Economic Resilience to Disasters

CARRI Research Report 8

Community & Regional RESILIENCE Institute

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ECONOMIC RESILIENCE TO DISASTERS

by

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RESEARCH FINDINGS ABOUT COMMUNITY AND REGIONAL RESILIENCE

One of the commitments of the Community and Regional Resilience Institute (CARRI) is to understand what resilience is and how to get there, based on research evidence.

As one resource for this effort, CARRI has commissioned a number of summaries of existing knowledge about resilience, arising from a number of different research traditions. This report is one in a series of such summaries, which will be integrated with new resilience explorations in several CARRI partner cities and with further discussions with the research community and other stakeholders to serve as the knowledge base for the initiative.

For further information about CARRI's research component, contact Thomas J. Wilbanks, wilbankstj@ornl.gov, or Sherry B. Wright, wrightsb@ornl.gov.

COMMUNITY AND REGIONAL RESILIENCE INSTITUTE

Oak Ridge National Laboratory's (ORNL) Community and Regional Resilience Institute (CARRI) is a program of the Congressionally funded Southeast Region Research Initiative. CARRI is a regional program with national implications for how communities and regions prepare for, respond to, and recover from catastrophic events. CARRI will develop the processes and tools with which communities and regions can better prepare to withstand the effects of natural and human-made disasters by collaboratively developing an understanding of community resilience that is accurate, defensible, welcomed, and applicable to communities across the region and the nation.

CARRI is presently working with three partner communities in the Southeast: Gulfport, Mississippi; Charleston/Low Country, South Carolina; and the Memphis, Tennessee, urban area. These partner communities will help CARRI define community resilience and test it at the community level. Using input from the partner communities, lessons learned from around the nation, and the guidance of ORNL-convened researchers who are experts in the diverse disciplines that comprise resilience, CARRI will develop a community resilience framework that outlines processes and tools that communities can use to become more resilient. Of critical importance, CARRI will demonstrate that resilient communities gain economically from resilience investments.

From its beginning, CARRI was designed to combine community engagement activities with research activities. Resilient communities are the objective, but research is critical to ensure that CARRI's understanding is based on knowledge-based evidence and not just ad hoc ideas—we want to get it right. To help with this, CARRI has commissioned a series of summaries on the current state of resilience knowledge by leading experts in the field. This kind of interactive linkage between research and practice is very rare.

In addition to its partner communities and national and local research teams, CARRI has established a robust social network of private businesses, government agencies, and non-governmental associations. This network is critical to the CARRI research and engagement process and provides CARRI the valuable information necessary to ensure that we remain on the right path. Frequent conversation with business leaders, government officials, and volunteer organizations provide a bottom-up knowledge from practitioners and stakeholders with real-world, on-the-ground, experience. We accept that this program cannot truly understand community resilience based only on studies in a laboratory or university. CARRI seeks to expand this social network at every opportunity and gains from each new contact.

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LIST OF RESEARCH REPORTS BY NUMBER

CARRI Report 1: Susan L. Cutter, Lindsey Barnes, Melissa Berry, Christopher Burton, Elijah Evans, Eric Tate, and Jennifer Webb, *Community and Regional Resilience: Perspectives from Hazards, Disasters, and Emergency Management*, September 2008.

CARRI Report 2: Susanne C. Moser, *Resilience in the Face of Global Environmental Change*, September 2008.

CARRI Report 3: Craig Colten, Robert Kates, and Shirley Laska, *Community Resilience: Lessons from New Orleans and Hurricane Katrina*, September 2008.

CARRI Report 4: Betty Hearn Morrow, *Community Resilience: A Social Justice Perspective*, September 2008.

CARRI Report 5: Lance Gunderson, *Comparing Ecological and Human Community Resilience*, January 2009.

CARRI Report 6: Kathleen Tierney, *Disaster Response: Research Findings and Their Implications for Resilience Measures*, March 2009.

CARRI Report 7: Thomas J. Wilbanks, *How Geographic Scale Matters in Seeking Community Resilience*, August 2009.

CONTENTS

RESEARCH FINDINGS ABOUT COMMUNITY AND REGIONAL RESILIENCE iii
COMMUNITY AND REGIONAL RESILIENCE INSTITUTE v
LIST OF RESEARCH REPORTS BY NUMBER vii
LIST OF TABLES xi
LIST OF FIGURES xi
ACKNOWLEDGEMENTS xiii
1. INTRODUCTION 1
2. BACKGROUND 1
Ecological Origins 2
Engineering-Based Definitions 3
Organizational Behavior 5
Planning 6
Economic Resilience 7
3. DEFINING ECONOMIC RESILIENCE 8
4. ECONOMIC RESILIENCE OPTIONS 10
Examples of Resilience and Applicability to Inputs and Outputs 10
Characterization of Microeconomic Resilience Strategies 12
5. QUANTIFICATION OF ECONOMIC RESILIENCE 18
6. TIMING OF ECONOMIC RESILIENCE 19
The Time Path and Dynamic Economic Resilience 20
Time Stages of Resilience Strategies 22
7. MEASURING RESILIENCE 25
8. ENHANCING AND ERODING RESILIENCE 26
Enhancing Resilience 26
Eroding Resilience 28
9. THE COST OF RESILIENCE 31
10. RECAPITULATION 33
REFERENCES 36

LIST OF TABLES

TABLE 1. RESILIENCE OPTIONS: BUSINESS (CUSTOMER SIDE) 14
TABLE 2. RESILIENCE OPTIONS: BUSINESS (SUPPLIER SIDE) 15
TABLE 3. RESILIENCE STRATEGIES: HOUSEHOLDS 16
TABLE 4. RESILIENCE STRATEGIES: GOVERNMENT 17
TABLE 5. STATIC RESILIENCE APPLICATIONS TO SOCIAL, ECOLOGIC, PHYSICAL, AND ECONOMIC RECOVERY BY TIME PERIOD 23
TABLE 6. EVALUATION OF INDIVIDUAL BUSINESS RESILIENCE ACTIONS..... 30

LIST OF FIGURES

FIG. 1. STATIC AND DYNAMIC RESILIENCE IN THE CONTEXT OF BUSINESS INTERRUPTION. 20

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ECONOMIC RESILIENCE TO DISASTERS*

1. INTRODUCTION

In the past few years, nearly every analysis of the impacts of a catastrophe in the United States has highlighted the resilience of the economy (see, e.g., Chernick, 2005; Boettke et al., 2007; Flynn, 2008). The term *resilience* is sometimes used to explain why regional or national economies do not decline as much as might be expected or recover more quickly than predicted. Otherwise, the term is either poorly defined or defined so broadly as to be meaningless. For example, only one of the authors of *Resilient City: The Economic Impact of 9/11* (Chernick, 2005) defines resilience, nor is the term even included in the index of the collection of papers. This and several other recent studies in related fields on a broad range of disasters (see, e. g., Vale and Campanella, 2005) use resilience in the vernacular and appear to be unaware of three decades of formal refinement of the term in several different disciplines. As such, economic resilience is in danger of becoming a meaningless buzzword.

The purpose of this report is to explain how economic resilience has evolved into a meaningful, quantifiable, measurable, and actionable concept. The report summarizes the literature on economic resilience and how it can be expanded by work in related fields and on related concepts. It then focuses on a specific set of definitions of various dimensions of the concept, stemming from a combination of the author's own work and a general consensus of researchers in the field. This is followed by examples of resilience actions by various decision-makers (business, households, government) and how they are related to aspects of the economic production function. A precise definition of static economic resilience is offered, and a time path is explored in the context of dynamic resilience. Ways that resilience can be enhanced and eroded are discussed next. A summary of empirical findings on the benefits of resilience is then presented, followed by a section on its costs in isolation and in comparison with other strategies to reduce the risks of disasters. The report concludes with a summary of the many dimensions of resilience.

2. BACKGROUND

The etymology of the word "resilience" is the Latin verb "resilio," meaning to rebound. Ecologists were the first to embrace the general concept of resilience more than 30 years ago (see, e.g., Holling, 1973). Since then, it has been adapted or reinvented for the case of short-term disasters (see, e.g., Tierney, 1997; Bruneau et al., 2003; Rose, 2004; and Rose, 2007) and long-term phenomena, such as climate change (see, e.g., Timmerman, 1981; Dovers and Handmer, 1992). Few analysts other than Rose (2004; 2007) and Chang (2009) have delved deeply into its economic interpretation.

The formulation of economic resilience can benefit from precedents in the established literature in ecology, engineering, organizational behavior, planning, and related fields over the past 30 years. In the discussion that follows, we focus on points of agreement and incorporate the work of others into the formulation of economic resilience. Criteria for conceptual and operational definitions are consistency with fundamental economic principles, the needs of

* The views expressed here, however, are solely those of the author and not necessarily those of the institutions with which he is affiliated nor of his funding sources. Also, the author is solely responsible for any errors or omissions.

potential users, and the practical matters of data availability and computational manageability. To begin, I offer the following working definition of economic resilience: *the ability of economic entities to maintain function and recover quickly from a disaster.*

Ecological Origins

As in many other fields, some researchers on the subject of resilience have "re-invented the wheel" narrowly in their own discipline, rather than looking carefully for precedents or at the big picture. To begin, ecologists have pioneered a useful, broad definition of resilience relating to the survival of complex systems. Holling (1973; p. 17) is typically cited as the first to have defined *resilience,* his definition being "the ability of systems to absorb changes . . . and still persist." He sometimes refers to it as "buffer capacity," and resilience is measured in this paradigm in relation to the size of the shock that is absorbed. Pimm (1991) provides an alternative ecological emphasis to the definition of resilience in terms of the speed at which the system returns to equilibrium.

Adger (2000) suggests that there is no single definition of ecological resilience and offers two definitions analogous to the static and dynamic economic definitions explained in detail below. An important contrast in the static definitions exists, however. The ecological definition emphasizes the amount of disturbance the system can absorb without incurring a change in its state. In economics, only the most severe hazard (a catastrophe) results in such a change, and thus such a definition would be of very limited usefulness. In economics, the term *resilience* is more in line with the buffer concept, as the ability to mute the influence of the external shock. It is not just the decrease in economic activity but rather the actual decrease relative to the potential decrease (see also the mathematical definitions in Sect. 5). Perrings (2001; p. 322) also defines resilience in a relative manner: "As a first approximation, this may be measured by an index of the level of pollution or depletion relative to the assimilative or carrying capacity of the ecological system concerned." Subsequently, Perrings (p. 323) defines it in terms of the "gap between current and critical loads" to the ecosystem and even the ecological-economic system.

