1 Introduction

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1.1 Overview

The problem of disasters has gained considerable interest in the last decade. The 1990s was designated as the International Decade for Natural Disaster Reduction (IDNDR) by the United Nations General Assembly (resolution 42/169), and parallel national efforts were undertaken across the globe. Disaster losses nonetheless continued their rapid growth (Mileti, 1999; Red Cross, 2002). During this decade, a series of major natural and human-induced disasters struck large urban areas and plainly demonstrated the need to better understand, anticipate, and prepare for such calamities. For example, in the United States, record losses were caused by Hurricane Andrew which struck the Miami region in 1992, the Great Midwest Floods of 1993, and the 1994 Northridge earthquake in Los Angeles (NRC, 1999). By one estimate, the Northridge earthquake inflicted some $40 billion in damage (Eguchi *et al.*, 1998). In Japan, the 1995 Great Hanshin earthquake struck directly beneath the modern industrialized urban area of Kobe. It killed more than 6,000 people and resulted in an estimated $100 billion in damages, or about 2 percent of Japan's gross national product (Scawthorn *et al.*, 1997). The 1999 Chi-Chi earthquake in Taiwan caused an estimated $8 billion in loss and, significantly, caused sizable spatial repercussions as semiconductor prices spiked worldwide (Chang, 2000). The terrorist attacks of September 11, 2001, in New York City killed close to 3,000 people and caused some $83 billion in direct and indirect loss to the city's economy. Adjusting for insurance and federal government reimbursements, the net loss may have amounted to some $16 billion (NYC Partnership, 2001). Each of these events demonstrated, moreover, how disasters not only inflict human and physical damages but can also cause considerable economic disruption to vulnerable cities and regions. For developing countries, disasters can have devastating consequences for their development and growth (Red Cross, 2002).

It is useful to clarify the concept of disaster in order to provide a common reference for this volume. The terms "hazard" and "disaster" are often used interchangeably in the literature, leading to some confusion. Within the social science literature, numerous definitions have been proposed, debated, and reconceptualized over the last several decades (see Tierney *et al.*, 2002, for an excellent review). For example, the functionalist approach of the classic sociological literature defined "disasters" as events that exceed the capacities of communities or social units to perform necessary functions, whereas early geographers in the field considered "natural hazards" to be extreme natural events that, by definition, intersect with human choices and adjustments. Some more recent definitions reflect social constructionist, political economy, or ecological vulnerability perspectives. While regional economists and regional scientists have written little on conceptually defining disasters, they commonly consider these to be extreme events, whether natural or human-induced in origin, that shock an economic system and produce measurable impacts.

Here, we make a distinction between hazards and disasters. John Whittow (1979) distinguished between these two terms as follows: "*A hazard is a perceived natural event which threatens both life and property—a disaster is the realization of this hazard* (p.19)." This definition can be extended to other types of threats such as technological accidents, terrorism events, riots, and even wars. In his way, *hazard* is the occurrence of the physical event per se, such as an earthquake, and *disaster* is its consequence. Not all hazardous events necessarily lead to disaster; disasters result when the physical event intersects with vulnerable built and socio-economic environments. This suggests that while research on hazards should involve the mechanism and/or prediction of occurrence of these events, research on disasters should incorporate the societal impacts, reconstruction, and recovery from them.

From the perspective of spatial economic modeling, disasters caused by natural and human-induced events reflect many similarities, although a discussion of their differences is useful. A major difference is that in contrast to natural disasters, many human-induced disasters are designed intentionally to cause destructions. Consequently, the resulting damages are often concentrated on facilities or areas that are of great significance to the well-being of the impacted society, whether strategically, economically, or symbolically. In addition, within the scope of natural hazards, certain types of hazards create some specific implications for modeling. The effects of sudden-onset hazards, such as earthquakes, hurricanes, and floods, are more readily captured in spatial economic models than slow-onset disasters such as droughts and epidemics. In the context of scientific and technological advances, a further distinction can be made between predictable hazards, such as hurricane and floods, and unpredictable ones, such as earthquakes. Predictions and predictability affect human behavior, trigger preparedness actions, and affect mitigation options that can modify the impact of an event when it occurs. While different types of hazards lead to different features in their consequences and impacts, to some extent, many common attributes extend across disasters. These include the occurrence of direct business interruption and consequent indirect losses, reconstruction and recovery processes, etc. In many cases, therefore, modeling and analysis can apply similar frameworks across disaster types. Detailed study of the transferability of models across disaster types remains, however, an area needing further research.

