EARTHQUAKES AND EARTHQUAKE PREDICTIONS: SIMULATING THEIR ECONOMIC EFFECTS

by

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Executive Summary

This report summarizes research to develop a methodology for assessing the regional economic effects of earthquakes and earthquake predictions. Traditional regional economic models must be modified so as to account for: (1) supply side constraints; (2) the potential use of new or currently unused technologies; (3) the timing of investment decisions by firms and consumers; and (4) the decisions by firms and individuals to relocate in response to an event or the prediction of an event.

To respond to these requirements, we have altered the typical regional modeling methods in two ways: (1) by including in the econometric equations variables that will reflect structural and supply-side changes in the event of an earthquake or the prediction of one; and (2) using equations in the regional economic model that are based on a process analysis model of technology.

A number of econometric innovations appear to be relatively successful. These include: (1) incorporating capital stock data and explanatory equations for the change in these stocks in the manufacturing sector; (2) specifying the regional data as spatially specific as possible; (3) including migration equations that depend to some degree on perceptions of risk or, failing that, on economic variables that are directly affected by an earthquake or the prediction of one; (4) including transportation flows from and to different sectors in the region with equations explaining these flows and equations specifying the economic effects on these flows.

The regional econometric model was used to establish a baseline forecast of regional economic growth from 1981 through 1990. Then we ran five

simulations to assess the net effects of an assumed earthquake occurring in 1983 with and without a prediction and mitigation measures. Three simulations were made of an unanticipated quake with different damage assumptions and with different replacement of damages sustained following the event. Next, we simulated a false alarm, a prediction without an occurrence, to show the dampening effects upon the economy of reduced housing starts, investment, and net migration because of the prediction. The fifth quake simulation was an anticipated quake (a correct prediction) to show the combined effects of mitigation, dampened investment, and then subsequent recovery from the prediction and the event. The simulation results in terms of aggregate regional effects upon population, employment, and personal income show that the regional economy is resilient, and that it can recover even when pessimistic assumptions are employed as long as the national growth factors driving the regional economy are maintained.

One of the most important contributions of this study stems from the analysis of measures to determine economic losses from natural disasters in Chapter 2. Conventional measures of loss are shown to be defective. The problems of how to measure losses and benefits using a regional model are carefully examined. It is clear that losses as measured from a regional standpoint will usually exceed losses seen from a national point of view. Therefore, the optimal level of mitigation, in terms of balancing expected losses averted (in present value terms) with expected costs of adjustment and mitigation, may differ depending upon whether a regional or national point of view is adopted.

In the five earthquake simulations, estimates of the present value of regional losses are made for the various contingencies. The losses are a hybrid combination of differential income flows from non-property

income plus non-residential capital income combined with capital stock losses in terms of residential housing and social capital. Losses are shown for the region as a whole and also for each of the three counties. The regional losses are the highest in the unanticipated quake simulations followed by the anticipated quake and the false alarm simulations. Losses in capital stocks tend to dominate regional income losses because the recovery from the event stimulates employment and income. The simulation effects of reinvestment and recovery can even yield positive income gains (relative to the baseline projections) under some reasonable assumptions.

The attempt to use process analysis models in the regional model could be judged as moderately successful for the set of supply equations developed for the housing sector. However, the problems encountered raise many questiosn as to whether this technique will be successful for general application. The major problems of incorporating process models in regional models include: (1) altering regional models to contain specific supply and demand sectors with prices endogenous; (2) developing process models at the appropriate level; (3) validating the process model's ability to simulate real world behavior; (4) incorporating uncertainty and attitudes toward risk; and (5) summarizing the process model's solutions in a useful form.

We believe this research marks a significant step forward for the analysis of earthquakes, earthquake predictions, and other policies for hazard mitigation. The next steps require more and better data to calibrate empirically the economic linkages we have discussed.

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CHAPTER 1

INTRODUCTION AND OVERVIEW

The Economics of Hazard Mitigation

Much of the literature on hazard mitigation is based upon the presumption that reduction of damages from such natural hazards as floods, tornadoes, hurricanes, and earthquakes is desirable in and of itself. Relatively little effort has been expended in estimating and comparing the expected damages to be averted by mitigation procedures with the expected costs of the mitigation. Apart from considerations of equity and the distribution of income stemming from natural disasters, the efficient level of mitigation would be obtained when the total costs of adjustment (residual losses plus the costs of mitigation) are minimized. In other words, additional mitigation effort is justified to the extent that the extra damages averted exceed the incremental mitigation costs.

Earthquakes differ from other natural hazards in two important respects. First, earthquakes are events of low probability and potentially high levels of damage. Second, there is a significant potential that accurate, long range predictions of earthquakes, in terms of an annual probability, are likely. Given a long range, reliable prediction of a major catastrophic event, there are many possible economic consequences. A number of adjustments may be undertaken by individuals and firms to reduce potential losses, including migration out of the region that is predicted to experience an event. Both the scientific process of making the prediction and the hazard mitigation steps are costly. Further, a catastrophic event, as well as a prediction, would affect an entire economic system as opposed to many hazards that principally cause only capital losses but do not upheave economic processes.

In contrast, existing earthquake economic damage estimates are based primarily upon property losses inthe affected region. To structural damages are added damages of the contents of buildings, damages to public facilites, and sums are added for lives lost and injuries sustained. No estimates usually are made of direct and indirect income and employment losses. No attempt is made to estimate probable response patterns of the economic system to damage disruption and the expected path of economic recovery.

Coupled with limited knowledge of economic effects, there is a potentially large public role for earthquake hazard mitigation. Mitigation strategies for earthquake hazards abound: siting decisions, land use regulations, construction codes, earthquake insurance, warnings and predictions, evacuation and relocation, emergency planning, and relief and reconstruction aid; to highlight. Several economic questions come to mind when reviewing these strategies, and a perusal of the earthquake hazard literature makes it clear that the economic rationale for public action in this area is not well specified. Moreover, we should better understand the potential or existing role of private markets and other current institutions, as well as the preferences of individuals, in evaluating direct public regulation.

Before we can make judgements as to the costs and benefits of particular policies for hazard mitigation, it is necessary to have better procedures for estimating economic impacts and costs of adjustment for consumers, producers, and government. The performance of the economic system is a fundamental issue: How will the system respond to earthquakes, to predictions which are probabilistic in nature, and to other public policies for the mitigation of earthquake hazards?

Purpose of This Research

Against this background of the potential for earthquake disruption and the strong role for public intervention, the purpose of this research is to develop a methodology to assess the economic effects of earthquakes and the consequences of alternative policies in this light. The first task is to establish a framework for economic linkages and interdependencies that highlight the variables that are likely to be affected by earthquakes and earthquake policies, such as: capital stocks in industry, social capital stocks (highways, bridges, and the like), demographic factors, financial and capital flows, housing and construction, transportation networks, and utilities' services. The methodology should specify how such factors are interrelated spatially and chronologically with the remainder of the economic system. Crucial, in this regard, is the timing of various effects and the consequent responses.

The second major task is the development and estimation of a model based on this conceptual framework. A major problem in this regard is that historical data, the usual source for calibration of a model, often does not contain the kind of variation that is likely to occur in a catastrophic event or under new policies, such as earthquake predictions, that have not occurred before or, at least, recently. Thus, a major emphasis of this research project is to evaluate the potential for incorporating technology based models that go beyond the range of historical observation including the potential use of new technologies as well as existing but cost ineffective techniques that are not reflected in recent data.

The third purpose of this research is to simulate the economic effects of alternative assumptions about an earthquake with and without a prediction. Given these simulations of economic activity, the fourth task is to estimate the costs of earthquakes, under alternative assumptions, compared with the costs when various policies are undertaken. Finally, our purpose in this effort is to assess the extent to which we are able to carry out the foregoing four tasks.

The Plan of Attack

To accomplish these tasks, it is first necessary to develop a basic conceptual framework upon which our analysis is based. This is essential, either explicitly or implicitly, and given what we perceive to be limitations in the existing literature, we need to be fairly careful in outlining the fundamentals. Chapter 2 contains the overall methodological framework for this research. There we review in detail the potential for predictions, the possible economic responses, and why estimation of losses is important. Then we present the fundamental assumptions of individual choice upon which losses are defined. The proper measures of these losses from a practical standpoint are then analyzed and the need for a regional model given. Conventional models have many limitations which we review and suggest improvements or alternatives.

The specifics of the Charleston, South Carolina setting: the earthquake potential, the economic base, vulnerability, and potential earthquake damages; are given in Chapter 3. This sets the stage for the development of a model of the Charleston economy. The details of the important equations and model structure are presented in Chapter 4.

The model in Chapter 4 is purely econometric, although with innovations. The baseline simulations and five earthquake simulations are discussed and compared in Chapter 5.

Chapters 6 and 7 are devoted to developing and utilizing a technology based model for housing supply. The methodology, including the strengths and weakness of technology based versus purely historical data-based models, is covered in Chapter 6, while Chapter 7 presents the specifics of the housing supply model and the simulations with it incorporated in the model described in Chapter 5.

Our conclusions and final observations are presented in Chapter 8.

Chapter 2

ASSESSING THE ECONOMIC EFFECTS OF EARTHQUAKES AND EARTHQUAKE PREDICTIONS

Predictions May Be Coming

Earthquakes are events of low probability and potentially high levels of damage. Between 1906 and 1971, thirty major earthquakes occurred in the United States with a total damage of over three and one-half billion dollars, measured in 1958 base year dollars (Munroe and Carew, (1974). Of the thirty earthquakes, a single one, the 1906 San Francisco earthquake, caused over one-half of the total damage. It has been estimated that an earthquake, similar to the 1906 San Francisco earthquake, occurring today in a major metropolitan area, such as Los Angeles or San Francisco, could easily result in as many as 12,000 deaths, 48,000 injuries, and property damage in excess of $25 billion (California Earthquake Response Plan, Preface).

Until recently earthquakes were viewed generally as random events which struck without warning. Certain areas, however, had long been perceived as being more seismically active than others, such as the Pacific Coast of the United States, and statistical statements had been made concerning the relative hazard of earthquakes in various areas. The development of the plate tectonics paradigm, along with increased knowledge of the underlying geological structure, permitted more sophisticated statements concerning the general probability of an earthquake in various regions. But what was now foreseen as a possibility went far beyond such statements of seismic risk. It was hoped that it would be possible to make specific statements that an earthquake of a given magnitude would occur in a certain area at a specific time.

The first realization of the new earthquake prediction technology in the United States came with the apparently successful prediction of a minor earthquake in the State of New York in 1973 (Scholz, et al., (1973)). This was followed by the first documented prediction of a major earthquake in Haicheng Province, China (Haicheng Earthquake Study Delegation) and by additional successful predictions in China, the Soviet Union, Japan, and the United States. The Haicheng prediction was of particular interest in that it involved a prediction of a major earthquake and that the prediction was widely believed and acted upon. Consequently, buildings were evacuated and other steps taken that significantly reduced the loss of lives and property (Chu Fung-Ming (1976)). The current consensus among seismologists is that there is reason to expect that reliable earthquake predictions will be possible within ten years in well instrumented areas although large earthquakes present a difficult problem.

Economic Considerations

Given that it is likely that reliable earthquake predictions will be possible in the near future, a number of economic questions arise as to the benefits of such predictions. One of the central concerns of public officials has been the fear that the prediction itself will cause economic disruption.

Assuming these predictions are relatively accurate, widely disseminated, and generally believed, they would enable government agencies and private individuals to mitigate the effects of an earthquake by: (1) acting to reduce the direct damage to existing structures and facilities caused by earthquakes; (2) altering the design and construction of new facilities to reduce damage; (3) delaying investment in existing or new structures until after the event occurs; (4) relocating facilities to seismically safer areas, including outmigration and reduced immigration of individuals; (5) preparing plans and resources to respond to the occurence of an earthquake; and (6) organizing resources beforehand to facilitate the rehabilitation and recovery process.

The direct 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 areas; (3) the number and location of structures within the affected area; (4) the nature of the construction within an 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.

In addition, an earthquake and the prediction of its occurrence will have, although different, distributional consequences which will be a function of the following: (1) the extent to which losses are insured and the form of the insurance; (2) the perceived geographical accuracy of the prediction; (3) the extent to which private philanthrophy and government assistance become available prior to and following the earthquake; and (4) the extent to which the value of existing assets is altered as a result of changed market conditions.

The social losses from an earthquake include the following: (1) deaths; (2) injuries; (3) psychological trauma; (4) social dislocation; (5) property damage; and (6) disruption and alteration 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. Existing earthquake economic damage estimates are based primarily upon property losses in the affected region. To structural damages are added damages of the contents of buildings, damages to public facilities, and sums are added for lives lost and injuries sustained. No estimates usually are made of direct and indirect income and employment losses. No attempt is made to estimate probable response patterns of the economic system to the damage disruption and the expected path of economic recovery.

Until we have better procedures for estimating economic impacts and 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 economic system is at the heart of the matter. How will the economy respond to earthquakes and to possible predictions?

Why Estimation of Economic Losses is Important: The Optimal Level of Hazard Mitigation

Before embarking on a discussion of the principles and problems associated with the estimation of the economic effects of earthquakes and earthquake predictions, it is important to have a clear view of the economic rationale for loss estimation. Much of the literature dealing with the mitigation of natural hazards seems to imply that a reduction of losses is a desirable goal in and of itself. Little consideration is given to the point that the costs of mitigation must be balanced against the losses to be prevented to justify the action. That is to say, mitigation policy cannot be efficient unless the extra costs are related to the additional losses avoided.

Russell (1970) was one of the first writers to define the optimal adjustment to a natural hazard as is illustrated in Figure 2.1. On the horizontal axis is the relative level of adjustment (A) to a given natural hazard. The vertical axis measures annual dollar amounts (they can be shown in present value terms). The curve C is the annual cost of achieving various levels of adjustment. Usually, the costs of adjustment climb rather rapidly as the level of adjustment is increased. The curve L represents the expected losses which often decline rapidly at first for initial levels of adjustment. The efficient level of adjustment is the one which minimizes the sum of L+C. This is shown at A*. To the left of A*, the extra losses avoided are greater than the extra costs of adjustment. To the right of A*, the extra costs of

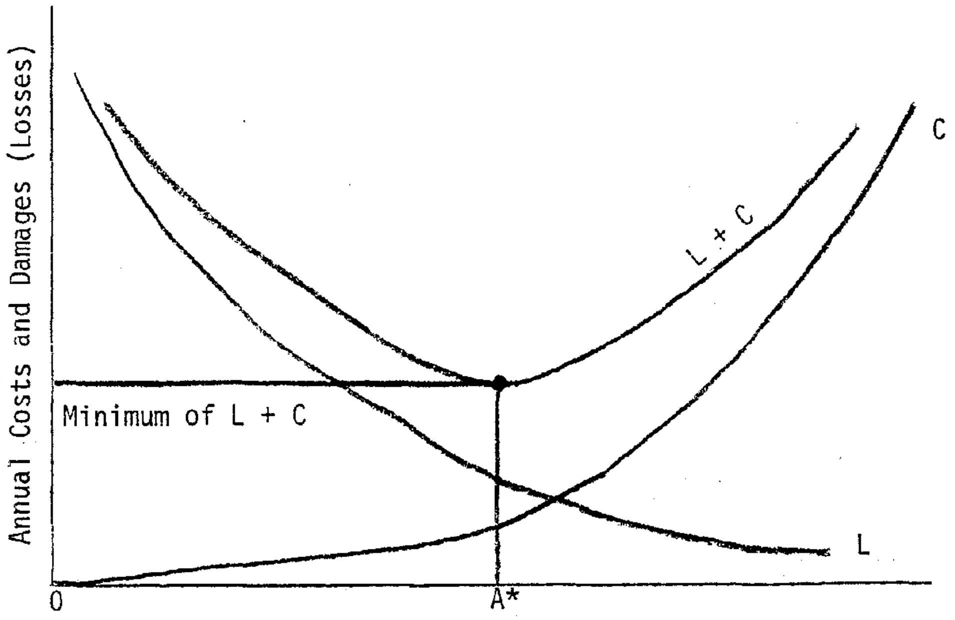


Figure 2.1 - The Optimal Level of Hazard Mitigation

adjustment exceed the extra losses prevented. Note that residual losses or residual hazards persist or remain at the efficient level of mitigation. Moveover, extra mitigation can be justified on economic terms only up to the point that extra benefits (losses averted) exceed the extra costs of mitigation. Most of the earthquake mitigation policies we have studied do not systematically compare the costs of mitigation with the expected losses to be averted. For example, the excellent review of the issues of earthquake hazard reduction by the Office of Science and Technology (1978) does not even mention this problem as an issue.

To some people the notion that there is an optimal level of hazard mitigation is a very disturbing idea. Yet, it is difficult to argue that all amounts of expected residual damages from natural hazards should be eliminated despite enormous costs. Of course, how one applies the logic developed here can be a source of controversy. Estimation of the L and C curves will always be a difficult task for which there may never be precise answers. Calculation of the probability of an earthquake and calculation of damages given an event are both plagued by many uncertainties. Neither calculation is easily defined or measured. How conservative or careful should we be?

It is also clear that the distribution of costs (who pays) and the benefits (whose losses are reduced) will influence decisions and can be a source of public debate. Nevertheless, the notion that there is a theory of optimal adjustments to natural hazards is central to policy formation and implementation. We must take care to be as precise as possible in estimation of expected losses to be averted and expected costs of various mitigation practices.

The appropriate measure of losses and benefits and, hence, the optimal level of mitigation will depend on individual preferences, technology, subjective probabilities of disasters, and the existence of markets. This requires a conceptual framework of individual choices.

The Conceptual Framework of Individual Choices

The conceptual framework we have adopted for determining the economic effects of earthquakes, predictions of earthquakes, and mitigation possibilities is an extension of the state preference approach (Arrow (1953), Debreu (1959), Arrow (1963), Pratt (1964), Yaari (1969), Marshall (1976), and Cook and Graham (1977)). The details of this approach are given in more detail in Appendix A. The basic notion is that individuals are assumed to have a well defined preference ordering that can be represented by a single-valued, quasi-concave function: $U = U(X^1, \ldots, X^n)$. Included in each state vector, X^i, are contingent claims on economic goods and services as well as other measures that affect the individual's well being, such as physical injury to the individual or to others, if the ith state occurs. A special case of the state preference approach is the expected utility maximization model as developed by von Neumann and Morgenstern (1947). Even more restrictive is to assume variables are normally distributed so that expected utility can be expressed in terms of the mean and variance of the random variables. David (1974) and Smith (1979) have used this to analyze regional location decisions. Kunreuther (1976) and Kunreuther, et al. (1978) have used the expected utility model to argue that consumers "misprocess" information or otherwise behave with "bounded" rationality. In Appendix A it is demonstrated that this result depends on highly restrictive (and unrealistic) assumptions about preference spaces.

Appendix A also contains an analysis of the effects of direct aid and assistance, subsidized insurance, and increasing awareness on mitigation and migration decisions by firms and individuals. The following partial equilibrium propositions are demonstrated:

1. the more aid and assistance that is perceived, the less mitigation undertaken and less insurance purchased; and

2. the more insurance rates are subsidized the less mitigation undertaken and the more insurance purchased.

Along with a newly perceived hazard:

3. the more aid and assistance that is perceived, the less net outmigration; and

4. the more insurance rates are subsidized, the less net outmigration.

If, in addition, individuals maximize expected utility, then;

5. with no insurance, the greater the subjective odds on the disaster, the more mitigation undertaken;

6. with no insurance, the greater the subjective odds on the disaster, the greater the net outmigration; and

7. with insurance rates held constant, the greater the subjective odds on a disaster, the more insurance purchased.

Section IV of Appendix A extends the analysis to a general equilibrium framework indicating how the competitive supply of insurance will change as subjective odds, perceived aid and assistance, and mitigation possibilities change. Also, property values are shown to be inversely related to equilibrium insurance rates. From a policy perspective, increasing the subjective odds of a disaster through information flows raises insurance rates and lowers property values. However, the more insurance rates are subsidized, the higher property values will be.

Measuring the Losses and Benefits to Individuals

The conceptual measure of the losses and benefits to individuals of an event: an earthquake or an earthquake prediction; is the sum of the difference in the value of nominal wealth (replaceable objects) plus the difference in the individual's nominal wealth valuations of "irreplaceable" objects. The valuation of irreplaceable objects depends on an allocation of property rights, as discussed in Appendix A, but has upper and lower bounds.

Only the losses of property damage and disruption of economic activity, the nominal wealth losses of "replaceable" objects, readily lend themselves to quantification, and even for these, the task is not easy. Monetary measures of other losses (death, trauma, social dislocation, etc.) require that individuals reveal their preferences, for example, how much they would pay to reduce the probability of death. But these revelation techniques do not have common acceptance and are best handled as auxiliary analysis rather than as part of a model of an economic system. What we will be concerned with is the proper measures of nominal wealth losses in an economic system in the event of an earthquake, both with and without a prediction of the event. In the process, we recognize we are not fully accounting for all the social losses and benefits of earthquake prediction and mitigation steps.

Proper Measures of Economic Losses

Given that it is important to systematically measure expected economic losses in the event of an earthquake or a prediction of one, what are the proper measures of expected economic losses? We have pointed out that existing loss estimates are based upon damages to property and that few attempts (Cochrane (1974, 1975)), Edmunds (1982), Munroe and Ballard (1982), and Wilson (1982)) have been made to estimate income losses due to expected economic disruption. Cochrane (1974, 1975) has argued that the correct measure of economic loss (in his assessment of a hypothetical reoccurance of the 1906 San Francisco event) is the sum of expected property damages plus expected regional income losses. That is to say, Cochrane combines estimates of the "direct" damage to physical property (the primary impact) with the "indirect" damages of the decline in regional economic activity (the secondary impact) to derive an estimate of total economic losses. We suggest below that correctly measured, the economic losses can be estimated <u>either</u> as the present value of the loss of income (both explicit and implicit flows) <u>or</u> the decline in the values of <u>all</u> capital (stocks). In theory, the two concepts are equivalent and alternative ways to measure the damages to the economic system. One measure is a stock concept and the other measure is a flow concept. The two concepts can be equated in present value terms and properly stated in terms of expected values.

We believe that adding together all property damages and income losses involves some confusion between stock and flow concepts of economic activity. Therefore, such a procedure inevitably involves some double counting. Presumably, the damage to property causes a loss of income producing potential. Properly defined, then, damages should represent the present value of expected losses in net incomes or value added. In turn, this concept could apply to reductions in the value of human capital as well as non-human capital even though market analogues of the value of human capital are not as evident as market values for other forms of property (capital stock). As we shall point out below, conventional property damage estimates may be based upon crude estimates of book values or replacement costs, and thus may not accurately reflect the present worth (or capitalized value) of expected future income losses.

For some factors, such as labor, we should use the income differential approach. For other factors, such as owner occupied housing, it is probably easier to use the stock value differential approach. For some factors, such as government facilities, it should be determined to what extent these affect incomes of labor and capital, such as roads, and to the extent they do not, such as parks. If we use the income (or flow) approach as a measure of loss, we should try to measure the fall in real income caused by the event relative to what it would have been without the event. We must not fall into the conventional trap of comparing economic activity before and after; the correct comparison is with and without an event. In other words, we would need a baseline forecast of expected income for the period without a disruption to compare with the change in income expected to result from the event. Therefore, the degree of recovery should be measured not in terms of the former level of activity but rather relative to the expected level without the disaster. In addition, the analysis of income losses should extend over successive time periods (several years if necessary) to pick up production losses that might persist into the future. Finally, the sum of the expected losses in income should be converted to present value terms.

Of the various measures of disruption of economic activity (income losses) available to economists, which measure is the proper one, and can reliable estimates of it be made? Measures of reductions in employment and the loss of wages from baseline levels are useful indicators of losses. However, they are incomplete or partial measures because losses in labor income may reflect only two-thirds of the income losses. What about changes in Gross Product (the value of all final goods and services produced)? This is a familiar measure of economic performance. Gross Product is defective on several counts. Most importantly, it includes the value of intermediate goods and services imported into the region to produce the final products. In addition, allowance would have to be made for depreciation to compute net regional product. Also, techniques and data for estimating Gross Product at substate levels are not available on a regular basis.

The ideal measure of economic disruption would be the change in value added with and without the event. Value added is an estimate of the extra production (output) contributed by labor, capital, and land within the region. The value added concept would be equal to the incomes of labor, capital, and other factors of production resulting from production in the region. By contrast, personal income of residents would count all wages, salaries, rent, interest, and profits received by individuals in the economic system being modeled regardless of whether production took place in that system. Estimates of valued added at the substate level are difficult to make. On the county level it is possible to make estimates of total personal income of residents on a consistent basis. If we have some notion of the portions of personal income that are transferred into the region, e.g., interest, rent, and dividends received by individuals from entities outside the region, we can come pretty close to approximating value added.

Ironically, the loss in real income which may result from displacement of persons and the inconvenience of living in damaged or temporary shelter will not be picked up in a conventional estimate of value added lost in the disaster. In practice, the value added concept concentrates on the output of marketable goods and services which might be little affected by the housing inconvenience of some of the workers as long as they still reported for work. Therefore, value added data as conventionally measured will understate the real income losses of disasters resulting from damage to the housing sector. Apparently, in World War II the partial destruction of cities in Germany, France and England did not lead to a loss in war production commensurate with the extent of property damage (Ikle,(1958)).

To summarize, the proper measures of economic losses stemming from property damages and economic disruption of an earthquake or a prediction of one are either a flow concept or a stock concept. The stock concept would be the market's estimate of the loss of capital values of all assets reflecting future incomes or productivity lost. The flow concept would involve computing the reduction in expected values added over a stream of future time periods with and without the event. The present worth of this loss of value added should be equal (in theory) to the estimate of total capital loss. Conventional measures of loss are not conceptually sound. Also, conventional measures of loss which add together direct property damages and losses in economic activity due to disruption involve some double counting.

The theoretical equivalency of flow and stock concepts may not be achieved in the real world. Clearly, markets for all factors may be incomplete and equilibrium conditions may not be present. Nevertheless, conceptually, the present worth concept makes the loss of capital values equivalent to the present worth of the value added foregone with and without the event. When we settle for second-best measures of either income losses or of capital stock losses, we need to remember what it is that we would really like to measure.

The model we construct in Chapter 5 will attempt to measure wealth losses for the different economic sectors. Some of the wealth losses will be calculated using the difference in the present value of income streams. Some are more conveniently calculated by using changes in the price of capital stocks.

Problems With Conventional Estimates of Property Damages

The benefits of various kinds of mitigation measures for reducing the impact of earthquakes and other natural hazards are the expected losses to be averted. It is somewhat of a surprise to learn that data on public and private losses (actual and potential) from natural hazards are seriously deficient. This is true not only for such low probability events as earthquakes but also for such frequent events as flooding (NSF, 1980). The data on property losses from natural hazards are incomplete and inaccurate. There is ambiguity over which agency has responsibility to report damages and what standards to use. Initial damage estimates are usually crude and exaggerated, but they are seldom carefully revised and re-estimated later. Even estimates of the amount of external aid received by the disaster area are quite illusive (Friesema, et al., (1979)). White and Haas (1975) and Wright and Rossi (1981) argue that the poor quality of data on damages is a serious research problem and makes it difficult to evaluate mitigation policy.

Some of the problems associated with estimation of property damages are the use of original cost instead of the cost of replacement and repair. Even replacement costs can be highly subjective. At best, replacement cost sets a ceiling on damages. But we still have to determine replacement of what under what circumstances. What is the correct "with and without" basis of comparison? Restoration of historical buildings is a clearly different costing problem from the estimation of construction costs of new factories with improved technologies or costs of substituting new residential structures for older housing. The speed of rebuilding will affect the cost of construction, yet speed will also affect the extent of disruption losses. Replacement costing must deal with assumptions about the shape of the post-disaster economy. For example, do we expect the economy to return to producing essentially the same bundle of goods and services in the same ways at the same locations?

The extent of property damage should be related to the value of the total capital stock and to the size of the economy. Simple dollar totals are not meaningful. The important indicator is the amount of property damage in relation to the level of annual new construction and to the amount of replacement. For example, Brookshire and Schulze (1980) estimate that a 8.3 (Richter scale) earthquake on the San Andreas fault in Southern California would have an average ground shaking intensity for Los Angeles County of VII on the Modified Mercelli scale. Damage to single family dwellings was estimated at 3.5 percent of building replacement cost and damage to commercial structures at 5 percent. If the total capital stock in the county is about $240 billion a 5 percent loss of capital stock would amount to $12 billion. While this amount is large in absolute terms, it is not nearly so large in relative terms. Moreover, annual investments in the region are likely to be more than three times this figure so that the burden of replacement may not be nearly so heavy as might be assumed at first blush.

Of course, how much economic disruption occurs as a result of property damage will be a function of how much the economic base is affected and how soon damages to "life lines" such as transportation and public utility systems are repaired. With regard to repair of lifeline systems, experience in the United States has been that public utilities and roads tend to be repaired in relatively short periods of time so that the disruptive effects may not be long-lived. Naturally, the disruptive effects will be less painful in systems where excess capacity or redundancy exists.

The extent to which the economic base is affected by damage is very important. Friesema, et al. (1979) examined four disasters in the United States and found no lingering economic effects from the damage. However, such a finding should not be surprising when a close study of their findings reveals that the disasters did not seriously damage the economic base of any of the four areas. The short run damages were limited to the residential housing sector. Even in the housing sector, the percent of property damage in relation to the total value of residential property at risk was not large.

The Need for an Economic Model

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 assets. 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 total reduction in economic activity.

To analyze these interdependencies in the face of an economic change it is necessary to develop an economic model. First, such a model must be able to predict the level of economic activity (employment, value of product manufactured, value added, real personal income, and the total values of real property) without an earthquake (the baseline projection). Second, the economic model must be able to simulate the level of economic activity in the event of an earthquake, both with and without a prediction of the event. These simulations should also include a warning of an earthquake which proves to be a false alarm.

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 current economic 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(1969), 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(1974)).

It is true that even when the entire amount of direct losses in the affected 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 (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 land fill 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 predictable. 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.

The Scope of the Economic Model

The ideal economic model would incorporate all economic interdependencies and, in general, an economic model of the world might be desirable. Cost considerations of course preclude such detail. Given the trade-off between cost, complexity, and detail, we believe that the first step, given the kinds of effects an earthquake would have on the U.S. economy, is to construct a regional economic model. We discuss the issue of regional versus national or worldly losses after reviewing some deficiencies of conventional regional models. We note at this point, however, that regional losses may be offset by gains in other regions or may induce additional losses in these regions.

Deficiencies of Conventional Regional Models

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 explicitly model supply-side sectors.

Both types of models 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 of current models, 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. Historical observations involving catastrophic change are rare, yet it is in precisely that type of situation that reliable prediction is most needed.

Input-Output Models

An example of an application of current techniques in regional modeling to catastrophic change may be found in Cochrane (1974), who used input-output analysis in estimating losses from an earthquake. This type of 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 this aspect of 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, 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.

Traditional input-output analysis is further limited in analyzing the effects of eathquakes because it does not account for the level of capital stocks, including housing stocks, that would be damaged, the migration of individuals out of the region and within the region, the role of and change in the transportation network during and after the event, and other input factors of the economy that would be altered.

Regional Econometric Models

Regional econometric models are somewhat more flexible than input-output models. The econometric models do allow substitution of inputs and avoid the problem of fixed properties inherent in input-output models. Yet, there are some critical deficiencies in the current context. The econometric models are estimated from a relatively narrow range of historical variation. But a disaster may fall beyond the range over which the model has been estimated and predictions in this case may be questioned.

After the earthquake, the equilibrium path observed before the event will be disrupted by changes in demand and supply. Prices will rise for products that are short in supply, inputs to the region will increase and the possibilites of new methods of production will be apparent. Many econometric models do not have the capacity to generate prices for critical inputs within the model, e.g., housing prices, rental levels, and wage rates due to abrupt change within the region. Nor, has much evidence been accumulated on the magnitude of price changes in the initial period after the disaster.

Relatively little work has been done to assess the possible substitution of labor for capital and the application of alternative technologies under a catastrophe. Traditional econometric models will fail to incorporate technologies which will function over a wider range of prices and resource constraints than which has been historically observed. Another problem is that econometric models tend to treat technologies as being infinitely divisible which leads to practical estimation problems in predicting the recovery process. For example, building 300 square foot houses will not be the best way to alleviate a housing problem. There needs to be a potential for the incorporation of new technologies.

Finally, the export base framework built into most regional econometric models tends to concentrate on changes in export demands and fails to deal adequately with factor supplies and factor prices most likely to be the crux of disaster analysis. To be useful for simulating the effects of disaster and disaster recovery, the regional econometric model should incorporate supply-side changes in capital stock, in labor supply, differential locational or spatial responses, and changes in transportation flows within the region.

Problems with Baseline Forecasts

Our discussion of the deficiencies of conventional regional economic models has emphasized the difficulties of dealing with catastrophic change, but there is another problem which needs to be mentioned. As we indicated above, the estimate of prospective economic losses from a disaster involves a comparison of the estimated post-disaster economic path with a projected baseline simulation without the event, i.e. a with and without comparison. Both input-output and econometric models may be criticized for their abilities to produce credible baseline forecasts with which to compare the disaster simulations. Our emphasis until this section has been on what happens in the post-disaster period, and we have neglected the question of the credibility of the baseline forecast itself.

Both the input-output and the econometric models are estimated from historical data. Ideally, a baseline forecast into the future should take into account expected technological change affecting production functions and output mixes. Yet, how can this be done when the projection model is based upon historical data? The input-output model normally reflects production coefficients for a given year. Incorporation of expected technological change can be done by adjusting these coefficients in an ad hoc manner, but this is an awkward procedure and is not subject to statistical verification because any series of outcomes can be hypothesized.

By contrast, regional econometric models are estimated with time-series data so that technological changes that have incurred in the past are reflected in the estimating equations. Here, we do have some notions of how the economy has adjusted to shocks and technological changes in the past. Nevertheless, the baseline projection involves a projection into the future of economic growth which reflects historical patterns of change. For example, the Charleston econometric model discussed in Chapter 5 was estimated with data from the 1970's, a high growth period for Charleston in the context of a slowly growing national economy. When one makes a baseline projection for the 1980's with this model, with the assumption of "reasonable national" growth variables driving the regional economy in the 1980's, there will be a problem in determining whether the Charleston economy will continue the same relative regional to national employment growth patterns that occurred in the 1970's.

Moreover, the baseline projections for the 1980's with the Charleston model assume that the relation of non-residential capital to manufacturing capital stock and the relation of these capital stocks to social capital stocks remain relatively the same. Baseline projections, then, can not readily deal with changes in these relations.

The problem here is primarily the lack of detailed data regarding these kinds of complex technical relationships. Because of the lack of these data, the model builder is usually forced to rely upon crude ratios and assumptions. In theory, however, these projection problems are soluble. Future research on regional economic projections will not involve necessarily new theory but is largely dependent upon more and better data.

Regional Versus National Losses

As we indicated above, the estimation of losses from natural disasters ideally should involve taking into account possible interdependencies *throughout* a national or world economic system. For practical reasons we have pointed out that a regional economic approach is to be recommended because it is more manageable. But, it is clear that regional loss estimates fall short of what we really would like to know about total economic system effects. The question is whether national losses exceed, equal, or fall short of estimated economic losses from a regional point of view.

Upon reflection one can see that all three outcomes are possible depending upon the kind of interdependency that exists between the regional and the national (or world) economy. To the extent that production gains in other regions can offset or substitute for production losses in the region hit by a disaster, national losses will be *less* than regional loss estimates. By contrast, if regional production is not capable of being "substituted" by production in other regions, then national production may not only fail to make up for the regional losses but, in fact, may actually be less if the lost regional output causes additional reductions in production in other regions. This would be the case if the disaster-struck region produced a crucial input needed for production elsewhere. Therefore, national losses can be less than, equal to, or they can exceed regional disaster losses depending upon the degree of substitutibility involved.

We suspect however, that the most likely case is that regional loss estimates will exceed national loss estimates because the multiple and common substitution possibilities among inputs and outputs across regional boundaries is the more likely case.

In this regard, the attempt to estimate national losses from regional disasters by the use of regional and national input-output models and multipliers (Wilson, 1982) may be incorrect and may result in unduly large national loss estimates. Tying a regional input-output model to a national input-output model usually assumes that input coefficients are fixed and that no substitution is possible. Thus, a projected regional loss from a California earthquake is automatically assumed to have a cascading or mutliplying effect upon the national economy. We strongly suspect that this will not be the case. As we examine the regional production outputs in either northern or southern California, it becomes clear that there is a great deal of possible substitution for these outputs elsewhere in the national economy. The general conclusion, then, would be that regional losses in California would be less than losses viewed from the national point of view.

Measuring the Losses and Benefits with the Model

Above, we described the conceptual framework for measuring the economic effects of a disaster and the changes in these economic consequences when there is a prediction of the event. Now we are interested in empirical approximations based on our regional model. First, particularly with respect to earthquakes, we would conceptually like to measure wealth (broadly interpreted) in the normal state (baseline), x^n, compared with wealth in the case of the disaster, x^d, for every individual. As discussed above, individual preferences are assumed to be defined over both nominal wealth and other measures of the states of nature. Among these measures that are affected by economic conditions and by the states of nature, some are replaceable (easily purchased at a given price), and some are "irreplaceable" (can only be assigned a subjective monetary value). While recognizing that "irreplaceable" factors involve difficult measurement problems, we assume such measurements can be made independently and will talk in terms of nominal wealth in what follows. Second, we would like to measure the effects of a prediction on these variables and sum up these effects for the region.

Because net migration of both human and physical capital will be different in the disaster simulation than in the baseline simulation, in principle we need to determine "opportunity losses." For example, suppose a disaster occurs and a prospective migrant does not move into the region because wealth prospects have been reduced. His lost wealth because of the disaster is the difference between what he would have had in the normal state which includes migration and what he has by not migrating or migrating to some other region. Similarly, for someone who moves out of the region because a disaster occurs, the loss is the difference between what wealth would have been without the event and wealth at the alternative location. This would entail a model of not only the region but of all alternative regions as well. Since this is far beyond the scope of the current model, we can only approximately bind these alternative wealth levels. There are two practical assumptions in this regard: (1) economic units that move because of a disaster lose just as much as those that stay; and (2) economic units that move because of a disaster earn just as much elsewhere as they would have earned without the disaster. It seems likely that the correct answer lies in between: units move because they suffer fewer losses than if they stay, Let X^N and X^D be total regional wealth in the normal and disaster states, respectively, and N and D be the number of economic units in the region in the two states. If units that move suffer fewer losses than if they stay, and if those who move have incomes on average equal to those who stay, then actual wealth losses of those in the region, ΔX^a, are bounded by:

$$\left(\frac{X^N}{N} - \frac{X^D}{D}\right) D \leq \Delta X^a \leq \left(\frac{X^N}{N} - \frac{X^D}{D}\right) N.$$

Let X^M be total wealth of net outmigrants, M, in the disaster state. The left hand expression is correct if $X^M/M = X^N/N$, and the right hand expression is correct if $X^D/D = X^M/M$. If $X^M/M < X^D/D$ then actual losses would exceed the amount given by $\left(\frac{X^N}{N} - \frac{X^D}{D}\right)N$. In fact, certain groups (e.g., construction laborers) may benefit from the disaster. For these groups, $\frac{X^D}{D} > \frac{X^N}{N}$ and rather than losses, benefits are observed. A further problem is that those who do migrate are not likely to have incomes equal to those who do not migrate. For these reasons, it seems better to calculate aggregate regional losses first. This would be equal to assuming that those who migrate lose all income, that is, are unemployed elsewhere.

From the economic model, we need to construct these measures of wealth losses for the different economic sectors. Some of these wealth losses are more conveniently calculated using the difference in the present value of income streams, and some are more conveniently calculated by using changes in the price of capital stocks. The regional econometric model contains the following income variables that are relevant to this problem: (1) labor and proprietor's income by industry; (2) commuters' income (residential adjustment); (3) estimated regional capital income; (4) transfer payments; and (5) dividends, interest, and rents received.

The income flows to capital stock include interest and return on equity. Regional capital income can be estimated by multiplying an appropriate corporate interest rate or rate of return on equity at the national level by the level of regional capital. Since the amount of leveraged regional capital and the regional return on equity are unknown, as an approximation, we will take an average of corporate interest and return on equity for all U.S. manufacturing. The private nonresidential regional capital stock is estimated to be a constant multiple of manufacturing capital and equal to

4.3, the approximate rate of the gross stocks of fixed nonresidential, private capital to manufacturing capital for the U.S. (<u>Survey of Current Business</u>, Feb. 1981).

For determining losses to capital, the number of units is taken to be the amount of capital in the two states. This assumes that migration of all capital stock is proportional to migration of average manufacturing capital.

If we have an accurate measure of all regional capital stock, and if the average of corporate interest rates and the rate of return on equity in manufacturing is reflective of returns on all capital stock, then income in the form of dividends, interest, and rents except for rental income from residential units should be already counted. The effects on residential capital can be accounted for directly in the model. However, the dividends, interest, and rents component of the model can be used as a check on the reasonableness of the income to regional capital measure.

To the present value of these income losses, we need to add the losses of residential units, other consumer assets, and social capital. Losses of single family residential units will be based on the average replacement value as given by average house prices less average lot prices multiplied by the stock of single family housing. Losses of other consumer assets will be based on the damage to consumer durables. The stock of consumer durables in the region will be based on the ratio of the stock consumer durables to residential structures in the U.S. In 1977, Musgrave (<u>Survey of Current Business</u>, March 1979) estimates this ratio to be just under 60 percent whether using net or gross stocks or constant or current dollar values, and this ratio has been growing over time. Thus, the stock of consumer durables in the Charleston Region will be assumed to be 60 percent of residential capital.

We will base our estimate of social capital in the Charleston region on the ratio of gross government owned fixed capital to total private nonresidential capital in the U.S. This number was about 70 percent in 1977 and has been declining slightly over time (Survey of Current Business, March 1979). Thus, social capital in the Charleston region is taken to be 68 percent of total private nonresidential capital. A summary of these losses is presented in Table 2.1.