It is important to distinguish between the concept of resilience and related terms. For example, Holling (1973; p. 17) defines stability as "the ability of a system to return to equilibrium after a temporary disturbance." This definition is often put forth as the essence of resilience or at least a special dimension. However, it is clear that resilience and stability are distinct. As Handmer and Dovers (1996) point out, a stable system may not fluctuate significantly, but a resilient system may undergo significant fluctuation and return to a new (and, implicitly, an improved) equilibrium rather than the old one.

Several ecologists and ecological economists have linked resilience to the concept of *sustainability*, which refers to long-term survival and at a non-decreasing quality of life. Common (1995) suggests that resilience is the key to this concept. A major feature of sustainability is that it is highly dependent on natural resources, including the environment. Destroying, damaging, or depleting resources undercuts our longer term economic viability, a lesson also applicable to hazard impacts where most analysts have omitted ecological considerations. Klein et al. (2003) note that, from an economic perspective, sustainability is a function of the degree to which key hazard impacts are anticipated. However, I agree with the position that it is also a function of a society's ability to react effectively to a crisis, and with minimal reliance on outside resources (see Mileti, 1999; see also IFRC, 2004).

In the context of longer term disasters, such as climate change, Timmerman (1981) defined resilience as the measure of a system's capacity to absorb and recover from the occurrence of a

hazardous event. In the climate change context, however, most researchers now refer to this as *adaptation* (see, e.g., Pielke, 1998; IPCC, 2007). Dovers and Handmer (1992) note an important feature that distinguishes man from the rest of nature in this context—the human capacity for anticipating and learning (see also Resilience Alliance, 2005). They then bifurcate resilience into reactive and proactive, where the latter is uniquely human. I maintain that proactive efforts can enhance resilience by increasing its capacity prior to a disaster, but that resilience is operative only in the response/recovery/reconstruction (often referred to as post-disaster) stages. Adaptability is not just applicable to long-term events but is a major attribute of resilience to disasters. Moreover, this adaptability requires that we consider a revised equilibrium state in measuring stability and resilience. Most ecological economists view flexibility and adaptability as the essence of resilience (see, e.g., Levin et al., 1998). This makes intuitive sense for natural disasters as well, given their "surprise" nature in terms of infrequency and consequences.

Adger (2000) was one of the first to extend the ecological definition of resilience to human communities as a whole. He measured *social resilience* as related to social capital and in terms of economic factors (e.g., resource dependence), institutions (e.g., property rights), and demographics (e.g., migration). Norris et al. (2008) approached the matter in a similar fashion for community resilience. Mileti and collaborators (Mileti, 1999) analyzed many aspects of resilience to hazards in the attainment of sustainable communities. However, Mileti (1999; p. 5) went too far in defining a resilient community as not only one that "can withstand an extreme event with a tolerable level of losses" but also one that "takes mitigation actions consistent with achieving that level of protection." This comment is no way a criticism of mitigation, which has been found to be cost-effective in countless applications and is still underutilized (see, e.g., Rose et al., 2007a), but rather that mitigation is distinct from resilience for several reasons discussed in the following sub-section.

Timmerman and others also relate resilience to *vulnerability* (see, e.g., Cutter et al., 2003) Some have contended that resilience and vulnerability are opposites, while others see them as interrelated (Manyena, 2006). Specifically, Pelling (2003) decomposes vulnerability to natural hazards into three parts: exposure, resistance, and resilience. As does Blaikie et al. (1994), Pelling defines resilience to natural hazards as the ability of an individual to cope with or adapt to hazard stress. My view is that vulnerability is primarily a pre-disaster condition, but that resilience is the outcome of a post-disaster response. Resilience is one of several ways to reduce vulnerability, the others being adaptation and the entirely separate strategy of mitigation.

Engineering-Based Definitions

Bruneau et al. (2003) provide a comprehensive analysis of the many aspects of earthquake loss reduction all under the heading of resilience. The authors apply the concept at four levels: technical, organizational, social, and economic. They contend that resilience has four dimensions, which are listed below along with a definition applied to the economic level:

1. Robustness—avoidance of direct and indirect economic losses
2. Redundancy—untapped or excess economic capacity (e.g., inventories, suppliers)
3. Resourcefulness—stabilizing measures (e.g., capacity enhancement and demand modification, external assistance, optimizing recovery strategies)
4. Rapidity—optimizing time to return to pre-event functional levels

Bruneau et al. also stipulate that the resilience of a system has three aspects:

1. Reduced probability of failures
2. Reduced consequences from failures
3. Reduced time to recovery

The relationship between the dimensions and aspects of a resilient system differs from the definition of economic resilience presented below in the following ways (cf., Norris et al., 2008):

- Economic resilience excludes the dimension of reduced probabilities of failure because this is more pertinent to measures taken before an event, primarily for the purpose of mitigation.
- Reduced consequences from failure comes the closest to the definition of static economic resilience.
- Reduced time to recovery is the same as dynamic economic resilience, though the state of restoration is more general in my formulation.*
- Robustness is also similar to the definition of static economic resilience and is a commonly used term in engineering to convey this more narrow definition of resilience.
- Redundancy is primarily a supply-side mitigation strategy.
- Resourcefulness is a major feature affecting adaptive resilience.
- Rapidity is consistent with the definition of dynamic economic resilience, though the Bruneau et al. formulation is more restrictive in that it requires the condition of optimization.

This discussion is not intended as a criticism of the excellent analytical framework developed by Bruneau et al. (2003) per se. Rather, it is a criticism of their choice of terminology, which includes all aspects of hazard loss reduction under the banner of resilience. The exposition by Klein et al. (2003) is consistent with my argument to keep the definition of resilience from becoming too broad. They propose the concept of "adaptive capacity" as the umbrella concept that covers many of the features identified by Bruneau et al. This is also more consistent with defining resilience as an outcome or system attribute rather than as a tactic like mitigation.† Adaptation is also the complement to mitigation. When negative forces (e.g.,

* Bruneau et al. (2003) include "restoration of the system to its 'normal' level of performance" in their definition. This definition subsumes whether a system can "snap back" at all, that is, the concept of *stability* as typically used in dynamics. It would be preferred to use the term *desired state* as a generalization of possible responses, which would include return to pre-disaster status as a special case, but would at the same time allow for growth and change over time and implementation of mitigation practices, as well as considering obstacles to achieving the desired state.

† In a similar vein, Chang and Shinozuka (2004; p. 741) state that "It is useful to view robustness and rapidity as the desired *ends* of resilience-enhancing measures. Redundancy and resourcefulness are some of the *means* to these ends." Again, robustness and rapidity correspond to my static and dynamic definitions of resilience, respectively. The major difference between *ends* and *means* is an important reason not to extend the definition of resilience beyond the *ends* theme. Note also that subsequently in their paper, Chang and Shinozuka define robustness in economic terms as the reduction in Gross Regional Product, rather than its deviation from a maximum possible level given the characteristics of the hazard stimulus, thus failing to include a reference point. Rapidity is defined by them, independently, in the same manner as in this paper, however.

conventional hazards, climate change) cannot be or are not mitigated, we typically resort to adaptation.

It would appear that some analysts, such as Mileti and Bruneau et al., have envisioned a goal of a community that is able to take many steps to minimize its vulnerability to hazards. Resilience has become a convenient term to characterize all of these possibilities. However, this broad usage is inconsistent with the etymology of the term in general and its use in ecology, economics, and other areas of research. Ideally, another term can be found to modify this ideal community, so that the term "resilience" can be applied to the sub-set of characteristics to which it is well suited.

Organizational Behavior

Organizational (also institutional) behavior focuses on resilience as a process (Hill and Paton, 2005). As such, it is a strategy in risk management under the sub-heading of crisis and continuity management. Paton and Johnston (2001) define resilience in this dimension as "a capacity of people and systems that facilitate organizational performance to maintain functional relationships in the presence of significant disturbances as a result of a capability to draw upon their resources and competencies to manage the demands, challenges and changes encountered." This viewpoint extends even more fundamentally to natural ecosystems, whereby The Resilience Alliance (2005) includes as one of its three dimensions of resilience "the degree to which the system is capable of reorganization." Adger et al. (2005) extend this to the social-ecological nexus.

Comfort (1994) was one of the first researchers to venture into this area. Her definition is narrower than the generic one that was the focus of the previous sub-section because she confines resilience to actions and processes after the event occurs, or, as noted in the critique of Bruneau et al. (2003) above, appropriately limits the definition to reducing the *consequences* of failure. This also relates to process-oriented counterparts of the concept of dynamic resilience, where the focus is not on attaining a target level of output but rather a target level of "functioning." However, the trajectory of this functioning is clear from the major themes of non-linear and adaptive dynamics (Comfort, 1999). It also leaves no doubt that the dynamic version of resilience, the ability to bounce back (or the rapidity to do so), is uniquely applicable to the post-disaster stages. Moreover, the recovery process this characterizes is another way of reducing the consequences of the hazard ensuing from structural or system damage. Manyena (2006) contends that resilience has evolved from an emphasis on outcomes to an emphasis on process in holistic terms (see also Pfefferbaum et al., 2005).

Klein et al. (2003) have taken this even further to suggest that resilience goes beyond the Holling definition to include the functioning and interaction of interlinked systems (see also UN/ISDR, 2002). However, this still does not go as far as suggesting resilience includes all aspects of adaptation or mitigation.

