MODELING REGIONAL ECONOMIC IMPACTS OF EARTHQUAKES

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The Objective of the Paper

Existing earthquake economic damage estimates are based primarily upon property losses in the affected region. To structural damages are added damages to the contents of buildings, damages to public facilities, and sums are added for lives lost and injuries sustained. No estimates are made of direct and indirect regional income and employment losses. No attempt is made to estimate probable response patterns of the regional economy to the damage disruption and the expected path of economic recovery.

The purpose of this paper is to examine various types of regional economic models for their suitability of measuring economic impacts of earthquakes from a regional point of view. It also reports on a research project sponsored by the National Science Foundation[1] to develop an econometric model for the Charleston, South Carolina region to measure regional economic responses to earthquakes and to earthquake predictions. This model will link Process Analysis Models (PAM) with a regional econometric model which will make it possible to allow for substitution of inputs and outputs as well as the adoption of new technology in the recovery period. Traditional regional economic models are designed to deal primarily with changes in aggregate demand. In situations of catastrophic change where resource supply side constraints dominate, the problem is to model inadequate aggregate supply side aspects rather than the usual problems of changes in aggregate demand.

Until we have better procedures for estimating regional economic impacts and regional costs of adjustment for consumers, producers and government, we will be on uncertain ground in evaluating the benefits and costs of alternative ways to mitigate earthquake hazards. The performance of the regional economy is at the heart of the matter. How will the regional economy respond to earthquakes and to possible predictions?

Modeling Economic Consequences of an Earthquake

The economic consequences of an earthquake are primarily a function of the following variables:

1. the severity and duration of the earthquake;
2. the geology of the affected area;
3. the number and location of structures within the affected area;
4. the nature of the construction within the affected area;
5. the number and distribution of people within the affected area at the time the earthquake occurs;
6. the effectiveness of short run response in preventing secondary effects;
7. the nature and vulnerability of economic linkages; and
8. the speed and effectiveness of rehabilitation.

Furthermore, an earthquake will have distributional consequences which will be a function of the following:

1. the extent to which losses are insured;
2. the extent to which private philanthropy and government assistance become available following the earthquake; and
3. the extent to which the value of existing assets is altered as a result of changed market conditions.

The social losses as a result of an earthquake include the following:

1. deaths;
2. injuries;
3. psychological trauma;
4. social dislocation;
5. property damage; and
6. disruption of economic activity.

Only the last two classes of loss, property damage and disruption of economic activity readily lend themselves to quantification in monetary terms. Therefore, as a first approximation of the benefits of mitigation we will concentrate on these two types of loss, while recognizing that we may not be accounting for all losses averted by a warning.

At the same time, it has been pointed out [Milliman, 1975, p. 11] that caution must be taken to avoid double counting in measuring property damages and reduction of economic activity. The value of any asset is the present value of the future stream of services which that asset is expected to produce. If the asset is a "productive" asset, then its destruction could be counted as the loss of producers surplus which results from the loss of production, or as the loss of the value of the asset, but not both.

One of the central concerns of public officials is the fear that the earthquake prediction itself may cause economic disruption. It should be recognized that some economic relocation from areas at risk and some economic losses in the market value of properties at risk are to be expected. Policy makers should not be surprised at market discounting of expected future losses. Transfer of vulnerable activities to other areas may be a rational adjustment. By contrast investment in strengthening structures and other types of investment within the region could prove an economical way to reduce losses.

In a perfectly competitive market, each firm is independent of any other firm or household, and the loss of the production of any one firm would have no noticeable impact upon any other firm. In such a case, the loss of aggregate economic activity is exactly equal to the loss in value of the productive asset. For an urban economy, however, the analysis is complicated by the existence of many specialized and interdependent activities. The loss of output from one activity can affect the output of other activities.

Furthermore, the high degree of specialization implies that the value produced by a productive asset in its specialized use is considerably greater than the value produced in its best alternative use. In an urban setting, the disruption of certain activities is likely to force many resources into alternative uses, and the cost of doing so is likely to be very high. In such a case, the direct loss of value of assets is no longer a good measure of the total social costs incurred, and what is needed is some measure of the <u>total</u> reduction in economic activity.

To analyze these interdependencies in the face of an economic change, it will be necessary to develop a regional economic model. Such a model must be able to predict the level of economic activity in the event of an earthquake, both with and without warning.