Table 2.1

Summary of Losses From An Earthquake As Determined by Econometric Model

Present value of income flow differential for:

(a) labor and proprietor's income;

(b) commuter's income;

(c) transfer payments; and

(d) private nonresidential regional capital income.

Plus,

(i) residential losses = fractional damage x residential stock value (market) x 1.6 (to include consumer durables); and

(ii) social capital losses = fractional damage x private nonresidential capital stock value x .68.

CHAPTER 3

THE CHARLESTON SETTING

Charleston Seismicity

The Charleson-North Charleston (SC) SMSA was selected to model for a number of reasons. This SMSA, which is a tri-county area containing nearly one-half million inhabitants, has been hit by numerous large earthquakes including the major earthquake of 1886 which took over 60 lives.

The seismic risk to the Charleston area is well-recognized. It is located in the center of an area classified as Zone 3, the highest category of earthquake risk (Algermissen, 1969), and was classified as one of the 13 high hazard areas in The Earthquake Hazards Reduction Act of 1977 (PL 92-124, sec. 2). The seismic history of the area is lengthy with tremors having been recorded as long ago as 1698. Earthquakes with an estimated intensity of magnitude of V or more on The Modified Mercalli Scale occurred in 1799, 1817, 1843, 1857 and 1860 (Bollinger and Visvanathan, 1977, p. 36) preceeding the 1886 event).

At 9:50 p.m. on August 31, 1886, a major shock lasting less than one minute struck the Charleston area, resulting in about 60 deaths and considerable property damage (Rankin, 1977, p. 2). The modified Mercalli intensity of earthquakes was estimated at IX for the City of Charleston and X for the epicenter some thirty miles away (Bollinger, 1977, pp. 29-31). The shock was felt as far away as Chicago, where plaster was shaken from the walls and ceilings of some buildings. Bricks fell from chimneys and walls in Richmond and Charlottesville, Virginia, Charleston, West Virginia, and Lancaster, Ohio (Bollinger, 1977, p. 26).

Most of what is known of the damages in Charleston comes from a U.S. Geological Survey report by Captain C.E. Dutton (1889). According to Dutton's report, the damage to buildings included total demolition, partial and total loss of walls, horizontal displacement, distorted foundations, toppled chimneys, and varying degrees of cracked plaster. Numerous railroad tracks were twisted, particularly to the northwest of Charleston.

The nature and extent of damage to structures was found to vary, depending in part on the type of ground. In particular, the city of Charleston, is primarily contained on a peninsula between the Cooper and Ashley Rivers and hence, many areas of the city are built upon land-fills of low swampy ground or salt marsh. Captain Dutton reports that damage was generally greater for buildings constructed upon this land-fill or man-made ground. Land-fill ground includes many principal areas of the city such as the portions of Calhoun and Market Street running from Meeting Street to the Cooper River. Dutton reports that "...buildings on both sides of the street were without exception severely injured, portions of many walls being thrown into the street..." Major structures on land-fill ground which were heavily damaged included South Carolina Medical College, the city gas works, hospital buildings, and the county jail. Roper hospital was reported to be very nearly a total wreck, and an entire block of buildings on Wayne Street was completely demolished. Thus, the more severe structural damages were concentrated on, but not confined to, the land-fill areas.

Among the larger structures, the primary types of damages included: loss of porticos, gables, and cornices; badly fissured walls; and cracked plaster. The upper part of the Unitarian Church's tower broke away and fell through the auditorium roof below. The larger structures affected included church buildings, the police station, the Court House, hotels, and miscellaneous large halls.

While the damaged incurred by Charleston was wide-spread, Captain Dutton reports that the "...destruction was not of that sweeping and unmitigated order which has befallen other cities, and in which every structure built of material other than wood has been either leveled completely to the earth in a chaos of broken rubble, beams, tiles, and plankings, or left in a condition no better." Thus, instances of total demolition were reported as uncommon. Rather, the general nature of the destruction was such that most of the damaged structures were repairable and, in fact, a very large number of houses are reported to have escaped with only minor damages such as small cracks and broken chimney tops.

The Future Risk for the Charleston Area

Because of the depth, the intensity of the 1886 quake was attenuated very slowly with distance from the epicenter. This is characteristic of eastern U.S. intra-plate earthquakes. The earthquakes of the western U.S. generally occur along a boundary of tectonic plates and occur at relatively shallow depths (less than 1 km). By contrast, intra-plate earthquakes such as the New Madrid, Missouri earthquakes of 1811-1812 and the South Carolina events in the eastern U.S. occur at much deeper levels, resulting in less attenuation of seismic energy with distance. Nuttli (1973) states that the three New Madrid quakes had Richter magnitudes over 8.4 and were perceptible in Boston nearly 1000 miles away.

Because intra-plate earthquake are centered deep within the plate, they exhibit certain differences from plate boundary earthquakes which are releasing energy which has accumulated at much less depth. The dissipation of seismic energy with distance is a inverse function of the depth at which it is released. The shallower the center of the earthquake, the more rapidly its effects are attenuated over distance. Thus, the deeper the earthquake the more slowly the effects are attenuated over distance. Therefore, both the New Madrid and Charleston earthquakes knocked over buildings a hundred miles from their center and chimneys were toppled nearly 1000 miles away.

Despite the fact that intra-plate earthquakes are potentially more destructive than earthquakes on the boundaries of tectonic plates, their seismic risk is more difficult to assess. Apparently, the energy accumulates much more slowly than it does between two moving plates. Such intra-plate earthquakes occur more infrequently than plate boundary earthquakes. Given that recorded history for most of the intra-plate area in North America goes back less than two centuries, and given the infrequency of large intra-plate earthquakes, it is difficult to judge the seismicity of intra-plate areas. Prior to 1970, very little was known about the seismicity of the Charleston area. Because the 1886 event took place before seismological instrumentation, much of what is known today is derived from the report of Captain Dutton and other historical documentation.

A commonly held view, according to Rankin (1977), is that the 1886 event took place in an area that had been essentially aseismic for nearly two centuries. However, Bollinger and Visvanathan (1977) conducted an archival study and found that of 18 probable earthquakes in South Carolina between 1698 and

1886, 13 appear to have occurred in the Charleston area. They conclude that although South Carolina was not aseismic in the 50-year period before 1886, the seismic activity does not appear to have been anomalously high relative to the surrounding states, either in number of events of in energy level.

Rankin reports that the 1886 earthquake was followed by a series of aftershocks which may still be underway today. In fact, the 1886 event and its aftershocks dominate the seismic record of the Southeast. Between 1754 and 1975 more than 435 earthquakes have been reported to have taken place in South Carolina. Of these, 300 were aftershocks in the first 35 years following 1886 (Tarr, (1977)).

In a movement toward gaining an understanding of the nature and cause of the seismicity in the Charleston area and its relation to the 1886 event, the U.S. Geological Survey launched a multidisciplinary study of the area in March 1973. By 1974, a 10 station seismographic network had been set up in the coastal plane area and, in 1977, the number of stations was increased to 16. While much has been learned about the area, the geotechnical community has been unable to reach a consensus as to the cause(s) of seismic activity in the Southeast. However, most geologists do agree that the cause of the 1886 earthquake is still not very well understood.

In a preliminary paper, Talwani (1982) identifies 3 zones of seismicity in the coastal plane at Middleton Place, Bowman and Adams Run. According to Talwani, there are two main sources of seismicity: (1) a fault plane running collinear with the Ashley River, and (2) a deeper fault oriented NNE, referred to as the Woodstock fault. Talwani reports that first-hand accounts indicate that the main shock of the 1886 event occurred on the Woodstock fault. Thus, Talwani's findings indicate that the seismicity around Charleston is due to sources unique to the area. Others (Behrendt, et al. (1981), Westworth and Mergner-Keafer (1981) have argued that the Charleston seismicity is related to known faults running over large sections of the eastern United States.

For example, Bollinger (1972) suggests a diffuse zone of seismicity trending NW across South Carolina roughly perpendicular to the structural grain of the Appalachians. Thus, some geologists associate Charleston's seismicity with earthquakes in the southern Appalachians. Figure 3.2 is a map and caption from a recent study by Armbruster and Seeber (1981) in which the Charleston-Appalachians association is drawn. Whether the Charleston seismicity is part of a broad NW-trending zone or whether the seismicity originates in an isolated area is still a source of lively debate.

Since geologists are unable to agree on the source of current seismicity and its relation to the 1886 event, there is not sound, agreed upon scientific basis for making probabilistic estimates of a repeat of the 1886 disaster. Nevertheless, a number of geological papers have presented probalistic hazard maps covering portions of the United States. (e.g. Milue and Davenport (1969), Wiggins, Hirshbug, and Bronswicki (1974), and Algermissen and Perkins (1976)). These papers generally present probabilistic estimates of the maximum ground acceleration to be expected from an earthquake. They are based primarily upon historic seismic records which range from very incomplete before 1930 to moderately complete after 1960. While generally submitted as tentative, these maps present estimates of the relative hazard in various parts of the country. In one study (Algermissen, 1969), Charleston was located in the center of an area classified as zone 3 (the highest category of earthquake risk). In a subsequent study (Algermissen and Perkins, 1976), Charleston is ranked much lower in terms of potential hazard. There is generally much controversy as to the credibility of these studies, and therefore, the extent of the risk of earthquake hazard is not as yet accurately calculable. In fact, some argue that scientists cannot even say if future earthquakes in the Southeast and along the Eastern coast would be centered near the epicenters of earlier earthquakes. This is exemplified by the following quote,

> "...how good is the historic record for predicting future seismicity? Perhaps other favorably oriented zones of weakness that have not experienced historic seismic activity should be considered as places of potential earthquakes, particularly if they currently are sites of low-level seismicity?" (Hamilton, 1981, p. 10).

Thus, while the region may be very much at risk, it appears that there is little consensus on how to calculate this risk generally, let alone a time specific probability density function.

Charleston Vulnerability

The Charleston SMSA is composed of three counties (Charleston, Berkeley and Dorchester) with a land area of 2615 square miles and a 1980 population of 430,000. The area contains many rivers and bridges as well as a major harbor and naval base which make the area vulnerable to the effects of an earthquake.

The modern Charleston economy would seem to be particularly sensitive to the effects of an earthquake with a magnitude approaching the 1886 event. For example, the heavily populated portion of historic Charleston is composed of many old and irreplacable eighteenth and nineteenth century structures. We have used a damage assumption of eight percent of replacement value for the entire county area as a result of a repetition of an 1886 type earthquake today. This would be approximately $670 million if residential structural values and contents averaged $50,000 per unit.

The entire SMSA transportation network is also vulnerable. In particular there are five major bridges and eight other important bridges. While it is quite unlikely that all bridges would be rendered unusable in the event of a major earthquake, Pool (1981) has estimated that a repeat of the 1886 event might render 40 percent of the transportation system inoperable and that 30 percent would have to be rebuilt. Ground acceleration may have been perhaps as much as 0.44 g in the 1886 earthquake. However, accelerations to no more than 0.11 g will essentially do no damage to the Charleston road network. Following the 1971 San Fernando earthquake in California values of 0.40 g have been specified for much of California. Currently, highway bridge construction in the Charleston area calls for a peak acceleration of 0.10 g. For significant disruption of economic activity to occur, the repair and reconstruction would have to extend over several months. It is likely that minor repairs can take place in a few weeks time.

The Charleston area serves as a major seaport for the east coast. Also, the area serves as the naval base for the Atlantic Polaris Submarine forces and as the location of the Charleston Air Force Base. Government employment at these defense installations accounts for the largest single source of the area's jobs (30.2 percent). A majority of the employment (80 percent in 1980) of the region is concentrated in Charleston County. Therefore, disruption of the transportation network and possible blockage of the harbor could reduce transportation flows and disrupt the regional economy.

Possible earthquake damages to the electrical, natural gas, water and sewer systems initially appeared to be worrisome. However, the technical literature on this matter suggests that the utilities can restore service in a matter of days or weeks. In fact, damages to the electrical distribution system would probably be less than in the case of a severe thunderstorm. The natural gas systems are also designed to seal off distribution lines in sections to prevent the likelihood of fires in case of breakage from ground motion and shaking. Electricity can be moved across grids to compensate for damage to generating stations. Potable water is available from several sources and can be distributed by tank trucks in severe emergencies. Fortunately, the Charleston region is not threatened by possible failures of major dams or reservoirs in the urbanized areas. Appendix D contains some field reports on these issues.

The Charleston Economy

Table 3.1 shows that the tri-county Charleston SMSA reached an average employment of 152,000 in 1980. This is up 61 percent from the 1970 level of 94,700. During the 1970-1980 period population increased from 336,000 to 430,300, an increase of 28 percent. While some of the increase in employment came about from commuters who live outside the three county area, the increase in labor force participation rates, particularly for women, account for most of the increase.

The majority of the employment is centered in Charleston County. However, this dominance declined from 85.4 percent in 1970 to 79.7 percent in 1980. As Table 3.2 shows, this was due primarily to the shift in manufacturing employment to suburban counties. In terms of population, Charleston County grew only 12 percent from 1970 to 1980, while Dorchester County grew 80.5 percent and Berkely County's population increased 68.5 percent. In 1980, Charleston County contained 64.4 percent of the SMSA population compared to 73.6 percent of the SMSA population in 1970. Again, this is an indication that the metropolitan growth took place in the suburbs. The dominance of employment in Charleston County means that journey to work patterns involve suburban - central city routes.

The economic base in the Charleston SMSA is dominated by government employment (mainly at the naval base and at the airforce base) at 30.2 percent followed by retail and wholesale trade at 21.6 percent and services at 6.8 percent for a total of 68.6 percent of total employment. The large employment in the trade and services sectors reflect tourism and the role of Charleston as a regional trade center. Manufacturing employment grew only 13.6 percent from 1970 to 1980, far less than 61 percent increase in total employment. The relative importance of manufacturing in terms of total employment for the SMSA fell from 18.6 percent in 1970 to 13.2 percent in 1980. Employment in manufacturing is distributed equally between durable and non-durable goods. Again, Table 3.2 shows that new investment in manufacturing rose sharply in Berkeley County and actually declined in Charleston County.

Table 3.1
Charleston-North Charleston SMSA Employment

	Total SMSA		Berkeley Co.		Charleston Co.		Dorchester Co.	
	1970	1980	1970	1980	1970	1980	1970	1980
Total Employment	94.5	152.0	8.3	19.3	80.7	121.2	5.5	11.5
Contract Construction	6.2	11.6	0.7	3.0	5.4	7.5	0.1	1.1
	(6.6)	(7.6)	(8.4)	(15.5)	(6.7)	(6.2)	(1.8)	(9.6)
Manufacturing	17.6	20.0	2.6	5.4	13.0	11.4	2.0	3.2
	(18.6)	(13.2)	(31.3)	(28.0)	(16.1)	(9.4)	(36.4)	(27.8)
Trans. and Public Utilities	6.1	9.5	0.4	0.7	5.5	8.4	0.2	0.4
	(6.4)	(6.3)	(4.8)	(3.6)	(6.8)	(6.9)	(3.6)	(3.5)
Trade	18.5	32.8	0.6	2.1	16.9	27.9	1.0	2.8
	(19.6)	(21.6)	(7.2)	(10.9)	(20.9)	(23.0)	(18.2)	(24.3)
Fin., Insurance and Real Estate	3.7	6.6	0.1	0.3	3.5	6.0	0.1	0.3
	(3.9)	(4.3)	(1.2)	(1.6)	(4.3)	(5.0)	(1.8)	(2.6)
Services	10.8	25.6	0.5	2.7	9.8	21.7	0.5	1.2
	(11.4)	(16.8)	(6.0)	(14.0)	(12.1)	(17.9)	(9.1)	(10.4)
Government	31.6	45.9	3.4	5.1	26.6	38.3	1.6	2.5
	(33.4)	(30.2)	(41.0)	(26.4)	(33.0)	(31.6)	(29.1)	(21.7)
<u>Percentage of Total SMSA</u>								
Total Employment			8.8	12.7	85.4	79.7	5.8	7.6
Contract Construction			11.3	25.9	87.1	64.6	1.6	9.5
Manufacturing			14.8	27.0	73.9	57.0	11.4	16.0
Trans. and Public Utilities			6.6	7.4	90.2	88.4	3.3	4.2
Trade			3.2	6.4	91.4	85.1	5.4	8.5
Fin., Insurance and Real Estate			2.7	4.5	94.6	90.9	2.7	4.5
Services			4.6	10.5	90.7	84.8	4.6	4.7
Government			10.8	11.1	84.2	83.4	5.1	5.4

NOTE: Data in parentheses are percentages of Total Employment. Percentages may not add due to rounding.

TABLE 3.2

Charleston - North Charleston SMSA

Growth in Selected Indicators 1970-1980 All Numbers in Percentages

	SMSA	Berkeley Co.	Charleston Co.	Dorchester Co.
Total Employment	61%	133% (13)	50% (80)	109% (8)
Manufacturing Capital Investment (1972 $)	125%	297% (79)	32% (14)	132% (7)
Retail Sales (1972 $)	55%	135% (16)	43% (75)	81% (9)
County Operating Budget (1972 $)	254%	188% (14)	258% (74)	358% (11)
Total Income (1972 $)	52%	82% (16)	41% (71)	108% (13)
Per Capita Income (1972 $)	19%	8% NA	26% NA	15% NA
Population	28%	69% (22)	12% (64)	81% (14)
Manufacturing Employment	14%	108% (27)	12% (57)	60% (16)

Note: Parentheses depict the percentage of SMSA activity for 1980. Percentages may not add due to rounding.

NA - not appropriate.

Table 3.3
Charleston-North Charleston SMSA
Growth in Selected Indicators (1970-1980)

	Total SMSA		Berkeley Co.		Charleston Co.		Dorchester Co.	
	1970	1980	1970	1980	1970	1980	1970	1980
Total Nonfarm Employment[1]	94.7	152.0	8.3	19.3	80.9	121.2	5.5	11.5
Manufacturing Capital Investment[2]	369.0	852.1	169.5	673.1	172.9	117.3	26.6	61.7
Retail Sales[3]	848412	1315727	88770	208297	695488	991282	64154	116148
County Operating Budget[4]	8587	30379	1528	4399	6323	22606	736	2274
Total Income[3]	1143088	1742368	140260	273028	883819	1242369	109009	226971
Per Capita Income[3]	3402	4049	2674	2882	2570	4480	3377	2895
Population	336036	430301	56199	94727	247561	277308	32276	58266
Manufacturing Employment[2]	17.6	20.0	2.6	5.4	13.0	11.4	2.0	3.2

[1] In Thousands

[2] In Millions of Dollars

[3] In Dollars

[4] In Thousands of Dollars

CHAPTER 4

THE CHARLESTON ECONOMETRIC MODEL

Regional Econometric Precursors

In the last decade, regional econometric models have been widely utilized. Pioneering work by Glickman (1971, 1977) established the basic methodology that has been followed in most subsequent research. Glickman's initial efforts were focused on the Philadelphia metropolitan region, and there are several interesting features. First, the model was highly detailed. Output, employment, and income equations were in disaggregated form, and other important economic factors such as investment, banking, government, and retail sales were also included. A second feature is that the model was estimated for the City of Philadelphia and the region. Therefore, economic forecasts and policy simulations could also be derived for the residual suburban areas. Finally, many of the explanatory variables were national variables. Thus, Glickman's model was closely linked with the national economy, and this provided considerable ease of forecasting due to the recursive structure and allowed one to examine the effects of national economic policies on the Philadelphia region.

Fishkind *et al*. (1978) extended the Glickman framework in two major respects. First, they explicitly disaggregated the local government, financial/construction, and resource sectors. Examples include local revenues and expenditures, by type and source, major deposit and loan categories, housing starts, and electricity and water consumption by major users. The second extension is that the five equation blocks are fully simultaneous in structure. Since the purpose of this model was to assess the economic cost and benefits of alternative regional growth policies in the Gainesville, Florida SMSA, a recursive specification such as Glickman's was inappropriate.

Models by Rubin and Erickson (1980) and Duobinis (1981) also extend the Glickman framework. For the Milwaukee SMSA, Rubin and Erickson derive output, employment, and labor cost equations at the two-digit S.I.C. level for the manufacturing sector and also disaggregate the nonmanufacturing sector. The explanatory variables in their model are primarily national variables, and thus, the model is essentially recursive. However, Rubin and Erickson do analyze the relative costs in the region in addition to demonstrating a regional forecast. Duobinis' model of the Chicago SMSA also focused on output and employment. His extension was to base these sectors on microeconomic relationships in contrast to the specification of Glickman and Rubin and Erickson.

In summary, traditional urban econometric models have become increasingly sophisticated and disaggregated over time. As such, they are able to depict marginal changes to an urban area in great detail. These exogenous changes can result from either national or regional policy alternatives.

However, these models are inadequate for estimating the economic effects of catastrophic change for several reasons. First, supply-side constraints are rarely if ever binding in traditional models. Yet, in situations of catastrophic change, it is supply-side constraints which will dominate rather than changes in aggregate demand. Factors that must be considered include capital investment, net migration, housing, and transportation. Although most of the models discussed above incorporate capital investment, it is determined recursively either by national investment or some partial adjustment process. This is not sufficient because the effects of ex ante behavior cannot be analyzed. Moreover, net migration is rarely dealt with because of data problems, but it is of fundamental importance in determining the effects of catastrophic change. The housing sector, which is closely linked to economic and demographic characteristics, is also important. Finally, transportation flows will surely be affected by catastrophic change at least in the short run, and none of the above models consider this aspect.

A second problem with traditional urban models is that they are not spatially disaggregated. Although Glickman does stratify the Philadelphia region, there is little, if any, significant interaction between the city and suburbs for example. However, it is clear that catastrophic change will have differential effects across an urban area, and this can only be accomplished by some level of disaggregation.

Therefore, our Charlestion SMSA model addresses the issues of estimating the economic effects of catastrophic change by incorporating the factors cited above. New capital investment is estimated using an investment anticipations approach, and net migration is endogenous in the model. Housing starts and transportation flows are also incorporated. Therefore, the stock variables for capital, housing, and population are represented by identities. In addition, we have analyzed the urban area at the county level. Although a higher level of spatial disaggregation would be desirable, data limitations preclude this. However, this county specification provides a unique feature in that our model is simultaneous both within an individual county and between the three counties in the urban area. Thus, differential effects can be estimated for the SMSA.

The Model Overview

The Charleston (SC) SMSA is composed of three counties: Berkeley, Charleston, and Dorchester. Our model is not one model with three subareas, but three distinct models with appropriate linkages. This bottom up rather than a top down approach allows the economic effects of an earthquake to differ within the region. The data base for the model was developed entirely from secondary data sources, and annual observations were obtained from 1965-1980. Due to the changing character of the region, there were missing observations in some series, and these were interpolated with a spline function.

The relatively small number of observations necessitated a simple lag structure where appropriate and a rather straightforward specification. The model was estimated with two-stage least squares using principal components. When serial correlation occurred, a Cochrane-Orcutt procedure was employed.

The model for the Charleston SMSA contains 217 equations. One hundred thirty-six of the equations are stochastic and eighty-one are identities. Of the 136 stochastic equations, 44 are for Charleston County, while Berkeley and Dorchester counties each account for 43 equations. The model contains 22 exogenous variables, 11 of which are national and the remainder are state or regional in character. Three equations comprise the financial sector of the model. Unfortunately, consistent data were available only for savings and loan associations, and accordingly, commercial banks were not included. Finally, three equations estimate transportation flows between counties and within Charleston County.

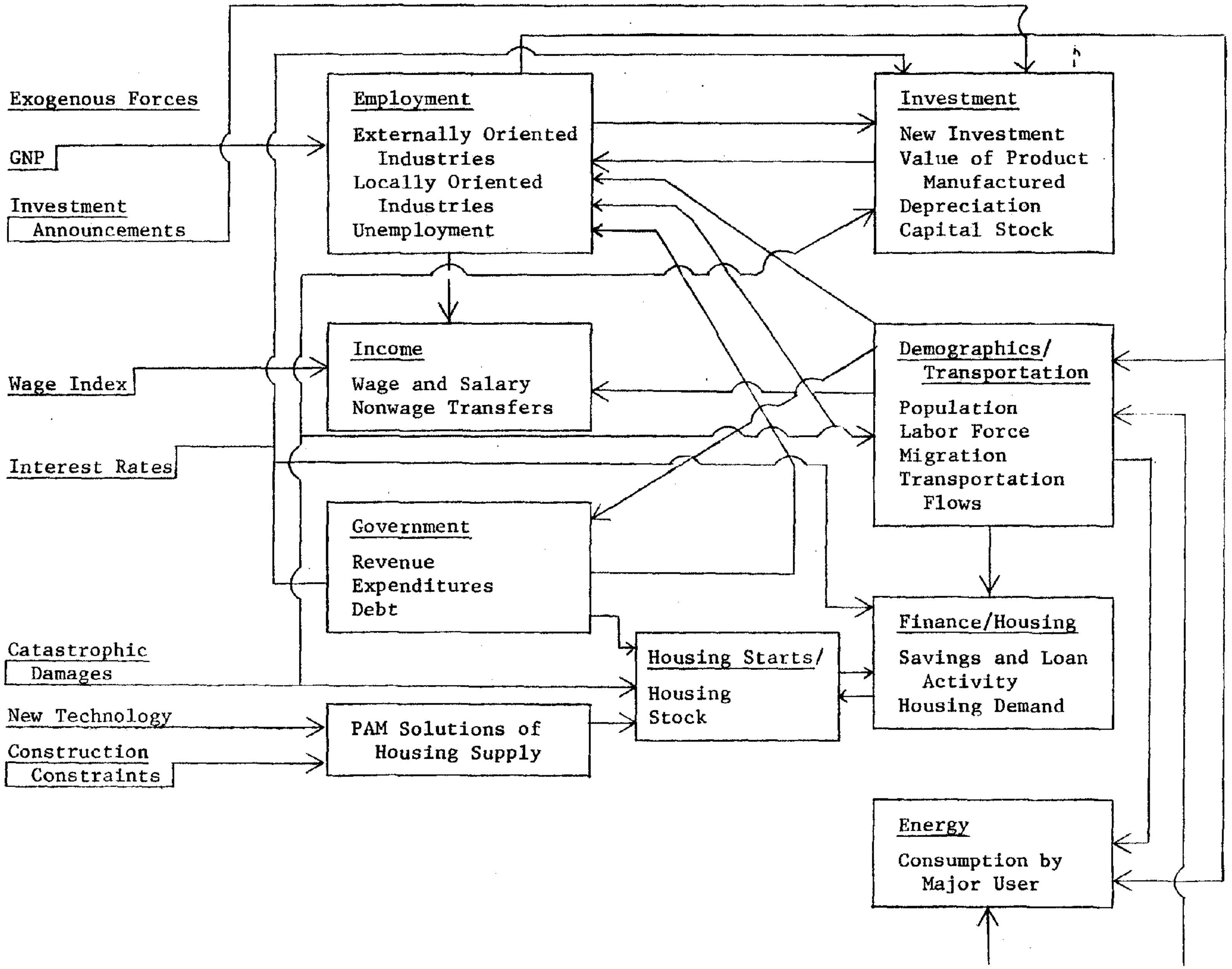
The basic linkages of the county models are provided in Figure 4.1. In general, the specification conforms to Fishkind et al. (1978) with the exception of the housing sector. In this chapter the housing sector explicitly models prices and rents in a regional economic framework. The housing supply process model is discussed in Chapter 6. In the housing sector, we have attempted to deal with basic structural changes in the production function caused by a catastrophe by using multiple equation summarization of process analysis model (MESPAM).

Each county model has (1) an employment block by one-digit SIC with the equations generally conforming to export base specifications, with the exception that manufacturing employment is dependent upon the value of product manufactured and the capital stock; (2) an income block for wage and salary disbursements by one-digit SIC and non-wage transfers, where the explanatory variables are one-digit SIC employment and a wage index; (3) a government block that includes revenues, expenditures and debt, where the equations are primarily based on population, interest rates, and the general level of economic activity; (4) an investment block containing equations on new investment, value of product manufactured, and the capital stock; (5) a demographic/transportation block that depends upon inter/intraregional economic growth; and (6) the energy block for residential, commercial, and industrial electricity and gas consumption which is based on the general economic activity plus energy prices.

We next describe the primary supply-side equations, which along with the process model for the housing sector, represent the major innovations we have made to modify existing regional econometric models to reflect the structural changes in a regional economy in the event of an earthquake or the prediction of one.

Figure 4.1

Linkage of County Models



We next describe the primary supply-side equations, which along with the process model for the housing sector, represent the major innovations we have made to modify existing regional econometric models to reflect the structural changes in a regional economy in the event of an earthquake or the prediction of one.

Manufacturing Investment and Capital Stock

Manufacturing investment and the stock of capital in the manufacturing sector is crucial to the model and simulations in two respects. First, the stock would be directly affected by the catastrophic event. Second, new capital investment will vary with prior expectations of the event as well as through the recovery process. The capital stock data are county specific. The level of capital stock is a function of new investment and the level of the capital stock in the previous period. At present, new investment is modeled as a function of national interest rates and announcements of new investments made by firms.[1] Announcements can be treated exogenously or modeled on the basis of economic incentives. Given county specific announcement data for 15 years, attempts to explain announcements on the basis of economic variables proved unsatisfactory because of the small sample size and the specialized nature of many investments. Therefore, we have announcements exogenous. The general specification for this sector is quite straightforward:

$$EKN = f(EKAT, IR), \text{ where} \tag{1}$$

EKN = new capital investment in real terms,

EKAT = announcements of new manufacturing investment in real terms, and

IR = the interest rate

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[1] These data were obtained from the South Carolina Industrial Development Board and the South Carolina Department of Labor.

The estimated equations are provided below (t - statistics are in parenthesis):[2]

$$\text{BEKN} = 264.2 + \underset{(2.21)}{0.25}*\text{BEKAT}(-1) - \underset{(-2.58)}{28.17}*\text{IR} \tag{1a}$$

$$\bar{R}^2 = .62 \qquad \text{SER} = 35.0$$

$$\text{CEKN} = 2.12 + \underset{(1.33)}{0.013}*(\text{CEKAT} + \text{CEKAT}(-1) + \underset{(15.3)}{0.79}*\text{CEKN}(-1) \tag{1b}$$

$$\bar{R}^2 = .96 \qquad \text{SER} = 6.25$$

$$\text{DEKN} = \underset{(3.75)}{11.45} + \underset{(3.75)}{0.11}*\text{DEKAT} - \underset{(-5.21)}{0.61}*\text{IR} \tag{1c}$$

$$\bar{R}^2 = .66 \qquad \text{SER} = 1.1$$

Therefore, the capital stock, EKT, can be estimated by the capital stock lagged one period and new investment which is additive:

$$\text{EKT} = \text{EKN} + \text{A1}*\text{EKT}(-1) \tag{2}$$

where all variables are in real terms.

$$\text{BEKT} = \text{BEKN} + \underset{(46.4)}{0.91}*\text{BEKT}(-1) \tag{2a}$$

$$\bar{R}^2 = .98 \qquad \text{SER} = 24.7$$

$$\text{CEKT} = \text{CEKN} + \underset{(5.37)}{0.40}*\text{CEKT}(-1) + \underset{(4.81)}{62.5}*\text{DUMMY} \tag{2b}$$

$$\bar{R}^2 = .26 \qquad \text{SER} = 22.0$$

$$\text{DEKT} = \text{DEKN} + \underset{(16.4)}{0.90}*\text{DEKT}(-1) \tag{2c}$$

$$\bar{R}^2 = .76 \qquad \text{SER} = 8.55$$

The equations conform to our prior expectations. The coefficients for the lagged capital stock in (2) indicate that 9-10 percent of the stock is reduced due to depreciation and plant closings. The equations for Charleston

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[2] The letters "B, C, and D" preceding any endogenous variable refer to Berkeley, Charleston, and Dorchester counties respectively. "T" represents the SMSA total. "US" is the United States total.

County were difficult to estimate due to substantial volatility in the data in addition to decentralization trends. The dummy variable captures some of these effects, but the coefficient on lagged stock does not reflect the true reduction in the capital stock as a result of the data problems.

It should be noted that announcements of investment intentions do not always materialize and there is a variable lag between announcements and actual investment. Further, some unannounced investment often accompanies announced investment. It is clear that further research on the empirical validity of the parameters determining the timing of manufacturing investment with and without predictions of earthquakes would be desirable, and some initial survey work has been done by Mileti, Hutton, and Sorenson (1981).

Migration

Migration is typically ignored in regional models because of either inadequate data or extreme volatility in the series. Yet migration is quite important for many regions, and in particular, changes in migration are crucial for the analysis of earthquakes and earthquake predictions. In the model, net migration to each county is a function of the relative unemployment rates in the county and several other economic variables. Additional research with a much larger data set show, in general, that inmigration and outmigration are affected differently by economic variables. Again, small sample size precluded a more general formulation. Also, we found migration sensitive to risk of death in terms of traffic fatalities per 100,000 inhabitants. The effects of an earthquake or warning on net migration can be simulated.

This sector is particularly important to our analysis. It will clearly be affected by both the expectation and realization of catastrophic change. Moreover, these equations provide one of the linkages between the county models so that differential intercounty effects can be estimated.

It can be argued that migration and transportation flows should be simultaneously determined. This was attempted, but it proved to be unsuccessful. Lagged transportation flows do appear in the net migration equations, and both are linked to the general level of economic activity. Since transportation flows are measured on major access routes between the outlying counties and Charleston County, our specification is appropriate because of the influence of nodal employment on migration decisions and accessibility.

In our model, the migration factor is represented by net migration to each county. In general form, these equations are specified in the following manner:

$$MIG = f(XPO,\ EUR) \qquad \text{where} \qquad (3)$$

MIG = net migration

XPO = transportation flows from one county to Charleston County, and

HE = housing stock

EUR = the (relative) unemployment rate.

The estimated equations for each county are:

$$BMIG = 10{,}888 + \underset{(8.56)}{0.87^{*}\,BHE} - \underset{(-2.15)}{7210^{*}\,TEUR/EURUS} + \underset{(7.50)}{12117^{*}DUMMY} \qquad (3a)$$

$$\bar{R}^2 = .87 \qquad SER = 1270$$

$$CMIG = -40{,}588 + \underset{(5.80)}{323.9^{*}\,CCXPO(-1)} \underset{(-4.67)}{-2197.7^{*}\,CEUR} + \underset{(6.62)}{9080^{*}DUMMY} \qquad (3b)$$

$$\bar{R}^2 = .90 \qquad SER = 1990$$

$$DMIG = -180.5 + \underset{(3.21)}{123.8^{*}DCXPO(-1)} - \underset{(-2.21)}{1308.3\ ^{*}DEUR/EURUS} \qquad (3c)$$

$$\bar{R}^2 = .71 \qquad SER = 550.1$$

Although this specification resulted in reasonably high $\bar{R}^2$ values, it has been suggested that the change in employment should be included as an explanatory variable. This was attempted in several forms, but it was either not significant or incorrectly signed in all cases. However, employment does enter indirectly in the equations through the XPO and EUR variables.

Transportation

Since Charleston County is the primary node in the region, the key determinant of intercounty linkages is transportation flows between Charleston and the outlying counties and within Charleston. Assuming that labor force participation rates are invariant across the region, transportation flows can be estiamted by the differences in employment-population ratios between the counties. The equations thus take the following form:

$$\text{XPO} = f({}^{\text{CEMP}}/_{\text{CPOP}} - {}^{\text{XEMP}}/_{\text{XPOP}}),\ \text{where}$$

XEMP = total nonfarm wage and salary employment and

POP = total population

The estimated equations are:

$$\text{BCXPO} = -79.6 + \underset{(13.95)}{4.94\text{E}} + 05*({}^{\text{CEMP}}/_{\text{CPOP}} - {}^{\text{BEMP}}/_{\text{BPOP}})$$

$$\bar{R}^2 = .93 \quad \text{SER} = 4.3$$

$$\text{DCXPO} = 6.04 + \underset{(8.34)}{55{,}598}*({}^{\text{CEMP}}/_{\text{CPOP}} - {}^{\text{DEMP}}/\text{DPSP});$$

$$\bar{R}^2 = .82 \quad \text{SER} = 1.32$$

$$\text{CCXPO} = 51.89 + \underset{(14.82)}{2.778\text{E}} + 05*(\frac{\text{CEMP}}{\text{CPOP}} - \frac{\text{BEMP} + \text{DEMP}}{\text{BPOP} + \text{DPOP}});$$

$$\bar{R}^2 = .94 \quad \text{SER} = 2.67$$

Thus, transportation flows are directly related to relative levels of economic activity in the region and are linked to the model through migration.

The important link between migration, transportation flows, and the demand for locally produced goods and services is the residential adjustment component of personal income. The residence adjustment represents the total inflows of commuters' labor income minus the total outflows. It is a significant component of total person income in each county. Consequently, interruptions in transportation flows directly impact personal income by place of residence and, in turn, affect the consumption of local goods and services. Thus, it acts as a proxy for income to commuters, and accordingly, the key explanatory variables is transportation flows:

$$YRA = f(XPO), \quad \text{where} \tag{5}$$

YRA = the residential adjustment component in real terms

These equations are estimated as:

$$\underset{}{LOG(BYRA) = 9.5 + \underset{(3.06)}{3.2*LOG(BCXPO)}} \tag{5a}$$

$$\bar{R}^2 = .38 \qquad SER = .07$$

$$CYRA = 3532.5 - \underset{(-14.58)}{1078.6*(DCXPO + BCXPO)} \tag{5b}$$

$$\bar{R}^2 = .94 \qquad SER = 7530$$

$$LOG(DYRA) = 1.57 + \underset{(6.69)}{0.69*LOB(DYRA(-1))} + \underset{(1.48)}{.57*\ LOG(DCXPO)} \tag{5c}$$

$$\bar{R}^2 = .33 \qquad SER = .097$$

It is worth noting that the residence adjustment, while a significant component of total personal income for each county, is positive for Berkeley and Dorchester counties and a net outflow for Charleston County.

In summary, the investment and migration and transportation equations provide the important intercounty linkages in the model. It is clear that supply-side constraints will dominate in the circumstances of catastrophic change, and the effects will be focused not only on the physical attributes of the region such as the stock of captial and housing and transportation modes, but they will also involve migration and investment decisions. We have incorporated these elements in a manner which will depict the likely differential effects across the region.

Financial and Capital Flows

Financial and capital flows are modeled for the entire region as is consistent with the usual notions of capital mobility. Loans closed by savings and loan institutions play an important role in the number of housing starts.

Because consistent data on the savings flows and lending activities of commercial banks could not be obtained, the financial sector of the model is focused solely on savings and loan associations. Furthermore, the data for S&L's were available for the SMSA only.

This sector is composed of three equations. Two relate to funds available to S&L's for lending purposes: interest credited and total savings capital. The third equation is total loans closed for home purchases. Interest credited is taken to be a function of total savings capital and a market interest rate which is the six-month Treasury bill rate. The estimated equation with all values in real terms is:

$$\text{LOG(INC)} = \underset{(-12.5)}{-11.44} + \underset{(21.5)}{1.66}\ *\text{LOG(SAV)} + \underset{(2.1)}{0.17}\ *\text{LOG(TB6)} + \underset{(1.98)}{0.12}\ *\text{FDUM} :$$

$$\bar{R}^2 = .98 \qquad \text{DW} = 1.65 \qquad \text{SER} = 0.053$$

Total savings capital was derived as a function of personal income and the market rate of interest to reflect disintermediation. Clearly, many regulatory changes have occurred in recent years, particularly new savings instruments. However, efforts to differentiate these effects were unsuccessful. The values again are in real terms.

$$\underset{}{LOG(SAV)} = \underset{(-2.5)}{-4.29} + \underset{(9.54)}{1.19}\ {*}LOG(TPY) - \underset{(-1.5)}{0.1}\ {*}LOG(TB6)$$

$$\bar{R}^2 = .88 \qquad DW = 1.7 \qquad SER = 0.046$$

Total loans closed for purchase is a function of single-family housing starts, the change in mortgage rates, and loans closed lagged one period. Mortgage rates are exogenous in the model.

$$LOG(LCP) = \underset{(-0.67)}{-2.4} + \underset{(2.02)}{0.85}\ {*}LOG(THSF) - \underset{(-2.1)}{2.16}\ {*}LOG(FMOR/FMOR(-1))$$

$$+ \underset{(11.3)}{0.63}\ {*}LOG(LCP(-1))$$

$$R^2 = .90 \qquad DW = 1.31 \qquad SER = 0.4$$

This variable is simultaneously linked to single-family housing starts which is a direct determinant of construction employment.

This sector can be expected to be significantly affected by a disaster or the prediction of one. Both savings flows and lending practices will be reduced given a prediction. However, lending activity would be expected to increase in the post-disaster period.

The Housing Sector

Traditional regional econometric models have analyzed the housing sector by estimating equations for single and multifamily housing starts. These equations are generally specified in reduced form with the key explanatory variables being: (1) a disequilibrium variable represented by the change in population over some interval divided by housing starts over the interval;

2) lagged starts; and (3) an appropriate interest rate or a relative interest rate such as the mortgage rate-cost of funds differential for example.

The key element here is that prices are ignored, which is typical of most sectors in macro models. However, the role of prices and rents is crucial to the analysis of a regional housing market, and this clearly manifested itself in the decade of the 70's. Moreover, a catastrophic event can be expected to have significant effects at least in the short run.

Thus, we have modeled equations for demand and supply of housing in addition to the average price and average rent. With three counties, the result is a system of 14 equations since the price and rent equations are for the SMSA only. Below we discuss each of the sets of equations. In chapter 6, we utilize the process model approach in developing a housing supply model under conditions of structural change.

The endogenous and exogenous variables are given below. The prefix B, C, D, and T again refer to Berkeley, Charleston, and Dorchester counties and the SMSA total respectively.