In contrast to resilience activities emphasized in the economics literature (e.g., import substitution, relocation, market strengthening), the focus of organizational theory is on "competencies and systems" (Hill and Paton, 2005; see also an extension of this theme to the community as a set of networked adaptive capacities). The relationship between the two approaches can be viewed as follows: most standard treatments of resilience in economics identify a set of options and assume that managers can optimize among their choices (see, e.g., Rose and Liao, 2005). Organizational analysis identifies vulnerabilities and limitations in managerial abilities and how they can be overcome through resilience. The economics approach

to reconciling these two views would be to assume some form of "bounded rationality" (see, e.g., Gigerenzer and Selten, 2002) and to view managerial resilience as an improvement over the basic outcome. Hill and Paton (2005) analyze several aspects of the theory and practice of business continuity management and how it relates to resilience. They emphasize that a major prerequisite of success in this area is the willingness of an organization to adapt to its new environment (see also UNISDR, 2005).*

Planning

Sustainable communities and smart growth emanate from the collaborative visions of ecologists, economists, and planners. Thus far, the planners have been most prominent at practical approaches to the broader design, while the two former disciplines have been more niche oriented, including the nexus of ecological economics in reorienting individual business operations to principles of industrial metabolism (see, e.g., Ayres and Simonis, 1989; Daly and Farley, 2004).

The planning profession has as a goal the creation of hazard-resilient communities (Burby et al., 2000; Godschalk, 2004), primarily through the area of land use. This holistic approach is superior to the piecemeal way that ordinary hazard mitigation is usually promulgated, which has actually enticed development in hazardous areas. For example, the presence of dikes and levees in New Orleans gave residents a feeling of false security. Many similar examples have led to the general trend of fewer disaster events, but the ones now taking place have relatively much larger damages. Smart growth has tended to avoid such outcomes. Mileti (1999) has stated that "no single approach to bringing sustainable hazard mitigation into existence shows more promise at this time than increased use of sound and equitable land use management."

Burby et al. (2000) identify four major themes of how to integrate mitigation in land-use planning that can promote community resilience, but only one of them, and only in part, pertains to the post-disaster period. This points to the tension in the planning field about terminology, similar to the discussion in other fields. Godschalk (2003; p. 137) concludes that "Traditional hazard mitigation programs have focused on making physical systems *resistant* to disaster forces" [my emphasis added]. He goes on to state, however, that "future mitigation programs must also focus on teaching the city's social communities and institutions to reduce hazard risk and respond effectively to disasters, because they will be the ones most responsible for building ultimate urban resilience." In fact, Geis (2000) has explicitly stated a preference for the term "disaster-resistance" with respect to planning themes and practices in this area, concluding it is more "fitting and more marketable than disaster resilient." At the same time, other planners have come to apply the term "resilient" to the interaction of physical and social systems (Olshansky and Kartez, 1998).

Godschalk makes the point, however, that "resilient cities are constructed to be strong and flexible, rather than brittle and fragile." It is this flexibility (adaptability) that is the key to resilience as interpreted by others (e.g., Comfort, 1999; Rose, 2007). Foster (1997) interprets this in terms of coping with contingencies. He has put forth 31 principles for achieving resilience, among them in the general systems realm, such characteristics as "being diverse, renewable, functionally redundant, with reserve capacity achieved through duplication, interchangeability,

* Broader dimensions of resilience in terms of the social fabric or community are not discussed here because they are beyond the scope of this paper (see, e.g., Tobin, 1999; Paton and Johnston, 2001). These dimensions focus on aspects of resilience, such as psychology, sociology, and community planning, that are important to a holistic view of the topic of resilience.

and interconnections." Godschalk summarizes the work of several researchers to identify eight categories of resilience responses, seven of which have been emphasized by Rose (2004; 2007) and in this report: redundant, diverse, efficient, autonomous, strong, adaptable, and collaborative. Finally, Godschalk proposes a more enlightened set of mitigation measures for social and institutional resilience through the reduction of business interruption impacts, though the specific policy instruments he mentioned are limited to loans and general government assistance, rather than the self-motivated coping behavior emphasized in this report.

Economic Resilience

Resilience has four roles in the economics literature. Most generally, it is noted as an attribute of the economy in studies of economic shocks. In ecological economics, it is a major focus of analysis as a key attribute necessary for sustainability. Some attempts have been made to extend this research to the socioeconomic arena and have it overlap with the study of institutions. In the disaster literature, it has been an important dimension of hazard economic loss estimation and terrorist consequence analysis.

Many types of economic shocks, such as the Arab Oil Embargo or subsequent price spikes over the decades, business cycles, and changes in the terms of trade, often conclude with a statement that the impacts have been moderated by resilience (see, e.g., Dhawan and Jeske, 2006). Resilience is accepted in the broader economic literature as a vague concept. There is no generalizable explanation of what causes resilience but only case-specific explanations. For example, Dhawan and Jeske (2006) emphasize that oil price shocks no longer have an effect on factor productivity, and this is why there was no recession in 2005. Moreover, in this case, there is no deeper explanation for the absence of a negative impact.

The most in-depth study of resilience in the economics literature is in the area of ecological economics. This research is very advanced conceptually, and much progress is being made empirically (Perrings, 2006). It is typically couched in the form of non-linear, adaptive systems (see, e.g., Perrings, 1998). Resilience relates to the latter characteristic in a Darwinian sense—a species that cannot adapt is unlikely to survive. Major underpinnings of this body of research have been discussed at the outset of this section, so we will confine our attention to those features most relevant to disasters. These include the need to take into account the lack of predictability and the disequilibrium nature of dynamics. Yet another aspect is catastrophe theory, whereby small changes can be magnified to the point of a complete reversal of the time path of the system in a trajectory leading to its demise. This is typically not observed in the case of all but the most dramatic natural disasters to affect humans—perhaps the most recent disaster that comes close was the temporary unraveling of the some major elements of the social fabric in the immediate aftermath of Hurricane Katrina.

Attempts have been made to extend the work in ecological economics to the more general socioeconomic domain, though not everyone agrees that this provides any additional insights (Hanley, 1998). For example, Levin et al. (1998; p. 230) state that "In economic systems, resilience depends on comparable mechanisms: the coupling of stimulus and response and a diversity of resources." They note that this is consistent with North (1990) and others on the importance of key institutions that provide these services, such as the market and government. These institutions are often very helpful in disaster situations but may lead to disasters themselves (e.g., in the current financial meltdown and Hurricane Katrina, respectively). Other extensions of the basic ecological economics paradigm have been more direct, as exemplified by

the work of Reggiani et al. (2002) that focuses on the dynamics of technological innovation and adaptive behavior of firms and markets.

In the disaster literature, resilience has been inserted as a new factor in the risk equation:

Risk = f(Threat, Vulnerability, Consequences, Resilience)

It has been emphasized for more than a decade with progress on its definition with the work of Tierney (1997), Bruneau et al. (2003), Chang and Shinozuka (2004), and Rose (2004; 2007). In all but the work of Bruneau et al. and Rose, it has not been extended beyond a simple definition and a cursory explanation. In the former, economic resilience is one of four major dimensions of the broader concept of resilience. However, beyond providing a few examples and relating economic resilience to dimensions in related disciplines, the work offers limited insights. Moreover, as noted earlier, it confuses some issues, such as including hazard mitigation as a subset of resilience.

Another insight into resilience in the face of disasters comes from the work of Horwich (1995). Again, resilience is not really defined and almost all of it is ascribed to the workings of the market. Even without a clear definition, however, several authors have contributed to our understanding of how awareness of the concept has helped to improve policy responses (see, e.g., Coaffee, 2006). Of course, a clear definition sharpens the picture considerably in identifying and evaluating actionable resilience options (see, e.g., Rose and Wein, 2009).

3. DEFINING ECONOMIC RESILIENCE

Definitions below represent the synthesis of knowledge on the topic of economic resilience coming from within the profession and other disciplines as well. The definitions do not resolve several conundrums, nor are some aspects of it based on a consensus of major points. However, it is a comprehensive, consistent, and operational framework.

I define *static economic resilience* as the ability of an entity or system to maintain function (e.g., continue producing) when shocked (see also Rose, 2004; 2007). It is thus aligned with the fundamental economic problem—efficient allocation of resources, which is exacerbated in the context of disasters.* This aspect is interpreted as static because it can be attained without repair and reconstruction activities, which affect not only the current level of economic activity but also its future time path. Another key feature of static economic resilience is that it is primarily a demand-side phenomenon involving users of inputs (customers) rather than producers (suppliers). It pertains to ways to use the resources still available as effectively as possible. This is in contrast to supply-side considerations, which typically require the repair or reconstruction of critical inputs.

A more general definition that incorporates dynamic considerations, and can be termed *dynamic economic resilience*, is the speed at which an entity or system recovers from a severe shock to achieve a desired state. This also subsumes the concept of mathematical or system

* Other considerations relating to resource allocation besides efficiency are appreciated by the author, as, for example, the importance of equity, or fairness (see, e.g., Rose and Kverndokk, 1999). However, they are beyond the scope of this paper. To date, equity plays a more prominent role in defining resilience in disciplines like Geography (see, e.g., Adger, 2000) and Sociology (see, e.g., Norris et al., 2008).

stability because it implies the system is able to bounce back. This version of resilience is relatively more complex because it involves a long-term investment problem associated with repair and reconstruction, which are processes uniquely applicable to post-disaster stages.

Ability implies a level of attainment will be achieved. Hence, the definition is contextual--the level of function has to be compared to the level that would have existed had the ability been absent. This means a reference point or type of worst-case outcome must be established first. Further discussion of this oft-neglected point is provided below.

Resilience, as I define it, refers to post-disaster conditions and response, and limits the definition to reducing the *consequences* of failure (Comfort, 1994), as distinguished from pre-disaster activities to reduce potential losses through mitigation (cf., Bruneau et al., 2003). Another way to express the distinction is that economic resilience is stated in flow (rather than stock) terms in relation to economic output for a given period in time. Similarly, in relation to ecosystems, Holling (1973) defines resilience in terms of flow (productivity) measures as opposed to stocks. Resilience of more conventional capital assets (buildings, infrastructure) pertains to the ability of the stock to absorb shocks (e.g., a building to withstand ground motion or the blast from a terrorist bomb) and is best considered in the purview of engineering resilience under the heading of "resistance or robustness."