This model must focus on the supply side constraints which are likely to arise in the event of a catastrophe, such as an earthquake. Much of the current regional modeling involves analysis based on the Keynesian model. The concern of these models is with the maintenance of an adequate level of aggregate demand and the assumption is that no supply side constraints are binding. In the event of a catastrophe, however, this is not likely to be the case. Supply constraints are likely to become paramount. Also, from recent experience in the United States, insurance payments, capital inflows, and private and public philanthropy will combine to assure a more than adequate level of aggregate demand. In the case of the Alaska Earthquake of 1964, Federal assistance and loans alone provided 115% of property damages [Dacy and Kunreuther, p. 88]. In the San Fernando earthquake of 1971, Federal loans and grants combined with insurance payments amounted to 102% of tangible damages [Munroe and Carew, Table 15].

It is true that even when the entire amount of losses in the region is offset in aggregate, there will be effects on the distribution of wealth as well as distributive effects on the structure of activities. The former will depend upon the nature of the reimbursement, e.g., the mix of insurance and government direct grant and subsidized loan payments, as has been demonstrated by Kunreuther [1968, 1974, 1973]. The latter will depend upon the spatial distribution of activities and of damages. Certain activities may be concentrated in high risk areas, such as landfill sites, or may tend to be situated in older, more vulnerable buildings. This problem of spatial distribution of damages can be treated in a rough aggregate manner. The problem of wealth distribution is less tractible because the structure of compensation is complex and not very predictible. As a first approximation in the prototype model, it will be necessary to assume that wealth redistribution will be neutral with respect to resource use decisions, and hence to the overall level of economic activity which is generated and the nature of the adjustments. At the same time it is recognized that, in addition to equity questions, redistribution of wealth can, in effect, alter the adjustment process because capital markets are not frictionless and individual preferences for investment and personal consumption expenditures will vary.

Regional Models and Supply-Side Constraints

Regional models which have attempted to incorporate supply side constraints currently fall into two categories: input-output analysis and econometric models. The input-output models specify a fixed coefficient production function based on current ratios of inputs and outputs in various sectors. Econometric regional models attempt to allow for substitution in the input and output ratios, basing their estimates of the elasticities of substitution upon historical data. However, these efforts are often incomplete because these models usually fail to model supply-side sectors explicity.

Both types of model suffer other deficiencies, which have been treated in the literature. One problem is that the observations upon which the models are based may be in disequilibria. Another problem is that the models cannot deal with new technology for which there are no observations. Perhaps the most serious problem current models suffer, at least in the present context, is their inability to deal with changes of great magnitude. These models are fairly effective in predicting in the face of small changes, because they are empirically based on past observations which generally involve small changes at the margin. Observations involving catastrophic change are rare, yet it is in precisely that type of situation that reliable prediction is most needed.

An example of an effort to apply current techniques in regional modeling to catastrophic change may be found in an attempt that was made to use input-output analysis in estimating losses from an earthquake [Cochrane, 1974]. The analysis is limited because it assumes that each industry will continue to produce the same output mix and will be constrained to the same input ratios as before the catastrophe. Changes in input constraints simply result in a commensurate reduction in output, with no possibility of input substitution. The recovery process is seen as the elimination of the input constraint, at which point the industry returns to its former level of activity, with its former product and input mix.

The imposition of the assumption that the economy is so inflexible results in a severe overstatement of the economic consequences of an earthquake in the region. Furthermore, the assumption of constant product mix probably leads to overestimation of the length of the recovery period. It is reasonable that a catastrophic event would change the level of demand for many outputs and that industries would respond to the changed demand by shifting its product mix to favor outputs which are useful in the recovery. Thus, the input-output analysis in the context of catastrophic change is unsatisfactory in the static analysis and even less satisfactory in dealing with the dynamic process of recovery and adjustment prior to events in case of prediction. To the best of our knowledge, no one has successfully developed models designed to deal with these problems of catastrophic change in the regional economy.

We propose to develop such a model for the Charleston, South Carolina area. This area has been selected for a number of reasons. It has a long history of seismic activity, including the earthquake of 1886 which took over 60 lives. It is located in the center of an area classified as Zone 3 (the highest category of earthquake risk), and was listed as one of the 13 high hazard areas in the Earthquake Hazards Reduction Act of 1977 PL 95-124, sec. 2(1) .