In the recent years, there has been a growing recognition that disasters cannot be adequately handled within the framework of conventional spatial economic models. While Econometrics, Input-Output, Social Accounting, and other types of economic models have been applied to study the impacts of disasters, they are based on a number of assumptions that are questionable in catastrophes. In their excellent summary of issues and modeling strategies for disaster impact studies, West and Lenze (1994) noted that researchers need to address issues such as double-counting, the response of households, and the evaluation of financial situations. A recent report by the National Research Council (1999) argued the main problem as follows:

The core of the problem with statistically based regional models is that the historical relationships embodied in these models are likely to be disrupted in a natural disaster. ...In short, regional economic models have been developed over time primarily to forecast future economic conditions or to estimate the effects of a permanent change (e.g., the opening or closing of a manufacturing plant). The abruptness, impermanence, and often unprecedented intensity of a natural disaster do not fit the event pattern upon which most regional economic models are based. The models are thus inappropriate for simulating natural disaster losses. (p.40)

This problem can be recast as a series of challenges that disasters pose to conventional modeling. These challenges concern: (a) data availability; (b) scope; (c) broad influences; (d) uncertainty; and (e) stability and dynamic process:

- Data on disasters are sparse and difficult to interpret. Not only are disasters rare, but also their consequences are unique to each event. Empirically, it may be difficult to distinguish the effects of the disaster from changes that would have occurred in any case. Moreover, disaster data are mostly available at the physical and localized levels, providing little information on socio-economic damages or spatial effects.
- Conventional models usually reflect stylized and limited aspects of society. The damages and losses caused by disasters reflect complex linkages between the natural, built, and socio-economic environments. Thus, disasters cross disciplinary boundaries.
- In addition, disasters expose the underlying vulnerability or resiliency of socio-economic agents and groups which may not be realized in the pre-disaster period, so that impacts are influenced by broad factors other than physical damage. Issues of financial assistance greatly influence disaster outcomes.
- Most conventional models are based on the assumptions of perfect information and foresight. Many disasters occur suddenly and with little warning or anticipation. Risk information is also imperfect. Risk perception and related behaviors, such as purchasing insurance, influence disaster impacts.
- Conventional models assume incremental and steady changes and are equilibrium-oriented. Disasters often create chaos and economic disequilibrium, and can also cause unexpected long-term, structural changes. In addition, the speed of adjustments is a critical dimension of impacts and recovery. Dynamic interactions among agents and behavioral adjustments in a disaster are very complex.

Notable progress has been made in recent years in tackling many of these challenges. Researchers have developed increasingly sophisticated models of the spatial economic impacts of urban disasters. This volume brings together a comprehensive cross-section of the state-of-the-art in socio-economic disaster modeling. Many of the chapters have been motivated by recent catastrophes and the need to better understand and prepare for future events. Each of the chapters addresses one or more of the challenges noted above, often proposing refinements to conventional methods or innovative new modeling frameworks. Collectively, they indicate that while issues still remain, significant inroads have been made.

The chapters are organized into three parts. Chapters in Part I elaborate on the discussion of conceptual and modeling issues. Part II proposes major refinements for modeling disasters in the context of conventional economic frameworks. Part III expands upon the economic approaches by adopting integrative strategies. These focus on linking economic models with the models of physical environment and disaster damage.

1.2 Conceptual and Modeling Issues

The three chapters in Part I explore issues and challenges for modeling the spatial economic impacts of disasters. Rose (chapter 2) sets the stage by discussing foundational concepts and identifying current issues and research priorities. By clarifying economic principles and key terms, such as issues of double-counting, stocks vs. flows, and direct vs. higher-order effects, he addresses some important sources of current confusion. Rose also identifies current issues in the literature and makes the case for others requiring attention. Recent research has raised such questions as non-market effects, the dynamic nature of impacts, and economic resiliency. At the same time, some topics that have long been neglected in disaster studies, like distributional impacts and sustainability, remain essential for public policy. Rose also provides an unusually candid discussion of data availability and model validation, and concludes that the greatest research need for hazard loss modeling is to improve its empirical basis. This, he argues, is necessary to broaden popular acceptance of the idea of economic impacts among researchers and policy-makers alike.