Static and dynamic resilience relate to the economic concepts of short run and long run. In the short run, at the level of the individual business or organization, some productive inputs are fixed, and in the long run, all inputs are variable. The fixed input would usually be capital—plant and equipment—because a certain amount remains in place, but it takes time to repair or rebuild. Variable inputs are usually labor, natural resources, and intermediate goods (goods used in the production of other goods, such as semi-finished steel), because these can be more readily increased or decreased in a short time. In the *very* short run, all inputs may be held constant because of the difficulty of increasing even labor or material inputs, which is the situation for static resilience when we use existing inputs as best we can. Dynamic resilience changes the availability of all inputs, by increasing productive capacity, and therefore corresponds to the long-run requirement that inputs are variable. In general, the more inputs that are fixed, the fewer the resilience options and the less likely the economy achieves an ultimate level of efficient resource allocation.*

Resilience emanates both from internal motivation and the stimulus of private or public policy decisions (Mileti, 1999). In disaster research, resilience has been emphasized by Tierney (1997) in terms of business coping behavior and community response, by Comfort (1999) in terms of non-linear adaptive response of organizations (broadly defined to include both the public and private sectors), by Petak (2002) in terms of system performance, and by Norris et al. (2008) in terms of communities. These concepts have been extended to practice. Disaster recovery and business continuity industries have sprung up that offer specialized services to help firms during various aspects of disasters, especially power outages (see, e.g., Business Continuity Institute, 2002; Salerno, 2003; Rose et al., 2009a). Key services include the

* In relation to some concepts mentioned earlier, we point out another important feature of the time dimension of disasters. Dovers and Handmer (1992) emphasize a major distinction between natural ecosystems and society–the latter's greater ability to anticipate and learn. These features are keys to adaptive capacity. They are operable not only during the course of a single event but also over multiple and disparate events. For example, the rush of companies in Los Angeles to buy back-up electricity generators after the Northridge Earthquake in 1994, and after the rolling blackouts (caused by poorly designed deregulation) in 2000-01, makes them less vulnerable to the possibility of a terrorist attack on the electric power system.

opportunity to outsource communication and information aspects of the business at an alternative site. There is also a growing realization of the broader context of the economic impacts, especially with the new emphasis on supply chain management (Sheffi, 2005).

At the time of crisis, the ability to absorb losses or speed recovery can already be operational (inherent) or acquired (adaptive). *Inherent* resilience refers to the ordinary ability to deal with crises (e.g., inventories, the ability of individual firms to substitute other inputs for those curtailed by an external shock, or the ability of markets to reallocate resources in response to price signals). These abilities are already in place, can be enhanced prior to disaster, and implemented in the disaster aftermath if not damaged or eroded. For example, the act of emergency response and recovery planning increases the pool of inherent resilience strategies. By definition, the potential for inherent input substitution is constant, since any improvement in it is assigned to the adaptive version.

Adaptive resilience refers to the ability in crisis situations to maintain function on the basis of ingenuity or extra effort (e.g., increasing input substitution possibilities in individual business operations, recontracting or strengthening the market by providing information to match suppliers with customers). Conservation can be increased after the shock through improvements in technology. Adaptive resilience follows from post-disaster learning and pushes the production efficiency frontier outward, though it does not necessarily require any investment.

Most resilience strategies can be both inherent and adaptive, but there are exceptions. For example, inherent water substitution is the use of bottled water for piped water, and adaptive water substitution is the drilling of new water wells. Production recapture (using available capacity to make up lost production via overtime work or extra shifts) is likely to be unwise to enhance in advance; for example, it may not be economically prudent to increase productive capacity to make up lost production if this additional capacity is needed only sporadically. However, planning drills to facilitate re-starting production lines would always be a worthwhile strategy.

4. ECONOMIC RESILIENCE OPTIONS

Examples of Resilience and Applicability to Inputs and Outputs

There are many ways to achieve and enhance economic resilience relative to the use of inputs and the production of outputs at the *microeconomic level* of individual firms, households, or organizations. Economic resilience operates at two other levels of the economy: the *mesoeconomic* refers to economic sector, individual market, or cooperative group, and *macroeconomic* is all individual units and markets combined, including interactive effects. Here, we select and define categories specific to static and dynamic economic resilience.

Static resilience strategies that mute losses at the microeconomic level include the following.

- *Conservation* is maintaining production with fewer inputs.
- *Input substitution* is shifting input combinations to achieve the same function or level of productivity.
- *Inventories* include both emergency stockpiles and ordinary working supplies of production inputs.

- *Excess capacity* refers to idle plant and equipment. A special case is *redundancy* that refers to back-up systems that do not increase productive capacity but rather compensate for damaged capital.
- *Relocation* is changing the site of business activity.
- *Resource unimportance* refers to the portion of business operation that can continue without a critical input.
- *Import substitution* is importing resources from other regions, including new contractual arrangements.
- *Export substitution* refers to selling goods to other regions that cannot be sold otherwise to local customers.
- *Technological change* allows for easier manipulation to restore function, to increase production, change hours of operation, and to respond to altered product demands.
- *Production recapture* refers to working overtime or extra shifts to recoup lost production.
- *Delivery logistics* refers to reducing impediments to the delivery of goods and services.

Dynamic resilience strategies to speed recovery include the following.

- *Removing operating impediments* involves debris removal and related complications, and streamlining paperwork for insurance claims and government assistance.
- *Management effectiveness* refers to skills that promote restoration, repair, and reconstruction.
- *Speeding restoration* refers to a range of options such as alternative means of access to repair sites and incentive contracts.
- *Input substitution, import substitution, inventories,* as above, also speed restoration but pertain to materials and labor needed for repair activities rather than normal production operations.

Each of these resilience strategies may operate on one or more inputs or the output of economic activity. For example, management training involves only labor, but input substitution is more general and can refer to a range of possibilities, such as substituting portable trailers for office space (capital), substituting labor that has been cross-trained (labor), substituting portable power generation for centralized-grid-provided electricity (infrastructure), and substituting coal for gas (materials).

Resilience at the mesoeconomic (sector or market) level includes pricing mechanisms, industry pooling of resources and information, and sector-specific types of infrastructure such as rails. What is often less appreciated by disaster researchers outside economics and closely related disciplines is the inherent resilience of market prices that act as the "invisible hand" to guide resources to their best allocation in the aftermath of a disaster. Some pricing mechanisms have been established expressly to deal with such a situation, as in the case of non-interruptible service premia that enable customers to estimate the value of a continuous supply of electricity and to pay in advance for receiving priority service during an outage (Chao and Wilson, 1987). The price mechanism is a relatively costless way of redirecting goods and services. Those price increases, to the extent that they do not reflect "gouging," serve a useful purpose of reflecting highest value use, even in the broader social setting (see also Schuler, 2005). Moreover, if the allocation does violate principles of equity (fairness), the market allocations can be adjusted by income or material transfers to the needy. Of course, markets are likely to be shocked by a major disaster, in an analogous manner to buildings and humans. In this case, we have two alternatives for some or all of the economy in a manner similar to addressing market failures under normal circumstances of externalities (e.g., pollution), public goods (e.g., highways), and market power (e.g., monopolies: (1) substitute centralized decree or planning, though at a

significantly higher cost of administration, and (2) bolster the market, such as by improving information flows (e.g., the creation of an information clearinghouse to match customers without suppliers to suppliers without customers). Both approaches are forms of resilience.

At the macroeconomic level, there are a large number of interdependencies through both price and quantity interactions that influence resilience. That means resilience in one sector can be greatly affected by activities related to or unrelated to resilience in another. This makes resilience all the more difficult to measure and to influence in the desired manner. This includes situations in which the whole is not simply the sum of the parts. An example is offered by Rose and Benavides (1999), where a system of individually structured non-interruptible service premia may not be socially optimal, because individual businesses make decisions on whether to pay the premium on the basis of their own benefits but ignore benefits to their direct or indirect suppliers and customers. In this context, macroeconomic resilience is not only a function of individual business or household actions but also of all the entities that depend on them or that they depend on directly or indirectly.

There are also several other types of macro-resilience. Macroeconomic structure refers to features such as economic diversity, which reduces vulnerability to overall impacts when some individual sectors are greatly affected. Geographic proximity to other economies makes it easier to import goods and receive aid from neighboring communities. Agglomeration economies refer to advantages of large city size in reducing costs of production that can remain intact and keep the city competitive after a disaster (see, e.g., Chernick, 2005). All of these forms of static resilience have dynamic counterparts as the macroeconomy changes during the reconstruction process.

Characterization of Microeconomic Resilience Strategies

In this section, the focus is on microeconomic resilience strategies for businesses, households, and government. This is the most plentiful and most actionable set of options at the three levels.

Business resilience has two sides. Customer-side resilience copes with the disruption (quantity and timing) of the delivery of inputs and pertains to ways to use resources available as effectively as possible by both businesses and households (i.e., it is primarily associated with static resilience). For example, at a given point in time, meaning with a given fixed capital stock, resilience is completely a demand-side issue in the context of electricity, or any critical input, supply disruption. In contrast, supply-side resilience is concerned with delivering outputs to customers and could include the establishment of system redundancy (a form of static resilience), but usually requires the repair or construction of critical inputs (i.e., dynamic resilience). Repair of the capital stock in particular, or supply-side efforts in general, is the domain of the input provider and is a completely separate matter from customer-side resilience.

Government has both demand-side and supply-side resilience features in a manner similar to business. Of course, government at various levels plays a key role in economic recovery, so this is an added dimension of resilience in this sphere. Improvements in the quality and quantity of emergency services can be thought of as resilience enhancement. Increases in financial or in-kind disaster assistance and the effectiveness of their distribution to the affected parties promote recovery as well. However, the provision of aid can have disincentive effects on resilience, just as it does for mitigation in the "bail-out" sense.

In addition to customer-side resilience, households can be thought to have supply-side resilience considerations with respect to providing their own services (e.g., cooking to prepare

meal) or providing labor. However, household activities are not counted in national income accounts and are difficult to value, so supply-side resilience is less meaningful for households, and I have not included a separate table for it.