ENDOGENOUS

HMF = multifamily housing starts

HSF = single-family housing starts

PRICE = average price of single-family homes (SMSA only)

RENT = average rent of multifamily units (SMSA only)

RPRICE = real price of single-family homes

RRENT = real rent

EXOGENOUS

MIG = net migration

POP = total population

FMOR = mortgage rate

TB6 = rate on 6 month T-bills
FYPR = prime rate
GD = GNP deflator, 1972 = 100

Single-Family Housing

Basic economic theory states that the demand for any good is determined by its price, the price of available substitutes, income, and the number of consumers. For housing, we must also consider a speculative component given that the series extends from 1965-80. Since the demand for a durable good such as single-family housing can be readily postponed in the short-run, mortgage rates must also be considered. Finally, lags from construction to purchase suggest that a partial adjustment framework may be appropriate. The estimated demand equations are provided below (t-statistics are in parentheses).

$$(1)\quad \text{BHSFD} = \underset{(6.59)}{0.65} * \text{BHSFD}(-1) - \underset{(0.86)}{0.021} * \Delta\text{RPRICE} + \underset{(2.41)}{0.03} * \text{RPRICE} - \underset{(1.51)}{42.4} * \text{FMOR} + \underset{(1.86)}{0.03} * \text{BMIG}$$

$$\bar{R}^2 = .83 \qquad \text{SER} = 143.0 \qquad \text{DW} = 1.96$$

$$(2)\quad \text{CHSFD} = \underset{(3.09)}{0.05} * \text{RPRICE} - \underset{(1.40)}{0.041} * \Delta\text{RPRICE} + \underset{(4.94)}{21.87} * \text{RRENT} - \underset{(3.04)}{2457} * \text{FMOR}/\text{FMOR}(-1) + \underset{(0.99)}{0.01} * \text{CMIG}$$

$$\bar{R}^2 = .42 \qquad \text{SER} = 228.5 \qquad \text{DW} = 1.61$$

$$(3)\quad \text{DHSFD} = \underset{(1.11)}{0.29} * \text{DHSF}(-1) - \underset{(1.89)}{0.02} * \Delta\text{RPRICE} - \underset{(2.07)}{344.1} * \text{FMOR}/\text{FMOR}(-1) + \underset{(3.20)}{0.02} * \text{DPOP}$$

$$\bar{R}^2 = .68 \qquad \text{SER} = 110.4 \qquad \text{DW} = 1.87$$

In general, the estimated equations conform to our prior expectations. Of some note however, are the price variables. The real price of single-family housing should be negative, but it is positively signed in (1) and (2). This can be explained by the fact that price appreciation or the expectation thereof strongly influenced the demand for housing. The change in price does have a negative sign, and this reflects affordability and qualifying standards for home purchase.

The supply of single-family housing is a function of the real price and construction costs. Since data were not available for the latter, two proxies were used. First, the 6 month T-bill rate reflects the cost of funds to lenders, and second, the prime rate serves as the basis for construction loans to builders.

$$(4)\quad \text{BHSF} = -33.8 + \underset{(2.74)}{0.024} * \text{RPRICE} - \underset{(1.05)}{171.7} * \text{TB6/TB6(-1)} + \underset{(7.06)}{0.71} * \text{BHSF(-1)}$$

$$\bar{R}^2 = .80 \qquad \text{SER} = 138.7 \qquad \text{DW} = 1.85$$

$$(5)\quad \text{CHSF} = 1394 + \underset{(1.31)}{0.03} * \text{RPRICE(-1)} - \underset{(1.72)}{69.9} * \text{FYPR}$$

$$\bar{R}^2 = .06 \qquad \text{SER} = 262 \qquad \text{DW} = 1.87$$

$$(6)\quad \text{DHSF} = -24.3 + \underset{(2.68)}{0.03} * \text{RPRICE(-1)} - \underset{(1.87)}{57.49} * \text{TB6} + \underset{(3.40)}{0.71} * \text{DHSF(-1)}$$

$$\bar{R}^2 = .62 \qquad \text{SER} = 124 \qquad \text{DW} - 1.87$$

These equations are in line with the discussion above. The extremely low corrected R-squared term for Charleston County indicates that the series is nearly perfectly autoregressive since the regression was estimated with a Cochrane-Orcutt procedure.

Multifamily Housing

Multifamily housing starts are inherently difficult to model for several reasons. First, the construction cycle is significantly more volatile than for single-family units, and this is best evidenced by the over building that occurred in the early 1970's. Second, government subsidies have accounted for a significant proportion of multifamily activity in recent years. Finally, the financing sources are more dispersed, and hence, more difficult to track.

The estimated equations for the demand side are based primarily on real rents, population, the availability of the substitute which is single-family housing, and lagged starts.

$$\text{(7)} \quad \text{BHMFD} = \underset{(1.26)}{-8.61} * \Delta\text{RRENT} + \underset{(5.21)}{0.03} * \text{BMIG} + \underset{(4.18)}{0.46} * \text{BHMF}(-1)$$

$\bar{R}^2 = .74$ SER = 93.7 DW - 2.28

$$\text{(8)} \quad \text{CHMFD} = \underset{(0.86)}{-1.80} * \text{RRENT}(-1) + \underset{(2.79)}{0.041} * \text{RPRICE}(-1) + \underset{(2.44)}{0.59} * \text{CHMF}(-1)$$

$\bar{R}^2 = .53$ SER = 463.3 DW = 1.66

$$\text{(9)} \quad \text{DHMFD} = \underset{(3.52)}{0.022} * \text{RPRICE}(-1) - \underset{(2.70)}{1.85} * \text{RRENT}(-1) + \underset{(1.27)}{0.34} * \text{DHMF}(-1)$$

$\bar{R}^2 = .65$ SER = 131.4 DW = 2.06

In (8) and (9), the lagged real price of single-family housing demonstrates the affordability problem faced by potential owners and the substitution effect. As the real price increases, the demand for multifamily rental dwellings will increase. The real rent had the appropriate negative sign in each of the equations. However, population growth in the form of net migration was significant only for Berkeley County.

The supply of multifamily housing starts is a function of real rents, lagged starts, and the (relative) cost of financing.

$$\text{(10)}\quad BHMF = -1663 + \underset{(2.06)}{7.14} * RRENT(-1) + \underset{(4.00)}{81.58} * FMOR + \underset{(4.28)}{0.73} * BHMF(-1)$$

$$\bar{R}^2 = .72 \qquad SER = 97.7 \qquad DW = 2.18$$

$$\text{(11)}\quad CHMF = 1941.6 + \underset{(4.33)}{190.5} * \Delta RRENT - \underset{(2.14)}{956.8} * FMOR/TB6 + \underset{(3.89)}{0.86} * CHMF(-1)$$

$$\bar{R}^2 = .71 \qquad SER = 376.7 \qquad DW = 1.97$$

$$\text{(12)}\quad DHMF = \underset{(2.00)}{31.4} * \Delta RRENT + \underset{(2.40)}{18.1} * FMOR + \underset{(2.27)}{0.70} * DHMF(-1)$$

$$\bar{R}^2 = .57 \qquad SER = 158.5 \qquad DW = 2.25$$

The mortgage rate in (10) and (12) reflects profit opportunities to developers. As this rate increases and affordability becomes a greater problem for home purchasers, developers will shift to multifamily construction. Similarly, the spread between the mortgage rate and the cost of funds provides more incentives for lenders in single-family construction and thus, this ratio is negatively signed.

Price and Rent Equations

The average real price and rent are determined by the degree of disequilibrium in the respective housing market and the lagged real price and rent. Disequilibrium is proxied by the change in total population divided by the prior year's starts. Therefore, an increase in this ratio should indicate excess demand *ceteris paribus*, and accordingly, the real price of housing should increase.

$$(13)\quad \mathrm{LOG(RPRICE)} = \underset{(2.04)}{0.48} * \mathrm{LOG(TPOP/THSF(-1))} + \underset{(4.28)}{0.76} * \mathrm{LOG(RPRICE(-1))} - \underset{(2.34)}{0.76} * \mathrm{LOG(RRENT(-1))}$$

$$\bar{R}^2 = .85 \qquad \mathrm{SER} = .117 \qquad \mathrm{DW} = 1.93$$

$$(14)\quad \mathrm{LOG(RRENT)} = \underset{(0.83)}{0.014} * \mathrm{LOG(TPOP/THMF(-1))} + \underset{(21.47)}{0.96} * \mathrm{LOG(RRENT(-1))}$$

$$\bar{R}^2 = .94 \qquad \mathrm{SER} = .016 \qquad \mathrm{DW} = 1.93$$

Over this period (1965-80), rents were considerably more stable than housing prices. In general, rents declined in real terms. This is explained by some overbuilding in multifamily units and a strong shift in the demand for single-family housing. Hence, the lagged real rent variable is negative in (13).

Testing and Validation of the Model

In any estimation process, it is often essential to examine how closely the predicted value of an equation tracks its actual series. This evaluative procedure is certainly a necessary feature of the simultaneous system. However, this is not done by simply examining the standard deviation of each equation. Due to the simultaneous nature of the system of equations, errors appearing in each equation often accumulate in the simulation process. Consequently, additional statistical measures are often utilized.

One measure of comparison between the actual and simulated time paths is the Root-Mean-Square Error, or RMSE (Pindyck and Rubinfield, 1976).

In percentage terms,

$$\mathrm{RMSE} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}\left(\frac{Y_t-\hat{Y}_t^{\,2}}{Y_t}\right)} \;,$$

where:

Y_t is the actual value of the endogenous variable;

$\hat{Y}_t$ is the corresponding simulated value; and

T denotes the number of simulation periods

In addition to the RMSE, an essential feature of the simulation procedure is the assessment of the turning points in the data. For example, a sudden change in the historical data should be reflected in the simulated values. Unfortunately, no statistic can adequately achieve this objective. The researcher must scrutinize the data for all relevant changes.

The described testing and validation procedure is tedious and difficult. The researcher is usually faced with a trade-off. The RMSE may be quite acceptable for some endogenous variables, whereas the RMSE may be unappropriately large for others. Additionally, some variables may accurately catch the turning points, while other variables fail to accurately track the data. Nevertheless, in order to simulated with an adequate degree of reliability, the researcher must be able to accurately balance these effects to develop the appropriate model.

In line with the testing and validation process described above, the model was simulated over the historical period. The RMSE for the period 1965 to 1980 was generally within acceptable limits for most variables. Nearly 60 percent of the variables had an RMSE less than 10 percent, 75 percent were less than 15 percent, and 85 percent were less than 20 percent. In addition, the model reasonably followed the turning points in the sample period.

An assessment of the stochastic equations by block shows that the employment and income equations performed most adequately. The employment sector had 73 percent of the equations with an RMSE of less than 10 percent and 100 percent of the equations with less than a 15 percent RMSE. The respective percentages for the income block were 80 and 87 percent. For the most part, the high RSME errors appeared in Dorchester county equations, principally as a result of the small magnitude of some variables.

The stochastic equations of the demographics/transportation block and the financial/housing block had RSME less than 15 percent in approxmately two-thirds of the equations; 75 percent of the equations (in each block) had a RMSE less than 20 percent. The lower RMSE totals of the demographics/transportation block were due exclusively to the migration equations, whereas the high RMSE errors in the latter block were due to the high volatility of housing sector series.

RSME appearing in the investment sector and the government sector (a RMSE of 20 percent or less comprised 80 percent of the investment equations and 70 percent of the government) were principally the result of the high volatility of some of the series. This is particularly true of investment, where the location of one firm may grossly influence the totals. Finally, equations in the energy block had the largest RMSE (only 50 percent of the equations had an RMSE less than 20 percent). Since the data for this sector were extremely poor, and the equations were not linked simultaneously with the other blocks, it was ultimately eliminated from the model.

Chapter 5

BASIC SIMULATIONS OF THE CHARLESTON ECONOMETRIC MODEL

In this chapter we will discuss the six basic simulations or forecasts provided by the econometric model for a series of five scenarios concerning a possible earthquake in Charleston in 1983. The time frame for the econometric forecasts is the period from 1981 to 1990. The first simulation is the baseline forecast for the period with no event. We then simulate the effects of an unanticipated quake in 1983 with three combinations of assumptions concerning damages and the recovery path. Next, our fifth simulation assumes that a prediction of an event is made in 1981 for an earthquake to take place in 1983. The prediction is later declared to be incorrect. This simulation shows the possible dampening effects on the regional economy of a prediction. Our sixth simulation show the effects of a prediction for a 1983 earthquake which proves to be correct so that we can analyze the effects of mitigation on damage reduction. Only one recovery path is presented.

Measures of regional losses compared to the baseline simulation are presented for each of the five earthquake simulations. In addition, the distribution of these losses is shown across the three counties. Finally, an appraisal of the regional econometric model and the simulations is presented.

In Chapter 7, the housing supply process model is integrated with the regional econometric model and a new set of simulations is performed. The problems of incorporating process models in regional simulation models are then analyzed.

The Baseline Simulation 1981-1990

The baseline forecast serves as the basis of comparison for the other simulations. It represents a regional forecast of economic activity without a prediction or a catastrophic event. This is simply a traditional forecast. The forecasted values of the exogenous variables are held constant through the remaining simulations.

Briefly, we expect the Charleston economy in the 1981-1990 period to experience a relatively rapid rate of growth given our assumption of a 3 percent real growth rate in national GNP. In the first four years total employment in the region is predicted to increase at an annual rate of 6 percent, which equals the growth rate in the prior decade. This rate of growth is exceeded in the 1985-1990 period. The capital stock in manufacturing, which rose by 131 percent from 1970-80, jumps another 205 percent in the next decade. However, the increase in manufacturing employment is only 4,900 jobs, (22.8% incre

Real total personal income growth is projected to be close to that of the past decade. The average annual growth rate was 5.2 percent from 1970-80, and it would fall somewhat to 4.1 percent under our assumptions. Population growth in the region, which averaged 2.8 percent annually in the 1970's, would rise to 3 percent in the 1981-1990 period. Of the total population increase of 130,841 persons, nearly 90,000 is attributable to net migration. Real retail sales average a 6.5 percent annual increase in comparison to 5.5 percent from 1970-80.

From 1981-1990, housing starts total 117,860 units, an annual rate of nearly 11,800. Dividing the increase in population by housing starts yields a ratio of 1.5, which appears to be about right considering depreciation of existing stocks. Nearly 50 percent of the housing starts during the period are multifamily units, and this would tend to depress the population to starts ratio. Finally, the unemployment rate for the region averages 6.2

percent over the baseline forecast period.

The Three Unanticipated Quake Simulations

In these three simulations an earthquake is assumed to strike the region in 1983 with no prior warning. The quake is assumed to be centered in Charleston County and to be roughly of the same magnitude as the 1886 event with an average Modified Mercalli intensity of VII for the three-county region. Damage assumptions and loss estimates for two unanticipated quakes simulations are shown in Table 5.1. In the first simulation an optimistic view is assumed about the recovery path in that the damage to the housing stock and to the capital stock sustained in the event is assumed to be fully replaced in 1984, 1985, and 1986 as shown in the replacement ratios in Table 5.1. Thus, the lost structures are assumed to be cost-effective and will be replaced. This replacement is in addition to investment in housing and capital stock predicted by the model given the event.

By contrast, the second simulation of an unanticipated quake takes a more pessimistic view of the recovery path in that the damage to the housing stock and to capital stock suffered from the quake is not assumed to be replaced in 1984, 1985, and 1986. Investment that does take place in 1984, 1985 and 1986 is only the amount predicted by the model given the event so that only some recovery and replacement takes place.

The third simulation relating to an unanticipated quake shows the effects on the regional economy if the damage assumptions shown in Table 5.1 are doubled. Table 5.2 shows the double damage assumptions in this simulation. In addition, this simulation adopts the no replacement assumption of the second unanticipated quake scenario so that a very pessimistic outcome is shown.

Table 5.1

Damage Assumptions and Loss Estimates for Two Unanticipated Quake Scenarios

Death Rate		Deaths
Charleston County	100/100,000	292
Berkeley County	50/100,000	52
Dorchester County	50/100,000	34
		378 total
Housing Stock Damage		Units destroyed
Charleston County	6.5%	6754
Berkeley County	4.0%	1487
Dorchester County	4.0%	945
		9186 total
Capital Stock Damage		Losses millions of dollars
Charleston County	8.0%	22.8
Berkeley County	7.0%	103.5
Dorchester County	7.0%	8.4
		134.7 total
Transportation Flows (annual)		Trips lost - thousands
Charleston County	10.0%	17.6
Berkeley County	5.0%	7.0
Dorchester County	5.0%	1.5
		26.1 total

If replacement of damaged housing and capital stock takes place - ("The Replacement" Scenario)

	1984	1985	1986
Capital Stock Replacement	42%	42%	16%
Housing Stock Replacement	42%	42%	16%

Table 5.2

Assumptions for Unanticipated Quake With Double Damages and No Replacement

Death Rate		Deaths
Charleston County	200/100,000	584
Berkeley County	100/100,000	104
Dorchester County	100/100,000	68
		756 total
Housing Stock Damage		Units destroyed
Charleston County	13.0%	13,508
Berkeley County	8.0%	2,974
Dorchester County	8.0%	1,890
		18,372 total
Capital Stock Damage		Loss millions of dollars
Charleston County	16.8%	45.6
Berkeley County	14.0%	207.0
Dorchester County	14.0%	16.8
		269.4 total
Transportation Flows (annual)		Trips lost - thousands
Charleston County	20.0%	35.2
Berkeley County	10.0%	14.0
Dorchester County	10.0%	3.0
		52.2 total

The unanticipated quake will have the effect of reducing the stock variables in the model and will also damage the transportation network. We have assumed higher levels of destruction in Charleston County because of the greater age of the building stock, more multi-family housing structures, and the greater vulnerability of the transporation system.

The risk of death in an earthquake varies with the time of occurence and depends on whether the population is at home or at work. Brookshire and Schulze (1980) quote studies of a major earthquake on the San Andreas fault in Los Angeles with likely deaths as low as 32 per 100,000 population. This would mean a loss of 297 persons. We have assumed higher estimates. Charleston's rate is taken as 100 per 100,000 or 292 deaths. For Berkeley and Dorchester Counties, with lower risk factors, the death rate we use is 50 per 100,000 persons. This results in 52 deaths in Berkeley County and 34 in Dorchester County. Total death loss for the three county area is 378 persons. We do not make assumptions about the extent of injuries.

Damage to buildings varies with height, age of building and type of construction. Single family woodframe structures are less affected by ground shaking, but those with fireplaces and chimneys suffer more damage. Commercial-industrial structures and multi-family dwellings are more vulnerable. Brookshire and Schulze (1980) estimate that an average ground shaking intensity of a Mercalli VII for Los Angeles County would give an approximate damage of 3.5 percent of replacement cost to single family dwellings and a 5 percent damage for commercial structures. These are blended rates based on the age of structure, degree of reinforcement, and building height.

For our unanticipated quake scenario Table 5.1 we have assumed that damage to housing stock is 6.5 percent in Charleston County and 4 percent in Berkeley and Dorchester Counties. The loss of housing stock in Charleston County is equivalent to 6,754 units. In Berkeley County 1,487 units are lost and 945 units are destroyed in Dorchester County. The total loss of housing is 9,186 units. That compares to a baseline forecast of 164,750 housing units for the three-county region in 1983.

Regarding manufacturing in Table 5.1, for capital stock, which covers plant, equipment, and inventory, we have assumed that the damages are 8 percent in Charleston County and 7 percent in Berkeley and Dorchester counties. These damage rates are influenced by the presence of a number of wholly or partially unreinforced concrete and brick commercial structures in the region. Earthquake resistant building codes are not in force in the region. The capital stock losses are estimated at $103.5 million in Berkeley County, $22.8 million in Charleston County, and $8.4 million in Dorchester for a total of $134.7 million. Most of the manufacturing plants are located in Berkeley County.

Finally, we assume that damage to the bridges and highways in the area will be severe at least in the short-run. We suspect that initial transport flows within Charleston County will decline 25 percent and the Berkeley to Charleston and Dorchester to Charleston flows will decline 10 percent. However, with repairs to roads, bridges and overpasses taking place, we assume that on an annual basis, transportation flows with Charleston County will be down 10 percent for all of 1983 and down 5 percent for each of the outlying counties. The trips lost as seen in Table 5.1 will be largely in Charleston County and are 26,100 for the region as a whole.

Given the demand and supply equations for housing starts, some of the recovery process is endogenous for this sector. We would expect that changes in housing prices and rents to adjust the rate of starts following the earthquake. With full replacement of the lost housing stock, we assume, as Table 5.1 shows, that 42 percent of the housing losses are regained in both 1984 and 1985 and the remaining 16 percent in 1986.

More pessimistic outcomes are shown with the original damage assumptions and no replacement. The third anticipated quake scenario combines the double-damage assumptions seen in Table 5.2 with the no replacement assumption. As we show below, there is a striking difference in the present value of the regional losses across the various simulations despite the fact that 1990 estimates of total employment, total population and total real personal incomes for all seven simulations are remarkably similar.

The False Alarm: A Prediction Without an Occurrence

The fifth basic simulation assumes that a prediction is made in 1981 indicating an earthquake will take place in 1983. During the next 24 months following the prediction, revisions and update of the prediction are assumed to be presented to the public similar to the scenarios in Mileti, Hutton, and Sorrensen (1981). During this period we assume that capital investment in manufacturing, new housing starts, and net migration fall off at an increasing rate as 1983 approaches. We assume that the effects of the prediction on these variables are invariant across counties.

Finally, we assume that late in 1983, the official government agencies decide that the prediction has been based upon incorrect assumptions and that the entire prediction is in error. In spite of considerable embarrassment and criticism, the public is now told that the probability of a future earthquake for the Charleston region is really unknown. In effect an "all-clear" signal is given, and people are told to proceed as "normal". We assume that the reduced investments in the 1981-1983 period are totally regained in the 1984-86 period. The rationale for this assumption is that investments occur in the region because they are optimal. When a prediction is made, some investments are no longer optimal, assuming the prediction is believed.

After the "all-clear" prediction is made, the investments that were not made become optimal again. In other words, for this simulation no direct investent is permanently lost, some investments are only delayed from '81-'83 to '84-'86.

The specific add factors regarding this "false alarm" scenario are as follows:

	81	82	83	84	85	86
Capital Investment	(10)	(20)	(40)	30	30	10
Housing Starts	(10)	(20)	(40)	30	30	10
Net Migration	(5)	(15)	(30)	20	20	10

These figures are approximately equal to the precentage changes from the baseline scenario. (They are not exactly percentage changes because of changing bases over time.) In other words, there is a cumulative decline of about 70 percent of annual housing starts in the 1981-1983 period. About 40 percent of the housing starts not made in the 1981-1983 period are added to the 1984 baseline level, with the remainder added in 1985 and 1986.

We do not have any scientific way of verifying the assumptions about the decline in capital investment, housing starts, and net migration for the "false alarm" simulation. We have studied the scenario reactions to prediction of an earthquake in California developed by Mileti, Hutton, and Sorrenson (1980), and our numbers are consistent with their description of public and private sector reactions. The dampening effect on the economy from the prediction is likely, but how great will be the declines in new investment, housing starts and net migration is a matter for future research. The results of the simulation appear very plausible.

The economic effects of the incorrect prediction are estimated by the model by county and by year. For example, reduced capital investment for the 3 county area for the 3-year period is estimated at $133.7 million with Berkeley County taking the brunt at $107.6 million. By contrast, new capital investment in Dorchester County is down only $4.2 million.

Total net in-migration for the three county region is down 3,318 persons over the 1981-1983 period. Charleston County net in-migration losses are 1206, Berkely County losses are 984, and Dorchester County net in-migration is down 1128 persons.

Housing starts for the three county regions for the 1981-1983 period are off 6137 units. We have estimates by year and by county for both new single-family and multifamily construction. For example, Charleston County would lose 967 single-family units and 1976 multifamily units.

This scenario assumes tnat the reductions in capital investment, housing starts and net migration in the 1981-1983 period are fully replaced in the 1984-1986 period. Yet, because of the decreases in housing starts and new capital investments as a result of the prediction, there are decreases in employment and income.

The Anticipated Quake: A Correct Prediction

This is the sixth of our basic simulations. It is obvious that almost any number of simulations can be run to incorporate different assumptions about the timing, location, and magnitude of responses and the severity of various events. We feel that these basic simulations incorporate reasonable assumptions and are useful for illustrative purposes.

This simulation incorporates features of the recovery with replacement from the unanticipated quake plus the mitigation and dampening effects of the prediction from the "false-alarm" scenario (simulation number five) discussed above. A prediction is made in 1981 for an earthquake to occur in 1983. The specific assumptions regarding reductions in capital investment, housing starts and net migration are assumed to hold for 1981, 1982, and 1983 because of the prediction. For example, housing starts and new capital investment for 1981, 1982, and 1983 are reduced 10,20, and 40 percent from the baseline calculations.

After the quake takes place in 1983, the recovery takes place in 1984, 1985, and 1986. The recovery is assumed to compensate for the losses in activity prior to the quake plus the full replacement of damages suffered by the quake in 1983. Thus, the specific assumptions of this scenario exactly track those of the prediction and the unanticipated earthquake with replacement. The percentage reductions in economic activity relative to the baseline for the prediction and the recovery scenario are:

	81	82	83	84	85	86
Capital Investment	(10)	(20)	(40)	30	30	10
Housing Starts	(10)	(20)	(40)	30	30	10
Net Migration	(5)	(15)	(30)	20	20	10

Approximately 42 percent of the housing losses are recovered in 1984 and 1985 and the remaining 16 percent in 1986. These same percentages hold for recovering capital stock losses following the earthquake.

During the 1981-1983 period, it is assumed that various mitigation measures are undertaken which will reduce the damage assumptions we used above for the unanticipated quake. Table 5.3 shows the differences in damage assumptions between the scenarios for the unanticipated quake and the prediction (mitigation)-quake or anticipated simulation. The differential damages resulting from these different damage assumptions between an unanticipated quake and an anticipated quake are seen below in Table 5.4.

From Tables 5.3 and 5.4, it can be seen that mitigation is assumed to cut the death rate in half, and total deaths fall from 378 to 189. By the same token, mitigation measures are assumed to achieve substantial, reductions

Table 5.3

Damage Assumptions for Simulations of Unanticipated Versus Anticipated Earthquake

Unanticipated Earthquake		Prediction (Mitigation): Anticipated Earthquake
Death Rate		
Charleston County	100/100,000	50/100,000
Berkeley, Dorchester Counties	50/100,000	25/100,000
Housing Stock		
Charleston County	6.5%	5.5%
Berkeley, Dorchester Counties	4.0%	3.0%
Capital Stock		
Charleston County	8.0%	6.0%
Berkeley, Dorchester Counties	7.0%	4.5%
Transportation Flows (annual)		
Charleston County	10.0%	8.0%
Berkeley, Dorchester Counties	5.0%	4.0%

Table 5.4

Selected Damages for Charleston SMSA in Simulations Unanticipated Versus Anticipated Earthquake

	Unanticipated Earthquake	Prediction (Mitigation): Anticipated Earthquake
Deaths (persons)		
Charleston	292	145
Berkeley	52	27
Dorchester	34	17
total	378	189 total
Housing Stock Destroyed (units)		
Charleston	6754	5625
Berkeley	1487	1055
Dorchester	945	684
total	9186	7364 total
Capital Stock (million $)		
Charleston	$ 22.8	$17.1
Berkeley	103.5	66.5
Dorchester	8.4	5.4
total	$134.7	$89.0 total
Transportation Flows Trips Lost (annual)		
Charleston	17.6	14.0
Berkeley	7.0	5.6
Dorchester	1.5	1.2
total	26.1	20.8 total

in damages to housing, capital stock, and transportation flows. What is not shown here is the present worth of these reductions in losses stemming from the mitigation measures themselves. As we suggested in Chapter 2, the present worth in expected losses averted should be compared with the present worth of the costs of mitigation if we are to determine an efficient level of mitigation.

Finally, we should point out that the comparisons shown in Table 5.4 only show the damage effects of the earthquakes themselves - one anticipated and the other unanticipated. But, as we noted above, the effect of a prediction is to reduce economic activity in advance of the predicted event. Thus, despite some increases in expenditures for induced mitigation measures, the prediction itself will dampen housing starts and new capital investment. Presumably, the postponement of such expenditures will reduce losses below those of an unanticipated quake and will serve as one kind of mitigation measure. However, from an economic point of view, the regional economy at the end of 1983 could conceivably have lower amounts of capital stock and fewer housing units with a correctly predicted quake than would be the case with an unanticipated event. The crucial variables are the differences in the quake damages between the two events (one anticipated, one not) and the pre-quake dampening effects on new investment in capital stock and housing units of the prediction.

Table 5.5 illustrates the seeming paradox of the regional economy at the end of 1983 having less housing stock and less capital investment in the prediction-quake scenario compared to the unanticipated quake simulation. It can be seen that the assumed dampening effects of predictions on new expenditures prior to the quake produces reductions in stocks that are almost as large as the physical damages from the quakes themselves. Certainly, the reductions in stock from baseline because of the predictions are greater than the savings from the mitigation measures we have assumed.

Table 5.5

Reductions in Housing and Capital Stock at End of 1983:
Unanticipated Versus Anticipated Quake Simulations

Unanticipated Earthquake	Prediction (Mitigation): Anticipated Earthquake		
	From Prediction	From Quake	Total
Housing Stock (units)			
9,186	6,137	7,364	13,501
Capital Stock (million $)			
$134.7	$133.7	$89.0	$222.7

There are several comments to make on this apparent paradox. First, it is possible that we have been too severe in our estimates of the dampening effect of a prediction on new investment. This is possible because the damage coefficients we have assumed for the quake (both versions) are relatively small in relation to the annual new investments in capital stock and housing. Second, we also may not have assumed sufficient reduction in damage due to mitigation measures. A third factor is that Table 5.5 stops the comparison in 1983, and therefore is unfair. What is more relevant is a 1990 comparison. By that time we can take into account the boost to the regional economy which may come about from twin measures: (1) investment pressures for new housing and capital stock postponed by the dampening effects of the prediction; and (2) the pressures and resources for reconstruction and rebuilding of damaged physical plant. The correct perspective should include these two factors.

Although in several of the simulations we have assumed that there will be full replacement of the damaged capital stock and housing stock sustained in the 1983 earthquake and also that the postponed investment as a result of the prediction prior to the quake is made up, "full replacement" will not mean that the regional econony of Charleston will achieve the same baseline growth path projected before the prediction and the quake. Even though regional investment may be replaced, the delay in timing of the investment to later in the period may result in a lower level of regional output and income. We say "may" result in a lower level of income and a lower growth path because we have not specified the possible introduction of new technology or production functions relative to the baseline forecast. Thus, the lagged investment and the lower capital/labor ratio from 1981 through 1986 can result in less output in 1987 through 1990 even though the investment and damages were "replaced" by 1986. If, however, the delay in investment meant also improved technology and new production functions, as it did when Japan and Germany rebuilt in the Post-World War II period, then the growth path could conceivably be above the baseline projection. Ideally, our baseline projections should take into account improved technology and changing production functions over time so this point is not "really" relevant. In fact, however, the actual econometric baseline forecast does not deal with this kind of change. Therefore, it is quite possible that delayed investments coming in large lumps may, indeed, involve improved technology, more efficient production functions, and a changed output mix.

These comments, however, should not be taken to imply that Germany and Japan were made better off because of the war time destruction. Neither, is a region likely to improve its economic position because of large natural disaster. The point is that disasters do cause damage and losses which are very real and are often measurable. In Chapter 2 we have discussed how these net losses may be calculated. Our point here is that the calculation of these net losses is affected by what one assumes will be the future regional growth path, which is a function of many complicated uncertainties.

Comparison of Earthquake Simulation Results

We now compare and analyse the simulation results of the baseline simulation with the five earthquake simulations for the Charleston SMSA over the 1981-1990 period as provided by the regional econometric model. To recapitaluate: (1) both the unanticipated and the anticipated quake are assumed to occur in 1983; (2) both the incorrect prediction (false alarm) and the correct prediction for a 1983 quake are initially made in 1981 and have similar dampening effects upon housing starts, new capital investment and net migration in 1981, 1982, and 1983; (3) the basic unanticipated quake simulations assume full replacement of postponed investment in housing starts and capital stock as well as replacement of units and stock destroyed in 1984, 1985, and 1986; (4) in two unanticipated quake simulations "full replacement" of damaged housing and capital stock is not assumed and one of these simulations assumes "double damages" to illustrate the worst outcome; and (5) in all quake simulations it is assumed that repair of lifelines such as utilities takes place within a period of weeks.

In the next section we will describe the simulation results in terms of the aggregate regional effects upon population, total non-farm employment, personal income, and real personal income in 1972 dollars. Second, we will set forth the regional loss measures terms of differential income flows and differential stock (assets) in present value terms as described in Chapter 2. We will show these losses for the region as a whole and also the distribution of losses across the counties.

Effects upon the Regional Economy - 1981-1990

In this section we compare the effects of the five earthquake simulations with the baseline simulation in terms of the projections of total population, total non-farm employment, total personal income and total real personal income for the Charleston SMSA over the 1981-1990 period. Even though the regional losses sustained (as shown in the section below) are substanial, one is struck by the resiliency of the regional economy and its ability to recover from an earthquake disaster and the prediction of one even when pessismistic assumptions are employed. What is clear is that the health of the regional economy is determined more by the assumptions one makes about the national (exogenous) growth factors driving the regional economy than by the disruptive effects of an earthquake whose severe effects are largely temporary and tend to dimish over the longer run.

Tables 5.6, 5.7, 5.8, and 5.9 show the baseline projection for the Charleston SMSA for the unanticipated quake (1983), the prediction without an occurence, and the anticipated quake (1983) over the 1981-1990 period. In Table 5.6 the simulation results for total population are given. The baseline projection shows an increase of 125,647 persons over the decade or an average annual increase of about 2.86 percent. For the unanticipated quake simulation the population effects show up in 1983 when there are quake induced deaths and a slight fall in net migration. In 1984, net migration to the region continues to decline,but in the following years we can see that total population begins to catch up to the baseline figure so that the baseline population is actually exceeded in 1989 and 1990. The reason for this is seen in Tables 5.7, 5.8 and 5.9 which show that the employment and income effects of the recovery from the disaster (which

Table 5.6

Simulation Results for Total Population - Charleston SMSA

Year	Baseline	Unanticipated Quake (with full replacement)	Prediction without Occurance (with full replacement)	Quake Anticipated (with full replacement)
1981	439,157	439,157	438,862	438,862
1982	450,995	450,995	449,921	449,921
1983	463,116	461,606	460,265	459,247
1984	475,527	468,932	473,029	467,897
1985	488,384	483,097	486,207	481,898
1986	501,838	497,459	499,178	495,438
1987	516,072	513,449	513,063	510,519
1988	531,226	530,299	527,931	526,564
1989	547,247	547,822	543,706	543,392
1990	564,804	566,616	561,051	561,609

include full replacement of damaged housing and capital stock) drives the economy above the baseline figure.

For the "false alarm" (prediction without occurrence) and the anticipated quake simulations, Table 5.6 shows the population differentials compared to the baseline appear in 1981, 1982, and 1983 because of the effects of the prediction on net migration. In both prediction simulations population growth is resumed in 1984. By 1990 all four simulations show a Charleston SMSA population in excess of 560,000 with the difference in the totals from highest to lowest being 5565 persons - approximately one percent.

Perhaps the most important Table is 5.7 because it is regional employment that drives (for the most part) net migration, and it is regional employment that is a major determinant of movements in personal income. The contrasts across the four simulations of total non-farm employment in Table 5.7 really tell the tale of the regional economy. As the baseline simulation shows, we expect a rather healthy growth in total non-farm employment over the decade of approximately 7.7 percent on an average annual basis. By 1990 Table 5.7 shows that total employment exceeds the baseline employment in the unanticipated quake scenario, just about equals baseline employment in the anticipated quake scenario and is about 1.8 percent below it in the "false alarm" simulation.

What the simulations show is that the dampening effects of the prediction (correct or false) over 1981, 1982 and 1983 we have assumed put brakes on employment not seen in either the baseline or the unanticipated quake simulations. Given these dampening effects, the full replacement assumptions do serve as stimulants to building and reconstruction in 1984, 1985, and 1986, so the economy is pulled toward the baseline situation. In the anticipated quake simulation, the reconstuction of damaged stock is sufficient to stimulate the economy to makeup more than the postponed investment from

Table 5.7

Simulation Results for Total Nonfarm Employment - Charleston SMSA

Year	Baseline	Unanticipated Quake (with full replacement)	Prediction without Occurance (with full replacement)	Quake Anticipated (with full replacement)
1981	152,714	152,714	152,521	152,521
1982	157,640	157,640	156,743	156,743
1983	164,169	163,742	161,220	160,939
1984	172,587	172,731	168,415	168,587
1985	182,445	186,541	178,330	181,094
1986	194,489	201,596	190,333	195,024
1987	208,688	217,454	204,316	209,982
1988	225,787	235,161	221,080	226,991
1989	246,374	255,682	241,284	246,974
1990	270,698	279,479	265,172	270,324

the false alarm and in fact to put it ahead of the baseline projection in 1986, 1987 and 1988.

The most interesting simulation in Table 5.7 is the unanticipated quake with full replacement or recovery of damages assumed over the 1984, 1985 and 1986 period. With the stimulus to the economy from repair and replacement of housing and capital stock, employment in this quake simulation is only slightly below the baseline in 1983, and by 1985, it has shot ahead of the baseline employment. Because a prior prediction was not made, the economy started from a higher level when reconstruction began and the amount of reconstruction from the higher damages assumptions is sufficient to stimulate employment to drive it ahead of the baseline very rapidly. Note especially the comparison of employment in the unanticipated quake simulation compared to the baseline employment when the absolute and percentage differences are very large in 1987 and 1988. Also, we can see that the stimulative effects begin to taper off and by 1990, while the unanticipated quake simulation is still ahead of the baseline, the differences declines and the regional economy begins to approach its baseline growth path.

At this point, we urge the reader not to jump to the conclusion that the unanticipated quake shows a desirable outcome because it has higher nonfarm employment and somewhat higher total personal income. In the following section we show regional losses. We will show that, despite the stimulus to employment brought about by full replacement of damaged capital stock and housing in the unanticipated quake scenario, regional losses in present value terms (compared to baseline values) substantially exceed the loses of both the anticipated quake and the false alarm simulation. And, as expected the smallest regional losses are seen in the false alarm simulation which has no earthquake. We need to stress that recovery from earthquakes and their predictions may stimulate employment and construction and drive up labor and business income, but this is not sufficient to offset the very real and substantial income and wealth losses to the region caused by the event: Note also that the social losses in terms of death, injuries, trauma and dislocation of people, which we have not counted, should also be considered.

Tables 5.8 and 5.9 show the simulations of personal income for the Charleston SMSA over the 1981-1990 period for the four simulations. In the baseline simulation, personal income growth in real terms rises about 4 percent a year over the decade. The employment effects seen in Table 5.7 drive up construction salaries, wages, and profits more than enough to offset components of personal income such as interest, rent, and dividends which are adversely affected by the damage sustained in the quake simulations. The net effect is that the personal income paths in Tables 5.8 and 5.9 closely follow the employment results seen in Table 5.7 across the four simulations. However, the differences are less pronounced because personal income figure pick up some losses not shown in employment totals per se.

Tables 5.6, 5.7, and 5.8, and 5.9 deal with the effects on regional population, employment, and personal income in quake simulations when full replacement of damaged and/or postponed investment is assumed to take place in 1984, 1985 and 1986. It is now important to look at some more pessimistic simulations where no replacement is assumed. We will also look at the double damage scenario with the no replacement assumption.

Tables 5.10, 5.11, and 5.12, and 5.13 show simulation results for the Charleston SMSA for total population, total non-farm employment, personal income and real personal income. The first two columns in each table duplicate the first two columns in Tables 5.6, 5.7, 5.8, and 5.9 covering the baseline projection and the unanticipated 1983 quake with full replacement of damaged housing and capital stock. Columns three and four show first simulations of the unanticipated quake without recovery (under the standard damage

Table 5.8

Simulation Results for Personal Income - Charleston SMSA
(Billions of Dollars)

Year	Baseline	Unanticipated Quake (with full replacement)	Prediction without Occurance (with full replacement)	Quake Anticipated (with full replacement)
1981	3.441	3.441	3.440	3.440
1982	3.797	3.797	3.788	3.788
1983	4.210	4.205	4.180	4.177
1984	4.684	4.672	4.641	4.636
1985	5.213	5.233	5.172	5.190
1986	5.821	5.866	5.780	5.816
1987	6.511	6.573	6.467	6.514
1988	7.311	7.381	7.262	7.314
1989	8.241	8.315	8.186	8.239
1990	9.303	9.377	9.240	9.293

Table 5.9

Simulation Results for Real Personal Income - Charleston SMSA (Billions of 1972 Dollars)

Year	Baseline	Unanticipated Quake (with full replacement)	Prediction without Occurance (with full replacement)	Quake Anticipated (with full replacement)
1981	1.811	1.811	1.810	1.810
1982	1.852	1.852	1.848	1.848
1983	1.914	1.911	1.900	1.898
1984	1.985	1.980	1.966	1.964
1985	2.052	2.060	2.036	2.043
1986	2.132	2.149	2.117	2.130
1987	2.215	2.236	2.200	2.216
1988	2.314	2.336	2.298	2.314
1989	2.431	2.453	2.415	2.431
1990	2.549	2.569	2.532	2.546

assumptions, Table 5.1) and, next, the simulation of the unanticipated quake with double damages (Table 5.2) and again without full replacement of damaged housing and capital stock. There is some partial replacement, as we indicated above, because the price effects in the housing market equations would stimulate some replacement.

As can be seen from Tables 5.10, 5.11, 5.12, and 5.13, the no replacement assumption gives the population, employment, and personal income totals which are lower than either the baseline simulation or the unanticipated quake with full replacement. The differences are most striking in Table 5.11 showing total nonfarm employment. Here we can see that 1990 employment with replacement for the unanticipated quake is over 12,000 higher than the same quake without replacement of damaged units and investment.

It is interesting to see that doubling the damages (which would double regional losses!) does not drastically lower estimates of population, employment, and personal income compared to the use of standard damage assumptions and no replacement. Again, we note that these tables are not full measures of regional losses. Also, as we suggested above, the regional econometric model is largely driven by national (exogenous) factors so that the economy is pulled along a growth path which is not dramatically lower than the baseline sumulation despite double damages and little replacement of housing units destroyed and capital stock damaged. Again, refer to Table 5.2 and note that double damages are assumed to be 14 percent of capital stock in Berkeley County where most of the manufacturing is located.