The following chapter by Cochrane (chapter 3) complements the discussion of direct and higher-order effects. Cochrane broadens the conceptualization of higher-order (indirect) effects to include not only ripple effects from production disruptions, but also systemic risk in the form of disaster-induced shortages of credit and insurance. He first discusses HAZUS, a landmark disaster loss model developed in the late 1990s by the U.S. Federal Emergency Management Agency (FEMA). As the principal architect of HAZUS' indirect economic loss module, Cochrane provides a useful summary of its methodology and generalized statements about economic loss patterns. He then extends the discussion of indirect losses to issues of systemic risk. While the financial market may have significant influence on disaster mitigation, reconstruction, and recovery, it has been largely neglected in the literature with the exception of a few studies on disaster relief and the role of insurance (*e.g.*, Kunreuther and Roth, 1998). Cochrane addresses this gap by examining the question of disaster-induced systemic loss in the insurance arena, emphasizing recent cases in California and Florida, as well as New York following the World Trade Center attacks in 2001.

The economic impacts of the events of September 11, 2001, on the economy of New York City are thoroughly analyzed in chapter 4 by Bram *et al.* Terrorist incidents represent another type of disaster or unscheduled event. While differing in some respects from natural disasters (*e.g.*, intentional causation by human beings, selection of targets, and potential avoidance), they also exhibit many similarities (*e.g.*, uncertainty of consequences, fear of repeated occurrences, and stages of reconstruction and recovery). Bram *et al.* find that while the attack caused a sharp temporary disruption, the New York economy is likely to keep its previous pace of economic growth over the medium term. However, they warn that much depends upon economic policy responses. Based on their research, the authors concur with a number of issues discussed by Rose and Cochrane in the previous chapters and raise the importance of others for reconstruction and recovery, including fiscal impacts on local government, the effects on industry and population (labor) structures, and intergovernmental relationships.

Many of the issues discussed in Part I are addressed and integrated in the modeling frameworks presented in Parts II and III.

1.3 Economic Models

The chapters in Part II propose a variety of approaches to modeling the spatial economic impact of disasters from the perspective of conventional economic methodologies. Since the pioneering work of Dacy and Kunreuther (1969) and Cochrane (1975), many economic modeling frameworks have been proposed for analyzing natural disasters. Each of the recent approaches presented in Part II challenges different aspects of disaster modeling; for instance, temporal impacts, insurance, resiliency, long-term evolution, and risk perception. At the same time, the models cover many common features, such as uncertainty and macroeconomic consequences.

The first three chapters of Part II respectively employ the conventional frameworks of Input-Output, Social Accounting, and Computable General Equilibrium modeling. Their contributions entail developing novel modification schemes for dealing with the unique aspects of disasters.

As Rose notes in Part I (chapter 2), the Input-Output (I-O) model has been employed in many studies on economic impacts of disasters. Criticisms against I-O pertain mainly to the inflexibility of the model's fixed coefficients, its static nature, and its equilibrium orientation, in which the market always clears regardless of what disturbances have occurred. Many researchers have used the I-O model for the preliminary estimation of the total economic impacts of a disaster; however, some studies have modified the I-O framework to reflect the particular aspects of disasters and the recovery process[1]. Okuyama *et al.* (chapter 5) highlight the spatial and temporal distributions of the economic impacts of a disaster and overcome some of the drawbacks of the I-O model by utilizing an interregional I-O table within the Sequential Interindustry Model (SIM) framework. With this modification, a static I-O table is extended to a dynamic system with spatial dimensions. It is thus able to deal with certain aspects of disasters such as uncertainty, demand-supply mismatch, and technology replacement.

As discussed in the previous section, the modeling literature has largely neglected the important issue of insurance and, more generally, disaster protection. Building on the Social Accounting Matrix (SAM) framework, Cole (chapter 6) develops an

[1] In recent examples, Rose *et al.* (1997) combined I-O modeling with linear programming to analyze optimal rationing policies of electric power after a disaster, while Okuyama *et al.* (1999) used the Leontief-Strout-Wilson version of the multi-regional I-O model to assess the interregional economic impacts of hypothetical earthquakes in the central U.S.

insurance accounting matrix to assess the ways that disasters affect social agents and propagate through the economy. He provides some insightful simulation results for evaluating the effects of insurance under a series of repeated disasters. Cole's approach is unique in recognizing that uncertainties are pervasive in normal production and daily survival. Agents invest in insurance to ward against these uncertainties, and disasters occur when major events exceed their coping capacities. Moreover, Cole's work is unique also in considering both formal and informal types of insurance, an example of the latter being the development of social networks. The approach thus directly addresses issues relevant to developing countries, which are often characterized by a dual economic structure consisting of modern and traditional sectors.