Resilience options for business, households, and government are summarized in Tables 1–4. For businesses and government these strategies are specified on both the customer side and the supplier side. Each table lists a major category of resilience and provides examples. Each specifies a prior action that can be taken to enhance each type of resilience. Each table also specifies the extent to which the resilience category is inherent and adaptive. A capital letter "X" indicates cases where this type of resilience is strong, while a lowercase letter indicates cases where it is relatively weak. In addition, the applicability of the type of resilience to factors of production is specified in terms of the letters (K), labor (L), infrastructure (I), materials (M), as well as for the output (Q) that they produce. Again, capital letters associated with each of these inputs or outputs represent a strong application, while lowercase letters represent a weak one. Finally, obstacles to the implementation of each type of resilience are listed.

For example, Table 1 presents resilience strategies for businesses on the customer side. The first category is conservation, and examples include automated controls to monitor the flow of inputs (e.g., water) to help make sure they are used only in times when they are needed and the reduction of non-essential uses. Prior action can be taken to promote resilience by closing systems to promote recycling, such as in the re-use of circulating water. Conservation is only minimally inherent because economists typically assume that most inherent conservation options are currently being maximized. Thus, most conservation options pertain to adaptive applications. All inputs--capital, labor, infrastructure services, and materials-- can be conserved. The major obstacle is necessity of the input into the production process. Similar explanations are provided for other resilience options for the case of business customers.

An analogous table is provided for resilience strategies on the business supplier side (see Table 2). This includes a different set of resilience categories in several cases. For example, delivery logistics refers to the fact that suppliers must get their products to customers. Examples include shoring up the network of wholesale and retail trade, contingency contracts with transportation companies, and planning exercises. The rubric for prior action is "broadening the supply chain." These actions are strong at both the inherent and adaptive levels. As with most cases of supply-side resilience, they are applicable primarily to output. The major obstacle in implementing supplier-side resilience is the condition of the transportation network.

Many of the same resilience strategies that are associated with businesses and government are applicable to households. However, we only consider household strategies on the customer side. Households do "produce" goods and services for their own use, such as prepared food and entertainment. However, these are informal production processes and are more closely identified with standard household actions, as opposed to more formal activities of businesses.

The inputs into economic activity noted in Table 1 serve as the independent variables for a formal production function in which the influence of several types of resilience can be linked directly to them or to the production function parameters. For example, Rose and Liao (2005) and Rose and Oladosu (2008) have shown how conservation is linked to the productivity term and input and import substitution to the elasticities of substitution.

TABLE 1. RESILIENCE OPTIONS: BUSINESS (CUSTOMER SIDE)

Category	Prior Action	Inherent[a]	Adaptive[a]	Applicability[a]	Obstacles
Conservation • automated controls • reduce non-essential	close system to promote recycling	x	X	K, L, I, M	necessity
Input Substitution • back-up generators • cross-training	enhance flexibility of system	X	X	K, L, I, M	specialization
Import Substitution • mutual aid agreements • re-routing of goods	broaden supply chain	X	X	k, L, i, M	transportation
Inventories (Stockpiles) • fuel supplies • labor pool	enhance; protect	X	x	k, L, i, M	storage capacity
Excess Capacity • system redundancy • factor-in risk	build and maintain	X	X	K	dilapidation
Input Unimportance • decrease dependence • segment production	reduce dependence on critical inputs	X	X	K, l, I, M	integrated process
Relocation • back-up data centers • physical move	arrange for facilities in advance	x	X	K, L, I, M	coordination
Production recapture • information clearinghouse • restarting procedures	arrange long-term agreements	X	X	Q	capacity
Technological Change • change processes • alter product characteristics	increase flexibility	X	X	K, L, I, M, Q	lack of ingenuity
Management • emergency procedures • succession/continuity	train; increase versatility	X	X	L	pressure

[a] Lowercase letter indicates relatively minor role.

TABLE 2. RESILIENCE OPTIONS: BUSINESS (SUPPLIER SIDE)

Category	Prior Action	Inherent[a]	Adaptive[a]	Applicability[a]	Obstacles
Delivery Logistics • shore-up network of wholesale/retail trade • contingency contracts w/transport companies	broaden supply chain	X	X	Q	transportation
Export Substitution • expand markets • re-routing	enhance flexibility	X	X	Q	transportation
Inventories (Stockpiles) • strengthen storage facilities • pooling of resources	enhance; protect	X	x	Q	storage capacity
Excess Capacity • system redundancy • factor-in risk	build and maintain	X	X	K	dilapidation
Relocation • move closer to customers • field operations	arrange for facilities in advance	x	X	K, L, I, M	coordination
Production recapture • in relation to customer needs • practice restarting	arrange long-term agreements	X	X	Q	capacity
Technological Change • change processes • alter product characteristics	increase flexibility	X	X	K, L, I, M, Q	ingenuity
Management • project demand change • prioritize goods & services	increase versatility	X	X	Q	
Reduce Operating Impediments • assist family workers • streamline paperwork	recovery planning	X	X	K, L, I, M	cognition

[a] Lowercase letter indicates minor role.

TABLE 3. RESILIENCE STRATEGIES: HOUSEHOLDS

Category	Prior Action	Inherent[a]	Adaptive[a]	Applicability[a]	Obstacles
Conservation • pool resources • reduce non-essential	change tastes	x	X	I,M	necessity
Input Substitution • back-up generators • blankets/flashlights/radio	enhance flexibility; change tastes	X	X	I,M	specialization
Import Substitution • cross-regional shopping • e-shopping	broaden markets	X	X	k, L, i, M	transportation
Inventories • fuel supplies • food	enhance; protect	X	x	k, L, i, M	storage capacity
Excess Capacity • redundancy (in place) • factor-in risk	build and maintain	X	x	K	dilapidation
Input Unimportance • decrease dependence • segment chores	assess and reduce dependence	x	X	K, l, I, M	integrated process
Relocation • physical move • off-site communication	improve social network	x	X	K, L, I, M	coordination
Production Recapture • rescheduling activities • emergency exercise drills		x	x	Q	capacity
Technological Change • factor-in risk • change patterns	increase flexibility	x	x	K, L, I, M, Q	ingenuity
Management • emergency procedures • organization	designate leader	X	X	L	pressure

[a] Lowercase letter indicates minor role.

TABLE 4. RESILIENCE STRATEGIES: GOVERNMENT

Category	Prior Action	Inherent[a]	Adaptive[a]	Applicability[a]	Obstacles
Conservation • automated controls • reduce non-essential uses	closed system	x	X	K, L, I, M	necessity
Input Substitution • back-up generators • cross-training	enhance flexibility of system	X	X	K, L, I, M	specialization
Import Substitution • outside aid (gov't/private) • use imports	mutual aid agreements	X	X	k, L, i, M	transportation
Inventories (Stockpiles) • fuel supplies; groundwater • reserve labor pool/volunteers	Enhance; protect	X	x	k, l, i, M	storage capacity
Excess Capacity • system redundancy • factor-in risk	build and maintain	X	X	K	dilapidation
Input Unimportance • decrease interdependence • segment operations	assess and reduce dependence	x	X	K, l, I, M	integrated process
Relocation • back-up data centers • physical move	establish joint bases of operation	x	X	K, L, I, M	coordination
Production Recapture • info clearinghouse • emergency exercise drills	arrange long-term agreements	X	X	Q	capacity
Technological Change • change processes • alter character of service	increase flexibility	X	X	K, L, I, M, Q	ingenuity
Management • emergency management • restoration priorities	increase versatility	X	X	L	pressure
Reduce Operating Impediments • assist family emergency preparedness • streamline paperwork	recovery planning	X	X	K, L, I, M	cognition

[a] Lowercase letter indicates minor role.

5. QUANTIFICATION OF ECONOMIC RESILIENCE

In this section, I provide admittedly crude mathematical definitions of resilience in both static and dynamic contexts. Direct static economic resilience (*DSER*) refers to the level of the individual firm or industry (micro and meso levels) and corresponds to what economists refer to as "partial equilibrium" analysis, or the operation of a business or household entity itself. Total static economic resilience (*TSER*) refers to the economy as a whole (macro level) and would ideally correspond to what is referred to as "general equilibrium" analysis, which includes all of the price and quantity interactions in the economy (Rose, 2004). In terms of actual measurement of the "indirect" portion of resilience, input-output (I-O) models of disaster impacts capture only quantity interdependence, often referred to as multiplier effects. Computable general equilibrium (CGE) models and macroeconometric models capture both price and quantity interaction through the explicit inclusion of market forces (see Rose, 2005).

An operational measure of *DSER* is the extent to which the estimated direct output reduction deviates from the likely maximum potential reduction given an external shock, such as the curtailment of some or all of a critical input:

$$DSER = \frac{\%\Delta DY^{m} - \%\Delta DY}{\%\Delta DY^{m}} \quad , \tag{1}$$

where

$\%\Delta DY^{m}$ is the maximum percent change in direct output and
$\%\Delta DY$ is the actual percent change in direct output.

In essence *DSER* is the percentage avoidance of the maximum economic disruption that a particular shock could bring about. A major measurement issue is what should be used as the maximum potential disruption. For ordinary disasters, a good starting point is a linear, or proportional, relationship between an input supply shortage and the direct disruption to the firm or industry. Note that while a linear reference point may appear to be arbitrary or a default choice, it does have an underlying rationale. A linear relationship connotes rigidity, the opposite of the "flexibility" connotation of static resilience defined in this paper. Aspects of non-linearities in the context of an extreme disaster, or a catastrophe, are discussed below.*

Analogously, the measure of *total economic resilience (TSER)* to input supply disruptions is the difference between a linear set of indirect effects, which implicitly omits resilience, and a non-linear outcome, which incorporates the possibility of resilience. The former would be consistent with the context of an I-O model, which is inherently linear and which implicitly omits the possibility of resilience. From an operational modeling standpoint, *TSER* is the difference between the linear I-O multiplier and comprehensive, non-linear model (e.g., CGE or econometric) impacts as follows:

*Note that the static definition presented here [based on Rose (2004b)] is couched in deterministic terms. Though their definition of resilience [an off-shoot of the definition by Bruneau et al. (2003)] differs from the one presented here, Chang and Shinozuka (2004) make a major contribution by providing a framework and illustrative example for evaluating economic resilience in probabilistic terms and in relation to performance objectives.

$$TSER = \frac{\%\Delta TY^m - \%\Delta TY}{\%\Delta TY^m} = \frac{M \times \%\Delta DY^m - \%\Delta TY}{M \times \%\Delta DY^m} \quad , \tag{2}$$

where

M is the economy-wide input-output multiplier,
$\%\Delta TY^m$ is the maximum percent change in total output, and
$\%\Delta TY$ is the actual percent change in total output.