Tables 5.14 and 5.15 are important at this point to illustrate the relation of our damage assumptions to the capital and housing stock at risk and to annual investments in capital plant and equipment and housing. The extent of damage should always be related to the size of the housing and capital stock and to the size of the economy. Simple dollar or unit totals are

Table 5.10

Simulation Results for Population - Charleston SMSA

Year	Baseline	Unanticipated Quake (with full replacement)	Unanticipated Quake (no replacement)	Double Damages (no replacement)
1981	439,157	439,157	439,157	439,157
1982	450,995	450,995	450,995	450,995
1983	463,116	461,606	461,606	460,097
1984	475,527	468,932	468,250	460,984
1985	488,384	483,097	481,719	475,082
1986	501,838	497,459	495,782	489,768
1987	516,072	513,449	510,529	505,035
1988	531,226	530,299	526,107	521,042
1989	547,247	547,822	542,465	537,739
1990	564,804	566,616	560,270	555,792

Table 5.11

Simulation Results for Total Nonfarm Employment - Charleston SMSA

Year	Baseline	Unanticipated Quake (with full replacement)	Unanticipated Quake (no replacement)	Double Damages (no replacement)
1981	152,714	152,714	152,714	152,714
1982	157,640	157,640	157,640	157,640
1983	164,169	163,742	163,742	163,313
1984	172,587	172,731	170,943	169,302
1985	182,445	186,541	181,012	179,580
1986	194,489	201,596	192,913	191,343
1987	208,688	217,454	206,898	205,116
1988	225,787	235,161	223,659	221,548
1989	246,374	255,682	243,747	241,149
1990	270,698	279,479	267,385	264,123

Table 5.12

Simulation Results for Personal Income - Charleston SMSA
(Billions of Dollars)

Year	Baseline	Unanticipated Quake (with full replacement)	Unanticipated Quake (no replacement)	Double Damages (no replacement)
1981	3.441	3.441	3.441	3.441
1982	3.797	3.797	3.797	3.797
1983	4.210	4.205	4.205	4.199
1984	4.684	4.672	4.657	4.629
1985	5.213	5.233	5.187	5.101
1986	5.821	5.866	5.794	5.766
1987	6.511	6.573	6.482	6.453
1988	7.311	7.381	7.278	7.245
1989	8.241	8.315	8.203	8.164
1990	9.303	9.377	9.257	9.211

Table 5-13

Simulation Results for Real Personal Income - Charleston SMSA

Year	Baseline	Unanticipated Quake (with full replacement)	Unanticipated Quake (no replacement)	Double Damages (no replacement)
1981	1.811	1.811	1.811	1.811
1982	1.852	1.852	1.852	1.852
1983	1.914	1.911	1.911	1.909
1984	1.985	1.980	1.973	1.962
1985	2.052	2.060	2.042	2.032
1986	2.132	2.149	2.122	2.112
1987	2.215	2.236	2.205	2.195
1988	2.314	2.336	2.303	2.293
1989	2.431	2.453	2.420	2.408
1990	2.549	2.569	2.536	2.534

not meaningful. What is the relation of damage to annual new construction and to annual replacement? This is the important indicator.

Table 5.14 shows the relation of gross investment in the three-county region to capital stock and to the standard assumptions we employed. The damage assumptions to capital we have used for the unanticipated quake are approximately only half of the ratio of estimated annual gross investment to capital stock under "normal" conditions. Although this is not a conclusive indicator of the resilience of the economy, it is indicative of the fact that the capital stock damage appears on the surface, at least, to be well within the tolerance of the regional economy for replacement.

Table 5.15 shows the ratio of housing starts (real and estimated) to total units of housing stock. Again, the damage assumptions we have used for the anticipated and unanticipated quake appear to be of approximately the same magnitude. In fact, the cyclical variation in housing starts over a boom-recession cycle is likely to be more than enough to cover the extra damage to the stock of housing than is an unanticipated quake unless one uses extreme damage figures - ones not found in the literature on the effects to U.S. housing from seismic stress. Our baseline forecast for 1985 has a ratio of housing starts to housing stock of 6.3 percent. We estimate the damage to housing stock from an unanticipated quake in Charleston County to be 6.5 percent and 4 percent in Berkeley and Dorchester counties. Again, the damage to the housing stock, while very real, is likely to be well with the tolerance of the regional economy for replacement, particularly if some allowance is made for a likely influx of construction firms and labor from other regions following the event.

Table 5.14

Relation of Gross Investment to Capital Stock and Damage Assumptions

	Gross Investment (millions of dollars)	Capital Stock (millions of dollars)	Ratio (GI/CS)
1970	78.7	337.4	23.3%
1975	76.9	547.3	14.1
1980	205.8	1511.4	13.6
1985*	327.4	2388.2	13.7
1990*	636.3	4573.1	13.9

*Baseline forecast

"Standard" Damage Assumptions to Capital Stock:

	Unanticipated Quake	Anticipated Quake
Charleston County	8.0%	6.0%
Berkeley, Dorchester Counties	7.0	4.5

Table 5.15

Relation of Housing Starts to Housing Stock and Damage Assumptions

	Housing Starts	Housing Stock (units)	Starts Stock
1970	2,971	103,033	2.9%
1975	2,976	124,056	2.4
1980	6,790	151,855	4.5
1985*	11,322	180,958	6.3
1990*	16,313	236,247	6.9

*Baseline forecast

Damage Assumptions to Housing Stock

	Unanticipated Quake	Anticipated Quake
Charleston County	6.5%	5.5%
Berkeley, Dorchester Counties	4.0	3.0

Estimates of Regional Losses in Five Earthquake Simulations

In this section we present the estimates of regional losses for each of the five earthquake simulations relative to the baseline simulation. The losses will be first shown for the three-county SMSA region as a whole. Then, we will show some (but not all) of the differences in losses across the three counties to illustrate the flexibility of the model to highlight spatial variations in losses at the county level. At present the model does not deal with the pinpointing of losses at the sub-county level, although this can be done on an *ad hoc* fashion if one knows the specific location of factories, bridges mutli-story construction and the like.

In Table 2.1 in Chapter 2, we presented a summary of how we estimate regional losses from an earthquake in the Charleston econometric model. The first category of losses as seen in Table 5.16 is regional non-property income which is composed of three parts: labor and proprietor income, commuter income and transfer payments. Commuter income is the adjustment made in earnings reported by place of work to place of residence. Transfer payments are government transfer payments such as social security, welfare, and unemployment benefits.

The second category of losses is nonresidential regional capital income. The private nonresidential regional capital stock is estimated to be a constant multiple (5.3) of manufacturing capital. The return on non-residential capital is taken as a blend of the average corporate interest rate and the return on equity (11.39 percent).

The two categories of income losses reported in Table 5.16 are losses resulting from disruption of economic activity and the damage to capital stock. These income changes (relative to the baseline) over the ten-year simulation period have been converted to present value terms by a discount rate of 11.39 percent.

The third and fourth categories of loss shown in Table 5.16 are best estimated directly in terms of capital losses (stocks) rather than income flows. Here the basis of loss is taken to be estimated replacement costs of residential housing units destroyed or damaged and the damage to regional social capital from the quake simulations. Ideally, we would like to measure the "willingness to pay" for such capital, but this can not be done so that estimates of replacement cost set an upper bound. Losses of consumer durables are assumed to be 60 percent of housing stock damaged. Social capital in the Charleston region is assumed to be 68 percent of private nonresidential capital.

Again, we emphasize that Table 5.16 shows the present value of losses over the 1981-1990 period relative to the baseline simulation. Note carefully that numbers in parentheses are thus to be interpreted as gains not losses. Table 5.16 deserves careful study. First, note the bottom line. The unanticipated quake (with full replacement assumed) has regional losses of one billion dollars; the anticipated quake, involving a prediction with dampening effects an investment in 1981, 1982, and 1983 plus a quake in 1983 (with full replacement of investment) has net losses of 900 million dollars; and finally the "false alarm" scenario has regional losses of approximately 294 million dollars due to dampening effects upon investment and net migration in 1981, 1982, and 1983 even though full replacement over 1984, 1985 and 1986 is assumed.

A study of Table 5.16 shows that these regional losses are dominated first by capital losses in residential housing, then by losses in social capital and third by losses in the present value of income losses from nonresidential private capital. This means that one can get a quick notion of regional losses by first looking at these three categories of loss.

For most readers, some explanation of labor and proprietor income will prove interesting. As can be seen in Table 5.16 labor and proprietor income for the unanticipated 1983 quake is positive in present value terms by approximately 149 million dollars. And, the losses in labor and proprietor income for the anticipated quake are less than the losses in labor and proprietor income from an incorrect prediction and no quake at all! How can these apparently strange results be explained?

The answer is that the stimulus to employment and reconstruction steming from the disaster (with full replacement assumed to take place in 1984, 1985 and 1986)is sufficient to increase labor and proprieter income relative to our rather optimistic baseline projection of employment and income. Cochrane (1975) was quite concerned about the distributive effects of adjustments to natural hazards,and he pointed out that little is known about the distribution impacts of a disaster upon the construction industry. Our simulations provide evidence that destruction of housing and capital stock appear to stimulate labor and proprietor income (we earlier saw the effects on regional employment) even though there are net regional losses of substantial amounts.

The full replacement assumption does not deal directly with the question of federal policy and outside aid for relief and reconstruction. We also have not examined the role of insurance. Thus, we do not consider the full range of distribution issues posed by Cochrane.

Table 5.17 shows the present value of regional losses for the unanticipated quake under full replacement, with no replacement and with double damages and no replacement. As we should expect, regional losses rise from one billion dollars to 1.3 billion dollars (no placement) to 2.65 billion dollars (with double damages). With less than full replacement, the unanticipated quake now shows losses in labor and proprietor incomes because the stimulus effect to the local economy from reconstruction is much reduced.

In many ways, a comparison of the unanticipated quake simulations as provided in Table 5.17 concerning full vs. little replacement is very instructive. What this table tells us is that policies that encourage rebuilding, such as disaster insurance and special aid, can have a substantial effect on regional income losses and the recovery path. In Table 5.17 we can see that the losses from the "no replacement" assumption exceed the losses of the unanticipated quake with full replacement by an amount in excess of 30 percent ($1 billion vs. $1.3 billion). Thus, regional losses from a disaster appear to be very sensitive to assumptions we make about replacement of damage and the recovery path. However, Table 5.17 also tells us that the bulk of the regional losses (even when income and employment effects of reconstruction are taken into account) are based upon the damage estimates to housing and capital stock assumed to be caused by the event.

In addition, it is important to remember that both Tables 5.16 and 5.17 show that the dampening effects of a prediction, which is believed, can have sustantial negative effects on regional income and employment. As Table 5.16 shows, the gains (less losses) of a correct prediction over an unanticipated quake are less than the losses of an incorrect prediction. These results stem, of course, from the rather sharp cutbacks we assumed in investment in housing and capital and in net migration in 1981, 1982, and 1983 because of a "credible" prediction. Nevertheless, our results do suggest that the dampening effects of a prediction even though it may reduce damages from a correctly predicted event (compared to an unanticipated event) must be carefully considered.

Tables 5.18, 5.19, 5.20 and 5.21 illustrate the flexibility of the model to show results of the simulation by year and by county. All four tables are based on the unanticipated quake simulation (with full replacement) as already seen in Tables 5.16 and 5.17. In the two earlier tables only regional totals over the ten year period were shown. Here we have the break out by county by year from 1981 through 1990. Similar tables could be developed for all five earthquake simulations.

As Table 5.18 shows, over half of the regional losses from an unanticipated quake are sustained in Charleston County with another 37 percent sustained in Berkeley County. By contrast, Table 5.19 shows that the gains (not losses) in regional non-property income appear in Berkeley and Dorchester counties while Charleston county shows losses in regional non-property income. This is the result of the replacement of capital destroyed in Berkeley and Dorchester counties and the residential adjustment factor for the income of workers living in the bedroom counties.

Table 5.20 shows the losses in nonresidential property incomes by county. The bulk of the losses are sustained in Berkeley and Charleston counties. However, Table 5.20 shows that the losses in 1983 from the quake are concentrated in Berkeley county where most of the manufacturing is located. The replacement assumption for capital stock then leads to a greater recovery of property income for this county than in Charleston county, which continues to show income losses relative to the baseline throughout the decade.

Table 5.21 shows that the loss of residential housing units is concentrated in Charleston county. This is a product of the higher damage rates assumed there because of older and more multi-story housing units.

Brief Appraisal of Simulations

A full scale appraisal of the econometric model and the simulations appears in Chapter 8. However, it is useful here to provide some comments on the five earthquake simulations we have developed.

First, we would like to stress again that we have dealt only with economic losses that are readily measurable. We have not dealt with the social losses of deaths and injuries, nor have we taken into account the social losses from trauma and dislocation. However, both the theoretical and empirical approaches we have taken do not conflict with these omissions and could be modified to take them into account if reasonable data were available.

Second, our econometric model is based upon annual data so that we are unable to show short-run responses. Note, also, that we have assumed that lifelines such as roads and utilities are restored in a matter of weeks, although we do assume annual reductions in trips across bridges and roads in 1983.

Third, our econometric model is largely constructed from data from the 1970 decade so that it may not fully reflect changes in the economy in the 1980's. Nevertheless, the regional losses we have shown are always in reference to a baseline projection so that needed improvements in the basic model would be more important in affecting possible recovery paths than in merely improving the baseline forecasts. For the most part, we have had to rely on crude ratios in our estimates of consumer durables, total non-residential regional capital and regional social capital. We believe the theoretical approaches we have taken are sound. The problem is that the empirical data are not what we would like. Also, we do not show effects at the sub-county level.

Fourth, it is possible to quarrel with the assumptions we have made about damages sustained with and without a prediction. It is also possible to question the assumptions we have made about the dampening effects upon housing starts, capital investment, and net migration from a credible prediction. Yet, we believe our assumptions appear "reasonable", and certainly we can point out that the model, itself, is capable of simulating a countless number of alternative assumptions. We have not explicitly dealt with relief and recovery policies. These, too, could be simulated. However, we have shown the effects of recovery with full replacement of damaged and/or reduced investment from the event and from a prediction so that we have bounded some of the relief policies.

Finally, we would like to emphasize that the losses we have measured are regional in scope and not national. We suspect that national losses would be less than regional losses. Yet, we would like to refer the reader again to Table 5.16. As we noted above, the bulk of the regional losses sustained appear in terms of damage to capital stock, to housing and to social capital. Nonresidential property income losses we have measured come about largely through reductions in housing starts, declines in new investment, and capital stock destroyed. By contrast, we have shown that the recovery process with replacement can stimulate total nonfarm employment and actually can increase labor and proprietor income relative to the baseline projection. When all of these regional effects (stock and flow) are taken into account, it is not obvious what the national balance would show.

Table 5.16

Present Value of Regional Losses, Charleston SMSA
(Millions of Dollars)

	Unanticipated Quake (Full Replacement)	Anticipated Quake (Full Replacement)	Prediction Without Occurance (Full Replacement)
Regional Nonproperty Income	(91.641)	81.106	163.388
Labor and Proprietor Income	(149.365)	69.740	194.452
Commuter Income	44.015	14.485	(16.344)
Transfer Payments	13.710	(3.118)	(14.720)
Nonresidential Regional Capital Income	177.562	162.281	130.363
Residential Housing	523.345	415.415	0
Social Capital	391.090	241.331	0
Total	1000.360	400.037	293.751

Note: Totals may not add due to rounding.

Gains are in parentheses.

Table 5.17

Present Value of Regional Losses, Charleston SMSA (Millions of Dollars)

	Unanticipated Quake (Full Replacement)	Anticipated Quake (Full Replacement)	Prediction Without Occurance (Full Replacement)
Regional Nonproperty Income	(91.641)	105.246	210.720
Labor and Proprietor Income	(149.365)	97.494	195.524
Commuter Income	44.015	10.727	20.760
Transfer Payments	13.710	(2.975)	(3.563)
Nonresidential Regional Capital Income	177.562	308.010	616.117
Residential Housing	523.345	523.345	1046.690
Social Capital	391.090	311.096	782.280
Total	1000.360	1327.700	2655.810

Note: Totals may not add due to rounding.

Gains are in parentheses.

Table 5.18

Unanticipated Quake (Full Replacement)
Present Value of Losses
(Millions of Dollars)

Total

	Berkeley County	Charleston County
1981	0	0
1982	0	0
1983	462.559	429.112
1984	23.373	26.043
1985	-8.562	23.696
1986	-21.363	23.300
1987	-22.858	19.728
1988	-21.641	15.896
1989	19.423	12.403
1990	-16.859	9.507
Total	375.225	559.684

	Dorchester County	Total SMSA
1981	0	0
1982	0	0
1983	92.149	983.819
1984	1.610	51.025
1985	-1.946	13.187
1986	-4.269	-2.331
1987	-5.400	-8.531
1988	-5.824	-11.568
1989	-5.691	-12.711
1990	-5.182	-12.533
Total	65.446	1000.360

Table 5.19

Unanticipated Quake (Full Replacement)
Present Value of Losses
(Millions of Dollars)

Regional Nonproperty Income

	Berkeley County	Charleston County
1981	0	0
1982	0	0
1983	1.560	1.472
1984	-1.466	12.346
1985	-13.050	9.685
1986	-20.108	8.978
1987	-21.752	7.336
1988	-20.667	5.867
1989	18.567	4.525
1990	-16.104	3.386
Total	-110.154	53.596

	Dorchester County	Total SMSA
1981	0	0
1982	0	0
1983	.843	3.875
1984	-1.133	9.746
1985	-3.638	-7.003
1986	-5.510	-16.640
1987	-6.481	-20.898
1988	-6.764	-21.564
1989	-6.507	-20.548
1990	-5.893	-18.610
Total	-35.082	-91.641

Table 5.20

Unanticipated Quake (Full Replacement)
Present Value of Losses
(Millions of Dollars)

Nonresidential Regional Property Income

	Berkeley County	Charleston County
1981	0	0
1982	0	0
1983	50.328	11.097
1984	24.839	13.697
1985	4.488	14.010
1986	-1.254	14.322
1987	-1.107	12.392
1988	-.974	10.030
1989	-.856	7.878
1990	-.755	6.121
Total	74.709	89.546

	Dorchester County	Total SMSA
1981	0	0
1982	0	0
1983	4.084	65.509
1984	2.742	41.278
1985	1.692	20.190
1986	1.241	14.308
1987	1.081	12.367
1988	.940	9.996
1989	.816	7.838
1990	.711	6.077
Total	13.308	177.562

Table 5.21

Unanticipated Quake (Full Replacement)
Present Value of Losses
(Millions of Dollars)

Residential Housing

	Berkeley County	Charleston County
1981		
1982		
1983	110.213	350.294
1984		
1985		
1986		
1987		
1988		
1989		
1990		
Total	110.213	350.294

	Dorchester County	Total SMSA
1981		
1982		
1983	62.838	523.345
1984		
1985		
1986		
1987		
1988		
1989		
1990		
Total	62.838	523.345

CHAPTER 6

METHODOLOGY FOR USING PROCESS MODELS

Introduction

Models based on historical data appear to have a number of limitations when it comes to assessing situations substantially outside the frame of observation. This applies to situations where new developments or processes may come into play, as well as to situations that may recur but for which there are little or no recorded data, such as with Charleston, where the last major earthquake was 1886. An alternative to historical data-based models are technology based models drawn from engineering specifications of economic processes. For the problem at hand--the assessment of the economic effects of earthquakes and the predictions of such events--this is a promising alternative to econometric modeling. Consequently, a substantial amount of research effort associated with this study was aimed at solving a number of technical problems involved with using process models.

The purpose of this chapter is to present a methodology for using process models to analyze the economic effects of disasters or predictions of disasters. The following section outlines the limitations of historical data-based models. Then the structure of process models is briefly presented and the advantages of technology based models outlined. However, process models also have a number of limitations, in their own right, and these are discussed in some detail. The final section of this chapter is a discussion of the added problems associated with combining process models with econometric equations.

The problems encountered with utilizing process models are formidable, and we have only limited success in dealing with these. Future research will be required to determine whether the approach can be successful generally. The moderate success of our use of a process model for housing supply in the Charleston econometric model is presented in Chapter 7.

Limitations of Historical Data-Based Models

Models that are estimated on the basis of historical observations have a number of limitations. First, such models are derived from a theoretical basis that, by necessity, involves abtraction and focuses on equilibrium conditions. If historical observations reflect disequilibrium conditions, the estimated parameters of the model will not likely produce an accurate picture of long-term conditions.

Second is the problem of multicollinearity. If a dependent variable is a function of two or more independent variables that historically have varied (nearly) proportionally (or in any linearly dependent way), it is impossible (or virtually so) to assign empirically the degree of causality of one variable versus the other(s). However, in simulations, often one would like to vary only one of these independent variables, and hence, a reliable estimate of its true coefficient is desirable.

The third problem concerns the range of historical observation. If firms or consumers have faced only a very limited range of relative prices for commodities, it is highly unlikely that equations based on such observations will be accurate in predicting responses to substantial variations in prices. No matter how sensitive one is, it is difficult to determine the shape of an elephant by feeling only a small part.

The fourth problem is that responses with new technologies or processes could be different from responses of old technologies that historical data mirror. This problem is similar to the third problem in that probable responses for simulations into the future lie outside the range of historical obsersvation.

Finally, all data contain errors of omission and commission occurring in the process of gathering, recording, and manipulating them. With historical data, however, it is usually impossible to verify or even check on the quality of the data.

The Structure of Process Models

In its simpliest form, a process model consists of a collection of technologies or processes of production (Chenery (1949), Manne and Markowitz (1963)). Each process is represented by a vector of numbers that gives the amount of each of n inputs required and the amount of each m outputs produced per unit of the activity. The activity is linearly homogeneous in that a doubling of the activity level doubles all input requirements and outputs produced. The model is usually solved to minimize cost or maximize net revenue subject to some set of constraints. In this form the problem is a linear programming problem and is efficiently solved by the simplex algorithm.

Since the processes are linearly homogeneous, maximization of profit without constraints either gives a solution of zero for all activities or the solution is infinite. With constraints, one obtains a restricted profit solution which will be a function of the parameters of the model: prices and the restricted levels of inputs or outputs. (Of course, the constraints may not insure an unbounded solution exists.)

If the model is to be applied to competitive market situations, then restriction of inputs or output is often not realistic. If the model is solved to maximize revenue subject to a cost constraint only, the one optimal solution will be to run one activity at a level to meet the cost constraint--the activity with the greatest net profit, which can easily be determined by hand calculation--the other activities to be set at zero.

Advantages of Technology Based Models

Given the structure of the process models, many of the limitations of historical data-based models outlined above are easily overcome. Solutions for optimal processes under given input and output prices can easily be determined to be equilibrium or partial adjustment solutions by the construction of the objective function and the nature of the constraints. Multicollinearity is easily obviated by changing parameters separately. The range of parameter changes can be made as broad as desired. New technologies can be directly incorporated as long as the engineering data are available. While errors of data collection may still occur, there is more recourse in case of error with the process model.

The principal gain over the historical data-based model for purposes of hazard assessment is, however, the ability to incorporate alternative technologies--both existing, unused technologies that are not cost effective, and new technologies that have not been adopted heretofore or are on the drawing boards. In addition, the structure of the process model allows one to easily incorporate explicit constraints on input usage. While not a criticism of historical data-based models, in general, most regional econometric models are based on the Keynesian model that assumes supply will be forthcoming to meet demand. Such models contain no (or few) supply-side constraints. While such constraints can be incorporated, it is another data requirement for the historical data base, one that is often hard to meet. Thus, the process model has an advantage in this regard.

Limitations of Process Models

The advantage of process models come hand in hand with a number of limitations, in and of themselves and with coupling the process model with other equations of the regional economy. The general problems associated with developing a process model for a particular economic sector include: gathering the technologies; aggregating; validation; timing process switching; extreme solutions to parametric changes; and the extent that sectors can be analyzed with process models.

The development of the process model can be a considerable and expensive undertaking. Details of existing technologies are usually available only at a very micro level. For example, in developing the housing process model for the Charleston SMSA (described more fully in Chapter 7), we used, among other sources, blueprints for general housing types which specify factor inputs down to the size of screws to be used. Thus, in using engineering data, one is talking about literally thousands of inputs for each activity in many cases. Furthermore, some technologies that are used may be easily obtained, but for others, the specific process may be confidential. (For other process models see Mann (1958) Russell and Vaughan (1976) or Thompson, Caldoway, and Nawalanic (1977).)

While collecting currently used technologies may be difficult, collecting existing, alternative processes is more difficult. Existing technologies are based on current or recent relative prices (Chenery (1949)). Where one obtains the detail on unused but existing technologies is not clear. The problem is further complicated by new technologies that have not been used. Engineers and scientists may not have had much of an incentive to think about processes that would only be viable with extreme variations in current relative prices. The profit motive in the face of substantial changes retains an important role in the market economy--to reward those who do innovate. Although this problem might be overcome to an extent by asking for extensive reflection and other considerations, this would add to costs of an already expensive project. Thus, not only may a substantial search be involved, but one has no quarantee that the entire range of alternative technologies will be incorporated.

Given the micro level of detail one finds in engineering specifications of technologies, it is essential to aggregate. The level of detail is far too unwieldy to be of use in a model of the regional economy. Further, the level of aggregation must be consistent with the level of detail contained in the regional model. For example, it is not useful to have a process model spell out the demand for skilled carpenters when there are no data on the supply of skilled carpenters. The way the data are aggregated are, to a significant extent, arbitrary, and, in any event, there will be the familiar index number problem (e.g. Diewert (1976)) associated with the aggregate measure.

Given that some technologies may be missing and that for any reasonable, manageable level, those used must be aggregated, there is a question as to whether the constructed process model is representative of real world observations. Thus, validation of the empirical relevance of the process model is methodologically important. Unfortunately, process models may be difficult or impossible to verify as to their ability to replicate the activities of the economic sector.

In addition to the question of having the right technologies, there is a question of the appropriate objective function to be used to solve the process model. Since there are many different objective functions that appear to be reasonable, the alternatives need to be tested. The standard method of validating a model is replication of observed economic behavior over time. While reproducing the past is no guarantee of predicting the future, it increases the probability of doing so. This leads us to somewhat of a logical contradiction: one of the arguments for using a process model is that historical data do not encompass future probable observation; hence, using a process model to incorporate such possibilities can not be validated by the referenced historical data. It may be possible, however, to validate process models by other means, but this is a further problem.

For the usual linear programming solutions to the process model, casual observation suggests these solutions are at variance with real world observations. Many times, the LP solution is an "extreme" solution with zero shadow prices for contrained inputs. For example, for a given set of input and output prices, the cost of minimizing or revenue maximizing solution of the process model of the housing industry would be one with one type of house being built. Associated with this problem is that small changes in parameters result in either no change or a dramatic change in the solution. For a process model of electrical supply for the nation, a fraction of a cent change in the price of nuclear fuel versus coal changes the solution for optimal electrical generation units from all nuclear powered to all coal fired. Even if the process model were correct in predicting radical changes in technologies, it is, by itself, silent about the timing of such changes over time. While one could easily impose partial adjustment contraints in the process model, it would be desirable to have these adjustments more firmly grounded in theory and empirical observation.

One rather obvious solution to many of these problems with the process model solved under static, certain conditions is to incorporate uncertainty. While this is a complex factor to add to a model, it deserves serious consideration for several reasons. First, we cannot be fully certain about the parameters of the technologies collected. Second, real world decision makers live in a world of uncertainty, and that affects the decisions that are made. Third, by properly formulating the sources of uncertainty and attitudes toward risk in the objective function, one can avoid getting too many "extreme" solutions and, further, obtain smooth, continuous responses of the solution vector to parametric changes. Fourth, incorporating uncertainty allows one to test the sensitivity of solutions to changes in probability distribution parameters and attitude parameters. From a methodological point of view, since one only has a "model" of the economic environment, the model will not likely be useful if small changes in parameters result in large changes in solutions.

Not all techniques for incorporating uncertainty in a process model are desirable given the simulation uses of the model. Much of the operations research literature on uncertainty in process models has approached the problem by finding a "certainty equivalent" programming problem. While this is highly desirable from a computational point of view, this takes away the "smoothing" attributes of including uncertainty in other ways in the model. Thus, the inclusion of uncertainty in the objective function appears to be quite advantageous, but can not be included in the ways most often suggested in the literature closely associated with process models. (See, for example Kall (1976) or Kolbin (1977).)

Given these many limitations, there still is promise for process models adding insight to historical data's limitations, however, not for all sectors of the economy. While many of the limitations alluded to above may be offset by the benefits gleaned in using a process model for some manufacturing sectors, it is hardly likely that a process model could be used for consumer demand, for example. Consequently, we conclude that if process models have a role, it must be in the context of other equations that are based on historical data.

Combining Process Models With Traditional Regional Economic Models

If we begin with the proposition of replacing a sector of a traditional econometric model of regional economic activity with a process model, as we have in this study, the first problem encountered is the specific input and output prices for the process model. Also, if we have a process model of housing technologies, we would want to replace a traditionally modeled supply of housing function. However, few national or regional econometric models contain explicit supply and demand functions for particular sectors. Most econometric models have for specific sectors "reduced form" equations where output, employment, etc. depends upon demand variables, and specific prices are implicit (at best). Aggregate prices in such models are generally determined by some variation of a Phillips curve with, perhaps, raw materials' prices being exogeneous. Prices for specific sectors, if they are calculated, are correlated with aggregate price indexes. Such "trickle down" techniques are totally inappropriate for using prices in process models. Consequently, to incorporate a supply of housing equation, based on a process model, in a traditional regional model, the entire sector must be remodeled specifying supply and demand for housing with prices endogeneous. The primary reason for traditional models not being explicitly supply and demand oriented is a lack of price data, particularly spatially specific price data. While this is less of a problem for housing supply, it is more significant problem for other sectors.

In practical applications, there is a significant problem associated with directly using a model in a simultaneous system. Process models that describe real world technologies tend to be quite large and solving them often requires several iterations for a given set of parameters. Since most simultaneous systems achieve convergence by a numerical iteration process, the combination of process models directly incorporated cannot be solved by standard, packaged algorithms. It is, therefore, highly desirable to be able to "summarize" the information contained in a process model in equations that can be incorporated into a simultaneous system of econometric and identity equations and solved using standard algorithms.

Summarizing Process Models

Griffin (1977a, 1977b, 1978, 1979) has presented an approach for summarizing process analysis models. He first formulates an appropriate cost minimization (or revenue maximization) problem as a linear programming problem and solves the optimization problem for different sets of input prices and output constraints. Then a cost (or profit) function, usually a translog, is fitted to these process analysis model (PAM) data. From the estimated continuous function, inferences are made about the different substitution elasticities. Maddala and Roberts (1979, 1980a, 1980b) have given two main reasons why Griffin's procedure to summarize a process model is not very satisfactory. First by varying input prices in a cost minimization problem, the solutions give input demands and shadow prices for the outputs. These, then, are the appropriate functions that should be fitted and used in linking together a simulation model, not cost functions.

The second reason is that Griffin varies price data to preserve orthogonality of the price vectors. But this is irrelevant to obtaining good approximations. The better strategy is to choose price vectors that capture all the corners in the solution of the process models. The PAM data should approximate the true kinked surface of the model as closely as possible. Then the summarizing function should fit the PAM data as closely as possible. There has been much discussion in the literature about the second approximation and not enough about the first one which is clearly as important. Thus, when generating the PAM data, it is desirable to adapt an algorithm (see Dyer and Proll (1977)) that would search out most if not all extreme points of the solution surface.

There is a second major problem that must be dealt with. Given linear technologies, the standard linear programming problem under certainty is generally unacceptable for simulating the real world. It is desirable, if not essential, that uncertainty be incorporated. Without uncertainty one obtains too many "extreme" solutions and zero values for shadow prices of inputs if they are not used to capacity. Further, often times under certainty, small changes in parameters will result in drastic changes in the optimal solution.

The addition of uncertainty to the process model poses a significant problem for the approximating function, which is how one should incorporate uncertainty into the approximating function. For example, suppose one wants to incorporate an input demand equation based on a process model in a simulation model. Given the PAM data points generated under conditions of uncertainty, how one should incorporate uncertainty and attitudes toward risk in the input demand equation depends on the sources of uncertainty and the objective function. In general, the answer is unknown. We have derived some specific results for the housing process model which are discussed more fully in Chapter 7. Also, Appendix B contains a broader technical discussion of the problem with additional results.

Summary

As a summary, process models offer an alternative to the limitations often found with historical data, but process models have their own problems. Even if the problems of constructing process models can be overcome, there are further problems in using them to assess the economic effects of disasters. The addition of uncertainty, or something similar, appears necessary to replicate the economy and for other methodological reasons. Process models cannot be developed for all sectors of an economy. Thus, they must be linked with other sectors. To incorporate process models into a system of equations, the appropriate information from the process model generally must be summarized. The optimal method for summarizing process models incorporating uncertainty is not known at this time.

CHAPTER 7

HOUSING SUPPLY BASED ON A PROCESS MODEL*

Introduction

To overcome the stated limitations of historical observations that econometric models may contain, we developed a process model of housing supply for the Charleston, South Carolina SMSA. In this chapter, the results of this effort are summarized. First the development of the technology matrix is discussed. Next the problems of using the process model in the econometric model are presented. These problems, which could not be satisfactorily overcome, are the appropriate form of the objective function, the appropriate form for the summarizing equations, and using these in a simulation forecasting model. Finally, we briefly discuss some simulations using process model equations. While we cannot, at this point, have much faith in the realism of these simulations (because of validation problems), it does seem clear that process model equations will be "more flexible" than equations based on limited historical data variation.

The Technology Matrix for Housing Construction

The technology matrix contains data for 27 output processes that cover four representative types of homes: (1) single family (approximately 1700 sq. ft. floor space); (2) four family townhouse (approximately 4000 sq. ft. floor space); (3) multi-family high rise (approximately 101,000 sq. ft. floor space); and (4) imported mobile home (720 sq. ft. floor space). The different processes represent alternative methods of construction: stick-built versus pre-fab, usual versus accelerated construction time, and vacant versus occupied land.

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*A portion of this chapter on the technology matrix was prepared by David Sykes, University of South Carolina.

Repair processes for the existing stock of housing are also included. (See Table C.1, Appendix C, for a complete break-down of the 27 processes.)

The choice of processes was motivated by the nature of the problem under study and the fact that this is a prototype study. Since the occurrence of a disaster such as an earthquake will very likely result in widespread damage to the existing housing stock, repair activities will become especially important during the restoration period. Many structures may be so severely damaged that it becomes economically expedient to completely clear the site and rebuild. Hence the choice of vacant versus occupied land. The timing (usual or accelerated) of new or replacement housing may become important if severe damage is so pervasive that large numbers of vicitims are left without shelter. This situation could also be mitigated by importing mobile homes. Finally, pre-fabricated construction represents a technological alternative to traditional (or stick-built) construction. The primary difference between the two technologies is that the former requires about one-third less on-site labor than the latter.

Data for the construction of the technology or input-coefficient matrix were generally available only at a very micro-level. In particular, most input data for the single family and townhouse units were taken from a materials-quantity breakdown provided by their designer. The designers also provided estimates of the number of skilled andunskilled labor hours required for the construction of the single family and townhouse units. Similarly, a construction engineer provided a materials-quantity breakdown and estimates of the unskilled/skilled labor hours required for the construction of a typical multi-family high rise unit. The quantity breakdowns did not provide data on electrical, plumbing, and heating/air conditiong. Dollar estimates of the required quantities of these materials were obtained separately by consulting with contractors in each of these areas. Otherwise, the materials-quantity breakdowns provided detailed data (down to the size and number of nails) on the quantity and type of all inputs used.

Where applicable, inputs were aggregated on the basis of price. For example, the disparate varieties of lumber were all expressed in terms of the linear feet which could have been purchased if all lumber dollars were spent on 2" X 10" boards. The level of input aggregation and unit measures are as follows:

1. Lumber - "squares" of 2" X 10"
2. Roofing - "squares" of roofing shingles
3. Brick - utility brick
4. Concrete - cubic yards
5. Sheetrock - sheets
6. Insulation - 3 1/2" X 15" units
7. Hardware - In dollars, all non-wood items otherwise not categorized (e.g., locks, nails, elevators)
8. Woodware - In dollars, all wood items otherwise not categorized (e.g., doors, window frames)
9. Steel - dollars
10. Land - square feet
11. Electrical - dollars
12. Plumbing - dollars
13. Heating/AC - dollars
14. Skilled labor - man hours
15. Unskilled labor - man hours
16. Demolition - dollars
17. Mobile Home Import Cost - dollars

18. Repairs: minimal - dollars
19. Repairs: moderate - dollars
20. Repairs: severe - dollars

Usual and accelerated construction time estimates were obtained from the designers and construction engineers referred to above. Based on consultation, an increase in labor by a multiple of 4/3 seems to be a reasonable estimate of what is required to accelerate construction to about 1/2 to 2/3 the usual time.

Data on the cost of razing existing structures were obtained from a local demolition company. The most important determinant of demolition cost is whether the structure is of a wood frame or steel frame construction. Wood frame demolition is estimated to cost hour $1.00 per square foot usual time, and $1.15 per square foot accelerated time; steel frame demolition cost estimates are $2.25 and $2.60 per square foot for usual and accelerated time, respectively.

As constructed, the repair processes require one "resource": a composite repair expense. Estimates on minimal repairs were furnished by a home-owner who is quite knowledgable of construction technology. This home-owner had kept meticulous records of home maintenance expense over the last 10 years. These records served as a basis for the estimates of the minimal repair coefficients for the single-family and townhouse units. Estimates of severe repair coefficients are based on consultation with personnel at the Federal Emergency Management Agency. This agency finances home construction repairs as part of its disaster assistance program. The agency's national average limit on such repairs was used to calculate the severe repair coefficients. Moderate repair coefficients are simply calculated as the average of these two extremes.

The public agency just mentioned also provided data on importing mobile homes to the Charleston area. According to this agency, the most likely source of these imports is Atlanta, Ga. Estimates of transportation cost per mile, set-up cost, total unit cost, and deactivation cost were provided and used as a basis for an import cost coefficient. Data were also obtained for calculation of land and time coefficients for this process.

The present pre-fabrication processes are simply a replication of the single-family unit with a 1/3 reduction in labor. This calculation is based on general literature on packaged or "kit" houses. In effect, it is assumed that the only significant difference between the stick-built and the prefab constuction technology is a reduction of on-site labor by 1/3, offset, of course, by the increased cost of prefabricated parts.

Formulation of the Objective Function

Process models are usually solved under conditions of certainty with short run constraints and used as a managerial aid. In the case of the housing industry in the U.S., constraints do not appear to be relevant. More materials can always be obtained in the time relevant for our model if one is willing to pay enough for them. If certainty is assumed, the process model gives the cost of various processes. For the prices of inputs as of 1981, these costs are given in Table 7.1. Further, if pure competition is assumed, then the supply of each type of house or repair is perfectly elastic at the prices shown in Table 7.1. Each supply equation would be the correspondin column of the technology matrix multiplied by input prices. For this approach to be of interest in the simulation model, input prices would have to be

TABLE 7.1

UNIT COST PER SQUARE FEET FOR HOUSING SUPPLY ACTIVITIES
BASED ON 1981 INPUT PRICES

Method: Housing Type:	Usual Construction Techniques	Usual Construction w/Demolition	Accelerated Construction Time	Accelerated Construction Time/w Demolition	Minimal Repair Activity	Moderate Repair Activity	Severe Repair Activity
Single Family Detached Housing	25.96	26.96	27.30	28.45	0.44	1.25	2.25
Pre-fabricated Single Family House	24.62	25.62	25.51	26.66	--	--	--
Four Family Townhouse Apartment	22.96	23.96	24.28	25.43	0.38	1.07	1.75
High Rise Apartment Buildings	18.42	20.67	19.68	22.28	0.10	0.75	1.50
Imported Mobile Home	17.28	18.28	--	--	--	--	--

endogeneous. Unfortunately, this detail is beyond the scope of tne present econometric model because of data limitations.

For these reasons as well as those discussed in Chapter 6, the addition of uncertainty to the process model is desirable for a number of methodological reasons as well as being intuitively appealing. However, there are several different ways that uncertainty may enter a process model and many ways of optimizing in an uncertain environment. General references include Kall (1976), Kolbin (1977) Sengupta (1972), and Vazda (1972).

Specific Assumptions

For this project, the simplest approach that seemed reasonable was to assume builders know the technology matrix with certainty, know input prices with certainty, but that future output prices are uncertain. A two period decision problem is assumed where nondurable inputs, x, must be chosen in the first period with known, constant prices, w, and output, y, is sold at the market price, p, in the second period. At the time x is chosen, p is random with a mean of $\overline{p}$ and finite variance, σ^2. The profits will be used in the second period for consumption or further investment. The producer's optimization problem is assumed to be to maximize expected utility of profits. The producer is assumed to be risk averse, so that there is some risk premium necessary before he will undertake investments with uncertain returns versus alternative, risk free investments such as government securities.

The probability distribution of output prices is assumed to be known. Thus, the form of the utility function along with the joint probabilibty distributions of output prices will give the objective function. Based on the extensive literature on the economics of uncertainty, two candidates for the utility function are: (1) constant absolute risk aversion and (2) constant relative risk aversion (Freund (1956), Pratt (1964), Arrow (1971)). Appendix B gives a detailed discussion of the consequences of both of these assumptions when combined with alternative assumptions about the distribution of output prices. For purposes of simulation here, we have assumed that output prices are normally distributed and there is constant absolute risk aversion.

Under these assumptions, the utility function is: $U = 1-e^{-r\pi}$; where π is profit, r is the constant index of risk aversion, and U is the utility level. The expected utility function is: $V = 1-e^{-r\bar{\pi} + r^2 y'Sy}$; where $\bar{\pi}$ is expected profit, y is the optimal vector of outputs, and S is the variance-covariance matrix of output prices. An equivalent, more convenient objective function is obtained by transforming V into $Z = \bar{\pi} - ry'Sy$. This is equivalent to the Freund's (1956) approach and has a rich history in the literature.