Computable General Equilibrium (CGE) models, like I-O and SAM models, are based on the general principles of a multi-sector general equilibrium-oriented framework. A relatively new modeling approach, they are distinguished by the inclusion of more sophisticated dynamic processes for price-quantity (supply-demand) adjustment, input substitution, and trade relationships. While CGE models have been proposed for disaster modeling in concept, Rose and Guha (chapter 7) present one of the few attempts to implement a CGE for an actual regional economy. Their case study of Memphis, Tennessee, focuses on the impact of electric power disruption in disasters. Simulation results reveal that in contrast to static I-O models, which overstate the rigidities in an economy, CGE models tend to exaggerate an economy's flexibility and resiliency. CGE models will thus understate economic losses unless properly adjusted. This analysis is accompanied by a discussion of how different types of models may be appropriate for capturing different stages of disaster recovery, from the emergency response period to the long run.

The long-term impact of a catastrophic event on an economy represents a critical research need that is difficult to address within the framework of traditional economic models. Reggiani and Nijkamp (chapter 8) approach this topic through the recently introduced framework of Self-Organized Criticality (SOC). In this framework, a major exogenous force (*i.e.*, a disaster) drives the economy (at the macro-level) to a critical state, together with strong localized interactions between individual elements of the system (at the micro-level). To illustrate the application of SOC to a disaster situation, Reggiani and Nijkamp assess the fall of the Iron Curtain as a socio-economic crisis, analyzing major shifts or jumps in regional labor markets in West Germany during the 1990s. Their findings suggest that the SOC concept may also be useful for explaining the dynamics and dislocations of natural disasters.

In contrast to the preceding chapters, which largely concern *ex post* analyses of disaster impacts, Tatano *et al.* (chapter 9) address from an *ex ante* perspective the spatial economic implications of risk and risk perception. This study is more traditional in the sense that it employs a purely theoretical approach using mathematical modeling techniques from neo-classical economics. It explores the effects of information provision regarding local vulnerability in potential future disasters. Tatano *et al.* show that, with imperfect risk information, perception gaps may lead to a divergence between equilibrium land use patterns and optimal ones. They conclude that appropriate planning is needed for achieving optimal land-use. This chapter thus addresses a new dimension in the spatial economic modeling of disasters, the effects of risk information and risk perception. This is another crucial public policy issue that needs to be studied thoroughly.

1.4 Integrative Models

The spatial economic consequences of disasters derive in a complex manner from the interactions between physical damages and the regional economy. To a much greater extent than the chapters in Part II, those in Part III focus on the integration of damage estimation and economic modeling. In many cases, this involves engineering as well as economic analyses. Such comprehensive and typically large-scale modeling approaches have gained notable interest in recent years with increasing efforts in multi-disciplinary research, methodological advances, and improvements in computational power.

A major challenge in modeling the spatial economic impacts of disasters is the need to accommodate non-economic information. This includes inputs on the direct social and physical damages caused by disasters, such as loss of human lives and damage to the built environment, as well as information regarding potential future disasters such as geologic and meteorological data. Because no economic model can deal with these physical data directly, they must be interpreted in ways that allow economic models to treat them as inputs. This task is critical, as economic estimates are only as good as the quality of the disaster-related inputs; however, it is daunting, due to differences in such factors as units of analysis and sensitivity between physical data and economic models (West and Lenze, 1994). Each of the chapters in Part III propose novel approaches to integrating physical damage and economic models for disasters.

The dynamic processes of disaster recovery present a major challenge for conventional economic models and an important void in the literature. Chang and Miles (chapter 10) address the complexities of recovery through an innovative simulation model. Building on the empirical literature, they first present a comprehensive yet parsimonious conceptual framework for disaster recovery. In contrast to conventional approaches, this framework emphasizes interactions between households, businesses, infrastructure systems, neighborhoods, and community government. This work is also distinctive in its attention to urban spatial disparities in recovery. Chang and Miles use Object Modeling Techniques (OMT) to simulate the disaster recovery process for individual agents and an earthquake-stricken community as a whole. Their findings reveal how interactions between agents and across scales may magnify and complicate the impacts of public sector decisions regarding mitigation investment, emergency response, and recovery. The rapid restoration of transportation systems, for example, is the key to facilitating urban disaster recovery.

The economic importance of elevated highway systems in particular, which carry substantial volumes of commodities and people on a daily basis, has been strikingly demonstrated in recent earthquake disasters. Highway disruption was particularly noteworthy in the 1989 Loma Prieta earthquake that struck the San Francisco Bay Area, the 1994 Northridge earthquake in Los Angeles, and the 1995 earthquake that struck Kobe, Japan. Inspired by these events, Gordon *et al.* (chapter 11) develop an integrated, operational model for Los Angeles that emphasizes how damages to transportation and to industrial production capacity affect the metropolitan economy. This model links a spatial Input-Output model with a transportation network and earthquake damage model. Their ultimate goal is to present a full-cost approach to estimating disaster impacts that can help policy makers evaluate the costs and benefits of earthquake retrofit and reconstruction strategies. In this chapter, Gordon *et al.*

estimate that a magnitude 7.1 scenario earthquake could cost the region – as a lower bound estimate – in excess of $94 billion. This includes not only structural damage and business interruption, but also the repair costs, increased freight and travel costs, and changes in travel behavior associated with highway system damage.

