

FIGURE 1

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:

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

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:

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

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:

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

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:

$$r_z = -t/q^* - V\, U_L\, L_z = -t/q^* - V\, U_z \tag{6}$$

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:

$$r_y = y/q^* > 0 \tag{7}$$

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:

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

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

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

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:

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

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

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

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:

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

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.

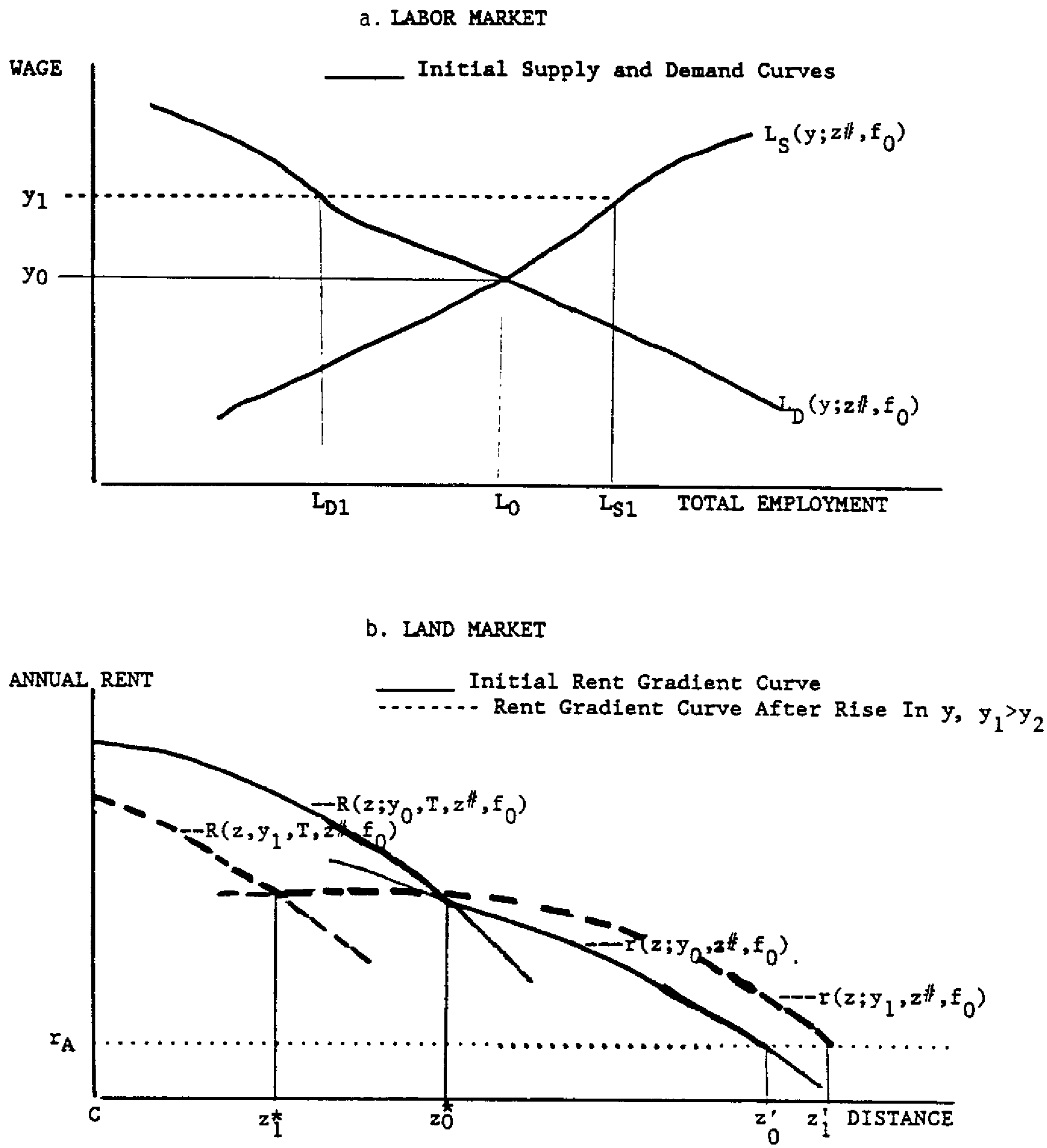

FIGURE 2

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

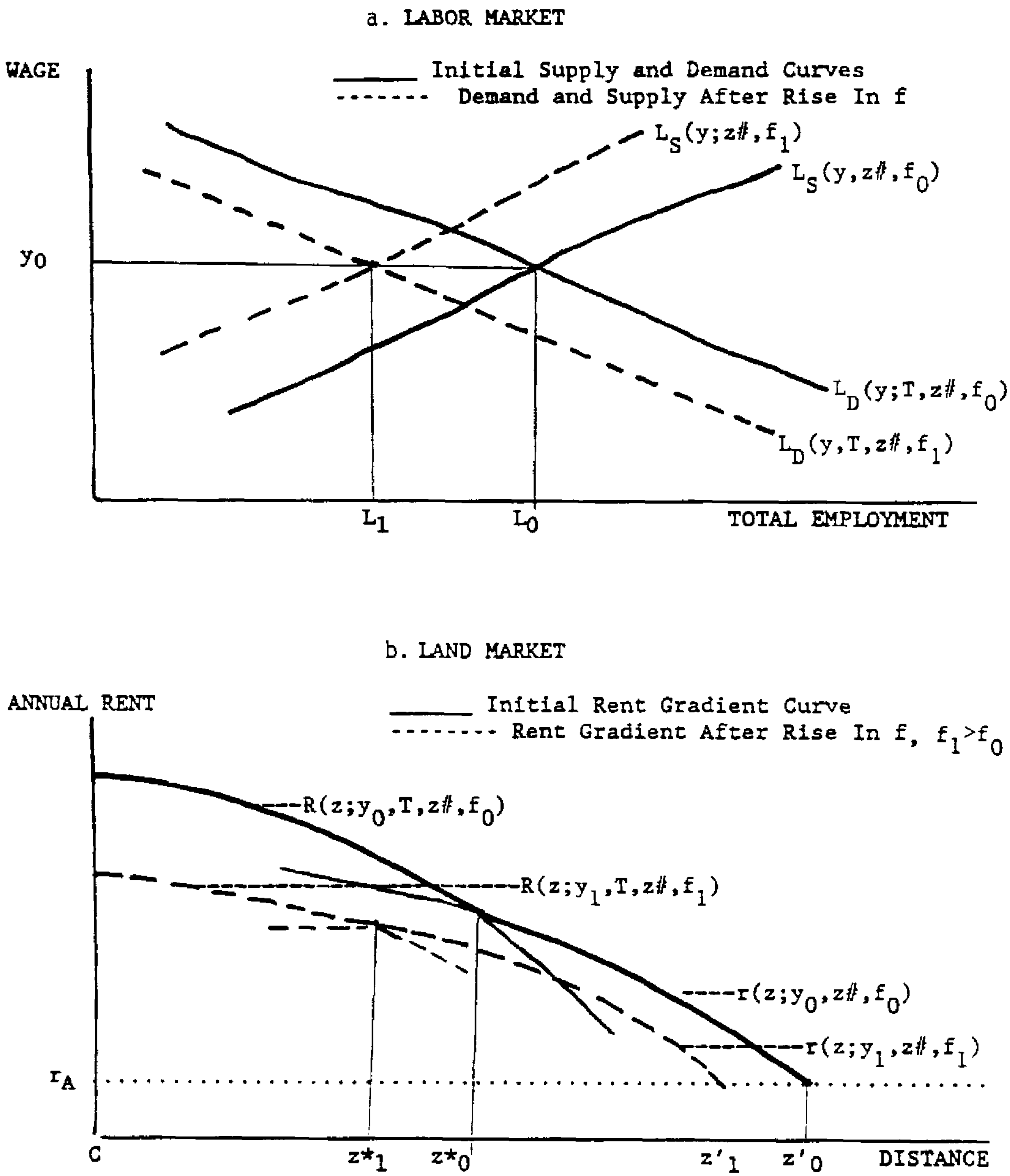

FIGURE 3

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.