The necessary conditions for an interior maximum for Z are:

$$(7.1) \quad \bar{p} - c(y) = rSy$$

where c(y) is the vector of unit costs for y. Solving, gives:

$$(7.2) \quad y = S^{-1} (\bar{p} - c(y))/r$$

If the covariance between output prices is assumed to be zero, then the supply function for the ith type house is:

$$(7.3) \quad y_i = (\bar{p}_i = c(y_i))/\sigma_i^2 r$$

where σ_i^2 is the variance of the ith output price.

These supply functions can be directly incorporated into the simulation model, and no econometric summarization is needed. The problem that remains is the estimation of r, $\bar{p}$, $c(y_i)$, and S^{-1} over the simulation period as seen by the decision makers. This is a formidable problem to overcome in a way that gives any faith in the solution. The question is: How can estimated values for the parameters be tested or validated? Because of lack of degrees of freedom stemming from limited data, the answer appears to be: The parameters cannot be validated to any significant degree.

To illustrate this, consider the following approach to estimating these parameters. The first problem is to establish a plausible method for how decision makers in the housing supply industry forecast. Table 7.2 contains some relevant data in this regard for the Charleston SMSA. Usual data on an average single family house prices consist of different house sizes and different lot prices over time. Column (1) in Table 7.2 represents the average price of houses of approximately 1800 square feet in the "suburban" Charleston area as advertised in the local papers during the first week of July. Column (2) gives the average price per acre of improved building lots, determined from the same sources. Assuming average lot size is constant at 75' X 150' or approximately 1/4 acre, column (3) gives the real price of house construction, which is the nominal price of column (1), less land costs, divided by the Boeckh construction cost index for the area.

Column (4) gives the total number of housing starts for the Charleston SMSA. Based on average prices of all single family units, the starts for '77-'80 appear to be equal to the price for houses of 1800 square feet and lots of about 1/4 acre. For 1980, if the expected real price, $\bar{p}$, were determined by the average real prices form 1970-1979, then $\bar{p}$ = \$20,712. The real cost of house construction is \$15,291. Thus, the value of $r\sigma^2$ that equates housing supply in 1980 to the supply function is:

$$r\sigma^2 = (20712 - 15291)/3433 = 1.579$$

This assumes that the covariance of real prices for single family houses and real prices for other housing is zero (or insignificant). (Since we have no good data on other prices, this is a necessary assumption.) The

TABLE 7.2

SINGLE FAMILY HOUSING PRICES AND STARTS 1970-1980

Year	Avg. Price New 3 Bdrm. (1800 Ft.^{2})[1]	Improved Lots $/acre[3]	Real Price of House Construction[3]	Single Family Housing Starts
1970	19,000	8,597	18,872	2,434
1971	20,228	9,484	17,857	3,136
1972	23,325	10,464	20,325	3,058
1973	25,031	11,544	20,673	2,123
1974	25,006	11,928	19,123	2,283
1975	30,710	12,325	22,428	2,112
1976	35,303	18,374	24,058	2,461
1977	35,504	27,393	20,187	2,673
1978	40,780	40,838	18,920	3,005
1979	50,882	46,082	21,827	3,219
1980	54,504	52,000	21,826	3,433

[1] Average of prices advertised in newspapers for the first week in July, Charleston SMSA suburban areas, 3 bedroom, 2 bath homes of approximately 1,800 sq. ft. on lots approximately 75'x150' or ¼ acre.

[2] Average price per acre of improved lots in Charleston SMSA suburban area as advertised in the newspaper during the first week of July.

[3] Column (1) less ¼ of column (2), all divided by the Boeckh building cost index.

variance of real prices in column 3 is $3.153 \cdot 10^6$. Thus, the risk aversion index is $5.008 \cdot 10^{-7}$. This value seems fairly reasonable for housing supply. Given this, when faced with a 1% probability of a \$2 million loss, the maximum insurance premium that would be paid for full insurance would be 1.7% of \$2 million.

The corresponding supply function for single family houses based on these assumptions is:

(7.4) $y = (\bar{p}_B - 15291)/1.579$

$\bar{p}_B$ is the expected real price of housing construction annually, and y is the corresponding number of single family housing starts.

For purposes of simulation, we will assume "rational expectations" in the sense that $\bar{p}_B$ will be the real price of housing construction that is consistent with the demand for single family houses, so that annual starts equal demand.

Given these assumptions and our technology model, we can now simulate. However, the restrictiveness of these assumptions is obvious. A review of the major assumptions illustrates: (1) technology is known with certainty; (2) input prices are known with certainty; (3) output prices are normally distributed with known parameters; (4) inputs are all purchased before output prices are known; (5) all producers are identical and maximize expected utility of profit; (6) the utility function exhibits constant risk aversion; (7) covariances of output prices are zero; (8) expected price and variance are given by data from 1970-1979 as gathered from newspaper ads; (9) risk aversion index is based on 1980 output; (10) for simulations, builders will have "rational expectations" and produce exactly the supply to meed demand with simulated real prices being equal to expected real prices.

Given all of these (and others), the model may not be so bad for simulation purposes, or it may be. We have no way of generally validating these assumptions. For example, housing markets are never in equilibrium over a year. Starts and/or completions are not equal to sales of new homes annually, although over a long enc period these markets are in equilibrium in the sense that starts will equal sales with some allowance for abandoned starts. But accurately modeling this process on an annual or a quarterly basis is complex and requires more and better data. (See Ellson and Roberts (1982) for an example of such a model.)

The next section presents a comparison of the model simulation using (7.4) compared with the econometrically estimated equation. Because of our inability to validate the process model assumptions, it is not clear what this comparison means, however.

Simulations Incorporating the Process Model

We ran a number of simulations, however the nature of the differences is illustrated by the two simulations reported in Table 7.3. As suggested, the incorporation of the housing supply equation based on the process model made the housing sector in the simulation model "more sensitive" to price changes. However, the effect of hazards and hazard predictions is not as straight forward as we had expected.

Because the process model equation is more responsive (supply is more elastic) with respect to price changes, the entire simulation with the process model equation (PMS) is quite different from the pure econometric model simulation (EMS). The demand for housing grows in each baseline simulation. However, in the model with the process model equation, housing supply response is much greater over the entire simulation period. As can be seen in Table 7.3, by 1990 the process model equation simulation forecasts a total housing stock in the Charleston SMSA of about 392,000 units compared to the econometric baseline forecast of around 236,250 housing units. That is a difference of 66 percent over a ten year period. In other words, the process model supply equation is more responsive, and this manifests in a much higher level of housing starts and resulting housing stock over the simulation period for the baseline projection.

The somewhat surprising result is that the unanticipated earthquake does more damage in relative terms (absolute terms was to be expected given a higher base) in the process model simulation than the pure econometric simulation. But upon reflection, we discover responsiveness works in both directions: the process model simulation baseline is much higher given demand conditions than the econometric model simulation, but then an unanticipated quake, via its effect on income and, hence, on demand prices, reduces supply in relative terms more in the process model simulation.

Thus, we see that in the process model simulation the unanticipated quake reduces total housing stock by over four percent by the end of 1990 relative to its baseline compared with the 3.6 percent reduction in the pure econometric simulation - very similar impacts but with much different bases. The differential of the real price of housing is more pronounced between the two models, reduced by 2.4 percent in the PME and by 1.6 percent in the EMS. Housing starts are down by nearly 3 percent in the PMS but only off 1.2 percent in the EMS.

The difficulty here, as discussed above, is that changing any of the many assumptions used in the process model gives a different supply equation and a different simulation, some of which are higher than the EMS and some of which are lower. The EMS and its equations have some basis in fact. The many PMS's have no basis for selecting one over the other.

Consequently, until a way is found of validating the process model's simulation ability - including the specific objective functions used, probability distributions used, and so on down the list - the PMS will remain an arbitrary one. This is a substantial area for future research. The likelihood of success, however, is problematic.

TABLE 7.3

COMPARISON OF PURE ECONOMETRIC MODEL SIMULATIONS WITH PROCESS MODEL INCORPORATED MODEL SIMUATIONS

	Baseline Simulation		Unanticipated Quake		% Difference	
	EB[1]	PB[2]	E1[3]	P1[4]	EB/E1	PB/P1
Housing Stock:	164,705	190,179	156,004	179,677	-5.28%	-5.52%
'83	164,705	190,179	156,004	179,677	-5.28%	-5.52%
'84	172,428	207,850	163,886	197,094	-4.97%	-5.17%
'90	236,247	391,924	227,780	376,248	-3.58%	-4.01%
Real Price of Housing:						
'83	$41,183	$41,246	$41,119	$41,238	-0.15%	-0.02%
'84	$44,612	$44,853	$44,234	$44,437	-0.85%	-0.93%
'90	$70,281	$87,926	$69,190	$85,785	-1.55%	-2.44%
Total Housing Starts:						
'83	9,365	15,227	9,364	15,223	-0.01%	-0.003%
'84	10,409	17,671	10,396	17,418	-0.12%	-1.93%
'90	16,313	44,511	16,113	43,224	-1.20%	-2.89%

[1] Econometric Model Baseline Simulation

[2] Model with Process Model Equation Baseline Simulation

[3] Econometric Model Simulation of Unanticipated Quake

[4] Process Model Incorporated Simulation of Unanticipated Quake

CHAPTER 8

CONCLUSIONS AND FINAL OBSERVATIONS

Introduction

In this chapter we present the major findings and contributions of this study. Our initial goal was to develop a methodology for using technology based models in a regional simulation model. This was primarily to assess the effects of recently unexperienced events - specifically for an earthquake in Charleston, S.C. where the last major event was 1886. Upon embarking we found it was first necessary to develop a conceptual framework for analyzing the economic effects as existing approaches to measuring losses were found to be defective. The actual efforts to use technology based models ran into severe methodological difficulties. In the next section we highlight the major findings of our research. In the final section, we present our overall evaluation of the project and assess what we feel to be the next major areas of research.

Overview of the Major Findings

The major findings and contributions of this study fall into five major categories: (1) the development of a general conceptual framework for analyzing economic effects of policies on hazards and the proper measures of these effects; (2) the development of an economic simulation model that incorporates variables affected by hazards or important to determining the effects of policies; (3) the simulation of earthquake effects on a regional economy; (4) the estimation of regional losses from five quake simulations; and (5) the research on the utilization of a technology based model in a simulation model.

Development of a Conceptual Framework

Chapter 2 of this report contains a methodological framework for measuring the losses and benefits of earthquakes and the changes in these losses and benefits induced by various policies. In our development of this conceptual framework five main points stand out:

1. hazard reduction is not necessarily desirable;
2. a conceptual framework of individual choice is necessary, implicitly or explicitly;
3. proper measures of losses involve stock measures or flow measures, not both;
4. an economic model is essential if the earthquake affects the economic system; and
5. measuring the losses with a model has limitations particularly when the question of regional versus national losses is raised.

The calculation of losses is important because there is, in virtually all instances, an optimal level of hazard mitigation. It is often assumed or asserted that hazard reduction is desirable regardless. That is clearly not the case, and seismic requirements in building codes or the extent of seismic monitoring for earthquake detection are examples where costs could far exceed the benefits.

Measuring the losses and benefits requires a conceptual model of individual choice and response to determine what constitutes value and the proper considerations that should be made in this regard. We have adopted state preference theory as our framework of choice in Chapter 2, and Appendix A contains details of individual responses, in terms of mitigation and migration, to such things as subsidized insurance and aid and assistance. Also, it is shown that Kunreuther's (1976) analysis that individuals "misprocess" information is not as conceptually clear as is widely believed.

Given a conceptual framework, losses can be defined. The next problem is the proper measure of these losses. We find that existing estimates of nominal losses are seriously deficient. In particular, there is often a confusion of stock concepts and flow concepts of losses. Correctly measured, losses are one <u>or</u> the other. Thus, existing measures contain omissions, on the one hand, and double counting on the other hand.

Because individuals exist in an economic system, one needs an economic model of the system to determine the effects of earthquakes. Direct damages are not approximate, conceptually, to losses incurred. However, existing regional models have a number of deficiencies when it comes to assessing the losses of an earthquake. The principal shortcomings are the lack of stock measures that are spatially specific and the undefined relation between capital stocks, including social capital, and economic activity.

Given a regional model of economic activity, the next task is measuring the losses and benefits using the model. Since models are models, there are naturally limitations of what can be measured compared with conceptual ideals. One important aspect is the measure of losses viewed at the regional level versus losses viewed at the national level. We believe that in the majority of cases, losses for the nation are less than losses for the region.

Development of an Economic Simulation Model

The simulation model developed in Chapter 4 is a pure econometric model. Traditional regional econometric models are inadequate for estimating the economic effects of catastrophic change for several reasons. First, supply-side constraints are rarely if ever binding in traditional models. Yet, in situations of catastrophic change, it is supply-side constraints which will dominate rather than changes in aggregate demand. Factors that must be considered include capital investment, net migration, housing, and transportation. Although most regional models incorporate capital investment, it is usually determined recursively either by national investment or some partial adjustment process. This is not sufficient because the effects of *ex ante* behavior cannot be analyzed. Moreover, net migration is rarely dealt with because of data problems, but it is of fundamental importance in determining the effects of catastrophic change. The housing sector, which is closely linked to the economic and demographic characteristics, is also important. Transportation flows will surely be affected by catastrophic change at least in the short run, and typical regional models do not consider this aspect.

Finally, traditional regional models are not spatially disaggregated. It is clear that catastrophic change will have differential effects across an urban area, and this can only be accomplished by some level of disaggregation.

Our Charleston SMSA model address the issues of estimating the economic effects of catastrophic change by incorporating each of these factors. New capital investment is estimated using an investment anticipations approach, and net migration is endogenous in the model. Housing starts and transportation flows are also incorporated. Therefore, the stock variables for capital, housing, and population are represented by identities. In addition, we have analyzed the urban area at the county level. Although a higher level of spatial disaggregation would be desirable, data limitations preclude this. However, this county specification provides a unique feature in that our model is simultaneous both within an individual county and between the three counties in the urban area. Thus, differential effects can be estimated within the SMSA.

Simulation of Earthquake Effects on a Regional Economy

We have reported the results of six basic simulations of economic activity for the Charleston, S.C. SMSA for 1981-1990. The first simulation is the baseline forecast for the period with no event. The next three simulations are of the effects of an unanticipated quake in 1983 with combinations of assumptions concerning damages and the recovery path. The fifth simulation assumes that a prediction of an event is made in 1981 for an earthquake to take place in 1983. The prediction is later declared to be incorrect. This simulation shows the possible dampening effects on the regional economy of a prediciton. The sixth simulation shows the effects of a prediction for a 1983 earthquake which proves to be correct so that we can analyze the effects of mitigation on damage reduction.

In measuring losses, we have dealt only with economic losses that are readily measurable. We have not dealt with the social losses of deaths and injuries, nor have we taken into account the social losses from trauma and dislocation. However, both the theoretical and empirical approaches we have taken do not conflict with these omissions and could be modified to take them into account if reasonable data were available. This would be an expensive endeavor, however, and schemes to elicit willingness to pay are only in their infancy. But conceptually, these estimates could be added into our loss estimates.

Second, our econometric model is based upon annual data so that we are unable to show short-run responses. A better model would be based on quarterly or monthly data. Since there is a substantial literature comparing models with different periodicity, this presents no substantive problems.

Third, our econometric model is largely constructed from data from the 1970 decade so that it may not fully reflect changes in the economy in the

1980's. Nevertheless, the regional losses we have shown are always in reference to a baseline projection so that needed improvements in the basic model would be more important in affecting possible recovery paths than in merely improving the baseline forecasts. For the most part, we have had to rely on crude ratios in our estimates of consumer durables, total non-residential regional capital and regional social capital. We believe the theoretical approaches we have taken are sound. The problem is that the empirical data are not what we would like. Also, we do not show effects at the sub-county level.

Fourth, it is possible to quarrel with the assumptions we have made about damages sustained with and without a prediction. It is also possible to question the assumptions we have made about the dampening effects upon housing starts, capital investments, and net migration from a credible prediction. Yet, we believe our assumptions appear "reasonable", and certainly, we can point out that the model, itself, is capable of simulating a countless number of alternative assumptions. We have not explicitly dealt with relief and recovery policies. These, too, could be simulated. However, we have shown the effects of recovery with full replacement of damaged and/or reduced investment from the event and from a prediciton so that we have bounded some of the relief policies.

Finally, we would like to emphasize that the losses we have measured are regional in scope and not national. We suspect that national losses would be less than regional losses. As we noted above, the bulk of the regional losses sustained appear in terms of damage to capital stock, to housing, and to social capital. Nonresidential property income losses we have measured come about largely through reductions in housing starts, falls in new investment, and capital stock destroyed. By contrast, we have shown that the recovery process with replacement can stimulate total nonfarm employment and actually can increase labor and proprietor income relative to the baseline projection. When all of these regional effects (stock and flow) are taken into account, it is not obvious what the national balance would show.

Utilization of a Technology Based Model

In Chapter 6 we have presented a review of the advantages and disadvantages of a technology based process model compared with historical data-based models. Particularly for assessing the economic effects of earthquakes and earthquake predictions where new technology utilization seems quite likely, this would appear to be a promising alternative. Historical data-based models often would have no basis on which to calibrate the effects of new technologies. In addition pure econometric equations are limited because of disequilibrium conditions reflected in the data; problems of multicollinearity; a small number of observations made on a consistent basis; and errors in the data that cannot be checked.

Technology based models can overcome many of the limitations of historical data-based models. Solutions for optimal processes under given input and output prices can easily be determined to be equilibrium or partial adjustment solutions. Multicollinearity is easily obviated by changing parameters separately. The range of parameter changes can be made as broad as desired. New technologies can be directly incorporated as long as the engineering data are available. While errors of data collection may still occur, there is more recourse in case of error with the process model. The prinicipal gain is the ability to incorporate alternative technologies--both existing, unused technologies and new technologies. In addition, the structure of the process model allows one to easily incorporate explicit constraints on input usage.

Process models, however, have several limitations, in and of themselves, and others arise in coupling the process model with other equations of a simulation model. The general problems associated with developing a process model for a particular economic sector we have discussed include: gathering the technologies; aggregating; validation; timing process switching; extreme solutions to parametric changes; and the extent that sectors can be analyzed with process models.

The major conclusions we have reached because of these limitations of process models are: (1) uncertainty should be incorporated in the process model; (2) process models cannot be used for all sectors and must be combined with econometric equations; and (3) the information in a process model needs to be summarized into conventional equations for use in a simulation model. Exactly how to accomplish these three conclusions is not well understood. Appendix B contains a technical discussion of the problem with some results in this regard.

We developed a process model for housing supply and have described it in Chapter 7. The difficulty we encountered was the inability to empirically validate the simulation properties of the process model. Results were obtained, but they had to be based on a large number of assumptions - assumptions that are "reasonable" but that could be replaced by a number of other "reasonable" assumptions that produce different simulations. Consequently, while we were easily able to simulate with housing supply based on the technology model, we have no basis to evaluate whether we can have any confidence in these simulations. Only future research will determine the conditions and extent that process models can be validated - not in terms of their reflection of technology (although this is a problem to contend with) but in terms of being able to simulate market behaviour of decision makers in a world of uncertainty.

Some Final Observations

As a final summation, which is certainly very tentative, it appears to us that a more fruitful approach to solving the problems inherent in historical data-based models is more and better data. For example, to simulate the possible reactions in Charleston to an earthquake for which we have no data, it would probably be better to use data from other regions or other events with a theoretical development to account for the differences between earthquakes and other disasters. Unitl we have more research, though, this is little more than a hunch.

The econometric modeling innovations and resulting simulation model worked well. For futher research, the need is for more and better data in three major areas (and many minor ones): (1) capital stocks; (2) migration decisions; and (3) firm location and investment decisions. Detailed data on private nonresidential, nonmanufacturing capital stocks and investment and also on social capital that are spatially specific would greatly enhance our understanding of the relation of these data to economic activity. Here we had to rely on simple ratios and, thus, coefficients contain too much structure of the economy that we would like to have explicit. Although migration and firm investment are endogenous to the model, we had to use guesses as to how firms and individuals would react to predictions and events. Much more could be learned in this area.

Finally, there are many other aspects we have touched upon that deserve further analysis, such as estimating willingenss to pay, for example. In fact, the entire research area is chocked full of challenging and important issues that are not only relevant to hazard mitigation research but to several other aspects of social science as well.

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APPENDIX A

An Analysis of Individual Choices
in Response to Hazards and
Hazard Predictions

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I. Introduction

Optimal policies for responses to and the mitigation of hazards requires a balancing of the marginal costs of the policy to the marginal benefits. Not all steps to reduce hazards are desirable, although much of the current literature seems to ignore this fact. (See Milliman (1982) for a further discussion on this and related economic issues of policy formulation.) The costs and benefits of particular policies, in turn, depend upon choices made by consumers and producers in light of the hazard, their perceptions of it, and the effects of the policies. Traditional cost-benefit analysis is based on a theory of choice under certainty. Given that hazards, by definition, occur at random and that policies are often designed to change information flows and perceptions of the nature of the hazard and mitigation possibilities, a framework based on certainty is inappropriate.

The purpose of this paper is to set forth a general conceptual framework of individual choices under uncertainty and to demonstrate the effects of general kinds of policies. Section II sets forth the basic model following the state preference approach developed by Arrow (1953, 1963), Debreu (1959), and others. A special case of the state preference approach is the expected utility maximization model as developed by von Neumann and Morgenstern (1947). Even more restrictive is to assume variables are normally distributed so that expected utility can be expressed in terms of the mean and variance of the random variables. David (1974) and Smith (1979) have used this to analyze regional location decisions. Kunreuther (1976) and Kunreuther, et.al. (1978) have used the expected utility model to argue that consumers "misprocess" information or otherwise behave with "bounded" rationality. In Section II, it is demonstrated that this result depends on highly restrictive (and unrealistic) assumptions.

Section III contains an analysis of the effects of direct aid and assistance, subsidized insurance, and increasing awareness on mitigation and migration decisions by firms and individuals. The following partial equilibrium propositions are demonstrated:

1. the more aid and assistance that is perceived, the less mitigation undertaken and less insurance purchased; and

2. the more insurance rates are subsidized the less mitigation undertaken and the more insurance purchased.

Along with a newly perceived hazard:

3. the more aid and assistance that is perceived, the less net outmigration; and

4. the more insurance rates are subsidized, the less net outmigration.

If, in addition, individuals maximize expected utility, then:

5. with no insurance, the greater the subjective odds on the disaster, the more mitigation undertaken;

6. with no insurance, the greater the subjective odds on the disaster, the greater the net outmigration; and

7. with insurance rates held constant, the greater the subjective odds on a disaster the more insurance purchased.

Section IV extends the analysis to a general equilibrium framework indicating how the competitive supply of insurance will change as subjective odds, perceived aid and assistance, and mitigation possibilities change. Also in section IV, property values are shown to be inversely related to equilibrium insurance rates. From a policy perspective, increasing the subjective odds of a disaster through information flows raises insurance rates and lowers property values. However, the more insurance rates are subsidized, the higher property values will be.

Summary and conclusions follow in Section V.

II. The Conceptual Framework of Individual Choices

The conceptual framework appropriate for determining the economic effects of disasters, predictions of disasters, and mitigation possibilities is an extension of the state preference approach as developed by Arrow (1953), Debreu (1959), Arrow (1963), Pratt (1964), Yaari (1969), Marshall (1976), Cook and Graham (1977) and others. Let x be a vector that completely measures the relevant aspects of state i and suppose there are n possible states that may occur. Individuals are assumed to have a well defined preference ordering that can be represented by a single-valued, quasi-concave function: $U = U(x^1, \ldots, x^n)$. Included in each state vector x^i are contingent claims on economic goods and services as well as other measures that affect the individual's well being, such as the extent of physical injury to the individual or to others if the ith state occurs. The individual's initial endowment, contingent on the ith state, is denoted $\bar{x}^i$. The individual is assumed to attain the most preferred point of contingent claims subject to his initial endowments, available technologies (e.g., mitigation steps), and market conditions.

Let x_1^i be nominal wealth in state i. For simplicity at this point, suppose there are two possible states: a normal state, denoted as n, and a disaster state denoted as d. Thus, $x_1^n - x_1^d$ is the nominal wealth loss if state d occurs. If the individual only cared about wealth, then $x_1^n - x_1^d$ would reflect the total loss to the individual if a disaster were to occur. $x_1^n - x_1^d$ is, in this case, the maximum amount the individual would be willing to pay to avoid the disaster with certainty when it was certain the disaster would occur if the payment were not made.

This is illustrated in Figure 1. The horizontal axis measures wealth in the disaster state and the vertical axis measures wealth in the normal state. With an endowment of $\bar{x}$, the horizontal distance to the 45° line measures the income loss $x_1^n - x_1^d$. The indiffernce curve $U°$ represents the individual's willingness to exchange other contingent claims for his initial endowment $\bar{x}$. Any point about $U°$ is preferred to $\bar{x}$.

With mitigation possible, the individual faces an opportunity to move from $\bar{x}$. Mitigation, here, is construed to mean real physical investments (as opposed to financial transactions such as insurance) that reduce losses in the event of the disaster occurring. Figure 2 illustrates a mitigation possibilities locus, labeled MP. Since MP cuts the indifference curve, some mitigation steps will be taken. Specifically, $\bar{x}_1^n - x_1^n$ will be spent on mitigation and if the disaster occurs, wealth will be x_1^d rather than $\bar{x}_1^d$. The curve MP reflects decreasing returns to mitigation as it approaches a wealth level in state d asympotically. Depending on available technology and preferences, the optimal amount of mitigation,

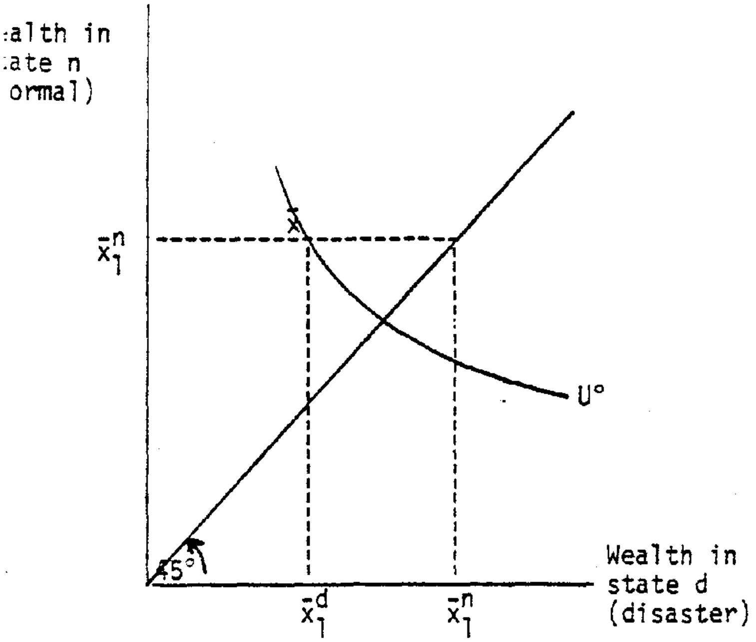

Figure 1. Willingness to Pay to Avoid Disaster

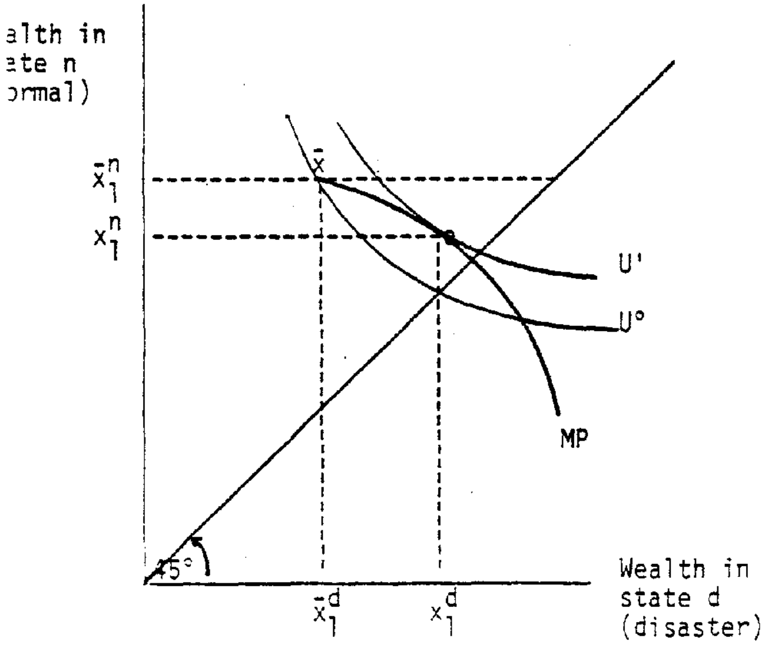

Figure 2. Locus of Mitigation Possibilities

in general, may be such that wealth in state d would be less than, equal to, or greater than wealth in state n. In general, we would expect the optimal solution to lie above the 45° line in Figure 2.

Insurance is another means by which the individual may move from his initial endowment. Figure 3 illustrates a case where the individual may purchase any amount of insurance at a constant rate along the line MO. The distance $\bar{x}_1^n - x_1^d$ is the premium paid for the insurance policy and $x_1^d - \bar{x}_1^d$ is the net payment to the individual in the event of the disaster. Insurance with a fixed premium and a deductible would be represented by a point such as a in Figure 3.

The slope of the indifference curve depends, in part, on the individual's assessment of the likelihood of each state occurring. If we assume that the preferences can be described by the maximization of expected utility, then we can be more specific about the individual's subjective odds. In particular, if preferences only depend on wealth in the two states, then the individual's subjective odds on state d (the subjective probability that state d will occur relative to the subjective probability that state n will occur) are equal to the absolute slope of the indifference curve as it crosses the 45° line. This well-known result is easily shown by letting p be the subjective probability that state d will occur. Set the level of utility at U° so that:

$$U^\circ = pU(x^d) + (1-p)\, U(x^n)$$

Differentiating with respect to x^n and evaluating at $x^d = x^n$ gives:

$$-dx^n/dx^d = p/(1-p)$$

This result has strong implications, which are at variance with empirical data (e.g., Kunreuther (1976), Kunreuther, et.al. (1978)). If preferences depend only upon wealth, when faced with fair insurance - defined to be insurance such that the net benefit relative to the premium is equal to the individual's subjective odds, or, if actuarial odds are equal to the individual's odds, then fair insurance is insurance with no loading - and when he may buy any amount of insurance, the individual will "fully insure", in the sense that he will move from any risky endowment to the 45° line. Since utility is only a function of wealth in this case, the 45° line is also called the "certainty locus" since utility will be the same regardless of which state occurs. Accordingly, on the certainty locus the individual is indifferent as to which state occurs. Since many disaster insurance programs are highly subsidized and individuals do not take advantage of this, the usefulness of the expected utility model has been questioned (e.g., Kunreuther (1976)).

If preferences depend on other factors besides wealth, the foregoing result will not be obtained. In fact, a rational individual may not insure at all when faced with "fair" insurance. Suppose there are losses of "irreplaceable" objects in the disaster in addition to wealth losses. Replaceable objects are defined as those for which there are markets and can be readily purchased at a given price. A loss of a replaceable object is formally a nominal wealth loss and needs no special consideration. By contrast, in decisions regarding possible losses of irreplaceable goods such as health, maximization of expected utility with fair odds may require not insuring against loss, but just the opposite - betting that the loss will not occur (Cook and Graham (1977)).

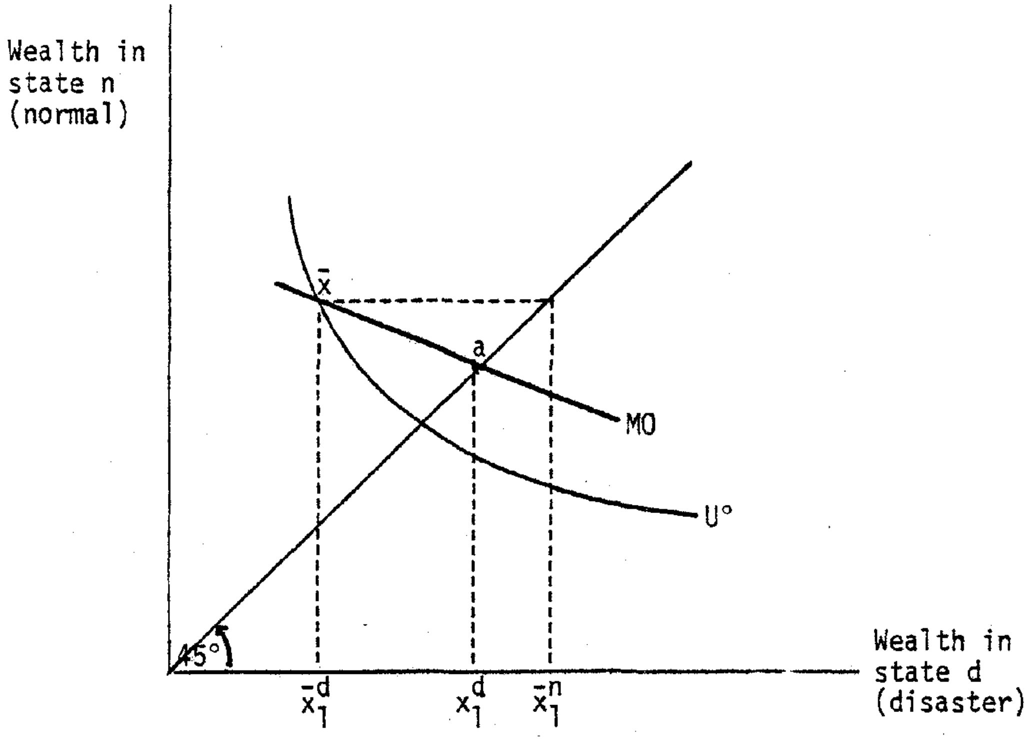

Figure 3. The Purchase of insurance

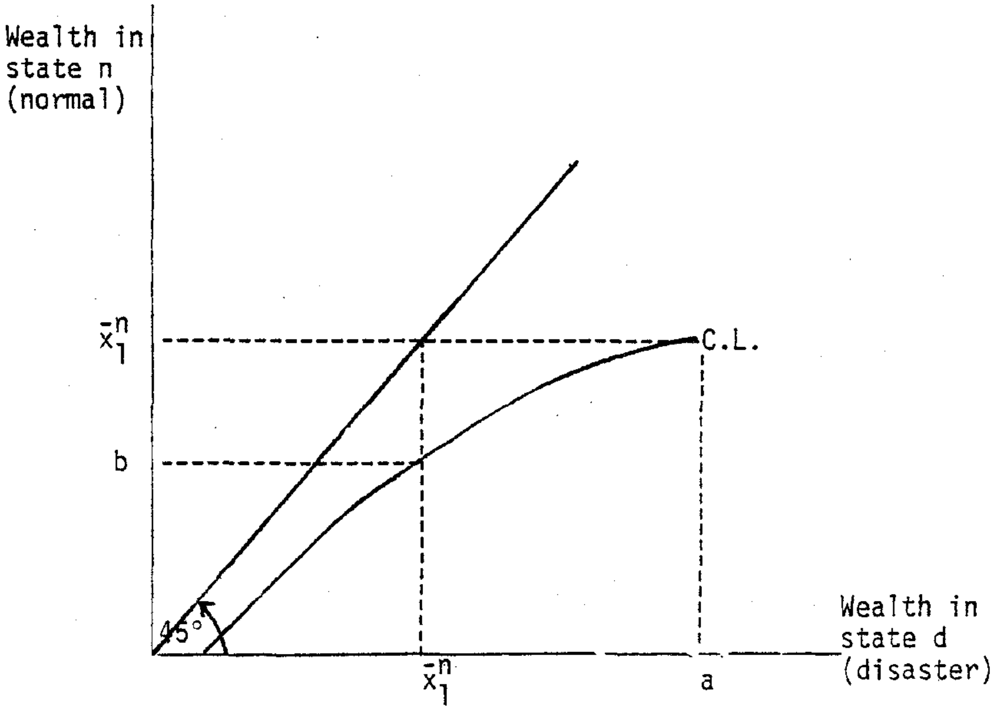

Figure 4. Certainty Locus of Preferences Not a Function of Wealth Alone

For purposes of exposition, suppose there are two factors that affect well being: wealth, x_1^i and health, x_2^i, for the two states i = d, n. If the disaster results in a lower level of health $x_2^d < x_2^n$, then the subjective value of the health differential can be determined by the additional amount of wealth in state d that would just compensate for the lower level of health as determined by (1).

$$(1) \quad U(x_1^d, \bar{x}_2^d) = U(\bar{x}_1^n, \bar{x}_2^n)$$

From (1), the nominal value of lower health, $\bar{x}_2^n - \bar{x}_2^d$, is equal to $x_1^d - \bar{x}_1^n$.

In general, the value of x_1^d that solves equation (1) will depend on $\bar{x}_1^n$. If health, x_2, is a "normal" good, then the subjective value increases as endowed wealth, $\bar{x}_1^n$ increases. Equation (1) defines the certainty locus when preferences are state dependent, that is, not a function of wealth alone. Figure 4 illustrates the certainty locus, CL, when x_2 is normal. Given the certainty locus, there are two alternative measures of the value of health. With an endowment in state n of wealth equal to $\bar{x}_1^n$, the subjective value of the health differential, $x_2^n - x_2^d$, may be defined either $a - \bar{x}_1^n$ or $\bar{x}_1^n - b$. $a - \bar{x}_1^n$ is the minimum "bribe" the individual would accept to enter state d when it could be avoided with certainty. $\bar{x}_1^n - b$ is the maximum the individual would pay to avoid state d with certainty when it was certain state d would occur without the payment.

These two measures differ because of wealth effects. Which one is the "correct" measure depends upon an allocation property rights. For the measure $a - \bar{x}_1$ to be correct, the individual is construed as having a "right" to the higher level of health and must be bribed to give it up. For the measure $\bar{x}_1^n - b$ to be correct, the individual has a "right" to only the lower level of health and must pay for the higher level to attain it.

With state dependent preferences under the assumption of expected utility maximization, the individual's subjective odds depend on the slope of the certainty locus. If health is a normal good, as pictured in Figure 4, subjective odds on state d will be greater than the absolute slope of the indifference curve as it crosses the certainty locus. This is shown by letting:

$$U^\circ = p\ U(x_1^d,\ x_2^d) + (1-p)\ U(x_1^n,\ x_2^n)$$

Differentiating with respect to x_1^d and holding x_2^d and x_2^n constant gives:

$$0 = p\ \partial U(x_1^d,\ x_2^d)/\partial x_1^d + (1-p)\ \partial U(x_1^n,\ x_2^n)/\partial x_1^n \cdot \partial x_1^n/\partial x_1^d.$$

Solving,

$$(2)\quad -\partial x_1^n/\partial x_1^d = \frac{p}{1-p} \cdot \frac{\partial U(x_1^d,\ x_2^d)/\partial x_1^d}{\partial U(x_1^n,\ x_2^n)/\partial x_1^n} = \frac{p}{1-p} \cdot \left.\frac{\partial x_1^n}{\partial x_2^d}\right|_{U(x_1^d,\ x_2^d) = U(x_1^n,\ x_2^n)}$$

The second term on the far right hand side of (2) is the slope of the certainty locus. Thus, if the certainty locus has a slope less than one, the absolute slope of the indifference curve as it crosses the certainty locus will be less than subjective odds.

The importance of this result is that the individual endowed in a risky situation with state dependent preferences where goods other than wealth are normal (which is highly likely) and when faced with "fair" insurance odds on state d (equal to his subjective odds) will never fully insure. That is, he will never be in equilibrium on the certainty locus. In fact, he may not insure at all.