Charleston was felt to be an ideal and important area for study because of its history of seismic activity and high risk of being subject to another major earthquake, its similarity to other eastern, U.S. high risk areas which have not been studied, the vulnerability of the area to destruction and economic disruption, and its strategic national defense role.

The Proposed Modeling Framework

The methodology being developed is an extension of existing regional models in several respects and will concentrate upon catastrophic change from the outset. Careful attention is paid to modeling the spatial distribution of the following supply side aspects of the regional economy over time:

- demographic factors;
- financial and capital flows;
- housing and construction;
- transportation network (railroads, highways and bridges); and
- water, sewer, gas, and electrical systems.

The methodology will specify how these sectors are interrelated, both spatially and chronologically with the rest of the economic system and how they will be affected by the catastrophic event and by an accurate prediction of the event. The timing of these effects, both before and after the event, and the dynamic adjustment process of the economy are crucial and will be given careful consideration.

The following are illustrative examples of the types of spatial and chronological interrelations for a simulation of a catastrophic event with no prediction that will be incorporated into the regional model: (1) The housing stock will be specified spatially. Then a catastrophic event that severs the sewerage system to a particular area would become a constraint that would limit housing construction in that area until the sewer system was restored. (2) Location specific manufacturing may have railroads as a predisaster least cost shipping alternative. A catastrophic event could be assumed that cut both rail and truck routes initially, thus halting all output. Overtime, the truck routes may be restored prior to rail and thus allow some resumption of manufacturing activity before rail service is fully restored.

The major limitation of conventional regional models in the context of analyzing catastrophic changes is that they generally rely on historical observations. For events that cause major structural changes, this is clearly untenable. To solve this problem, the methodology will utilize the multiple equation summarization of process analysis models (MESPAM) technique for the areas where there are major structural changes.

The MESPAM approach involves the specification of alternative technologies for a particular economic and geographic sector that exists or that will exist in the future. Data on the input requirements and the outputs of these technologies are obtained from engineering studies, rather than historical observation. These technologies are collected into a process analysis model (PAM) and the optimal processes can be solved for, under various assumptions, by traditional linear programming techniques for situations under certainty or by various nonlinear programming techniques that allow the incorporation of uncertainty.

The difficulty with process analysis models is they are usually far too large and unwieldy to be incorporated in a regional economic model. This has led to the summarization of these models by continuous equations estimated on the basis of data generated by the models. The technique has recently been applied in several areas (see the papers by Griffin [1979] or Smith and Vaughan [1978]) and has many advantages as well as disadvantages (see the papers by Maddala and Roberts [1979] [1980]). However, for dealing with catastrophic changes, it would appear to solve some of the very difficult problems associated with conventional, historically based models.

The demand side equations can be modeled in a conventional manner using time series observations. The primary linkages in the model among the various sectors are illustrated in Figure 1.

The common practice would be to simulate the expected employment, wages, and capital invested which would in turn generate employment, income and government expenditure/tax base multipliers. Since regional models assume that sectors such as utilities and transportation are perfectly elastic in supply, the multipliers generated will be unbounded by any capacity constraints. Such a procedure is clearly inadequate for estimating the effects of an external shock such as an earthquake with and without the implementation of mitigation measures. Some infrastructure would be destroyed, and the recovery would be constrained on the basis of both capacity and the timing of reconstruction. Furthermore, the structure of the sectoral linkages within the model would also change.

Therefore, the proposed modeling framework will incorporate these supply considerations along with the recent extensions of traditional models. The model will be composed of six equation blocks: economic, demographic, finance-construction, government, resource, and transportation.

Estimation of the economic block will be based on the traditional economic base approach. External demands will drive local export industries, which in turn are linked to ancillary locally oriented sectors. Personal income will be affected by employment, wage rates, and nonlocal public and private transfers.