My definitions of economic resilience have been stated in flow terms in relation to economic output for a given period in time. Is resilience applicable to stocks, that is, property damage, as well? While property is important, the flow of goods and services it contributes to economic well-being is paramount. In relation to ecosystems, Holling (1973) defines resilience in terms of flow (productivity) measures as opposed to stocks. Resilience of more conventional capital assets (buildings, infrastructure) would pertain to the ability of the stock to absorb shocks (e.g., a building to withstand ground motion or the blast from a terrorist bomb). This would best be considered under the purview of engineering resilience. A more complex system, however, raises other issues. For example, an electricity system might be said to be less likely to fail if it has incorporated redundancy of power lines, or better communication between operators to avoid cascading failures (see, e.g., Lave et al., 2007). Again, this might be considered engineering resilience or perhaps economic resilience on the supply side (as opposed to the demand-side resilience that is the focus here).*

Also, while the entire time path of resilience is key to the concept for many analysts, it is important to remember that this time path is composed of a *sequence of individual steps*. Even if "dynamics" are the focal point, it is important to understand the underlying process at each stage, that is, why an activity level is achieved and why that level differs from one time period to another. As presented here, static resilience helps explain the first aspect, and changes in static resilience, along with repair and reconstruction of the capital stock, help explain the second. See the following section for more details of the time path of dynamic resilience.

6. TIMING OF ECONOMIC RESILIENCE

A further challenge to incorporating economic resilience into loss estimations and choosing ways to promote it is the temporal variation of the feasibility and effectiveness of resilience strategies. For example, import substitution is highly vulnerable to damage to the transportation systems, such that the option may not be immediately available in widespread disasters. Also, available inventories will be depleted after a period of time. Thus, over time, static resilience may first be enhanced by adaptation but then weaken, and thus the effectiveness of a feasible static strategy may therefore erode with time. The dynamic process of repair and reconstruction restores productive capacity and can enhance static resilience over time. It can also erode it if it limits the flexibility of business operations, for example.

*Note that Manyena (2006) and others suggest that resilience is best conceived as a process, which makes it pro-active, and that defining it in terms of outcomes is a step backward into the reactive.

The Time Path and Dynamic Economic Resilience

Thus, dynamic and static resilience create a time path composed of a sequence of steps that is illustrated in Fig. 1 (see also Rose, 2007). Several considerations discussed thus far are illustrated in this figure, which represents resilience in the wake of a total power outage caused by a natural or man-made hazard. In it, the vertical axis represents the level of economic activity, Y, and the horizontal axis represents time, t. The normal level of output (abstracting from considerations of economic growth for ease of exposition and without loss of generality) proceeds at Y_N until some external shock takes place. The result of this disruption in the presence of static resilience is a reduction in output to Y_D, as opposed to a total shutdown of the economy to Y_0.

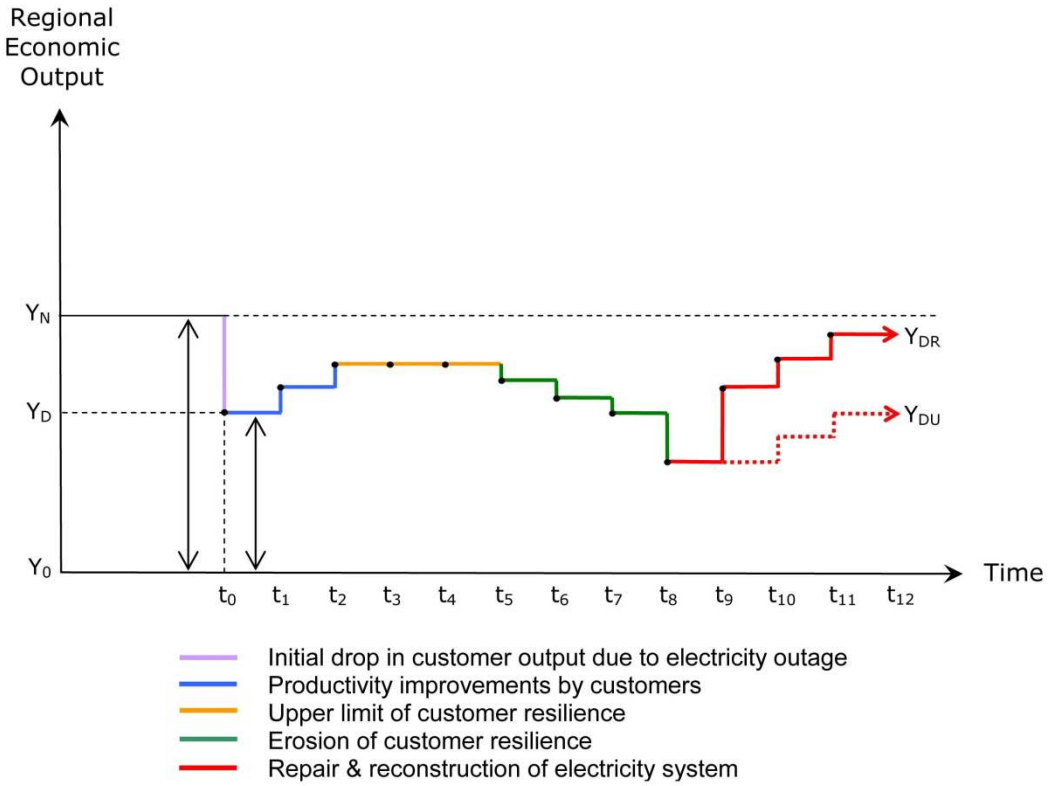

Fig. 1. Static and dynamic resilience in the context of business interruption.

In relation to the basic definition presented in the previous section, static resilience is the ratio of the avoided drop in output and the maximum potential drop to Y_0, or

$$(Y_D - Y_0)/(Y_N - Y_0) \ ,$$

or the ratio of line segments A and B (A/B). In the initial period, adaptive behavior (ingenuity) is likely to be minimal, and the measure is likely to be dominated by inherent resilience.

Total static resilience in Fig. 1 is related to the "loss area" between Y_N and Y_D. (This is typically depicted as the "loss triangle" in hazard loss estimation because the standard analysis assumes recovery is monotonically increasing.) Total static economic resilience is the complement of the loss area divided by the maximum potential loss area up to a given point in

time, and in the absence of any repair or reconstruction. For the first nine time periods, it is the area under the recovery path divided by the area of the rectangle $(Y_N - Y_0)(t_9 - t_0)$. This percentage provides a relative measure that can be compared across disasters and aspects of the economy at micro, meso, and macro levels.

Figure 1 also provides some important insights into dynamics of the issue. In the literature on resilience, dynamics often refers to the issue of stability or to the speed of recovery. A related question is the pattern of recovery—how much recovery takes place in each time period and why. The case of individual business recovery, as distinct from the repair and rebuilding of the capital stock, provides us with considerable insight. In this regard, suppose the disruption of the electricity network is due to the destruction of a major transformer that requires several time periods (t_i) to replace. The upward movement in output following the initial decline due to the disaster, Y_D, would represent basic improvements in static resilience through adaptive behavior in t_1 and t_2. A temporary equilibrium is reached at t_2 and persists until t_5, when deterioration in static resilience might start to take place (e.g., inability to sustain Draconian conservation, depletion of inventories, permanent loss of customers that reduces the possibility of production rescheduling, and even dissipation of inherent resilience such as substitution possibilities). The next upswing in Y_D then does not take place until t_9, and then as a combination of repair/replacement of the transformer (and its phasing in of operation) *and* of remaining static resilience capabilities.*

Dynamic resilience would then be defined as the loss-reducing effect of hastening repair and reconstruction of the capital stock, time path Y_{DR} over and above business as usual practices, time path Y_{DU}. It is best defined in terms of its total effect:

$$TDER = \sum_{t=0}^{n} Y_{DR} - \sum_{t=0}^{m} Y_{DU} \quad , \quad \text{where } m > n \text{ signifies less time to recovery} \quad . \tag{3}$$

This measure has two components. First is the overall reduction in the "loss area," that is, the area between Y_N and the path of Y_D. The second would be reduction from the difference between the resilient response path, Y_{DR}, and the "normal" course of the recovery, Y_{DU} (note that Y_{DR} and Y_{DU} overlap until t_9). Thus, this definition would include static resilience and the loss reducing effects of hastening repair and reconstruction. A purist, however, would probably argue that it should only include the latter feature:

*Haimes et al. (2005a) combined engineering and economic considerations in a useful disaster impact and policy framework—the Inoperability Input-Output Model. "Inoperability" notes the system's *dysfunction*, "expressed as a percentage of the system's 'as planned' level of operation" (p. 68). They define resilience in dynamic terms in two contexts: (1) for sector damage by a terrorist attack, it is the recovery rate, and (2) for a sector affected by an ensuing (interdependent) demand reduction, it is the production adjustment rate. An important contribution is their dynamic model, which explicitly includes capital stock variables critical to the ultimate recovery process. Although they acknowledge the pace of recovery is variable, they offer no additional insights into variations in resilience, beyond equipment-related considerations pertaining to the electric power sector or electrical equipment (see Haimes et al., 2005b). In fact, they emphasize how "hardening" and other risk mitigation efforts increase resilience during recovery (Haimes, 2005a; p. 74) and otherwise neglect post-disaster considerations. Ironically, they overlook the obvious definition of static resilience as the complement of their inoperability definition.

$$TDER' = \sum_{t=0}^{n} Y_{DR} - \sum_{t=0}^{m} Y_{DU} - TSER \quad . \tag{4}$$

For the sake of consistency, one would want to exclude the repair and reconstruction aspects from the static definition. This would mean using only the Y_{DU} time path as the point of reference.