If x_1 and x_2 are complementary in the sense that, $\partial^2U/\partial x_1\partial x_2 > 0$, then when offered "fair" insurance, the individual will be in equilibrium only if $x_1^n > x_1^d$. This means that to be in equilibrium, the individual must be above the 45° line in Figure 4, or that the individual will bet on the disaster not occurring . To demonstrate this, assume (without loss in generality) that $\bar{x}_1^d = \bar{x}_1^n$. Let b be the money difference from $\bar{x}_1^n$ the individual receives if state d occurs and c be the money difference from $\bar{x}_1^n$ he pays if state n occurs. Fair odds means that p b - (1-p)c = 0. The individual's optimization problem is:

$$\text{Max } pU(\bar{x}_1^n + b,\ x_2^d) + (1-p)\ U(\bar{x}_1^n - c,\ x_2^n)$$

Using the definition of fair odds, the necessary condition for utility maximization implies:

$$\partial U(\bar{x}_1^n + b,\ x_2^d)/\partial x_1 = \partial U(\bar{x}_1^n - c,\ x_2^n)/\partial x_1$$

Thus, if $\partial^2U/\partial x_1\partial x_2 = 0$, the necessary condition can be written $\partial U^*(\bar{x}_1^n + b)/\partial x_1 = \partial U^*(\bar{x}_1^n - c)/\partial x_1$ or b=c=0. If $\partial^2U/\partial x_1\partial x_2 > 0$, since $x_2^n > x_2^d$, $\partial U(x_1^n, x_2^n)/\partial x_1 > \partial U(x_1^n, x_2^d)/\partial x_1$. Therefore, risk aversion, $\partial^2U/\partial x_1^2 < 0$, implies $x_1^n = \bar{x}_1^n - c > \bar{x}_1^n + b = x_1^d$.||

This result means that if an individual with state dependent preferences, as shown in Figure 5 who is endowed on the 45° line (equal nominal wealth in either state), will not insure at all against the loss of $x_2^n - x_2^d$ but would like to "bet against" the disaster occurring by moving to the point a in Figure 5. Since it is reasonable that other losses

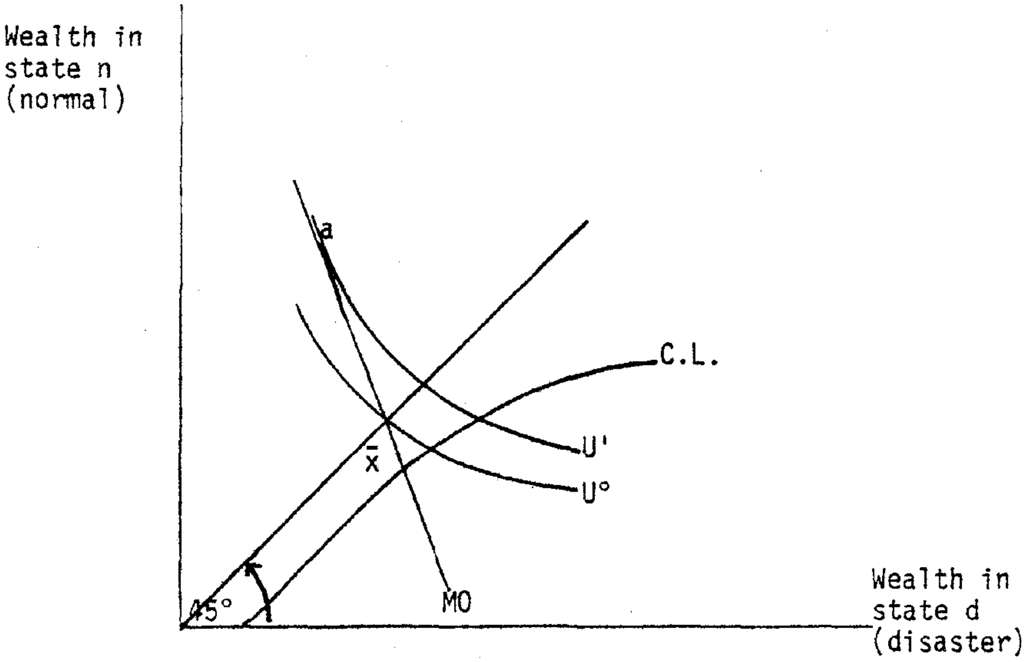

Figure 5. Certainty Locus and Failure to Purchase Insurance

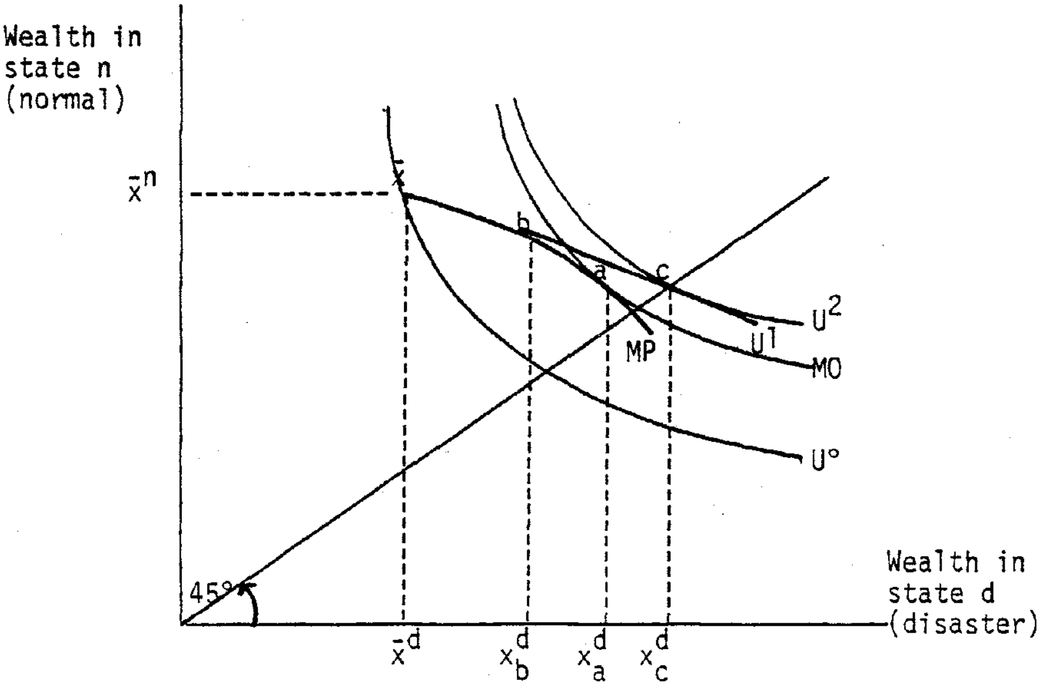

Figure 6. Effect of Insurance to Reduce Amount of Mitigation

in the event of a disaster would be complementary with wealth, the data that Kunreuther (1976) reports about the purchase of flood and earthquake insurance are not so much at variance with the expected utility model as is claimed.

Transactions costs, which can be significant, are another reason why people do not fully insure. This point is recognized by Kunreuther (1976) and others, so we will not elaborate on it here and continue to ignore them in what follows.

III. Policy Effects

The Effect of Insurance on Mitigation

The existence of insurance can reduce the amount of mitigation undertaken. However, the reduction in mitigation efforts should not be construed as a misallocation of resources. Assume the individual has state independent preferences defined over wealth in two states: n and d. The initial endowment is $(\bar{x}^n, \bar{x}^d)$ with $\bar{x}^n > \bar{x}^d$. Mitigation possibilities are represented by the function $x^d = M^*(x^n; \bar{x}^n, x^d)$. M^* is assumed to be strictly concave with $\partial M^*/\partial x^n < 0$ and $\partial^2 M^*/\partial x^{n2} < 0$. Mitigation steps reduce losses. In view of this, we will use the particular form $x^d = M(\bar{x}^n - x^n) + \bar{x}^d$ in much of what follows. Although somewhat restrictive, it does not appear to significantly reduce the generality of the results. If preferences are representable by the expected utility formulation, the absolute slope of the indifference curve at the point where $x^d = x^n$ will be equal to the subjective odds on state d: $p/(1-p)$. If mitigation steps are limited in the sense that $\partial M^*/\partial x^n > p/(1-p)$ at the point where $x^n = x^d$, then without insurance the individual will be in equilibrium with $x^n > x^d$. This would appear to be the most likely empirical observation. Indeed, it is quite probable that there would not exist real (as opposed to financial) mitigation steps that resulted in greater wealth in the event of a disaster than without the disaster. That is, mitigation expenditures are usually thought to save wealth losses if the disaster occurs rather than to generate more wealth in the disaster state than in the normal state.

Figure 6 illustrates a case where the individual is initially endowed at $\bar{x}$ and faces mitigation possibilities as indicated by the curve MP. Without insurance, mitigation would be undertaken up to the point a in Figure 6, putting the individual on the indifference curve U^1. At a the nominal wealth loss is only $x^n - x_a^d$, compared to the loss of $\bar{x}^n - \bar{x}^d$ without mitigation steps. Now suppose the individual is offered insurance, of any amount he chooses, at a rate equal to his subjective odds. The optimal solution with insurance is to undertake less mitigation, only up to the point b, and take out insurance to move to the point c and thus, to the indifference curve U^2. At c, if state d occurs, the individual will have nominal wealth of x_b^d plus the net insurance payment of $x_c^d - x_b^d$. If state d does not occur, wealth will also be x_c^d and $\bar{x}^n - x_c^d$ in the amount that is paid out for mitigation and insurance premiums.

The amount of mitigation undertaken with insurance is not a misallocation of resources as long as the insurance is offered under competitive conditions. Under competitive conditions, firms only offer insurance if it is profitable, and free entry forces the rate of profit to its lowest level. Hence, both insurance firms and individuals are better off if competitively offered insurance is allowed than without, and there is not social misallocation of resources even though mitigation is less. The reduction in mitigation is socially optimal and results because the insurance firms' offers reflect less risk aversion than the individual possesses. The misallocation of resources would occur if firms were prevented from offering the insurance under competitive conditions. With insurance restricted, too much mitigation would be undertaken for social efficiency.

The Effect of a Prediction on Individual Choices

The effects of a prediction of a disaster on the individual's decisions can readily be analyzed in the foregoing framework. A complete analysis however, must incorporate market equilibrium among all economic agents.

A prediction is assumed to increase the individual's subjective odds of a disaster occurring. Suppose initially the individual's subjective odds on state d were zero. With the probability of state d equal to zero, contingent claims in the event of state d are worthless, and given an endowment such as $\bar{x}$ in Figure 7, no mitigation or insurance is purchased. Initial preferences are represented by the horizontal line U^o. Suppose a prediction changes the individual's subjective odds on state d so that preferences are represented by V^o. With mitigation possibilities of MP and insurance market offerings of MO, the individual takes mitigation steps to a and insures to point b, partially covering his subjective valuation of "irreplaceable" object losses in state d. As demonstrated above, Figure 7 is only illustrative of the amount of insurance, if any, purchased.

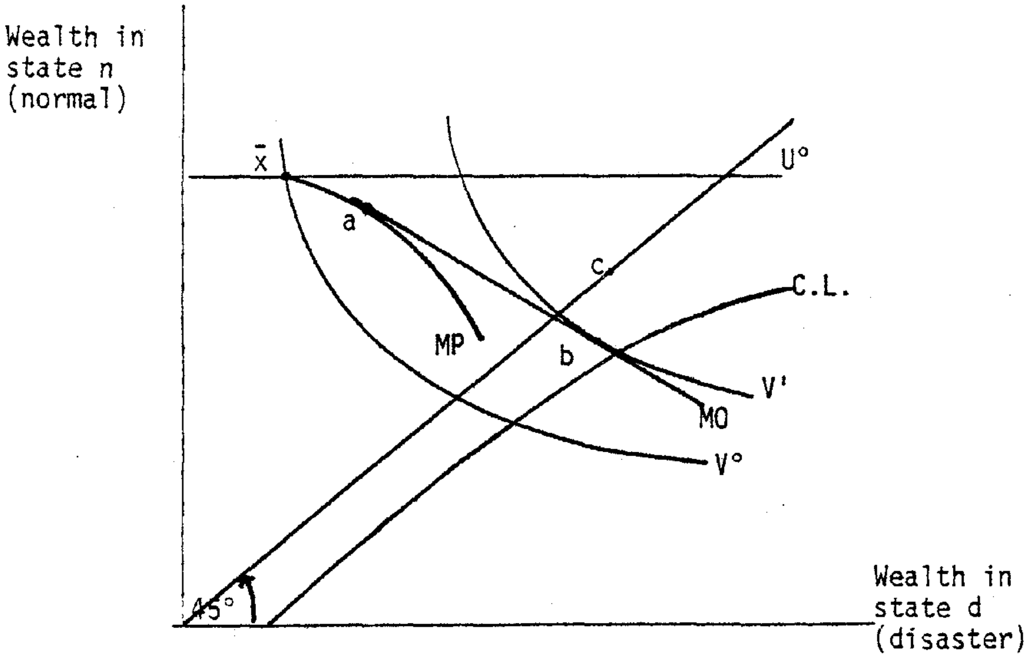

Figure 7. Decisions on Mitigation and Insurance Given a Prediction

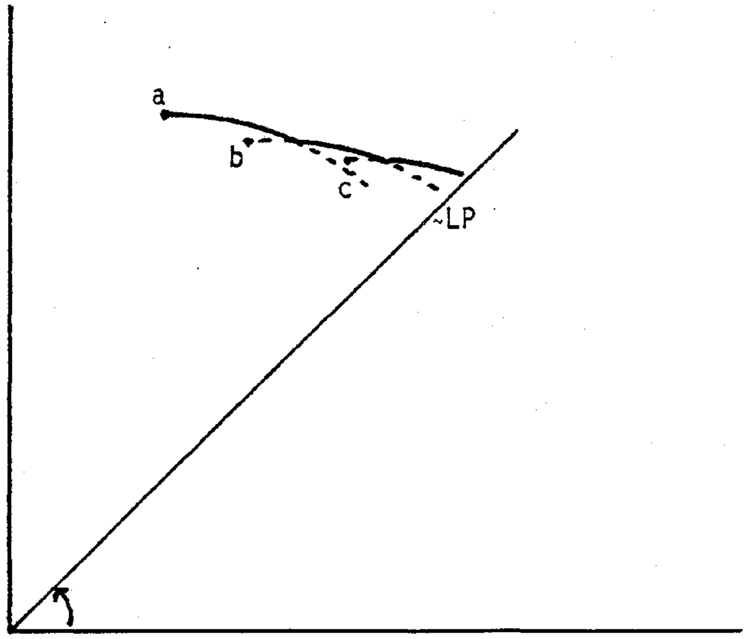

Figure 8. Regional Location Possibilities

Migration

An alternative to physical mitigation efforts to reduce wealth losses at the current location is to relocate. Thus, if there are other regions of lower risk that are better than point b in Figure 7, the individual will move. For example, suppose there is another location such as that indicated by c where nominal wealth loss in state d is zero. Since c lies above V^1, the individual would move and no mitigation steps would be undertaken by him at the original location.

Suppose next that there are many alternative locations for the individual. Each location, in general, would give the individual a different endowment in each state and each location would have various mitigation opportunities (real physical investments) to change these endowments at that location. Figure 8 illustrates the outer envelope for various locations with mitigation possibilities. This outer envelope of efficient location possibilities, labeled LP, certainly need not be convex. Each individual would have, in general, a different location possibilities frontier and individuals with identical preferences would locate in different places. Thus, in general, regional location depends upon the individual's endowments at each location, the mitigation opportunities, whether insurance is available, and individual preferences (in particular, subjective odds and degree of risk aversion). (This is in sharp contrast to the results of Smith (1979) whose restrictive version partitions individuals into regions according to their risk aversion.)

Aid and Assistance

A prediction of a disaster may also increase the individual's belief in the amount of aid and assistance that would be forthcoming.

The perception of aid and assistance effectively moves the disaster state endowment horizontally in Figures 1-8. Recent experience in the United States indicates that insurance payments, capital flows, and private and public phiilanthropy combine to equal or more than offset losses. In the case of the Alaska Earthquake of 1964, federal assistance and loans alone provided 115 percent of property damages (Dacy and Kunreuther (1969)). In the San Fernando earthquake of 1971, federal loans and grants combined with insurance payments amounted to 102 percent of tangible damages (Munroe and Carew (1974)).

Some Comparative Static Propositions

Given the foregoing conceptual framework, the following propositions that relate to policy decisions can be proved. For disaster insurance it is assumed that an individual can purchase as much as he wants at a constant rate. All of these are partial equilibrium propositions, ceteris paribus.

Assuming the Arrow-Pratt index of absolute risk aversion is nonincreasing in nominal wealth, and some mild continuity and convexity assumptions, then:

1. the more aid and assistance that is perceived, the less mitigation undertaken and less insurance purchased; and

2. the more insurance rates are subsidized the less mitigation undertaken and the more insurance purchased.

Along with a newly perceived hazard:

3. the more aid and assistance that is perceived, the less net outmigration; and

4. the more insurance rates are subsidized, the less net outmigration.

If, in addition, individuals maximize expected utility, then:

5. with no insurance, the greater the subjective odds on the disaster the more mitigation undertaken;

6. with no insurance, the greater the subjective odds on the disaster, the greater the net outmigration; and

7. with insurance rates held constant, the greater the subjective odds on a disaster the more insurance purchased.

(The following proof can be skipped without loss in continuity.)

Proof: It suffices to let utility be $U(x^d, x^n)$ for propositions 1-4. Maximization of utility given $x^d = M(\bar{x}^n - x^n) + \bar{x}^d$ requires for a regular interior solution that

$$(3) \quad \frac{\partial U(x^d, x^n)/\partial x^n}{\partial U(x^d, x^n)/\partial x^d} = M'$$

With multidimensional utility, absolute risk aversion is defined in each dimension as:

$$r^d = \frac{-\partial^2 U/\partial x^{d2}}{\partial U/\partial x^d} \quad \text{and} \quad r^n = \frac{-\partial^2 U/\partial x^{n2}}{\partial U/\partial x^n}$$

An increase in aid and assistance increases $\bar{x}^d$. If x^n were unchanged, x^d would be greater and with nonincreasing absolute risk aversion, condition (3) could not hold. To bring (3) into equality as $\bar{x}^d$ increases, thus requires x^n to increase, which means mitigation cannot increase. Assuming M is continuous and strictly convex, then mitigation declines.

Subsidizing insurance rates makes the market opportunities line MO flatter in Figure 7. Since mitigation is only undertaken if it is less expensive than insurance, with MP strictly convex a reduction in insurance rates reduces mitigation and increases the amount of insurance purchased.

Propositions 3 and 4 follow immediately on examination of Figure 7. Both an increase in perceived aid and assistance and lower insurance rates will increase the attractiveness of a disaster prone region relative to others. Consequently, assuming smoothly differing regions in terms of risk, then increased aid lowers net outmigration as does lower insurance rates.

For propositions 5-7, the necessary condition for an interior solution with expected utility given by $pU(x^d) + (1-p)U(x^n)$ and $x^d = M(\bar{x}^n - x^n) + \bar{x}^d$ is:

$$\frac{\partial U(x^n)/\partial x^n}{\partial U(x^d)/\partial x^d} = M' \; p/(1-p)$$

An increase in $p/(1-p)$ must be accompanied by a decline in M' and/or an increase of the left-hand side. Both will occur as x^n declines, i.e. mitigation increases. Holding mitigation constant, outmigration is an alternative. Mitigation will not stay constant of course; so, it is possible that outmigration would increase and mitigation would decline. Proposition 7 is immediate from the above discussion.||

IV. General Equilibrium Considerations

To consider some general equilibrium implications, suppose there are two (representative) individuals, U and V. If both have the same location possibilities locus and the same preferences, then both will locate in the same region and take the same risks. There will be no insurance or pooling of risk by other means. To emphasize the role of risk sharing, therefore, suppose on individual, U, faces location possibilities of either a with mitigation possibilities MP or b as shown in Figure 8. Individual V locates at some other location. Initially, suppose that the probability of state d is zero, so individual U locates at a. Next suppose information changes so that the probability of a disaster at location a is positive but for the other individual, the probability of a disaster is still zero. We will avoid confounding the issue by assuming U and V have the same subjective odds and are both risk averse. Then, equilibrium requires that insurance rates are "unfair" in the sense that V must be paid a reward for risk bearing by U. A possible equilibrium configuration is illustrated in Figure 9 in an Edgeworth box diagram. Individual U undertakes mitigation up to point b. Then U and V trade contingent claims to point c on MO. The slope of MO is greater than both individual's subjective odds on the occurrance of the disaster.

Suppose there is an increase in both individuals' subjective odds on the occurrance of the disaster such that with mitigation constant the equilibrium amount of insurance sold is just the same as in Figure 9, but with higher rates to reflect the increased odds. This will not be an equilibrium, however, because additional mitigation will be cost effective. Consequently, under these conditions, an increase in subjective odds on the disaster will increase mitigation steps, raise insurance rates, and reduce the amount of insurance purchased. Allowing for outmigration, in a more general context, then an increase in subjective odds of a disaster should increase outmigration, increase mitigation, increase insurance rates, and reduce the amount of insurance sold.

Property Values

This approach readily lends itself to an analysis of property values. In Figures 1-9, x^n and x^d are the present value of wealth in the normal state and the disaster state, respectively. One kind of asset is owner-occupied housing units. For this case we can interpret x^n as the present value of housing services from the house if the normal state occurs, while x^d is the present value of housing services if the disaster occurs. With an insurance market as illustrated in Figure 9, the equilibrium price of the house, P_H, will be given by:

$$(4) \quad P_H = px^d + (1-p)x^n$$

where $p/(1-p)$ is the absolute slope of the market opportunities line MO or the "insurance possibilities" line. In other studies, p in (4) is often assumed to be equal to the probability of the disaster. This assumption is implicitly based on market prices being determined by investors who are risk neutral on average. Of course there is no reason why the slope of MO could not equal the relative probability of the

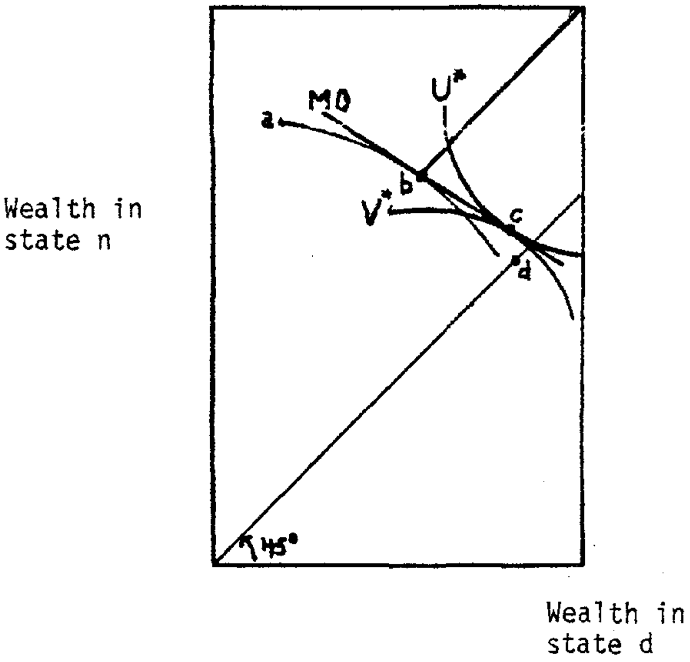

Figure 9. Edgeworth box for pooling risk

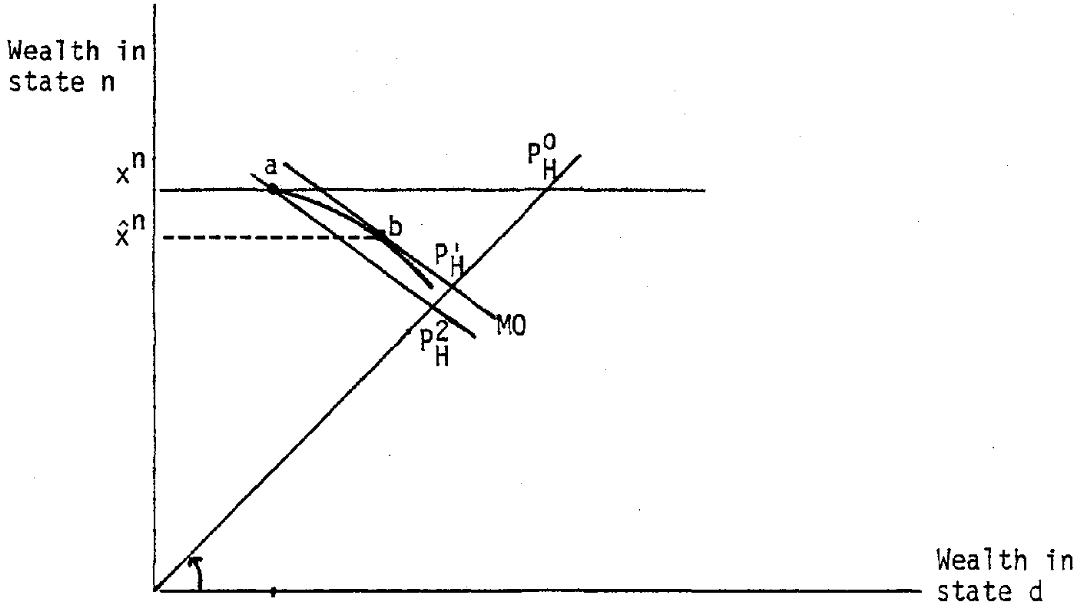

Figure 10. Capital losses associated with predictions

disaster, but it need not, in general, if insurance offerers are not risk neutral (or for other reasons). However, with the possibility of offering insurance to existing house owners that has a higher expected return than buying the house and holding it, no investor would buy the house and, hence, house prices would fall. Thus, under free markets (4) determines the price of the house.

Diagramatically, this is very convenient. It means that the price of the house (or assets, in general) is given by the intersection of the market opportunities line and the 45° line in Figures 1-9. To illustrate further, consider Figure 10. Suppose a house has a present value of services in a normal state as given by x^n and if a disaster occurs, of x^d. With the probability of a disaster equal to zero, the house price is $x^n = P_H^o$. With a positive probability of a disaster such that insurance is offered at rates given by MO, mitigation steps are undertaken to point b, the net cost of which is given by $x^n - \hat{x}^n$, and the price of house falls to $P_H^{'}$. Had mitigation not been undertaken, the price of the house would fall to P_H^2.

In this framework, property values are inversely related to competitive insurance rates: a rise in market equilibrium insurance rates is associated with a fall in equilibrium property values. From a policy perspective, this fact creates a strong incentive for someone who "knows" there may be a disaster and has property interest in the affected area not to want the information made public, since it is often difficult or impossible to sell real estate short. If short selling is possible, then for someone who "knows" a disaster is possible while others do not would have a strong incentive to have the information made public after he has taken a short position. (See Hirshleifer (1971) for an elaboration with respect to inventive activity.) The inverse correlation between insurance rates and property values would also give a strong incentive for a property owner who "knows" a disaster is possible to argue for subsidized insurance rates and to want pledges of aid and assistance if the disaster does occur.

V. Summary

In this paper a conceptual framework for individual choices under uncertainty has been set forth drawing upon state preference analysis. While many details have been ignored (transactions costs, differing degrees of information and belief, etc.), the propositions derived in Sections III and IV appear to conform to empirical observations (although this awaits rigorous testing). The policy implications have not been directly addressed. A formal derivation of optimal policy is first necessary. What the foregoing analysis does is to raise several questions about the economic soundness of many policy alternatives that are often discussed. In particular, many policies would appear to obtain economic rationale only from an argument of market failure - the validity of which is far from clear at this point. While other policies, such as direct aid, require an overall social welfare framework for rationalization. Much work remains for these issues to be clear.

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APPENDIX B

PRODUCER SUPPLY AND DEMAND FUNCTIONS UNDER UNCERTAINTY*

by

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I. Introduction

Duality theorems, in one of the more elegant formulations (Rockafellar (1970)), state that when given a proper, closed, and convex function, its conjugate dual is also a closed, proper and convex function. Further the dual of the dual is the original function. Thus, such theorems provide a one-to-one mapping between an unobservable function used in optimization and observable data; for example a production function and the dual normalized profit function. Such results are extremely powerful and are responsible for unifying theoretical developments with empirical applications. Even when a strict one-to-one correspondence does not exist, there are generally duality relations between optimizing behavior on the one hand and observed consumer or producer decisions on the other. These duality relations may be used in nonparametric tests of the theory (e.g. Varian (1982)) or as maintained hypotheses for estimating parametric differences among data sets.

Duality for static models of producer and consumer behavior under certainty has received wide attention, but relatively little has been given to more complicated models. A brief background on the literature analyzing the duality relations of models with uncertainty is contained in Section II.

The major objective of this paper is to develop some duality relations for specific models of decision making under uncertainty. Toward this end, the optimization problem is simplified to a two period problem of a producer who must choose inputs in the first period with known prices and will sell outputs and consume in the second period. In the first period, output prices are random with known density functions but second period prices of consumption goods are known. Duality relations are derived for two types of utility functions: constant absolute risk aversion and constant relative risk aversion; with four types of probability distributions for output price: normal, gamma, log normal, and uniform. The forms of the indirect functions are shown to be dependent on the specific functional forms used in the direct optimization problem.

In addition to the particular results for the specific models above, Section III contains theorems demonstrating the following. If the utility function is homogeneous of degree zero in scale of prices, the input demand and output supply functions are also homogeneous of degree zero in scale of prices. $U''' > 0$ is sufficient for output to be nondecreasing in the scale of random output prices and nonincreasing in the scale of input prices. Constant absolute risk aversion or constant relative risk aversion are sufficient for output to be nonincreasing in mean preserving spreads of the probability distributions.

Concluding remarks are contained in Section IV.

II. Background

Duality

The duality between a direct optimization problem (such as choosing inputs for a given technology to maximize profits under a given vector of input and output prices or choosing consumption commodities to maximize utility subject to a budget constraint with given prices and nominal income) and the indirect function that describes these optima in terms of the parameters (prices, income, and the like) can be traced back at least to Antonelli (1886), Konyus (1924) and, in the English language literature, Hotelling (1932). Yet the full ramifications and the power of duality theory for consistent theoretical and empirical analysis has only recently been developed. (See Diewert (1974) or (1978) for a review.) Given an optimization problem, it is clear that one can express the solution as a function of the parameters. What is not so clear is that such an indirect function can be used, under certain regularity conditions, to completely recover the direct objective function. This "full duality" was recognized by Hotelling (1932):

> "Just as we have a utility (or profit) function u of the quantities consumed whose derivations are the prices, there is, dually, a function of the prices whose derivatives are the quantities consumed." (p. 594)

Prior to the development of duality theory, the relation between rigorous theoretical models and empirical estimation was a loose one, with sophisticated mathematical optimization models only being used to suggest the appropriate variables to be included in a regression equation and, at most, suggesting the appropriate sign for these variables. The functional form of the regression equation was often linear and no restrictions were imposed on the coefficients. A major reason for this lacuna is that, except in the simplest of cases, it is impossible to derive an analytical solution from the necessary conditions for the optimum of the direct optimization problem. While the reverse is also true: it is generally impossible to derive the specific functional form for the direct objective function from an indirect function that is consistent with the data; duality theory prescribes all the restrictions for the indirect functional form that are implied by the theory and given an indirect function that is consistent with a set of data, one is assured that it could have been generated by optimization of a direct function that obeys the theoretical restrictions.

Duality theory is now well developed for static models of producer and consumer behavior under certainty (Diewert (1978)) and a number of empirical applications of these models have appeared in the literature (for example, Fuss and McFadden (1978)). There has been relatively little work with more complex models that contain intertemporal relations or uncertainty. Exceptions to this include the theoretical results for dynamic models defined in Epstein (1981), Epstein and Denny (1981) which also has some empirical work, and McLaren and Cooper (1980). These models are "dynamic" because they contain durable commodities or inputs under conditions of less than perfect markets so that decisions in one period affect decisions in subsequent periods. Properly specified, models of behavior in an uncertain world must also be time specific. It is necessary that decisions be made prior to the occurrance of a random event in models of uncertainty if they are to be of much interest.

Uncertainty Models

Larry Epstein (1975, 1978) has analyzed the duality properties of a two period model of consumer and producer behavior under uncertainty about second period prices. The consumer and producer models are quite similar, so only the consumer model is presented here. The consumer maximizes a regularly behaved utility function of current and future consumption, x and y, with known current prices, p, and random future prices, q, and income, I. This is a two-stage maximization problem. In the second period when the random variables are known, the consumer's problem is:

$$(1)\quad \max_{y\geq 0} \{u(x, y) \mid qy \leq I - px\} = g(I, q; p, x)$$

g is termed the variable indirect utility function. In the first period, the consumer maximizes expected utility which is (2):

$$(2) \quad \max_{x \geq 0} \int g(I(w),\, q(w);\, p,\, x)\, dF(w)$$

$$\text{subject to } px \leq I(w) \text{ for all } w \in W$$

The necessary conditions can be expressed as (3):

$$(3) \quad E(g_{x_i}) = p_i\, E(g_I)$$

From (3), Epstein derives comparative static properties for changes in consumption of first period commodities, dx, from changes in current prices, dp, changes in expected income, dE[I], and changes in income risk, d Risk [I], as defined by Rothschild and Stiglitz (1970). This is done using the usual technique of boardered Hession matrices with derivations of the expected value of the variable indirect utility function replacing the derivatives of the utility function found in certainty models. To obtain unambiguous qualitative results, however, it requires a lengthy set of assumptions about signs of various determinants and risk aversion functions that have no a priori plausibility. Furthermore, since these expressions depend on third derivatives of the utility function, the second order flexible functional forms, often used in empirical applications of duality theory of static models under certainty, are not adequate. Thus, Epstein suggests using a third degree flexible functional form such as (4).

$$(4) \quad g = s\Sigma\, a_{ijk}(q_i q_j q_k)^{-1/3} + s^{2/3}\, \Sigma\, b_{ijk}\, q_i^{-1/3} q_j^{-1/3} x_k^{1/3} + s^{1/3}\, \Sigma\, c_{ijk}\, q_i^{-1/3} x_j^{1/3} x_k^{1/3} + \Sigma d_{ijk}(x_i x_j x_k)^{1/3}$$

(4) assumes that preferences are linearly homogeneous but it can be easily modified for nonhomogeneous preferences by adding terms. Duality conditions require that the coefficients $a_{ijk} = a_{i'j'k'}$ and $d_{ijk} = d_{i'j'k'}$ if $\{i, j, k\} = \{i', j', k'\}$ and likewise for the b's and c's when i, j, and k are distinct. Further, duality conditions require all coefficients to be nonnegative.

There are two major problems with Epstein's results and suggestions. First, with only a few commodities, the number of parameters in (4) is unmanageable for sensible empirical work, let alone a generalization allowing for nonhomogeneous preferences. For three present and future commodities, (4) has 56 parameters! Second, (4) is not estimable. Epstein suggests, "Moreover, substitution of the above functional form [(4)] into equation [(3)] yields a system of equations linear in the unknown parameters. Therefore, if current price and quantity data are available and if future price and income expectations are known, linear regression techniques may be used to estimate the parameters." (p. 889) Expected values alone are not sufficient, however. One has to calculate $E[g_{x_i}]$ and $E[g_s]$ using some specific probability distribution and then solve the system of equations (3) for the commodity demand equations, which is not feasible except for the simplest cases.

In summary, Epstein's analysis generalizes some previous results (for example, Leland (1968) and Sandmo (1970)) and adds insight to the nature of the problems of decisions under uncertainty but his results are not very useful for empirical work.

Risk Independence

To overcome this intractability, the assumption of risk independence or risk invariance has been suggested and it does simplify the analysis considerably This notion has been defined and discussed in a series of papers by Stiglitz (1969), Deschamps (1973), Keeney (1973), Pollak (1973), Hanoch (1977), Willig (1977), and Epstein (1980). Letting the decision problem be represented as:

$$\max_{x \geq 0} EU(x; \varepsilon)$$

where ε is a random variable, then ε is risk independent of x if preferences in gambles in ε are independent of x. In other words, U is of the form $U(x; \varepsilon) = a(x) + b(x)\, v(\varepsilon)$. Keeney (1973) and Epstein (1980) have shown that risk independence is equivalent to invariance with respect to x of the Arrow-Pratt index of risk aversion or $\partial/\partial x\ (-U_{\varepsilon\varepsilon}/U_{\varepsilon}) = 0$. Risk independence implies that actions can be described as though the individual were acting under certainty with ε equal to its expected value plus a risk premium. This is easily seen by taking expectations: $EU = a(x) + b(x)\, Ev(\varepsilon)$ and, thus $Ev(\varepsilon)$ is simply a constant when maximizing U with respect to x. Thus, the effects of parametric changes are simplified to those under certainty and are dependent only on first and second order properties of utility or production functions. Consequently, traditional second order flexible functional forms may be used in empirical applications.

Given the virtual intractability of equation (4), these results from risk independence appear quite advantageous. However, there is a rather high cost. Risk independence places strict limitations on the functional form of the utility function. Stiglitz (1969) has shown the following. First, risk neutrality for all prices and income levels implies that preferences are homothetic. Risk neutrality in some open region implies the income-consumption curves are straight lines. The converse is also true. If the income consumption curves are linear, $x_i = g^i(p) + Uh^i(p)$. Thus, the expenditure function is $E = \Sigma p_i g^i + U \Sigma p_i h^i$. Thus, the utility function is of the form $V = a(p)\ y + b(p)$, which implies risk neutrality.

Second, for utility functions that have constant relative risk aversion equal to one, $r = 1$, then $V = w \ln y + v(p)$, or utility is Bernoullian, where w is a constant and preferences are homothetic if $r = 1$ throughout. A related converse is that if demands are of the form $x_i = \alpha^i y \ln y + \beta^i y$ then there exists a Bernoulli representation of the utility function.

Third, for $r \neq 1$ but constant throughout, the indirect utility function is of the form $V(y, p) = w(p)\ y^{1-r} + z(p)$ where $z(p)$ is homogeneous of degree zero in p, and preferences are homothetic in this case as well.

Fourth, constant absolute risk aversion implies that $V = a(p)e^{c(p)y} + b(p)$ where $ac > 0$ and a and b are homogeneous of degree zero, c is homogeneous of degree minus one, and preferences must be homothetic if there is aversion to risk, $c(p) < 0$, which, in turn, requires b to be constant.

Hanoch (1977) proves that if r is only a function of the level of utility, then the expenditure function must be of the following form $E = G(p)\ \emptyset(u, H(p))$ where $H(p)$ is homogeneous of degree zero in prices. Further if r is constant for any level of utility, u, then $g = H(p)$

$\ln (y/G(p))$ if $r = 1$, or $g = \frac{1}{(1-r)} [\frac{y}{G(p)}]^{1-r} - H(p)$ if $r \neq 1$ where $G(p)$ is linearly homogeneous and $H(p)$ is homogeneous of degree zero in p.

Willig (1977) extends these results to multivariate definitions of risk invariance. Dimension i strong risk invariance holds if an individual is indifferent between two bundles x and x' and indifferent between x and a lottery with gambles in terms of the ith commodity, then he is indifferent between x' and the lottery ticket as well. Strong risk invariance is when the individual is strongly risk invariant in all dimensions. Willig then proves two major theorems.

Strong risk invariance exists if and only if the utility function takes one of two forms: (1) $U(x) = c_0 + \Sigma c_j \prod_{i \in S_j} t_i(x_i)$ where S_j is a nonempty subset of $\{1,2,\ldots,n\}$ and $t_i(x_i) = x_i$ if the individual is risk neutral, otherwise $t_i(x_i) = e^{b_i x_i}$ where b_i is globally constant i<u>th</u> dimensional strong risk aversion index; or (2) $U(x) = T[\Sigma c_i x_i]$ where $T' \neq 0$ and $T'' \neq 0$. In other words, strong risk invariance implies at a minimum that the utility function is ordinally linear and more restrictive forms are implied if risk aversion is constant.

There is strong relative risk invariance when there is dimension i strong relative risk invariance for all i. In this case the utility function must be one of two forms: (1) if each dimensional relative risk aversion index is a constant, b_i, then $U = c_0 + \Sigma c_j \prod_{i \in S_j} t_i^* (x_i)$ where S_j is a nonempty subset of $\{1,2,\ldots,n\}$ and $t_i^*(x_i) = x_i^{b_i+1}$ if $b_i \neq 1$ or $t_i^* (x_i) = \ln x_i$ if $b_i = -1$; or (2) $U(x) = T(\Pi x_i^{c_i})$, $T' \neq 0$ and $T'' \neq 0$. Thus, strong relative risk invariance implies, at a minimum, that the utility function is ordinally Cobb-Douglas.

These strong results would tend to militate against the use of strong absolute or relative risk aversion. Although Willig argues these can be interpreted solely as outcomes under uncertainty, the advantage of the von Neumann-Morgenstern axioms is the consistenty between decisions under certainty and decisions under uncertainty and implied probabilities about alternative states of nature.

A weaker assumption dicussed by Willig is dimension i weak risk invariance. This holds if an individual is indifferent between a bundle x and a lottery ticket similar to x but with gambles in the ith dimension, then if he is indifferent between x and y with $x_i = y_i$, then he is also indifferent between y and the lottery ticket. Willig proves that weak risk invariance for all dimensions holds if and only if the utility function is ordinally additive: $U(x) = T(v_1(x_1)+\ldots+ v_n(x_n))$ where $v_i' \neq 0$ and $T' \neq 0$. These and additional special cases presented by Willig are quite useful for constructing utility functions from direct indifference judgements by individuals, but the duality implications for functional forms have not been derived.

Epstein (1980) derives the restrictions from risk independence for intertemporal models of producer and consumer behavior. For the following producer optimization problem:

$$\max_{x\geq 0} E(g(q;x)-px))$$

where q is a vector of ex post prices that are random when x must be selected ex ante, Epstein proves that if and only if q is risk independent of x, then the variable profit function can be written $g(q;x) = \alpha(x)h(q)$ and the transformation frontier is represented $G(y) = H(x)$, where y is the vector of ex post inputs and outputs selected when q is known.

The intertemporal consumer model is a two stage problem:

$$\max_{\substack{x \geq 0 \\ px \leq I}} E[g(I-px; q; x)]$$

where $g(I; q; x) = \max_{y \geq 0} \{u(x, y) | qy \leq I - px\}$. x is first period consumption with known prices p. y is second period consumption with random prices, q, and random wealth I. Let $s = I - px$ be the random amount available for future consumption. For this model, Epstein (1980) proves: (a) I and q cannot both be risk independent of x; (b) I is risk independent of x if and only if $g(s; q; x) = \alpha(x, q) + \beta(x, q)\, e^{-r(q)s}$ where α and β are homogeneous of degree zero in q; $r(q)$, relative income risk aversion, is homogeneous of degree -1 in q; and $\beta(x, q) < 0$; (c) q is risk independent of x if and only if $g(s; q; x) = \alpha(x) + \beta(x)\, h(s, q)$ where $\beta(x) > 0$ and h is an indirect utility function corresponding to homothetic preferences and has constant relative risk aversion. Further $h(s, q) = [s/a(q)]^{1-r} /(1 - r)$ if $r \neq 1$ and $h(s, q) = \log(s/a(q))$ if $r = 1$ where $a(q)$ is positive and linearly homogeneous.

A weaker notion, with weaker restrictions, is constant risk aversion along indifference surfaces. Hanoch (1977) has shown that absolute risk aversion cannot be independent of prices and constant along indifference surfaces but relative risk aversion can. Epstein (1980) shows that absolute risk aversion can be constant along indifference surfaces if, in the context of the intertemporal model above, s and x can vary holding q constant.

In this case: $R(s; q; x) = -g_{ss}/g_s = G(g(s; q; x), q)$, by definition; and Epstein proves that the variable expenditure function $e(u, q, x) = \min \{qy | u(x, y) \geq u\}$ is of the form:

$$e(u, q, x) = \int_{u_0}^{u} \frac{dv}{f(v, q) + H(x, q)} + F(x, q)$$

where $f_u = R(u, q)$ is homogeneous of degree -1 in q and H and F are homogeneous of degree -1 and 1, respectively, in q.

In conclusion, these analyses of the implications of risk independence or risk invariance further illuminate the problems of characterizing decision making under uncertainty and show that such assumptions have high demands on the functional form. A development of the duality relations for empirical applications, however, has scarcely been touched. In particular, what is noticeably absent is a specification of a probability distribution and how the parameters of such a distribution and other parameters of an optimization problem are related in an empirical specification of that optimization problem.