From a regional perspective, the Kobe earthquake also demonstrated that the impacts of a catastrophic disaster can spread through interregional trade to other regions. Sohn *et al.* (chapter 12) employ and calibrate an interregional commodity flow model for analyzing how transportation damage in a hypothetical earthquake may cause economic impacts across the United States. The model evaluates transport cost increases as well as reduced final demands due to the disruption of transportation networks. It is innovative in being able to deal with both highway and railroad networks in an interregional context and in allowing the partial closure of damaged bridges and links. As with the Gordon *et al.* model, it can be utilized to assess the economic impacts of a disaster and to support cost-benefit analysis of retrofit strategies by policy makers and planners.

As with transportation systems, other infrastructure lifelines such as electricity and water networks also provide essential services in a disaster situation. From a largely engineering perspective, Shumuta (chapter 13) develops a benefit-cost methodology for renewal planning of electric power systems. A case study is presented for an actual system in Japan. Shumuta's approach is distinctive in considering disaster risk not as an isolated problem, but rather within the context of infrastructure renewal planning. It also differs from others in this volume by evaluating system performance in the face of multiple hazards, including earthquakes, typhoons, and environmental factors associated with equipment deterioration. Moreover, Shumuta pays particular attention to assessing uncertainties related to such factors such as earthquake occurrence probabilities.

The following chapter by Shinozuka and Chang (chapter 14) also analyzes electric power systems, but places greater emphasis on measuring the social and economic impacts of power loss in disasters. This chapter introduces the concept of seismic resilience of infrastructure systems in general and of utility power systems in particular. A comprehensive methodology is developed for analyzing disaster resilience, from equipment damage to system functionality to social and economic impacts. The model is applied to the Los Angeles Department of Water and Power's system after the 1994 Northridge earthquake. Based on the analysis, a useful set of data is derived, and the robustness and rapidity for restoration of electric power networks and grids during and after a catastrophic event are investigated. Results are represented in the novel form of risk curves. The risk curves enable analysts to compare expected electric power performance against criteria of acceptable risk, as well as to evaluate the benefits of seismic retrofit investments.

1.5 Final Thoughts

The papers presented in this volume demonstrate the vast strides that have recently been made in modeling the spatial economic impact of disasters. Particularly important advances have been made in methods that address economic resiliency, dynamic adjustment processes, and integration of the physical and economic consequences of disasters. Collectively, researchers have addressed many of the shortcomings of traditional models in the disaster context that were outlined earlier in this chapter, while several challenges still remain; for example, more research is needed on long-term effects, distributional impacts, and common modeling frameworks.

Many of the models developed in this volume are applied to a specific type of disaster, and most can, to some extent, be generalized to become applicable to other types of disasters. It should be recognized, however, that each disaster poses a different set of threats and potentially entails different types of impact. For example, the duration of hazards such as earthquakes and hurricanes is relatively short, whereas floods can linger for months. The extent, to which modeling strategies are transferable across natural disasters, or between natural disasters and other major dislocations such as terrorism events or sudden economic change, remains to be explored. Recent efforts toward the development of a multi-hazard loss estimation model by the U.S. Federal Emergency Management Agency (FEMA) indicate the currency of this issue.

Better models are needed to improve the effectiveness of disaster reduction efforts. In a recent synopsis of the state of natural hazards research, Mileti (1999) claimed that:

> *Many disaster losses – rather than stemming from unexpected events – are the predictable result of interactions among three major systems: the physical environment, which includes hazardous events; the social and demographic characteristics of the communities that experience them; and the buildings, roads, bridges, and other components of the constructed environment. Growing losses result partly from the fact that the nation's capital stock is expanding, but they also stem from the fact that all these systems – and their interactions – are becoming more complex with each passing year.* (p.3)

While various disciplines—including engineering, economics, geography, sociology, and emergency management—have long histories of disaster research, multidisciplinary efforts that comprehensively investigate disasters are still at an early stage. Moreover, until recently, there have been few efforts to model how disasters affect urban and regional economies. It is our hope that by enhancing the understanding of disasters and encouraging multidisciplinary collaboration across fields, this collection may ultimately contribute to reducing the toll of disasters.

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