The definitions of resilience are sufficiently general to allow for an important extreme outcome. Note that in Fig. 1 the level of economic output increases beginning at t_9 but tapers off beginning at t_{11} to a level below the pre-disaster level (Y_N). This reflects the possibility that a lengthy recovery will cause customers of disrupted businesses to look to other suppliers, possibly on a permanent basis (see also the discussion in Section 8).

Another dimension of economic resilience is the existence of both demand-side and supple-side considerations. The discussion in this paper focuses on the demand side or customer side for a good reason. From Fig. 1, we see that customer resilience alone is responsible for the increase in output from t_0 to t_2. Recovery of the capital stock, or supply-side efforts, is the domain of the electricity provider and is a completely separate matter not beginning until t_9. At a given point in time, meaning with a given fixed capital stock, resilience is completely a demand-side issue in the context of an electricity, or any critical input, supply disruption. If the physical plant of the business is damaged as well, as would more likely be the case in an earthquake as opposed to a targeted terrorist attack on an electric utility, the situation becomes more complicated but can be addressed by evaluating the components of static resilience and dynamic resilience of the customer separately, as well as taking into account any interactive effects.

The reader unfamiliar with the literature on resilience in ecological economics may view the above definition as simplistic, because it is not placed in the context of a non-linear, adaptive, dynamic system (see, e.g., Levin et al., 1998). However, it does capture the essence of many of the key economic principles relevant to disasters. The reader is referred to the work of Reggiani et al. (2002) for a sophisticated analysis of the dynamics of resilience applied to general shocks to the economy. In terms of this approach in hazards research, there are few examples [Comfort (1999) on resilience in organizations is a notable exception].

Time Stages of Resilience Strategies

We generalize Fig. 1 with a narrative of a time line of static resilience strategies after a shock/disruption in terms of microeconomic and macroeconomic analysis. In Table 5, we summarize some resilience actions that can help reduce business interruption (BI) in relation to time phasing. We align these strategies within a broader context of recovery that is economic, physical (infrastructure, building), social, and ecological.

Immediate stage (<72 hours). Here the motivation is to maintain the supply of critical goods and services in order to keep the economy running. This would entail limiting any spread of property damage, as in protection against ancillary fires or hazardous material releases.

Options are limited here, such as simply doing without or using fewer or more expensive inputs to produce levels of output than previously (i.e., *conservation* and input *substitution*). Price increases will reflect the relative scarcity of inputs. Adaptive conservation applies to finding ways that were previously not thought possible or reasonable. Operating or emergency *inventories* can be used at this stage to compensate for the shortfall of critical goods. Also,

Table 5. STATIC RESILIENCE APPLICATIONS TO SOCIAL, ECOLOGIC, PHYSICAL, AND ECONOMIC RECOVERY BY TIME PERIOD

Stage	Emergency Response	Health & Safety	Utilities	Buildings	Environmental/ Ecological	Economic	Economic Resilience
Baselines & Relevant Trends	*Planning & Equipment*				*Quantity & Quality/ Vulnerability*	*Baseline Growth/Assets/ Vulnerability*	*Inherent/ Adaptive*
Immediate (< 72 hours)	Tactical emergency response	Deal with casualties/ reuniting families	Use emergency back-up systems	Remove debris	Limit further ecological damage	Maintain supply of critical goods & services; respond to price increases	Conservation/ inventory utilization
Emergency (3–7 days)	Strategic emergency response	Provide mass care	Begin service restoration	Provide shelter for homeless	Remove debris	Prioritize use of resources	Input substitution
Very short run (7–30 days)	Selective response	Fight infectious outbreaks	Continue restoration		Protect sensitive ecosystems	Shore up or override markets	Temporary relocation
Short run (1–6 months)	Assist in recovery		Complete service restoration	Provide temporary housing and business sites	Deal with ensuing problems	Cope with small business strain	Import substitution
Medium run (6 months–1 year)	Reassess for future emergencies	Deal with post-traumatic stress	Reassess for future emergencies		Initiate remediation	Cope with large business strain	Production recaptured
Long run (>1 year)	n.a.	Reassess for future emergencies	Mitigation	Rebuild & mitigation	Mitigation	Cope with business failures/ mitigation	Permanent relocation

inventories will run out over time. Analogously, some conservation is not sustainable; for example, employers may be willing to work with no air-conditioning for a short period but not indefinitely. Essentially, this is the very short run with all inputs being used in fixed proportions, except for any conservation, which reduces the proportion for a given input (e.g., water). Relocation is applicable here as well, for example, geographically distributed back-up data centers.

There will be temporary changes in the demand for goods, including will be reduced demand for some products (e.g., power), increased demand for others (e.g., cash), while the characteristics of some products will change (e.g., lending limits). Product flexibility is a form of individual market (meso) resilience.

Emergency stage (3–7 days). This involves prioritizing use of resources. This could entail searching for additional stocks of critical materials or removing impediments from the production of businesses that produce them. It may take some time to line up substitute inputs or to modify equipment to use the substitute (e.g., dual-fired steam boilers for generating electricity). This can be characterized as the very short run, but with substitution. Other examples are telework, shifting hours of operation, using cross-trained employees who are put on higher priority tasks, and reallocating skilled labor to accessible work sites.

Very short run (7–30 days). One approach during this next time period is to shore up markets that are in disarray. For example, customers without suppliers could be matched with suppliers without customers within the region. One might also override markets in rationing critical inputs. From a resilience standpoint, this might involve some limited mobility within the region as in shifting to a temporary relocation that might enable a firm to keep operating.

Short run (1–6 months). Here efforts would need to be taken to cope with strain on small business. These entities are less able to deal with a crisis than large enterprises, which have greater amounts of capital and which may have branch plants on which to rely. From a resilience standpoint, several of the previous resilience options are still likely to be in play, except perhaps inventories and some levels of conservation. An option at this stage would be import substitution, though it may take longer to implement than other resilience options because it requires that the transportation system be at some reasonable level of function.

Medium run (6 months to 1 year). At this level, it might be necessary to ease the strain on large businesses that were severely damaged or who were cut off from help from headquarters or branch plants elsewhere. A major source of resilience, production recapture, is likely to take place by this time. This might involve working extra shifts or weekends. Previous studies have found this to be one of the potentially most effective means of reducing business interruption losses. Ironically, the potential to recapture production decreases over time, as firms reach their productive capacity limits or lose market share permanently.

Long run (> than 1 year). At this point all but the most severe earthquakes are likely to have run their course in terms of business interruption and various adjustments. It will be necessary to cope with business failures and reassess whether the economy would be able to resume its pre-earthquake level of activity, let alone a projected upward growth trend. In addition, some businesses will thrive and take advantage of new opportunities. Here the best resilience response may in fact be relocation. Other resilient actions in the long run are technological change, or institutionalizing changes in the way the business operates that may have been brought about by reactions to the crisis. In fact, many analysts point out that disasters sometimes inspire future efficiencies, in addition to inspiring increased mitigation potential and enhanced resilience.

In addition to the longitudinal perspective of economic resilience, Table 5 exposes interdependencies of recovery functions over time. Lifeline (communication, power, water, and gas) recovery, a special case of business recovery, is essential to health and safety and economic activity. Worker productivity is affected by their health and safety. In the early days, employees cannot maintain focus without the assurance of their family's health and safety.

Other impact categories have a time line of their own. For example, emergency response often is more tactical than strategic in the initial aftermath of an earthquake, focusing on a narrower set of needs before scoping the situation allows a strategic response. The same can be said for health and safety. In the ecological/environmental realm, the immediate response stage can limit further damage by plugging leaks from oil pipelines, halting intrusion of pollutants into reservoirs, etc. More active protective measures may take several days to implement. Utility and building restoration, repair, and reconstruction come under the umbrella of dynamic resilience.

For most of the dimensions presented in Table 5, there is a need eventually to reassess the situation and prepare for future emergencies or to integrate mitigation into the recovery and reconstruction process. For mitigation, the earlier it can be integrated, the less expensive it is likely to be. However, some time will be needed to adequately assess the situation to determine whether resources are better spent on direct recovery of the past event than on dealing with future events.

7. MEASURING RESILIENCE

To date, most of the efforts to formally measure economic resilience in the face of disasters pertain to business interruption associated with utility lifeline disruptions. Admittedly, the examples refer only to an isolated type of shock to an economy, but they provide some important insights into the effectiveness of resilience. The first major attempt to measure resilience is that of Tierney (1997), who collected responses to a survey questionnaire from more than 1000 firms following the Northridge Earthquake. Note that maximum electricity service disruption following this event was 8.3 percent, and that nearly all electricity service was restored within 24 hours. Tierney's survey results indicated that direct output losses attributable to the electricity outage amounted to only 1.9 percent of a single day's output in Los Angeles County as interpreted by Rose and Lim (2002) from the Tierney data, meaning that the direct economic resilience is (8.3 – 1.9)/8.3 = 77.1%. Kajitani and Tatano (2007) also found indications of high levels of resilience in their survey work of Japan.

A study by Rose and Lim (2002) of the aftermath of the Northridge Earthquake used a simple simulation model of three resilience options to estimate direct static resilience of 95% and used an I-O model to estimate market resilience at 79.3%. Although this study did not include the full range of resilience strategies suggested by the Tierney study, it is also likely that in the Tierney study the effects of production recapture would be under-reported because not all businesses connect activities undertaken long after the event with the effects of the case of the power outage and 89.8% for the water outage. Market resilience was found to be almost as high. Resilience to these *targeted* attacks is likely to be relatively higher than that for natural hazards. The former are focused on a key aspect of a community's infrastructure in the absence of any other devastation. On the other hand, for natural disasters and more widespread terrorist attacks (e.g., a "dirty bomb"), other aspects of a regional economy are affected. This will reduce

the ability to substitute inputs, bring in additional imports, rely on an effectively working market, etc.