III. Results for Some Specific Decision Models

In this section, specific models of decision making under uncertainty are explored and their implications for empirical applications examined. In paving the way, the problem is simplified as much as possible. A two period, producer problem is used where nondurable inputs, x, must be chosen in the first period with known constant prices, w, and a single nondurable output, y, is sold in the second period. Output price, p, is random when input choices are made. Profits are used in the second period to purchase consumption goods at prices q. The vector of consumption good prices is known in period one. This is stated formally as the two stage maximization problem termed Model A.

Model A

Second state problem: maximize $U(z) = U(\pi, q)$
$z \geq 0$
subject to $qz \leq \pi$

First stage problem: maximize $EU(\pi, q) = V(p, w, q)$, where $\pi = py - wx$.
$x \geq 0$

$y = y(x)$ is a strictly concave neoclassical production function.
p is output price randomly distributed with mean $\bar{p}$ and finite variance σ^2. U is homogeneous of degree zero in all prices: p, w, q; and $U_\pi > 0$, $U_{\pi\pi} < 0$.

In the development that follows, the vector of input prices and consumption prices will be allowed to overlap. In particular, two extremes for the index of constant absolute risk aversion, r, will be examined. One is where q and w are completely different and, hence, $r_w = 0$. The second is where $q = w$. Since r is homogeneous of degree minus one in q, in this case $r_w w = -r$.

As noted in Section II, the assumption of risk independence can greatly simplify the analysis. For this producer problem, risk independence requires that input choices be independent of gambles on output prices, which means the utility function must be linear in real profits or the producer must be risk neutral. If risk is to matter, risk independence must be ruled out.

Constant Absolute Risk Aversion

Constant absolute risk aversion (CARA) means the utility function can be written as $U = 1 - e^{-r\pi}$. Profit, π, is linearly homogeneous in all prices and r, the absolute risk aversion index, is homogeneous of degree minus one in all prices. Thus, the utility function is homogeneous of degree zero in all prices. As long as r is not dependent on ramdon prices, then expected utility is:

$$EU = 1 - M_\pi\ (-r),$$

where $M_\pi\ (-r)$ is the moment generating function for random profits as a function of the "artificial" variable $-r$.

A second convenient property of this problem formulation is that the distribution of random profits is the same, with different parameters, as the distribution of output price. If p has an "x" distribution with mean $\overline{p}$ and variance σ^2, π is distributed "x" with mean $\overline{\pi} = \overline{p}y - wx$ and variance $y^2\sigma^2$.

CARA and the Normal Distribution (CARAN)

Theorem 1. If output price is distributed normally with mean $\overline{p}$ and variance σ^2, then let CARA for Model A be denoted as CARAN. CARAN implies input demands and, therefore, output supply are homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w:

$$x = x(\overline{p}, r\sigma^2, w) = x(\lambda\bar{p}, \lambda r\sigma^2, \lambda w) \text{ for all } \lambda > 0.$$

It follows that expected utility is also homogeneous of degree zero in $\overline{p}$, $r\sigma^2$, and w. y is nondecreasing in $\overline{p}$ and nonincreasing in σ, but may increase or decrease with w.

Proof: Since p is distributed normally, profit is normally distributed and, hence, CARA in Model A implies:

$$EU = 1 - e^{-r\overline{\pi} + r^2y^2\sigma^2/2}$$

The necessary condition can be written as:

$$r\bar{\pi}_x - r^2\sigma^2 yy_x = 0$$

or

(5) $(\bar{p} - ry\sigma^2)y_x = w$

Thus, let $p^*(y) = \bar{p} - ry\sigma^2$, $\frac{\partial p^*}{\partial y} = -r\sigma^2 < 0$. $p^*(y)$ is "utility" adjusted average revenue. Clearly, (5) is homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w. Let the solution to (5) be x. If r is homogeneous of degree minus one in all prices, x is also the solution for $\lambda\bar{p}$, $\lambda\sigma$, and λw, $\lambda > 0$. Differentiating (5) with respect to $\bar{p}$ gives $y_x - (r\sigma^2 y_x^2 - y_{xx})\, \partial x/\partial\bar{p} = 0$. The sufficient condition for (5) to be an interior maximum is $r\sigma^2 y_x^2 - p^* y_{xx} > 0$, which clearly will hold if $y_{xx} < 0$. Thus, y cannot decrease with an increase in $\bar{p}$ and for a regular interior solution will increase along with all normal inputs. Differentiation of (5) with respect to σ^2 yields $dx/d\sigma^2 = -ryy_x/(r\sigma^2 y_x^2 - y_{xx}) < 0$. However, differentiation with respect to w gives $dx/dw = (1 + r_w y\sigma^2 y_x)/(p^* y_{xx} - r\sigma^2 y_x^2)$. The numerator may be positive or negative depending on the size of the second term, which is nonpositive. If a factor price changes that does not affect risk aversion, then $r_w = 0$ and $dx/dw < 0$. Alternatively, consider the case of one input with $\bar{p} = 5$, $r = 3/w$, $\sigma^2 = 1$, $y = x^{\frac{1}{2}}$, and $w = 1$. The solution using condition (5) is $x = 1$. Differentiating (5) with respect to w and evaluating at the given parameter values yields $dx/dw = -(1 - 3/2w^2)/$ $[(5 - 3x^{\frac{1}{2}}/w)x^{-3/2}/4 + 3/4wx]$; which evaluated at $w = 1$ gives $dx/dw > 0$. An increase in factor price reduces the risk aversion index sufficiently so that input usage increases and output increases. However, as r_w goes to zero, dx/dw is clearly negative.||

The optimal solution for x depends on $\bar{p}$, σ, and w and is homogeneous of degree zero in these variables provided r is homogeneous of degree minus one. Likewise, since $y = f(x)$, y is a function of $\overline{p}$, σ, and w and is homogeneous of degree zero if r is homogeneous of degree minus one. Thus, the expected utility function is:

$$V = \max \ EU = 1 - e^{-r} \left(\bar{p}y(\bar{p}, \sigma, w) - wx(\bar{p}, \sigma, w) + r^2 y(\bar{p}, \sigma, w)^2 \sigma^2/2\right.$$

Let $Z = \frac{-1}{r} \ln (1 - V)$. Using the envelop theorem, the supply and demand functions, their slopes, and their elasticities are obtained from Z as shown in (6) - (8). The results in (6) and (7) hold regardless of the homogeneity of r in w. The conditions in (8) assume $r_w = 0$. No similar, convenient relations follow for r homogeneous of degree minus one in w. The pertinent effects of w on output can be obtained by further differentiation of equation (6).

$$(6) \quad Z_p = y, \ Z_{\bar{p}\bar{p}} = y_{\overline{p}} \ , \ \overline{p} \quad \frac{Z_{\bar{p}\bar{p}}}{Z_{\bar{p}}} = y_{\bar{p}} \frac{\bar{p}}{y} = \eta^{y}_{\bar{p}}$$

$$(7) \quad Z_\sigma = -ry^2\sigma, \ Z_{\bar{p}\sigma} = y_\sigma \ ,^{\sigma} \frac{Z_{\bar{p}\sigma}}{Z_{\bar{p}}} = y_\sigma \frac{\sigma}{y} = \eta^{y}_{\sigma}$$

$$(8) \quad \text{If } r_w = 0, \ -Z_w = x, \ -Z_{ww} = x_w, \ w\frac{-Z_{ww}}{Z_w} = -x_w \frac{w}{x} = \eta^{x}_{w}$$

There are several relations implied by (6) - (8) for the partial derivatives of y. For example, from (6) and (7) since $Z_{\bar{p}\sigma} = Z_{\sigma\bar{p}}$, one obtains $Z_{\sigma\bar{p}} = -2r\sigma \, Z_{\bar{p}} Z_{\bar{p}\bar{p}}$. Also, (6) and (7) imply $-Z_\sigma/r\sigma = Z^2_{\bar{p}}$. What is a convenient functional form for Z that satisfies these conditions is not clear, however traditional functional forms such as a translog for Z will not satisfy these conditions. When the production function is linearly homogeneous, one can be more explicit about the functional form of Z.

Theorem 1'. If f(x) is linearly homogeneous then the equivalent objective function, Z, for CARAN is: $Z = (\bar{p} - c(w))^2/2r\sigma^2$, where c(w) is the unit cost function. Z is convex in $\bar{p}$, w. Thus, the output supply function is:

$$Z_p = y = (\bar{p} - c(w))/r\sigma^2$$

The expected profit function is:

$$\bar{\pi}(\bar{p}, r\sigma^2, w) = (\bar{p} - c(w))^2/r\sigma^2$$

The output supply and input demand elasticities are independent of risk, assuming $r_w = 0$:

$$\eta^y_{\bar{p}} = \frac{\bar{p}}{\bar{p} - c(w)} > 1$$

$$\eta^y_{\sigma 2} = -1$$

$$\eta^y_{c(w)} = \frac{-c(w)}{\bar{p} - c(w)} < -1$$

$$\eta^x_w = w(c_{ww}/c_w - c_w/(\bar{p} - c(w))) < 0$$

Proof: Given that f(x) is linearly homogeneous, $Z = \bar{p}y - yc(w) - r\sigma^2y^2/2$. Maximizing with respect to y one obtains:

$$\bar{p} - c(w) - r\sigma^2 y = 0$$

which solving for $y = \frac{\bar{p} - c(w)}{r\sigma^2}$ easily gives Z, verifies $Z_{\bar{p}}$ and gives $\bar{\pi}$ as stated in the theorem. The convexity of Z in $\bar{p}$, w follows immediately since the unit cost function is concave in w. The elasticities follow from (6) - (8).||

The expected profit function could be estimated, but Hotelling's lemma, of course, does not apply. y must be obtained from Z or some other, equivalent envelop of the direct objective function, V. In estimating the expected profit function or the output supply function, the general flexible functional form Mean of Order R (MOR) (which contains translog, generalized Leontief, generalized square root quadratic, and other functions as special cases) could be used for the unit cost function:

$$c(w) = (\sum_i \sum_j \beta_{ij} w_i^\tau w_j^\tau)^{\frac{1}{\tau}}$$

Then equation (6) could be used to estimate r and the parameters of the unit cost function.

CARA and the Gamma Distribution (CARAG)

Although the normal distribution is widely used in economic analysis, it implies that output prices could be negative in the foregoing problem. Under the maintained assumptions, the producer is forced to dispose of his output if price is negative. Better probability distributions for many situations would be those where price ranges from zero or some positive constant to infinity or some maximum such as the exponential distribution and its parent the gamma distribution. The exponential distribution is a one parameter distribution given by:

$$(9) \quad f(p) = \frac{e^{-p/\bar{p}}}{\bar{p}}, \; p > 0$$

with mean $\bar{p}$ and variance $\bar{p}^2$. The gamma distribution is given by:

$$(10) \quad f(p) = \frac{\alpha^c p^{c-1} e^{-\alpha p}}{\Gamma(c)}$$

where $\Gamma(c)$ is the gamma function.

In (10), $c = \bar{p}^2/\sigma$ and $\alpha = \bar{p}/\sigma$. Thus, the exponential distribution is the special case of the gamma distribution when c = 1. Other than being unable to vary the mean of the exponential probability distribution without varying the variance accordingly, what is proved for the gamma in the following theorem holds for the exponential.

<u>Theorem 2</u>. If output price is distributed gamma with mean $\bar{p}$ and variance σ^2, then let CARA for Model A be denoted CARAG. CARAG implies input demands are homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w. y is nondecreasing in $\bar{p}$, nonincreasing in σ, and nonincreasing in w.

Proof: Using (10) expected utility is:

$$(11) \quad EU = \int_0^\infty (1 - e^{-r(py - wx)})\ \alpha^c \frac{p^{c-1} e^{-\alpha p}}{\Gamma(c)}\, dp$$

Differentiating with respect to x and setting the result equal to zero gives:

$$\frac{\partial EU}{\partial x} = \int_0^\infty e^{-r(py - wx)} \frac{\alpha^c p^{c-1} e^{-\alpha p}}{\Gamma(c)} (py_x - w) r\, dp = 0$$

Dividing through by constants and rearranging yields:

$$y_x \int_0^\infty e^{-p(ry + \alpha)} p^c dp - w \int_0^\infty e^{-p(ry + \alpha)}\, p^{c-1}\, dp = 0$$

or

$$y_x \frac{c!}{(ry + \alpha)^{c+1}} - \frac{w(c - 1)!}{(ry + \alpha)^c} = 0$$

Substituting for c and α, the necessary condition becomes:

$$(12) \quad \frac{\bar{p}^2\, y_x}{r\sigma^2 y + \bar{p}} - w = 0$$

(12) is homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w or in $\bar{p}$, σ, and w if r is homogeneous of degree minus one in these parameters. Consequently, the optimal solution x* for condition (12) is unchanged if $\bar{p}$, $r\sigma^2$, and w are multiplied by $\lambda > 0$.

The comparative static properties of an interior solution follow directly from differentiation of condition (12). First, let $d\bar{p} > 0$. (12) requires:

$$\frac{2\bar{p}\, y_x}{r\sigma^2 y + \bar{p}} + \frac{\bar{p}^2 y_{xx}\, dx/d\bar{p}}{r\sigma^2 y + \bar{p}} - \frac{\bar{p}^2 y_x (r\sigma^2 y_x\, dx/d\bar{p} + 1)}{(r\sigma^2 y + \bar{p})^2} = 0$$

Solving gives:

$$(13) \quad \frac{dx}{d\bar{p}} = \frac{-\bar{p}^2 y_x - 2\bar{p} y_x r\sigma^2 y}{\bar{p}^2 y_{xx}(r\sigma^2 y + \bar{p}) - \bar{p}^2 y_x^2\, r\sigma^2} > 0.$$

Similarly for $dx/d\sigma$, one obtains from differentiation of (12) and letting D be the denominator of the right hand side of (13), which is negative, the result:

$$\frac{dx}{d\sigma} = \frac{\bar{p}^2 y_x\, ry}{D} < 0.$$

For dw, one obtains:

$$\frac{dx}{dw} = \frac{(r\sigma^2 y + \bar{p})^2 + r_w\, \bar{p}^2 y_x\, \sigma^2 y}{D} < 0$$

if:

$$(14) \quad (r\sigma^2 y + \bar{p})^2 + r_w\, \bar{p}^2\, y_x\, \sigma^2 y > 0.$$

If r is homogeneous of degree minus one in w, $r_w w = -r$. Thus, using (12) to substitute in w, condition (14) becomes:

$$r\sigma^2 y < r\sigma^2 y + \bar{p}$$

or $\bar{p} > 0$, which is assumed, so that dx/dw is < 0. Note that $dx/dw < 0$ as long as $-r \leq r_w w \leq 0$. This will hold as long as r is homogeneous of degree minus one is all prices and $r_w \leq 0$ for all input prices $w > 0$.||

Carrying out the integration in equation (11) and substituting for α and c, the expected utility function for Model A with output prices having a gamma distribution is:

$$V = 1 - (\bar{p}/(ry\sigma^2 + \bar{p}))^{\bar{p}^2/\sigma^2} e^{rwx}$$

Making the monotonic transformation $Z = \sigma^2 \ln (1 - V)/\bar{p}^2 = \ln \bar{p} - \ln (yr\sigma^2 + \bar{p}) + \sigma^2 rwx/\bar{p}^2$ and using the envelop theorem, we obtain the following derivatives:

$$Z_{\bar{p}} = 1/\bar{p} - 1/(ry\sigma^2 + \bar{p}) - 2\sigma^2 rwx/\bar{p}^3$$

$$Z_{\sigma 2} = -ry/(ry\sigma^2 + \bar{p}) + rwx/\bar{p}^2$$

From which it follows that:

$$(15) \quad -\bar{p}^2(\bar{p}z_{\bar{p}} + \sigma^2 z_{\sigma 2})/\sigma^2 = rwx$$

Z is homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w or in $\bar{p}$, σ, and w if r is homogeneous of degree minus one in w.

If $r_w = 0$, then the output supply and input demand functions and their first derivatives can be obtained from the envelop function Z as follows:

$$(16) \quad Z_w = r\sigma^2 x/\bar{p}^2 \text{ or } x = Z_w \bar{p}^2/r\sigma^2, \; x_w = Z_{ww}\bar{p}^2/r\sigma^2$$

Further, let $\phi = -Z_{\bar{p}} - 2\, Z_w\, w/\bar{p} + 1/\bar{p} = 1/(ry\sigma^2 + \bar{p})$, then

$$(17) \quad (1/\phi - \bar{p})/r\sigma^2 = y \text{ and } (-\phi_{\bar{p}}\,/\phi^2 - 1)/r\sigma^2 = y_{\bar{p}}$$

Conditions (16) and (17) are quite complex and their general empirical usefulness appears questionable. If $r_w \neq 0$, then the results are more complex than (16) and (17).

As with CARAN, if the production function is linearly homogeneous, one can derive the output supply function directly without the need of (15)-(17).

<u>Theorem 2'</u>. If $f(x)$ is linearly homogeneous for CARAG, the output supply function is:

$y = \bar{p}(\bar{p} - c(w))/c(w)r\sigma^2$, where $c(w)$ is unit cost.

Hence, the mean price elasticity, risk elasticity, and unit cost elasticity of output follow directly as

$$\eta^y_{\bar{p}} = \frac{\partial y}{\partial \bar{p}} \frac{\bar{p}}{y} = \frac{2\bar{p} - c(w)}{\bar{p} - c(w)} > 1$$

$$\eta^y_{r\sigma^2} = \frac{\partial y}{\partial (r\sigma^2)} \cdot \frac{r\sigma^2}{y} = -1$$

$$\eta^y_{c(w)} = \frac{\partial y}{\partial c(w)} \cdot \frac{c(w)}{y} = \frac{-\bar{p}}{\bar{p} - c(w)} < -1$$

Proof: Let $Z^* = -\ln(1-v)$. Then y that maximizes V maximizes Z^*. With $f(x)$ linearly homogeneous, $Z^* = \bar{p}^2/\sigma^2(\ln(ry\sigma^2 + \bar{p}) - \ln \bar{p}) - ryc(w)$.

Then

$$\partial Z^*/\partial y = (\bar{p}^2/\sigma^2)\,(r\sigma^2/(ry\sigma^2 + \bar{p})) - rc(w) = 0$$

From which the result follows:

$y = \bar{p}(\bar{p} - c(w))/c(w)r\sigma^2$.||

Comparing the results of Theorem 1' with those of Theorem 2', assuming equal means, variances, and factor prices, output under CARAG is greater than under CARAN. This is reasonable since the gamma distribution is truncated at zero while the normal is not. The mean price elasticity of supply is greater for CARAG than for CARAN and output falls more from an increase in unit costs under CARAG than CARAN. The risk elasticity of supply is minus one for both. All three elasticities are independent of the level of risk.

Thus far we have used CARA and two parameter probability distributions and found the solution to model A homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w or in $\bar{p}$, σ, and w if r is homogeneous of degree minus one. The key to these results is the utility function, not the probability distribution as the next theorem should help clarify.

Unless the probability distribution has a one independent parameter that is the mean (which both the normal and gamma distributions do), it is not meaningful, in general, to talk about the effect on expected utility from a change in the mean in the probability distribution. This is because the mean can shift by the same amount for different reasons that have a different effect on expected utility. (An example with the uniform distribution is provided below.) A meaningful concept, however, is a shift in the scale of the probability distribution.

<u>Definition</u>. Given p is a random variable defined on the interval $a \leq p \leq b$ with a density function f(p) and cumulative probability function F(p), then p* is a shift in scale of p if $p^* = \lambda p$, $\lambda > 0$ where the density of p* is $f^*(p^*) = f(p)/[F(a^*) - F(b^*)]$.

For a nonrandom variable w, $w^* = \lambda w$, $\lambda > 0$ is a shift in scale.

<u>Theorem 3</u>. If the utility function is homogeneous of degree zero in the scale of p and w, the solution to Model A is homogeneous of degree zero in the scale of p and w.

Proof: Let $U = U(\frac{py - wx}{w_0})$ with f(p) the probability density function for output price. Then

$$EU = \int U(\frac{py - wx}{w_0})\ f(p)\ dp$$

$$\text{(18)}\quad \max_x EU \text{ implies } \int \frac{\partial U}{\partial(\pi/w_0)}(\frac{py_x - w}{w_0})\ f(p)\ dp = 0$$

Let U* be the utility function with a shift in scale of p and w.

$$\underset{x^*}{\text{Max}}\ EU^* \text{ implies } \int \frac{\partial u^*}{\partial(\pi^*/w_0^*)} \left(\frac{p^*y_x - w^*}{w_0^*}\right) \frac{f^*(p^*)}{F(a^*) - F(b^*)}\ dp^* = 0$$

which is equivalent to (18) since $F(a^*) - F(b^*)$ is simply a constant.||

In particular, output demands in general are not homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w. Consider the following example. Let p range from the integer values 1 to 5 and let f and f* be two density functions with the same mean and variance as shown in Table 1.

Table I

p	1	2	3	4	5	$\bar{p}$	σ^2
f(p)	.2	.2	.2	.2	.2	3	2
f*(p)	1/6	2/6	0	2/6	1/6	3	2

Let the utility function have CARA and let w = 1 with a single input. Then the optimal solution under f(p) is $y_x = .646$ but under f*(p), the optimal solution is given by $y_x = .626$. The solutions in Theorems 1 and 2 are homogeneous of degree zero in $\bar{p}$, $r\sigma^2$, and w because a proportional shift in $\bar{p}$ and σ^2 is a shift of scale for those two parameter probability distributions.

<u>Theorem 4</u>. For Model A, U''' > 0, is sufficient for output to be nondecreasing in the scale of p.

Proof: Consider the solution to the following two necessary conditions with the distribution f(p) and a change in scale $p^* = \lambda p$, $\lambda > 1$, and $f^*(p^*) = f(p)/(F(a^*) - F(b^*))$.

$$(19) \qquad \int \frac{\partial U}{\partial(\pi/w_0)} \left(\frac{py_x - w}{w_0}\right) f(p)dp = 0$$

$$(20) \qquad \int \frac{\partial U^*}{\partial(\pi/w_0)} \left(\frac{\lambda py_x - w}{w_0}\right) f(p)dp = 0$$

For all p, $U'(\lambda p) < U(p)$, since $\lambda > 1$ and $U'' < 0$, but $(\lambda py_x - w) > (py_x - w)$ for a given x. Let the solution to (19) be $\bar{x}$. $U'' < 0$ is the rate at which U' is lowered as p increases. Therefore, if $U''' > 0$ and p is shifted to λp with $\lambda > 1$, then with $x = \bar{x}$, the left hand side of (20) must be strictly negative. Consequently, if x^* is the solution to (20), it must be that $x^* > \bar{x}$ so that $y_{x^*} < y_{\bar{x}}$ for (20) to hold with equality.||

For a counter example where an increase in the scale of p reduces output, it is necessary that:

$$\int p y_x (\lambda U'(\lambda p) - U'(p)) f(p) dp - w \int (U'(\lambda p) - U'(p))\, f(p)\, dp < 0$$

or $U'(\lambda p)$ has to fall more than λ increases. For example, in Table II with p equal to 1 or 4 with $f(1) = 1/5$, $f(4) = 4/5$, and $w = 3$, the optimal solution is $y_x = 1$ given the marginal utilities $U'(1) = 2$ and $U'(4) = 1$. A shift in scale with $\lambda = 2$ and U''' sufficiently negative, as illustrated by the last line of Table II, produces a solution of $y_{x^*} = 5/4$ so that output declines with an increase in scale of p.

Table II

p	1	4
$U'(p)$	2	1
$f(p)$	1/5	4/5
λp	2	8
$U'(\lambda p)$	7/4	1/32

Theorem 5. CARA for Model A implies output is decreasing for a mean preserving spread in the distribution of p, where $0 < p < \infty$.

Proof: CARA for Model A means the necessary condition can be written as:

$$(21) \qquad y_x \int_0^\infty e^{-rpy} p\, f(p)\, dp - w \int_0^\infty e^{-rpy} f(p)\, dp = 0$$

Let $m(p) = \int_0^p xf(x)\,dx$ and $F(p) = \int_0^p f(x)dx$. $F(p)$ is the cumulative distribution for p while $m(p)$ is the mean of a truncated portion of the p distribution. $F(0) = 0$, $F(\infty) = 1$, $m(0) = 0$, and $m(\infty) = \bar{p}$, the mean of the distribution $f(p)$. Integrating by parts and using these definitions (21) becomes (22):

$$(22) \qquad y_x \int_0^\infty m(p)\, rye^{-ryp}dp - w \int_0^\infty ryF(p)e^{-ryp}dp = 0$$

A mean preserving spread (Rothschild and Stiglitz (1970)) means the new distribution "has more weight in the tails", while the mean, $\bar{p}$, is unchanged. Letting the more risky distribution be $f^*(p)$ with corresponding functions $m^*(p)$ and $F^*(p)$, then $m^*(p) \leq m(p)$ for $0 < p < \infty$ and $m^*(p) < m(p)$ for some values of p between zero and infinity. Since $-ryp$ is negative, a mean preserving spread also implies:

$$\int_0^\infty F^*(p)e^{-ryp}dp > \int_0^\infty F(p)e^{-ryp}dp$$

Thus, holding inputs constant at x, the solution to (22), we have:

$$(23) \quad y_x \int_0^\infty m^*(p)rye^{-ryp}dp - w\int_0^\infty ryF^*(p)e^{-ryp}dp < 0$$

Therefore, the optimal solution with $f^*(p)$ must be less than with $f(p)$ or $y^* < y$.||

Theorem 6. Constant relative risk aversion (CRRA) for Model A implies output is decreasing in a mean preserving spread in the distribution of p, where $0 < p < \infty$.

Proof: Constant relative risk aversion means the utility function can be written in the following form:

$$U = \frac{\alpha}{1-r} \left(\frac{\pi + k}{w_0}\right)^{1-r}$$

where α and k are positive constants and the distribution of p is such that $\pi + k \geq 0$. r is the constant index of relative risk aversion. The utility function is homogeneous of degree zero in the scale of p, w, and k.

For $r \neq 1$, the necessary condition for Model A and CRRA is

$$(24) \quad y_x \int_0^\infty \left(\frac{pf(p)}{(py - wx + k)}\right)^r dp - w \int_0^\infty \left(\frac{f(p)}{(py - wx + k)}\right)^r dp = 0$$

and the solution is homogeneous of degree zero in the scale of p, w, and k. Integrating by parts, (24) becomes:

$$(25) \quad \int_0^\infty \frac{y_x m(p) - wF(p)}{(py - wx + k)^{r+1}} dp = 0$$

A mean preserving spread from f(p) to f*(p) makes $m^*(p) \leq m(p)$ for all p with $m^*(p) < m(p)$ for some p and

$$\int_0^\infty \left(\frac{F^*(p)}{(py - wx + k)}\right)^{r+1} dp > \int_0^\infty \left(\frac{F(p)}{(py - wx + k)}\right)^{r+1} dp$$

since $py - wx + k > 0$. Thus, letting y be the solution with f(p) and y*, with f*(p), we have $y^* < y$. The proof is similar for $r = 1$.||

CRRA and the Log Normal Distribution (CRRAL)

Under constant relative risk aversion, the utility function can be written as:

$$U = \frac{\alpha}{1-r} e^{(1-r) \ln (\pi + k)}$$

Therefore, if $\pi + k$ has a log normal distribution with mean $\bar{\pi} + k$ and variance, $y^2\sigma^2$ then $\ln (\pi + k)$ has a normal distribution. Let the mean and variance of $\ln (\pi + k)$ be a and b, respectively. Then a and b are related to $\bar{\pi} + k$ and $y^2\sigma^2$ as follows:

(26) $e^{a + b/2} = \bar{\pi} + k$

(27) $e^{2a+b} (e^b - 1) = y^2\sigma^2$

Solving (26) and (27) gives the values of a and b in terms of $\bar{\pi}$,k and $y^2\sigma^2$:

(28) $b = \ln(\frac{y^2\sigma^2}{(\bar{\pi}+k)^2} + 1)$

(29) $a = \ln ((\bar{\pi}+k)^2/(y^2\sigma^2 + (\bar{\pi}+k)^2)^{\frac{1}{2}})$

Since $\ln(\pi+k)$ is normally distributed with mean a and variance b, the expected utility function is:

$$V = \frac{\alpha}{1-r} e^{(1-r)a + (1-r)^2 b/2}$$

Using (28) and (29) and letting $Z = \ln((1-r)V/\alpha)/(1-r)$, Z is an equivalent envelop function. From Z it is straightforward to derive the output supply and imput demand functions as given in Theorem 7.

Theorem 7. CRRA and the log normal distribution for output prices (CRRAL) for Model A has an equivalent envelop function given by Z:

$$Z = (1+r)\ln(\bar{\pi}+k) - \frac{r}{2} \ln(y^2\sigma^2 + (\bar{\pi}+k)^2)$$

The output supply function is:

$$y = (\bar{\pi}+k)Z_{\bar{p}}/(1 - 2\sigma^2 Z\sigma^2)$$

and input-output ratios are given by:

$$-Z_w/Z_{\bar{p}} = x/y$$

CARA and CRRA and the Uniform Distribution

The final specific results are for the uniform distribution for p on the interval $p_0 \leq p \leq p_1$. Since these results are straightforward given the preceding analysis, they are presented without proof.

Theorem 8. *Constant absolute risk aversion and output price with a uniform density of $1/(p_1 - p_0)$ over the interval $p_0 \leq p \leq p_1$, (CARAU), for Model A results in the expected utility function:*

$$V = 1 + \frac{(e^{-rp_1y} - e^{-rp_0y})e^{rwx}}{ry\,(p_1 - p_0)}$$

with output supply function equal to:

$$y = (V_{p_1} + V_{p_2})\ /EU' = (V_{p_1} + V_{p_2})/r(1-V)$$

Letting $p_1 = 1$ and $p_0 = 0$, the output supply function is:

$$y = \ln(1-e^{-rwx}(V_{p_1} + V_{p_0}))/-r$$

The input demand function is:

$$x = -V_w/EU' = -V_w/r(1-V)$$

Theorem 9. Constant relative risk aversion, $U = (\pi+k)^{1-r}/(1-r)$ where k is initial wealth, and p distributed uniformly $1/(p_1 - p_0)$ on the interval $p_0 \leq p \leq p_1$, for Model A gives an expected utility function:

$$V = [(p_1y + k - wx)^{2-r} - (p_0y + k - wx)^{2-r}]/y(1-r)(2-r)(p_1 - p_0)$$

The output supply function is:

$$y = (V_{p_1} + V_{p_0})/EU' = (V_{p_1} + V_{p_0})/V_k$$

and the input demand function is:

$$x = -V_w/EU' = -V_w/V_k.$$

IV. Conclusions

The purpose of this paper is to explore some duality relations for decisions under uncertainty. Toward this goal both specific and general results have been achieved; however, the models are simple ones. A two period model of a producer choosing inputs to maximize the expected utility of profits with known input prices and unknown output price has been assumed. There is a single output produced by a well-behaved neoclassical production function. Risk aversion is assumed to be a function of known prices and not dependent on random prices. Further, constant absolute risk aversion (CARA) or constant relative risk aversion (CRRA) is usually assumed.

With CARA and output price distributed normally (CARAN), the indirect envelop function is derived and the analogues of Hotelling's lemma stated. Further, if the production function is linearly homogeneous, the mean price elasticity of output is greater than one. The risk elasticity of output is minus one. The unit cost elasticity of output is less than minus one. All elasticities are independent of the level of risk and risk aversion measure.

With CARA and output price having a gamma distribution (CARAG), an indirect envelop function is derived. The general analogues of Hotelling's lemma in this case are much more complex than for CARAN. However, if the production function is linearly homogeneous, the output supply function is easily derived. The mean price elasticity of output is greater than one and, for the same parameters, greater than the mean price elasticity of output for the CARAN model. The unit cost elasticity of output is less than minus one and less than the corresponding elasticity for CARAN with the same parameters. The risk elasticity of output is minus one as with CARAN. Also these elasticities are independent of levels of risk and risk aversion.

With CRRA and output price having a log normal distribution (CRRAL), the output supply or input demand function is derived from an indirect envelop function. Analogous results are presented for output having a uniform distribution with both CARA and CRRA. In these cases, however; no simple forms for the output supply or input demand functions were found.

In a more general vein, if the utility function is homogeneous of degree zero in all prices the output supply and input demand functions are homogeneous of degree zero in all prices regardless of the price distribution. $U''' > 0$ is sufficient for output to be nondecreasing in the scale of random output prices and nonincreasing in all input prices. CARA or CRRA is sufficient for output to be nonincreasing in mean preserving spreads of the probability distribution of output price.

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APPENDIX C

THE TECHNOLOGY MATRIX OF THE PROCESS MODEL FOR HOUSING CONSTRUCTION

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I. Model Formulation and Data Collection

The technology matrix contains data for 27 output processes that cover four representative types of homes: (1) single family (approx. 1700 sq. ft. floor space); (2) four family townhouse (approx. 4000 sq. ft. floor space); (3) multi-family high rise (approx. 101,000 sq. ft. floor space); (4) imported mobile home (720 sq. ft. floor space). The different processes represent alternative methods of construction: stick-built vs. pre-fab, usual vs. accelerated construction time, and vacant vs. occupied land. Repair processes for the existing stock of housing are also included. See table 1 for a complete break-down of the 27 processes.

The choice of processes was of course motivated by the nature of the problem under study. Since the occurrence of a disaster such as an earthquake will very likely result in widespread damage to the existing housing stock, repair activities will become especially important during the restoration period. Many structures may be so severely damaged that it becomes economically expedient to completely clear the site and rebuild. Hence the choice vacant vs. occupied land. The timing (usual vs. accelerated) of new or replacement housing may become important if severe damage is so pervasive that large numbers of victims are left without shelter. This situation could also be mitigated by importing mobile homes. Finally, pre-fabricated construction represents a technological alternative to traditional (or stick-built) construction. The primary difference between the two technologies is that the former requires about one-third less on-site labor than the latter.

Data for the constrcution of the technology or input-coefficient matrix were generally available only at a very micro-level. In particular, most input data for the single family and townhouse units were taken from a materials-quantity breakdown provided by their designer. This designer also provided estimates of the number of skilled an unskilled labor hours required for the construction of the single family and townhouse units. Similarly, a construction engineer provided a materials-quantity breakdown and estimates of the unskilled/skilled labor hours required for the construction of a multi-family high rise unit. The quantity breakdowns did not provide data on electrical, plumbing, and heating/air conditioning. Dollar estimates of the required quantities of these materials were obtained separately by consulting with contractors in each of these areas. Otherwise, the materials-quantity breakdowns provided detailed data (down to the size and number of nails) on the quantity and type of all inputs used.

Where applicable, inputs were aggregated on the basis of price. For example, the disparate varieties of lumber were all expressed in terms of the linear feet which could have been purchased if all lumber dollars were spent on 2" x 10" boards. The level of input aggregation and unit measures are as follows:

1. Lumber - linear feet of 2" x 10"
2. Roofing - "squares" of roofing shingles
3. Brick - utility brick
4. Concrete - cubic yards
5. Sheetrock - sheets
6. Insulation - 3 1/2" x 15" units
7. Hardware - In dollars, all non-wood items otherwise not categorized (e.g., locks, nails, elevators)

8. Woodware - In dollars, all wood items otherwise not categorized (e.g., doors, window frames)
9. Steel - dollars
10. Land - square feet
11. Electrical - dollars
12. Plumbing - dollars
13. Heating/AC - dollars
14. Skilled labor - man hours
15. Unskilled labor - man hours
16. Demolition - dollars
17. Mobile Home Import Cost - dollars
18. Repairs: minimal - dollars
19. moderate - dollars
20. severe - dollars

Usual and accelerated construction time estimates were obtained from the designer and construction engineer referred to above. Based on consultation, an increase in labor by a multiple of 4/3 is a reasonable estimate of what is required to accelerate construction to about 1/2 to 2/3 the usual time.

Data on the cost of razing existing structures were obtained from a local demolition company. The most important determinant of demolition cost is whether the structure is of a wood frame or steel frame construction. Wood frame demolition is estimated to cost about $1.00 per square foot usual time, and $1.15 per square foot accelerated time; steel frame estimates are $2.25 and $2.60 per square foot for usual and accelerated time, respectively.

As constructed, the repair processes requires one "resource": a composite repair expense. Estimates on minimal repairs were furnished by a home-owner who is quite knowledgable of construction technology. This home-owner had kept meticulous records of home maintenance expense over the last 10 years. These records served as a basis for the estimates of the minimal repair coefficients for the single-family and townhouse units. Estimates of severe repair coefficients are based on consultation with personnel at a national emergency assistance agency. This agency finances home construction repairs as part of its disaster assistance program. The agency's national average limit on such repairs was used to calculate the severe repair coefficients. Moderate repair coefficients are simply calculated as the average of these two extremes.

The public agency just mentioned also provided data on importing mobile homes to the Charleston area. According to this agency, the most likely source of these imports is Atlanta, Ga. Estimates of transportation cost per mile, set-up cost, total unit cost, and deactivation cost were provided and used as a basis for an import cost coefficient. Data were also obtained for calculation of land and time coefficients for this process.

The present pre-fab processes are simply a replication of the single-family unit with a 1/3 reduction in labor. This calculation is based on general literature on packaged or "kit" houses. In effect, it is assumed that the only significant difference between the stick-built and the pre-fab construction technology is a reduction of on-site labor by 1/3.

II. Testing the Viability of the Technology

A. Context

In order to assess the viability or reasonableness of the constructed technology matrix, the following rather arbitrary, standard formulation was used:

$$\begin{array}{lll} \text{MAX1} & \max\ px + qy - wz & (1) \\ & \text{s.t: } wz \leq 100 & (2) \\ & A\begin{bmatrix} x \\ y \end{bmatrix} - Iz \leq 0 & (3) \end{array}$$

where,

$p=(p_j)$, $x=(x_j)$,	the price and level of the j^{th} new construction type, $j= 1, 2, \ldots, 18$.
$q=(q_j)$, $y=(y_j)$,	the price and level of the j^{th} repair type, $j= 19, 20, \ldots, 27$.
$w=(w_i)$, $z=(z_i)$,	the price and level of the i^{th} input, $i= 1, 2, \ldots, 20$.
$A=(a_{ij})$,	a 20x27 matrix where a_{ij} is the quantity of i^{th} input required per unit of the j^{th} process (construction or repair type), $i= 1, 2, \ldots, 20$ and $j= 1, 2, \ldots, 27$.
I,	a 20x20 identity matrix.

In words, MAX1 says that the housing industry, operating under certainty, maximizes industry profits (1) subject to a \$100 budget constraint (2) and a linear technology (3).

It should be noted that the technology (3) does not really represent constraints at all. To see this, consider the i^{th} row of (3):

$$a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{i18}x_{18} + a_{i19}y_{i19} + \ldots + a_{i27}y_{i27} - z_i \leq 0$$

or

$$a_{i1}x_i + a_{i2}x_2 + \ldots + a_{i18}x_{18} + a_{i19}y_{i19} + \ldots + a_{i27}y_{i27} \leq z_i \qquad (4)$$

Profit maximization implies that all the technology inequalities (i= 1, 2,..., 20) must be satisfied as equalities; otherwise, profits would not be maximized since more than necessary costs would be incurred. Therefore,

$$z_i = a_{ii}x_1 + \ldots + a_{i27}y_{27} \qquad (4')$$

can be substituted into the objective function (1) and the budget constraint (2). Thus, MAX1 can be more compactly written as:

$$\text{MAX1}' \qquad \max\ p'x + q'y \qquad (5)$$

$$\text{s.t: } w'\begin{bmatrix} x \\ y \end{bmatrix} \leq 100 \qquad (6)$$

where,

$w' = (w'_j)$, the total unit cost of the j^{th} process with

$$w'_j = \sum_{i=1}^{20} w_i a_{ij},\ j = 1, 2, \ldots, 27.$$

$p' = (p'_j)$, the unit profit of the j^{th} new construction type with

$$p'_j = p_j - w'_j,\ j = 1, 2, \ldots, 18.$$

$q' = (q'_j)$, the unit profit of the j^{th} repair type with

$$q'_j = q_j - w'_j,\ j = 1, 2, \ldots, 27.$$

By way of an illustrative example consider the following hypothetical 2 output-2 input case.

$$\text{MAX2} \qquad \max\ 110x + 105y - 20z_1 - 10z_2 \qquad (7)$$

$$\text{s.t: } 20z_1 + 10z_2 \leq 100 \qquad (8)$$

$$2x + 3y - z_1 \leq 0 \qquad (9)$$

$$4x + 3y - z_2 \leq 0 \qquad (10)$$

From (9) and (10), $z_1 = 2x + 3y$ and $z_2 = 4x + 3y$ can be substituted into (7) to get:

$$110x + 105y - 20(2x + 3y) - 10(4x + 3y)\,, \qquad (7')$$

and into (8) to get:

$$20(2x + 3y) + 10(4x + 3y) \leq 100\,. \qquad (8')$$

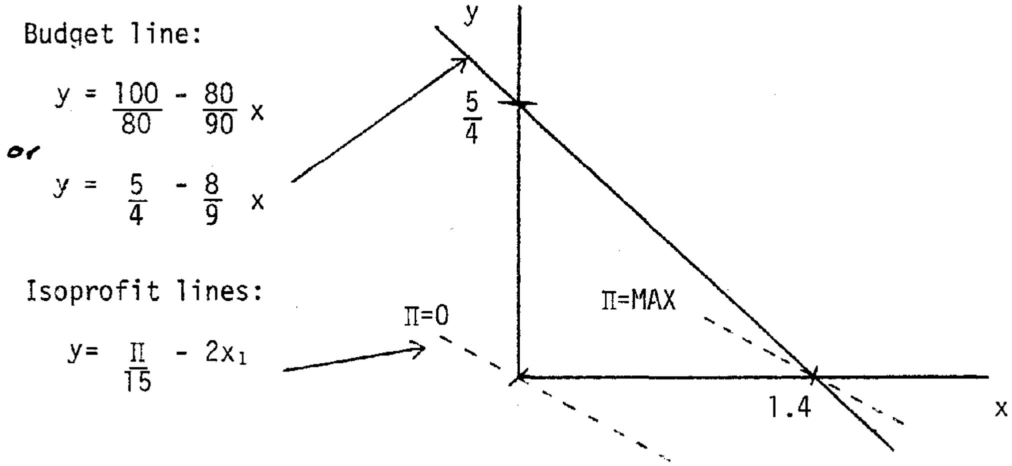
Thus, simplifying (7′) and (8′), MAX2 reduces to:

$$\text{MAX2}' \quad \max\ 30x + 15y \qquad (9')$$

$$\text{s.t: } 80x + 90y \leq 100 \qquad (10')$$

Figure 1 is a graphical representation of MAX2′. The solid line represents the constraint (10) and the 2 dotted lines are isoprofit lines.