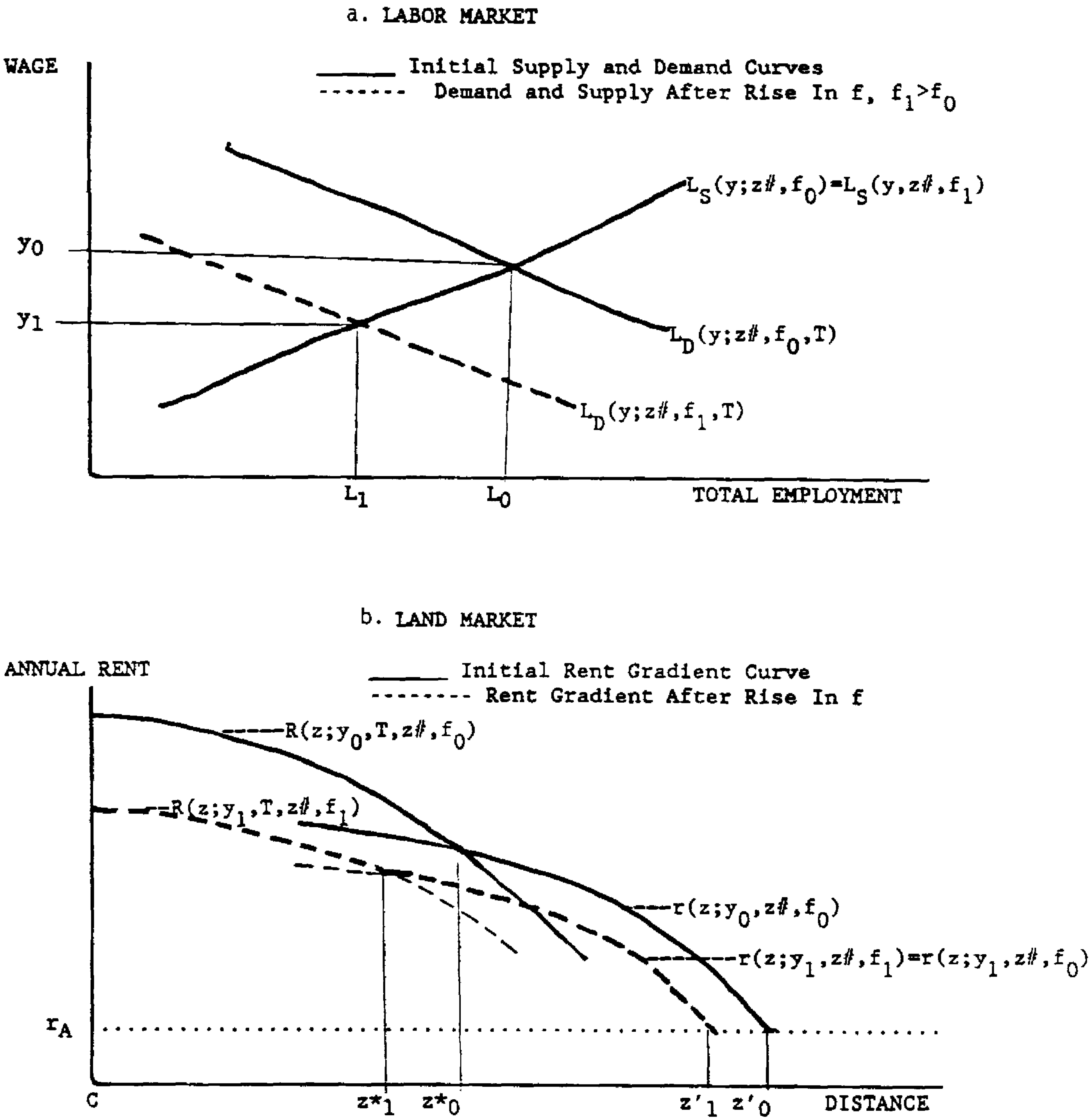

FIGURE 4

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