The economic block is in turn linked to population, finance and the government block in the traditional manner. Economic activity will

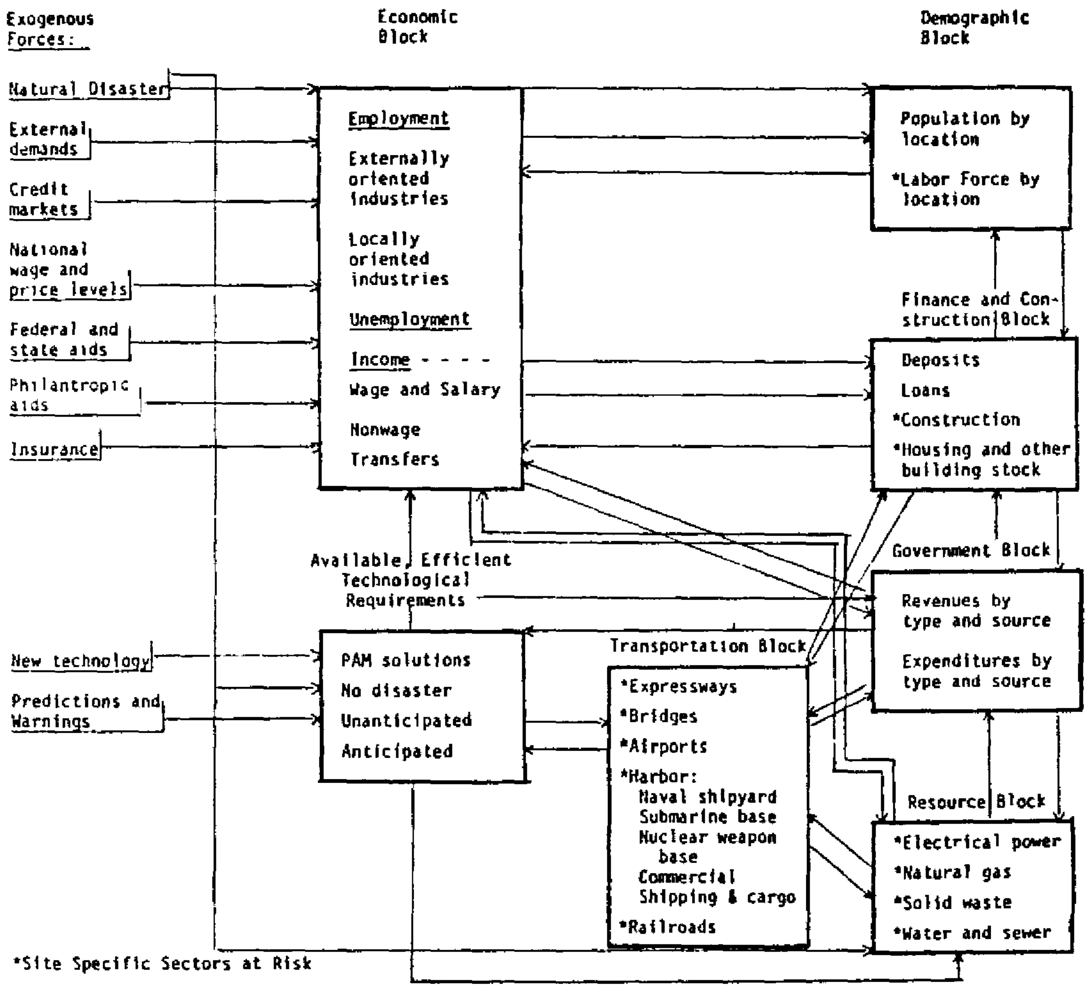

Figure 1

Basic Framework for Analysis of Economic Effects
of Catastrophies and Mitigation

determine savings flows and lending activity in conjunction with national credit markets. Government revenues and noncapital expenditures will also be estimated as part of the conventional component of the model.

The remaining blocks will be estimated using MESPAM techniques. These include transportation, resources, and housing. It is important to recognize that this methodology will provide information on spatial as well as the chronological characteristics of these sectors. Therefore, not only will supply side constraints be linked with the conventional sectors, but they will also be multidimensional.

Each process analysis model can be quite large by itself and even when there are only a few processes, these models are difficult to incorporate into a regional economic simulation model. One solution is to summarize these models by continuous equations. Then the continuous equations can be used in the regional model and the simulation process is much easier.

As an example, consider a manufacturing process that ships by rail. The level of economic activity will depend on costs of production and shipping as well as other factors. Historical observation will not identify the substitution of truck or other transportation for rail under conditions of extreme price changes as rail has always been the least cost alternative. In a process analysis model (PAM), one may specify the alternative processes (transportation systems) available using technological data. Then a wide variety of input and output prices are generated and the PAM solved several times to create PAM data (also termed pseudo data by Klein and Griffin). The PAM data are summarized by the fitting of continuous equations generally by least squares (termed multiple equation summarization of process analysis models: (MESPAM). Thus, large PAM can be approximated by a few continuous equations that will reflect the substitution of truck for rail under extreme, by historical standards, conditions.