Figure 1



As with any single-constraint linear program, MAX2´ will always yield "corner" solutions. That is, depending on the slope of the isoprofit line relative to the slope of the budget line, MAX2´ will solve for either x or y, but not both. (If the slopes of the isoprofit and budget lines are equal, the solution is indeterminant.) Thus $(x,y) \simeq (1.4,0)$ for all $p'_y < 33.75$, cet. par., and $(x,y) = (0,5/4)$ for all $p'_y > 33.75$, cet. par. And of course, since MAX1´ has only one constraint, it too will always result in corner solutions.

B. Testing the Technology Matrix

In order to assess the performance of the technology matrix A a set of plausible base input and output prices were selected so that x_1 was the resultant solution to MAX1´. These prices were then used as a base from which to conduct the following two part sensitivity analysis:

(1) holding all other prices constant, the price of x_j, $j= 2, 3,\dots, 27$, was raised incrementally until the solution switched from x_1 to x_j;

(2) holding all other prices constant, the solution to MAX1´ was examined for switching as,

  (a) the price of unskilled labor was raised and lowered incrementally,

  (b) the price of skilled labor was raised and lowered incrementally,

  (c) the price of skilled and unskilled labor were simultaneously raised and lowered incrementally,

  (d) the price of all nonlabor inputs were simultaneously raised and lowered incrementally.

Table 1 presents a list and description of the output variables, base output prices, and the results of the first part of the sensitivity analysis. For j=2 through 18, the base price of x_j was increased in increments of \$.50 until the solution to MAX1´ switched from x_1 to x_j. Because of relatively greater sensitivity, increments of \$.10 were used for j=19 through 27. The price at which switching occurred is shown in the far right-hand column of table 1. As an example, increasing the base price of \$77 by increments of \$.50 reveals that, at \$79, x_2 becomes more profitable than x_1, i.e., the solution switches from x_1 to x_2 at p_2=\$79.

The overall results presented in table 1 appear to be indicative of a reasonably plausible housing technology. The lower switching prices of group B as compared to group A properly reflect the assumption of a 1/3 reduction in on-site labor associated with prefabricated construction. The relatively lower switching prices of groups C and D are primarily reflective of economies of scale associated with multi-level construction.

The relative switching prices within groups A,B,C, or D are more or less as expected. For example, the additional requirement of clearing an existing structure from the building site has the greatest impact in the case of the high rise building (group D): operating under usual construction time, the necessity of clearing the site results in an additional unit cost of \$8 (\$76 vs. \$68); under accelerated construction time, clearing the site results in a differential of \$9.50 (\$82 vs. \$72.5). The intra-group relative price structure for A,B, and C follow essentially the same pattern as for group D.

As regards the imported mobil home (group E), the switching price may appear to be a little high considering the construction type. However, the technology here involves (1) transporting a mobil home from a major center such as Atlanta, Georgia, (2) set-up costs, (3) land use, and (4) break-down and

TABLE 1
RESULTS OF PART ONE OF THE SENSITIVITY ANALYSIS

	Xj	Description*	Base Price	Switching Price**
A.	1	SFD/UCT	$75	--
	2	SFD/UCTD	77	79
	3	SFD/ACT	78	80
	4	SFD/ACTD	79	84.5
B.	5	PSFD/UCT	65	70.5
	6	PSFD/UCTD	70	74
	7	PSFD/ACT	67	73.5
	8	PSFD/ACTD	73	78
C.	9	APTS/UCT	60	68.5
	10	APTS/UCTD	65	72
	11	APTS/ACT	63	73
	12	APTS/ACTD	70	77.5
D.	13	HR/UCT	65	68
	14	HR/UCTD	75	76
	15	HR/ACT	70	72.5
	16	HR/ACTD	80	82
E.	17	IMH/UCT	55	56.5
	18	IMH/UCTD	57	60.5
F.	19	SFD/MR	1.5	1.7
	20	SFD/MOR	4	4.6
	21	SFD/SR	8	8.3
G.	22	APTS/MR	1.2	1.4
	23	APTS/MOR	3.5	4
	24	APTS/SR	6	6.5
H.	25	HR/MR	10	.4
	26	HR/MOR	2.5	2.8
	27	HR/SR	5	5.6

*SFD - Single Family Dwelling
PSFD - Pre-Fabricated Single Family Dwelling
APTS - Four Family Townhouse Apartment Building
HR - High Rise Apartment Building
IMH - Imported Mobile Home
UCT - Usual Construction Time
UCTD - Usual Construction Time with Demolition of Existing Structure
ACT - Accelerated Construction Time
ACTD - Accelerated Construction Time with Demolition. . .
MR - Minimum Repair
MOR - Moderate Repair
SR - Severe Repair
**The Price At Which the Solution Switches From X_1 to X_j.

return transport to Atlanta. Thus, although this type of housing assistance is readily available to disaster victims, it is generally implemented only as a last resort because of the relatively high costs involved. Hence the somewhat high switching prices in group E are appropriate.

The repair groups F,G, and H are rather straight forward. For example, repairing minimal damage to existing single dwellings becomes more profitable than constructing new single family dwellings at a per square foot repair price of \$1.70. That is, the solution switches from x_1 to y_{19} at q_{19} = \$1.70. Making moderate repairs is, of course, more costly. Accordingly, this activity requires the greater price of \$4.70 before becoming more profitable than new construction. Similarly, for the solution to switch to severe repairs of single family dwellings (y_{21}), a price of \$8.70 is required.

Comparing the switching prices of groups F,G, and H, there appears to be economies of scale in repairs to multi-level structures. This is not an unreasonable nor unexpected result.

Part two of the sensitivity analysis involves examining the solution of MAX1´ for switching as the prices of certain inputs or groups of inputs are varied. The results are presented in outline form in table 2. Again, the technology performed in a fairly reasonable fashion. As the price of skilled and unskilled labor are raised, separately or collectively, a point is eventually reached at which the solution switches from x_1 to x_{17}. x_{17} has zero labor coefficients. Hence, as the labor prices increase, it eventually becomes more cost-effective to produce x_{17} rather than x_1 (which has positive labor coefficients). As labor prices are decreased, the solution tends to switch to x_3 from x_1. This is appropriate as the activity x_3 has the greatest labor input requirement.

TABLE 2

RESULTS OF PART TWO OF THE SENSITIVITY ANALYSIS

I. Unskilled labor price: W_1 = \$3.35 (base).

A. Increments of \$.25,
At W_1 = 4.70, the solution switches to X_{17}.

B. Increments of \$-.25,
Down to W_1 = 0, no switching.

II. Skilled labor price: W_2 = \$7.50 (base).

A. Increments of \$.25,
At W_2 = \$9.00, the solution switches to X12.

B. Increments of \$-.25,
At W_2 = \$2.50, the solution switches to X_3.

III. Unskilled and skilled labor prices varied simultaneously.

A. Increments of \$.25,
At W_1 = \$4.85, W_2 = \$8.25, the solution switches to X_{17}.

B. Increments of \$-.25
At W_1 = \$.85, W_2 = \$5.00, the solution switches to X_3.
At W_1 = \$.60, W_2 = \$4.75, the solution switches to X_{15}.

IV. All nonlabor input prices: W_k.

A. Increments of \$.01
At an increase of \$.05, the solution switches to X_{17}.

B. Increments of \$-.01
At a decrease of \$.40, the solution switches to X_5.

Raising the price of all nonlabor inputs simultaneously by \$.05 results in a switch from x_1 to x_{17}. This is entirely appropriate since x_{17} uses less of all the nonlabor inputs than any other output. Also, since x_5 uses more nonlabor inputs relative to labor inputs than any other output, it is appropriate that the solution switches to x_5 when the price of nonlabor inputs decreases by \$.40.

APPENDIX D

FIELD REPORTS ON EARTHQUAKE RISKS IN CHARLESTON SOUTH CAROLINA

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August 1981

Report on Field Investigation of
Bridges in Metropolitan Charleston

Major Structures

Cooper River Bridges - There are two major bridges which cross the Cooper River. The older bridge, which now serves southbound traffic only, was built about 1930. It has only 2 lanes and has a truck load limit of 10 tons. There are two separate three-span continuous trusses at the highest elevations. Leading up to the truss spans are several hundred feet of plate girder sections which are supported on steel framed bents which in turn rest on concrete piers. It is the writer's opinion that a major earthquake would tax these steel framed bents to the limit with the distinct possibility that some of them might very well fail. Naturally, if this occurred (a failure of any of these bents) that portion of the bridge which is supported would collapse.

The newer bridge, built about 15 years ago, is parallel to and just downstream from the older bridge. The profile of the bridge is much the same as the older bridge but it has obviously been designed for much more substantial loads than the older bridge. There are heavy two column concrete piers which support the bridge at frequent intervals. Just as the old bridge, there are two separate three-span continuous trusses at the high elevations. They are much heavier than the trusses of the old bridge. The approach spans to the trusses are initially prestressed concrete girders and then steel plate girders. The bridge is much wider and can accommodate several lanes most of which are for northbound traffic. At least one lane is kept open for truck traffic which is southbound.

A general observation which will be repeated later is the following. It seems apparent that the older bridge would be the one most likely to experience at least some partial collapse in the event of a major earthquake. I feel that steel pier bents are likely targets. On the other hand, natural frequencies of the bridges may be so sufficiently different as to cause a given earthquake to exert forces widely different on the two bridges. It is entirely possible, therefore, that the newer bridge could experience much greater forces and to the extent that it might fail whereas the older one could weather the forces unharmed.

It is my further belief, based on the history of earthquakes within the continental United States, that the probability of both bridges being rendered unusuable by a given earthquake is very remote. It seems likely that the worst possible situation which can occur is for the newer bridge to be put out of service. This would mean that the old bridge would be subject to highly increased usage and that truck traffic would have to be routed away from the bridge.

Ashley River Bridges - There are actually three bridges over the Ashley. Two of them serve US 17 and are twin structures which connect the Windemere area to downtown Charleston. The other bridge is about four miles north of the twin bridges and carries State Highway 7 traffic into the North Charleston area.

The twin structures serving downtown Charleston are discussed first. The upstream structure carries several lanes of traffic. It is supported by concrete arched girders which span 40 to 50 feet each. The total length of the bridge is more than a thousand feet. The girders are supported on fairly massive concrete piers. The downstream, and much newer bridge, is supported by short span prestressed concrete girders which rest on concrete pile caps supported by numerous concrete pile columns. Both bridges have steel draw spans near their center. There are sufficient differences in the construction of these two bridges to expect very different responses in the case of a major earthquake. This makes the probability of extensive damage to both from a given earthquake as being highly improbable. Therefore, no more than one of these bridges should be expected to be unusable in the event of a major shock.

The Ashley River bridge which serves North Charleston is 1000' to 1500' long and is a splendid multi-lane bridge. Piers supporting the bridge are heavy two column concrete bents. Longitudinal steel plate girder spans of approximately 90' length support steel floor beams and stringers. It is a major, well designed structure, and does not seem vulnerable to an earthquake.

Ben Sawyer Memorial Bridge - The total length of this bridge is about 600'. It has a steel draw span which opens for Intra-Coastal waterway traffic. If this bridge was closed, persons living on Sullivan's Island and the Isle of Palms would be isolated. Steel girders of 60'± spans, supported on massive two column concrete piers lead up to the draw span. Bearing points on piers could be dislodged as a result of a major shock which could render the bridge unusable. However, overall it is deemed as a substantial bridge.

Intra Coastal Bridge to James Island - This is a fairly high structure with a center draw span which is approached by 60'± steel girders spanning between massive pier bents. There concrete pier bents are made up with three 5' square concrete columns and cross beams. It is a very substantial structure which is the only direct access from Folly Beach, James Island and John's Island for many residents.

Other Bridges

While these bridges are not classified as major bridges, they are most important structures and are vital to many persons. Typically, these bridges are made up as follows:

A concrete slab deck is supported by concrete girders, some prestressed and forecast, and others apparently cast in place. These are supported on concrete pile bents located 30' to 40' on centers. Depending on the width of the roadway, there may be from three to eight pile columns in these pier bents. The construction is fairly simple and repairs could be affected in a short period of time (two weeks is a rough estimate). Bridges which fall in this general category include the following:

1. U.S. 17 over Rantowles Creek - There are twin structures here with a total length of about 400'. A marshland area. Piers are skewed, generally more vulnerable to shock.
2. U.S. 17 over Wallace River - Twin structures in marshland area. Total length about 300'.
3. State 171 over Folly River - Only access to Folly Beach, about 1000± long.
4. Oak Island Creek, Rt. 171, about 100' long.
5. Sol Legare or Folly Creek, Rt. 171, about 500' long.
6. Harbor View Bridge over James Island Creek, about 500' long.
7. Shem Creek, Mt. Pleasant, about 300' long. Pier bents have up to 10 columns.
8. Sullivans' Island - Isle of Palms Connection. About 600' long.

Although certainly not identical, the foregoing eight bridges are essentially of the same form and construction. Two other bridges which perhaps should have been classified as major bridges are those which serve John's Island. Fortunately, there are two bridges to the island and it is unlikely that both would be rendered unusable during a given earthquake. The first is on Route 20 leading from US 17 south of Charleston onto the Island. It is the Limehouse Bridge and crosses the Intra-Coastal Waterway. There is a center steel drawbridge which is reached on both sides with a concrete bridge supported by concrete girders and concrete bents. Total length is about 600'. On Route 700, the other John's Island Bridge is located. It probably carries much more traffic than the Route 20 bridge. Its construction is typical of Bridges 1 through 8 already listed except for a steel draw span near the center. Its total length is about 1000'.

Interstate Bridges and Trade Separations

This group of bridges constitutes a large number of structures within the Charleston area. Loss of some or almost any of these spans near the approaches to the Cooper River bridges could cause a major traffic disruption. Away from these locations, loss of any of the I-26 elevated sections in the city of Charleston would prove a major cause of long traffic tie-ups. It is possible to find alternate routes which in general preceded the construction of I-26. Once again, loss of any of these elevated bridge sections would result in heavy traffic congestion.

The general pattern of construction for these structures is that of simple spans which are 80'± long. A concrete slab is made composite with precast prestressed concrete girders. The supporting concrete piers are made from 2 or 3 round columns and a cap beam. This type bent is found near the Cooper River Bridge. In this area there are some sections which utilize a single 5'± diameter concrete column to support the roadway which may be continuous slabs with deepened haunches at the supports.

In other elevated areas, peirs up to 105' wide which are made up of 5-42 inch round columns and a cap beam are to be found. Some of them support up to 15 longitudinal steel beams with cover plates which span approximately 80'.

It was my opinion that the design and construction featured on most of these structures exhibited high quality. This does not mean that a sufficiently disastrous quake cannot cause major damage but it does indicate that it is highly unlikely.

General Quotes From Technical Sources

Earthquake Damages in Bridges (From "A European View of the Earthquake

Resistant Design of Bridges" by Arthur Ravara of National Laboratory of Civil Engineering, Lisbon, Portugal).

"A survey of bridge damage caused by recent European earthquakes brings out scarce yet interesting information on the topic. In fact, most of the reports do not mention bridges. Some just mention that bridges were not damaged. The two following reports deserve serious attention:

H. Sandi (on Lessons Learned From The Romania, 4 March 1977 Earthquake) reports that an earthquake, of magnitude M-7.2 (Richter) had its epicenter in the Vrancea region. According to official data 1570 victims have been identified (some 90% of them in Bucharest, at a distance of about 100 km from the main shock epicenter). More than 11,300 persons have been injured. 32900 dwellings have collapsed or been badly damaged and 35,000 families have lost their shelter. Many schools and hospitals were damaged. A large number of industrial enterprises have also been affected with important production losses.

In contrast with this somber picture, Sandi reports that "bridges have not been seriously affected. Only limited damage of support zones and slight displacements of a few piers, abutments, etc. have been put to evidence in some cases"...

A rather different situation is reported by CNEN-ENEL Commission on Seismic Problems Associated with the installation of Nuclear Plants after the Friuli, Italy earthquake of May 1976. According to this report the MM intensity reached was IX and the magnitude probably between 6 and 6.5. Epicenters were located at a densely populated zone near Udine, the focus depth being smaller than 30 km.

In this case all types of construction were strongly damaged, including bridges. The report states that investigations on the behavior of highway structures, which were concentrated on viaducts "clearly proved that the behavior of piers founded on piler was influenced by the characteristics of the foundation soil, and behavior of the decks was conditioned by the type of restraint which, being of the support type, allowed a remarkable displacement of the decks...

Development of Highway Bridge Seismic Design Criteria For the United States - By Roland Sharpe and Ronald Mayes - Directors of the Applied Technology Council

These men pointed out that the 1971 San Fernando, California earthquake presented a major turning point in the development of seismic design criteria for bridges in the United States. Prior to that, lateral force requirements resulting from earthquakes were based on provisions established for buildings. Specifications have now been established which include the soil types, importance of the structure, its natural period and other features. Suffice to say that a key parameter established by the council calls for a peak acceleration in the Charleston area of 0.10 g. This becomes especially interesting when compared with similar values of 0.40 g which have been specified for much of California.

These criteria also establish minimum bearing lengths for beam supports on piers which were found to be critically short in many cases in the San Fernando earthquake.

Retrofitting of Existing Highway Bridges Subject to Seismic Loading - Practical Considerations By Oris H. Degenkolt - California Department of Transportation

"The 1971 San Fernando earthquake pointed out that the bridge design specifications and practices that were in general use at that time were totally inadequate from a seismic point of view. Although there was a long history of buildings and other structures being damaged and collapsed by earthquakes, seismic damage to bridges in the contiguous 48 states was practically non-existent prior to February 9, 1971. The little bridge damage that did occur before that time was limited to minor spalling and crackling of concrete, damaged bearings and grout pads, and slight shifting of spans. The damage did not cause any serious disruptions to traffic, no lives were threatened, and repairing the damage was a relatively minor nuisance.

The San Fernando event demonstrated that many bridges designed and built before that time have one or more of the following deficiencies:

-Segments of the structure are not adequately connect-d.

-Columns have too few and improperly detailed ties and spirals.

-Lap splices of main column reinforcement are too short and the surrounding concrete is inadequately confined.

-Footing and bent cap concrete is inadequately reinforced.

-Design force levels were too low considering the seismicity of the location.

Few existing bridges with these deficiencies can economically be brought up to the same level of seismic resistance as a new bridge . . ."

The following from the book - "Seismic Risk and Engineering Decision - Elsevier Scientific Publishing Co.

From Chap. 3 - Geological Criteria For Evaluating Seismicity - Clarence R. Allen - Seismological Laboratory, California Institute of Technology

". . . It is significant that the earthquake catalogs of those parts of the world with the longest historical records are the very ones which give us the greatest pause in extrapolating there records into the future. This should be a lesson in terms of the temptation to draw far-reaching conclusion from a relatively short seismic history such as characterizes North America, and from such single events as the Charleston and New Madrid earthquakes. As an example of a long term history, consider the Chinese record based on valid chronicles of seismic activity for large parts of China extending back almost 3000 years - more than a quarter of the Holocene epoch. The startling thing about this record, as pointed out by our Chinese colleagues, is the lack of uniformity in both space and time. Most large earthquakes have indeed occurred in relatively well defined zones, and many of these zones have been the loci of continuing moderate activity, but there are so many conspicuous exceptions within the 3000 year record as to make on cautious in drawing generalizations. For example, Mei (1960) has plotted cumulative strain release from 466 BC to the present for the Kansu and North China region, an area four times larger than that of Californai and Nevada combined. This is a period during which she feels that the record of large shocks is relatively complete. The seismic activity during the first and last parts of the period is high, but during an 800-year period from 200 to 1000 AD large shocks are almost lacking. Yet the seismic hazard in this region cannot be considered low; the historic record includes at least two shocks of magnitude 8.5, one of which - in 1556 was the most disastrous earthquake in history, causing more than 820,000 deaths. The other great event - that of 1668 - occurred in a part of the region which neither before nor since has been characterized by high continuing activity. . . "

Conclusions

. . . "Those parts of the world that have the longest historical records of earthquakes are the areas that should give us the greatest pause in extrapolating that history into the future, because it is clear that even a 2000 - or 3000 - year history is not a suffuciently valid statistical sample to use as a firm guide to over-all activity. In areas such as California and Nevada, where our historical records barely exceeds one century, we must be exceedingly cautious in extrapolating from this very short history. The problem gets even mroe difficult as we get farther and farther away from active plate boundaries and into areas of low long-term seismicity. What conclusions, for example, can be drawn from the single great earthquake at Charleston, South Carolina, in 1886? Is Charleston really anymore dangerous in terms of another similar earthquake than in Washington, D.C. or New York City? The single historical event tells us essentially nothing in itself except that earthquakes of the same magnitude must therefore be considered credible events, however unlikely throughout the same entire tectonic province, at least until we understand from geological and geophysical studies why the Charleston earthquake occurred where it did and how other areas are truly different. While it is true that the one event at Charleston demonstrates that there is a structure capable of producing a large earthquake there, the fact that we have not identified that structure gives us little confidence that similar structures do not indeed exist elsewhere. The Charleston area should be the subject of a considerably more intensive seismotectonic research effort, in view of the tremendous stakes involved in the construction of new and critical facilities such as nuclear power plants throughout the east coast area". . .

From Chap. 9 - "Design" - By R.V. Whitman and C.A. Cornell

In this chapter on design, the authors present equations for calculations of total risk resulting from an earthquake. Numerous examples are presented for both buildings and bridges. Although much of the material is directed towards calculating risks versus increased building costs to provide seismic resistance, a statistician should be able to gather much useful information from the article.

Earthquake Damage and Earthquake Insurance
John R. Freeman
1932

This book is nearly 50 years old, but it is a rather exhaustive treatise on the earthquake damage levels experienced by many structures throughout the world, including a great deal of emphasis on the Charleston earthquake of 1886. Mr. Freeman visited Charleston three times before writing the book and his first visit occurred just 20 years after the quake. Even 45 years after the quake, he reported that 95% of the buildings existing at the time of the Charleston earthquake were still doing good service.

The Alaska Earthquake
March 27, 1964
Geol. Survey Paper 546
M 8.3 to 8.7

Primarily, this is a discussion of the geology associated with it. Interestingly, it reports that no significant damage was done to mines, tunnels, and deep wells. Great vertical, and horizontal land displacements were created. Also, fissures in the ground some thousands of feet long and several feet wide were detected. They caused considerable damage to buildings, roads and utility lines although not as much as from other sources.

The Alaska Earthquake - Effects on Transportation and Utilities
Geol. Survey Paper 545-B

This paper outlines damages to airports, being variable within Alaska. It also discusses shipping, especially harbor facilities, many of which were severely impaired. Communication systems, power and telephone poles were collapsed, thereby cutting off usage.

Studies Related to the Charleston, S.C. Earthquake of 1886
Geological Survey Professional Paper 1028

A good review of the earthquake and its effects. It does indicate that considerable damage was done to railroad tracks. Bridges were not given a a prominent place, so they apparently did not suffer seriously.

A Descriptive Narrative of the Earthquake of
August 31, 1886 - By Carl McKinley

This is a very graphic description which, I believe, tends to exaggerate the damage. However, there is no question about their being much damage.

San Fernando, Californai Earthquake of February 9, 1971 - U.S. Dept. of Commerce

Airports - A dozen airports were located within a 30-mile radius. The only structural damage was glass breakage in the control tower cabs at two airports, and at business establishments in several of the airports. In one hangar, several aircraft were bounced against each other causing minor damage. The most critical earthquake induced problem was the loss of commercial electric power. This caused the blackout of terminal buildings and other buildings at various airports. Most power was restored in 8 to 10 hours. Loss of power could have been disastrous if the highway system had been more heavily damaged because of the greater load on air travel as an emergency measure.

Damage To Freeway Bridges

The epicenter of the earthquake was located very close to four metropolitan freeway routes, with numerous freeway bridges. Approximately 62 bridges suffered damage varying from minor cracking and spalling to total collapse. Most of the damaged bridges were lcoated within a belt about five miles long and about 6 to 10 miles southwest of the epicenter. Structures located 5 to 7 miles northwest of the epicenter were moderately damaged. Hundreds of other bridges in the Los Angeles area, just outside this narrow band, were not damaged. About 25% of the 62 bridges sustained severe damage or total collapse, 50% were moderately damaged, and the remaining 25% suffered relatively minor damage.

Damage to Highways Resulting From the San Fernando Earthquake

This damage consisted of settlement at bridge approaches, and buckling, heaving, and cracking of concrete pavement at various locations. There was evidence of fill distortion in some of the higher bridge approaches. There were landslides occurring in cut slopes.

Embankments were found to be susceptible to shear failure, subsidence due to densification, spreading, and longitudinal and transverse cracks caused by ground motion. Generally, densification of foundation materials resulted in much greater amounts of fill subsidence than densification of the fill itself, because the deposits of alluvium affected by the ground vibrations were in a looser pre-earthquake condition than the fill and were substantially deeper at most locations than fill thickness. The overall effect of fill subsidence was a severe bump at cut-fill contacts and bridges. In some cases, especially at bridges, this abrupt change in profile was large enough to prevent traffic from using the road. In other cases, the bump at bridge approaches was accentuated, but traffic could still use the facility.

Direct Responses To Letter of May 13

1. Literature Search To Determine State of the Art in Predicition of Damages To Elements of the Transportation Network Resulting From Earthquakes

   Response - In the foregoing parts of this report, damage to highways, harbors, airports and bridges are discussed - In summary, they might be enumerated as follows -

   (a) Highways - Embankments of fill are subject to subsidence making approach to bridges at times impossible. In mountainous areas, landslides are set-up. Breaking up of pavement, both asphalt and concrete, occurs. Drainage structures under highways are susceptible to failure.

   (b) Bridges - Observed damage to bridges is generally related to the substructure. Concrete piers fail due to inadequate ties in the columns, or liquefaction of the soil occurs which removes all lateral support. Earthquakes produce forces which push embankment soil against abutments and often causes bridge beams to fall off their supports. Especially vulnerable are bridges with curved beams and skewed supports.

   (c) Airports - Planes in hangars may be damaged by being bounced against one another. Gloss breakage ahs occurred in airport towers. Loss of commercial electric power creates all sorts of problems such as inability to pump aircraft fuel, loss of navigation aids, lights, etc. Runways can be rendered unusable due to structural damage to pavements.

   (d) Harbors - Wharves can be damaged. During the Alaska earthquake, a number of ports were essentially closed due to damage from tidal waves.

(e) Estimates of Damage as a result of various magnitudes of earthquakes

In a paper to be published on September 14, 1981, Oppenheim and Anderson present the following equations -

Repair Cost $S = 0.00104\ I^{4.82}$

where

S = percentage dollar repair cost (100% = Full replacement)

I - Earthquake intensity on the Modified Mercalli Scale (between 6 and 11)

T = Repair period in days

$T = 0.187 + 2.78\ S + 0.044\ S^2 + 0.00065\ S^3$

There equations are evaluated as follows -

Intensity	S%	T=(Days)
6	5.85	18.1
7	12.31	42.3
8	23.44	97.9
9	41.35	236.3
10	68.71	609.8
11	108.8	New bridge

UNIVERSITY OF SOUTH CAROLINA
COLUMBIA, S. C. 29208

COLLEGE OF ENGINEERING

August 25, 1981

Dr. Richard Wallace
School of Public Health
Campus

Subject: Supplemental Comments on Earthquake Risks in Charleston, South Carolina

Dear Richard:

In accordance with requests made by you and Dr. Roberts at our recent meeting, I am furnishing further information.

In regard to costs to replace bridges which may be damaged by an earthquake, I met with Mr. Ralph Rubeiz of the South Carolina Department of Highways and Public Transportation. Mr. Rubeiz is their bridge estimator. He furnished me with rather detailed information on the cost of building new bridges at the present time. In his opinion these costs should be increased by about 50 percent if one is attempting to repair damaged bridges. I have information on the various details of a bridge, but a per square foot cost for an entire section of a bridge is probably most appropriate for your needs. Even the per square foot cost varies considerably, depending upon the particular bridge and its length of span. An average figure, however, is $50.00 per square foot. The width of bridges varies considerably also, but once again for purposes of rough calculations, each traffic lane may be assumed to occupy 15'. Therefore, for a two lane bridge, width equals 30'. If span lengths of 50' are assumed, and a whole span should be assumed to go, then the cost per span for repair would be 30 X 50 X $50 = $75,000 per span lost.

You have asked me to comment on my estimates of damages to bridges in Charleston for various magnitudes of earthquakes. The values which I am furnishing are my best estimates based on a study of many earthquakes. I am enclosing a map (Figure 2) which shows probabilistic peak accelerations for the conterminous United States. It should be noted that this map indicates a 10 percent probability that peak accelerations in the Charleston area will exceed 0.11 times the acceleration of gravity in 50 years.

I am of the opinion that accelerations equal to no more than 0.11 times g will essentially do no damage to the Charleston transportation system. It is probable that ground acceleration may have been as much as 0.44 g in the 1886 earthquake. There is historical evidence to indicate that there was much damage to trestles and railroad tracks in that earthquake. I believe that a repeat of that earthquake might render 40 percent of the Charleston transportation system inoperable and that 30 percent would have to be rebuilt.

For reference purposes, the recent San Fernando 1971 earthquake which did considerable damage to highway bridges was magnitude 6.6 on the Richter scale. The 1976 earthquake in Guatemala City was 7.5. Surprisingly, only two bridges in that city suffered major damage although many did have light to moderate damage.

The tabular values listed below are provided.

Richter Mag.	Damage Level	Probability
5.5	Minimum	75 year recurrence
6.5	10 % replacemwnt	150 year recurrence
7.5	30 % replacement	250 year recurrence
8.5	80 % replacement	500 year recurrence
8.7	100 % replacement	2000 year recurrence

Sincerely yours,

Richard B. Pool

Richard B. Pool

RBP:msb

Enclosure

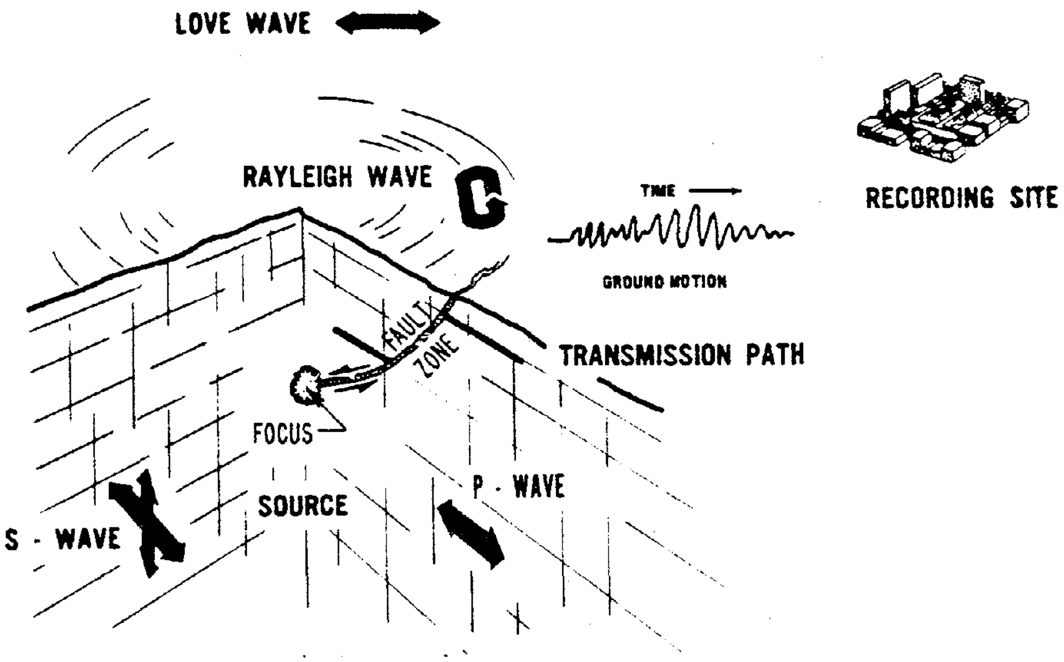

Figure 1. Elements involved in zoning of the ground-shaking hazard.

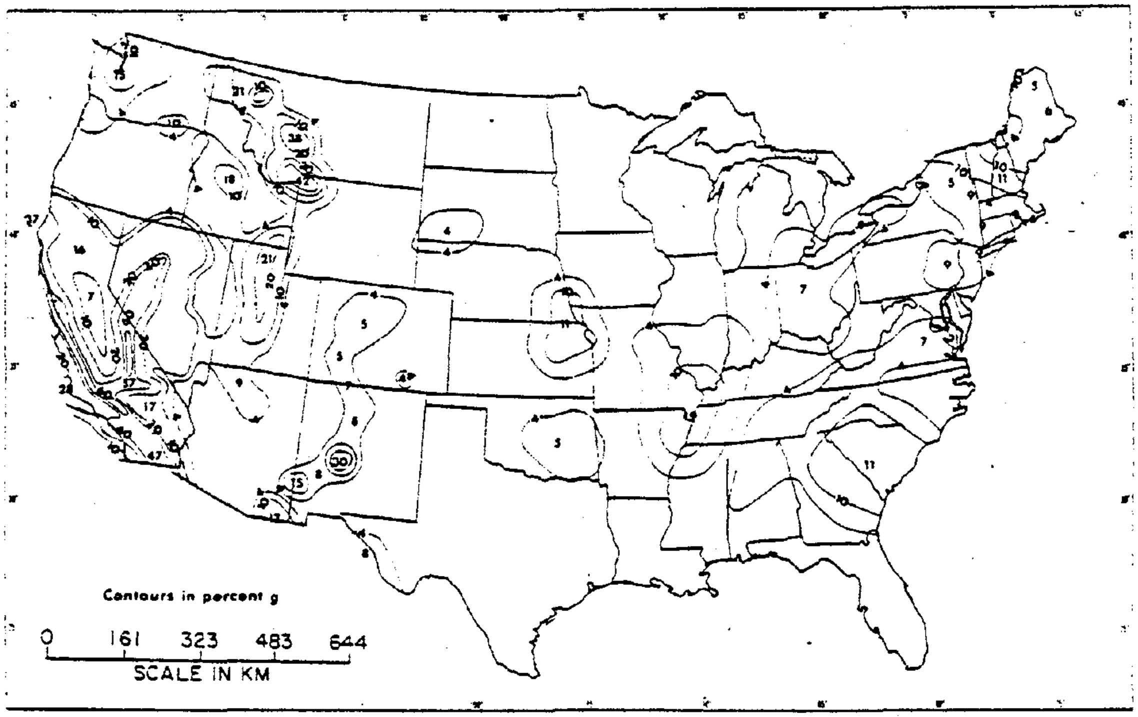

Figure 2. Probabilistic zoning map showing the peak acceleration at sites underlain by rock in the conterminous United States (Algermissem and Perkins, 1976). A 10-percent probability exists that the specified level of ground-shaking will be exceeded in 50 years.

TRANSPORTATION AND UTILITIES

One of the primary advantages of the use of process models in regional economic analysis is their ability to incorporate a spatial element lacking in traditional time series analysis. This is of particular importance for the current project, since much of the economic loss associated with an earthquake can be expected to arise from spatially induced supply side constraints. That is to say that the supply side constraints arise not from an inadequacy of resources, but rather from the inability of the surviving transportation system to move the resources to the points where they are required. Thus, it was decided that a close look at the transportation network was necessary and that transportation induced constraints should be incorporated into the model.

The data for the transportation system analysis comes from the South Carolina Department of Highways and Public Transportation and from the Charleston City Department of Traffic Engineering. Of this, the most useful information was the State Highway Department Charleston Area Transportation Survey (CHATS). The CHATS contains data on average weekday traffic flows at two hundred and thirty (230) locations in and around the urbanized parts of the three county area. Of the 230 locations, 16 have traffic counts recorded on an hourly basis. These counts are carried out for one week each quarter of a year. Unfortunately, because of incompleteness of these data, rigorous analysis is impossible, but it is still possible to get some rough idea of the purpose of trips by looking at hourly and seasonal variations in traffic counts at the 16 recording stations.

The counts of traffic in the CHATS can give a pretty good picture of the existing traffic patterns in the Charleston Area. The next question is what would happen to the existing patterns in the event of an earthquake. A number of possible types of damage suggest themselves:

1. blockage of roads by fallen rubble from collapsed structures,
2. buckeling and faulting of roads, and
3. collapse or weakening of bridges and approaches.

The problem is in our not knowing the severity and extent of each of the types of damage for an earthquake of given magnitude, and our inability to evaluate the engineering literature in the area. For these reasons we have engaged a civil engineer, Dr. Richard Pool, of the University of South Carolina Department of Civil Engineering, as a consultant to the project.

Dr. Pool's charge includes the following tasks:

1. Conducting a survey of the existing engineering literature concerning the types of damage to the transportation network. Of particular interest would be any work on probabilistic estimates of damage to the elements of the network in the event of an earthquake of a given magnitude.
2. Conducting a physical survey and making estimates of probabilities of damage for representative elements in the Charleston transportation network. The purpose of this task is twofold. In the first place, we wish to develop credible estimates of what will happen to the transportation network in the event of an earthquake. This will be necessary for simulation. In the second place, we need to have an idea of how costly and difficult accurate estimates would be.
3. Determining the availability and costs of measures to mitigate the effects of an earthquake on the region's transportation network. This includes steps which might be undertaken before an earthquake

to reduce damages, as well as time and costs required to repair or replace damaged elements after the earthquake.

In each of the above tasks, we have asked Dr. Pool to concentrate on those linkages in the system whose destruction could be expected to result in substantial economic disruption. That is:

1. linkages characterized by a high traffic volume,
2. linkages which have no redundant alternatives,
3. linkages which have a substantial probability of being damaged in the event of an earthquake, and
4. linkages which, if destryoed, would take a substantial amount of resources and especially time to repair or replace.

Dr. Pool is in Charleston at this time and is working on the consulting for the project. He expects to have a full written report to us by the 15th of August.

Use of the Transportation Data in the Regional Model

Some of the transportation data has been incorporated into the econometric model and is discussed under that report. Here we will deal with incorporation of the transportation data into the process model. In doing this, it seems that there are two possible approaches; we can either explicitely develop a process model for transportation and incorporate it with the rest of the process block, or we can treat changes in the transportation network as changes in costs and resource constraints in the process block.

The former approach is the theoretically more appealing of the two. The problem is first that we currently do not have sufficient engineering data to begin to specify a transportation process model, nor, at this point, do we know whether such data could be feasible obtained (this is, in part, the purpose of Dr. Pool's work). Even with the engineering data, we have the problem of insufficient precise data on origin, destination and purpose of trips to justify the precision of which a process model is capable.

The alternative is to use the transportation data in the process block as changes in prices and resource constraints. The treatment of constrained resources seems fairly straight forward if the disruption is such that a subregional area is completely cut off, then the resources in that subregion are treated as distinct resources required for production in that area. The problem is that over the length of time for which this model is sensitive (being incorporated with an annual model) it is inconcievable that a situation would pertain in which a subregional area was completely cut off. Certainly some transportation alternatives would become available, although admittedly at a much higher price. Therefore, generally it seems more appealing to incorporate transportation changes as price changes in the model rather than as changes in resource constraints. The problem, however, is in knowing what the alternatives are for transportation and the costs associated with them - in short, knowing the A matrix for a transportation process model.

This leaves us forced, in most cases, to take the expedient of incorporating transporatation changes into the model as change sin resource constraints. Then on a resource by resource basis, we may be able to develop step cost functions by looking at transport alternatives (e.g., airlifts, ferry boats, etc.).

"Public" Utilities

Examination was also made of the problem of public utilities, especially electrical, natural gas, and water production and distribution systems. The effect of an earthquake on these systems appears to be initially substantial, but of a transitory nature. Damages to the electrical distribution system would probably be less than in the case of a severe ice storm, 90% of service could be restored within a week, and virtually all service restored within two weeks.

The production of electricity could be interrupted by damage to the McKeetchen generating station, but power would be moved across the grid at peak load prices. Because of the regulatory rate setting mechanism which dictates uniform rates throughout the service area, the increased cost of electricity and of repairs would be spread over all South Carolina Electric and Gas customers, rather than being borne by those in Charleston. It is also not clear to me to what extent the company is insured against such losses. It is even less clear how the regulatory rate setting body (S. C. Public Service Commission) and the courts would treat uninsured losses, i.e., whether as a business expense to fall on consumers or a risk of business loss to fall on shareholders.

The problem of water and gas lines is more complex than that of electrical power. They should probably be subject to study by enineers, since there is a substantial body of technical literature (most of it beyond me) on the effects of type of line and soil conditions on damages in the event of an earthquake. Apparently most of the damage would be at a number of points where faulting occurred, and most service could be restored fairly quickly (i.e., within several weeks). Furthermore, most large users could adapt alternatives, such as compressed gas, which would not be that much more costly.

For the present time, I think there is not much for us in the public utilities area, especially since the process model we are using is for housing. Service restoration would be complete before any housing construction was completed, and so would probably not be a major factor in the decision on where to build. Furthermore, because of the nature of rate setting for public utilities, costs will be spread throughout the region. Although there will be higher costs for housing because of increased utility costs, there will be no price differential within the region. The effect of an earthquake on utilities may affect decisions as to migration in an out of the region, but not decisions as to where to locate within the region.