At this time we are unable to identify the specific hazard mitigation alternatives that are available. One reason is that the extent of possible or likely damages by specific sites has not been completely determined. Once the hazards have been identified, we will develop alternative mitigation programs that might be undertaken in the event of a prediction. Preliminary discussions with potential user groups suggest that the potential mitigation alternatives can be adequately characterized by two or three major alternatives.

As with the estimates of damages from an earthquake, we will utilize engineering information to determine the input and output requirements for the alternative hazard mitigation technologies. The question of whether these mitigation steps will be undertaken is a challenging one. We plan to take two approaches. The first is to ask the user groups which steps, in their opinion, would be undertaken given a believable forecast of an earthquake. The second will be to identify the costs and benefits of the alternative steps that could be taken, under the assumptions of a particular model simulation, (e.g., interest rates, external demands, etc.) and to assume that the most economical steps will be undertaken. Concomitant with this effort will be the assessment of the changes in damages that could be expected with each mitigation alternative.

The summarizing equations derived from the process analysis models will then be combined with the econometric and definitional equations for the remaining sectors to create the regional economic simulation model.

Simulation of the Model

Finally we plan to develop three major simulations with variations on the third. The first simulation will be a baseline forecast of economic activity in the Charleston area with no major structural changes and no earthquake.

This is the usual type of forecasting procedure for regional simulation models. We will take data from forecasts of macro models of the U.S. for the national demand variables and generate an appropriate forecast. This forecast will be analyzed for its reasonableness and stability and may lead to revision of the MESPAM equations in the model if the forecast displays unreasonable properties.

The second simulation will be one where an unanticipated earthquake occurs; that is, where no mitigation steps are taken prior to the earthquake. The catastrophic event will change prices and costs as well as generate a number of constraints, phased out over time, and capital losses.

The third simulation will be one where a prediction is assumed with a given lead time prominent geologists feel is reasonable and the most reasonable mitigation steps are taken for the major, critical sectors in the model. A number of variations on the third simulation should be quite easy to run.

Summary

The major research reports of the National Academy of Science dealing with the socio-economic effects of earthquake prediction [1975, 1978] have stressed that the economic consequences of earthquake hazard mitigation must be viewed within the context of an overall regional economic system. How might the regional economy respond to an unanticipated disaster? For comparison, how might the same economy respond to a prediction of an impending earthquake? Finally, we need to simulate the economic effects of alternative hazard mitigation programs within the context of a regional economy. With the exception of the preliminary effort by Cochrane [1974], the regional economic approach has not been developed and utilized.

The major benefits of successful completion of this research project will be four-fold: (1) the model will constitute a pioneering effort to examine the economic effects of earthquake prediction within the context of a demand and supply based regional economic framework; (2) the potential benefits of a simulation model which can be used by officials to evaluate alternative earthquake mitigation policies will be assessed; (3) the model should advance regional economic analysis by its linking of Process Analysis Models to a regional economic system; and (4) with modification, the model can be used to examine the regional and economic effects of hazard mitigation policies for other natural disasters and catastrophic changes.

With regard to the first consequence, it is expected that the methodology developed can be applied to other earthquake prone areas in the United States where the regional economic system is at risk. Moreover, the lessons learned from this effort can serve as a base for improved regional approaches in the future. In addition, this type of model can serve as an alternative to current regional models which are not satisfactory in dealing with other kinds of catastrophic change. For example, we would expect that with appropriate modification, this approach could be applied to hurricane or nuclear hazard mitigation evaluation.

Second, we believe that the regional economic simulation model should prove to be quite useful for policy makers. Efforts will be made to introduce local public planners to the kinds of uses to which the model output could be applied.

Finally, the Process Analysis Models employed have been previously used only for single industries. The problems of how to link such models to other industries within the context of an overall regional model have not received attention. We expect some new results in this regard during this research effort.

FOOTNOTE

1. A Model for Measuring Regional Economic Responses to Earthquakes and to Earthquake Predictions, NSF Grant PFR 80-19826 by Roberts, Milliman, Ellson, and Wallace, University of South Carolina, Columbia, South Carolina.

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