Rose et al. (2007a; 2007b) also evaluated the relative effectiveness of various resilience responses to water and power outages. Production recapture was estimated to be by far the most effective option, and this result generalizes to other contexts. On the other hand, the relatively high effectiveness of "alternative sources" of electricity (e.g., back-up generators and solar panels) is more site specific. Many businesses and even a good number of households purchased portable electricity generators in the aftermath of the Northridge Earthquake, and solar power is a cheap alternative source of supply in an area like Los Angeles. The relatively low effectiveness results for water storage and alternative sources of water are region specific—there is little storage in Los Angeles, no major rivers to tap, and groundwater extraction is severely limited by law. The conclusion from the Rose et al. study is that most types of resilience reduce potential losses by only a few percentage points each. The major exception is production recapture, which ranges from 30–99% in terms of potential loss reduction capability, depending on the sector [see FEMA (2004); Rose and Lim (2002)].

A recent study by Rose et al. (2009b) examined resilience in the aftermath of the September 11 attacks on the World Trace Center (WTC). Impressively, more than 95% of the directly affected firms and government agencies survived, essentially by relocating and almost entirely within the New York City metropolitan area. Adjusting for delays and transition time, the researchers estimated that direct business interruption losses were about 72% lower than they would have been had all WTC area tenants gone out of business; that is, direct static resilience was nearly 72%.

Most of the simulation studies performed on this subject come closer to measuring potential resilience rather than actual. For one thing, they fail to take into account factors beyond the disruption of utility services. A terrorist attack targeted at the electricity system will likely leave factories and shops unscathed, but an earthquake will not, thereby making it less than automatic to reschedule production. Also, the existence of coping measures does not mean they will be optimally used given the likelihood of the situation of bounded rationality and market failures. At the same time, all analysts on the subject may have underestimated human ingenuity. Overall, however, the estimates of resilience presented above are likely biased toward the high side.

8. ENHANCING AND ERODING RESILIENCE

Enhancing Resilience

While much resilience is inherent in the economic system and in the human spirit, and therefore a "natural" occurrence, resilience can be enhanced by deliberate action [see also Bockarjova (2007)]. For example Manyena (2006) points out that all societies have a basic survival level of resilience and that "the goal of any 'disaster resilience' programme will be to enhance the fundamental values, assets and resources that can be applied to the process of adapting to adverse circumstances" (p. 439).

The best but not the only time to do so would be before the disaster strikes. Note that I am not contradicting my earlier position that resilience applies to the post-disaster context, because this is the time period when it is actually implemented. Examples of resilience enhancement include the obvious increase in inventories, improving substitution possibilities for key inputs,

and broadening the supply chain. Most of these apply to inherent resilience. Allenby and Fink (2005) have pointed out the many changes in business practices and broader systems changes that improve disaster resilience secondarily.

More subtle forms of enhancement would affect adaptive resilience, such as making production processes more flexible in general and holding emergency planning drills that focus on business management and logistic decisions.* At other levels, these would include the establishment of information clearinghouses that can improve this decision-making, as well as compensate for information that that the market might be unable to provide during a crisis. The continued development and experience of the business continuity industry would overlap with both inherent and adaptive enhancement. Of course, government at various levels plays a key role in economic recovery, so resilience can be key here as well. Improvements in the quality and quantity of emergency services can be thought of as resilience enhancement. Increases in financial or in-kind disaster assistance and the effectiveness of their distribution to the affected parties promote recovery as well. However, the provision of aid can have disincentive effects on resilience, just as it does for mitigation in the "bail-out" sense.

The most profound approach to enhancing resilience was recently put forth by Flynn (2008). It extends further the emphasis I have suggested for several years that all of us can contribute to resilience by our actions as customers of goods and services in short supply and that of Norris et al. (2008) and others who have emphasized the participatory feature of community resilience. Flynn describes the empowering nature of resilience on individual citizens and the cohesion it provides to a nation. He emphasizes this role especially in the face of terrorism, where he notes the following: "The terrorists choose battlegrounds that are likely to be occupied by civilians, not soldiers" (Flynn, 2008; p. 2). He notes the importance of resilience as a weapon against the spread of fear, one of the terrorists' greatest objectives. Fear has major economic consequences. For example, a recent study by Rose et al. (2009b) found that nearly 85%of the $109 billion reduction in U.S. GDP following the September 11, 2001, terrorist attacks was due to a decline in airline travel and related tourism (even after adjusting for the downturn in both of these activities due to the pre-9/11 recession). Quelling such fears through resilience can significantly reduce losses. Flynn also takes the position that resilience can best be promoted by providing information on threats rather than suppressing it. He suggests that this would represent a less patronizing approach to the role of the citizenry by governments. Resilience is intertwined with the ability "to reawaken the spirit of community and volunteerism." Flynn also points out that many simple and inexpensive measures, such as the purchase of emergency kits, can go a long way to promoting resilience.

In some of the discussion above, there is a trade-off between resilience enhancement during pre-disaster and post-disaster time periods. Post-disaster initiatives have a cost advantage because they involve targeting of resources when they are actually needed rather than probabilistically anticipated. One needs to include the dual use or co-benefit of both mitigation and resilience that applies to activities unrelated to disasters in this calculation [see Allenby and

*In relation to some concepts mentioned earlier, we point out another important feature of the time dimension of disasters. Dovers and Handmer (1992) emphasize a major distinction between natural ecosystems and society—the latter's greater ability to anticipate and learn. These features are key to adaptive capacity. They are operable not only during the course of a single event but also over multiple and disparate events. For example, the rush of companies in Los Angeles to buy back-up electricity generators after the Northridge Earthquake in 1994, and after the rolling blackouts (caused by poorly designed deregulation) in 2000-01, makes them less vulnerable to the possibility of a terrorist attack on the electric power system.

Fink (2005)]. Two other trade-offs are even more important. The first is one between static and dynamic aspects of resilience. Improved resource allocation in a static sense may increase economic production but may get in the way of repair and reconstruction (and visa versa). This proper balance could be best determined by a dynamic optimization model.

This optimization process dovetails with the trade-off between resilience and mitigation. The funds for resilience enhancement could also go toward mitigating the disaster in the first place. Again, post-disaster resilience enhancement has the edge. In general, resilience (pre- or post-disaster) includes many low-cost and even cost-saving options. At the same time, mitigation has a relative advantage if society requires an initial target level of safety, that is, if saving lives is the priority or if there is a maximum level of economic disruption that can be tolerated, even if the economy is capable of bouncing back from breeching it.

The final set of trade-offs pertains to the extent to which resilience and mitigation may undercut each other. In a case study of hypothetical major earthquake, Rose and Liao (2005) found that economic resilience decreased slightly when mitigation was increased. This was explained as mitigation narrowing the set of resilience options, but this phenomenon can stand much closer scrutiny. Many examples of a resilience undercutting mitigation apply to post-disaster decisions and trade-offs. In a rush to improve static and dynamic resource allocation, opportunities for improving mitigation of future disasters may be compromised. Thus, the ideal economic model would be one of dynamic optimization over an extended time period that included a time sequence of potential disasters.

Finally, initiatives to enhance resilience are only one side of the coin. In the following section, we raise the issue that resilience can be eroded by ordinary and extreme conditions. Thus, preventing this deterioration is of a similar nature to resilience enhancement.

Eroding Resilience

Additional insight into resilience can be gained by more closely examining the context in which it operates and how changes in this context affect the concept. By context, we refer to internal and external conditions affecting a phenomenon. The former includes characteristics of businesses, such as size, age, inherent flexibility of production process, skills of management and workers, and location. Pertinent characteristics at other levels would be a business's connection to the supply chain, competitiveness of its market, etc. The external context refers to the frequency, magnitude, and duration of the external shock, interdependence of the market system, and inflow of external funds (both insurance and aid).

Here we examine how resilience changes in relation to two of the external factors: duration and severity of the disaster. More specifically, we examine the time trend and the effectiveness of different resilience responses and how effectiveness at a given point in time and over a period of time differs between an ordinary disaster and a catastrophe.*

Table 6 summarizes a set of individual business resilience actions in relation to a water service disruption for the sake of illustration. Column 1 lists the type of action, while column 2

*Note two considerations. First, duration and magnitude are not independent. Larger magnitude events are likely to have longer durations (duration here is defined from an economic standpoint as not simply being the period of ground shaking or flood waters but rather the subsequent period during which the business, market, or economy as a whole has not recovered). Second, we offer no specific definition of the threshold at which a disaster becomes a catastrophe. We simply point to clear-cut examples that we have in mind, such as Hurricane Katrina, Indian Ocean Tsunami, and World Trade Center attacks.

provides a concrete example. Column 3 lists the current effectiveness based on a study by Rose et al. (2007b),* which concludes that most types of resilience reduce potential losses by only a few percentage points each. The major exception is production rescheduling, which ranges from 30–99% in terms of potential loss reduction capability, depending on the sector [see FEMA (2004); Rose and Lim (2002)]. "Resource importance" refers to the proportion of business operation that can continue without water. ATC (1991) estimates that this ranges from 0–85%, depending on the sector.

The effectiveness of the various options over time is presented in column 4. By definition, inherent substitution is constant, since any improvement in it is assigned to the adaptive version, which increases with learning, as well as with availability of substitutes. The situation for import substitution is analogous. Adaptive responses, on the other hand, are likely to increase with learning and managerial and market efforts, such as re-contracting. Inventory (e.g., stored water in small containers or large tanks) is the most limited option for most businesses because it is a fixed amount that is not readily continued (replenished) over time; in fact, it is characterized by depletion. Resource importance is likely to be rather constant except if technological change takes place. Ironically, the most potent resilience option, production rescheduling, decreases over time, as firms reach their productive capacity limits or lose market share permanently.

Column 5 provides a summary of potential effects in the context of ordinary disasters. Inherent capabilities are limited by definition, though it is possible to enhance them before ("capacity building"). This is also the case for inventories by increasing storage capacity. Conservation and resource importance can be increased after the shock through improvements in technology. Production rescheduling is likely to defy improvement; for example, it is not worthwhile to increase productive capacity to make up lost production if this additional capacity is needed only sporadically.

Catastrophes can have major effects on resilience. Their sheer magnitude and associated duration are likely to challenge not only individual businesses but the economy as a whole (e.g., multiple failures in the provision of infrastructure). They may also reduce decision-making capability by reducing information flows or creating stress and trauma.

Several of these factors directly or indirectly affect resilience options. In the case of inherent substitution, a catastrophe, because it is relatively more widespread, is likely to reduce the availability of substitutes. This is also likely to be the case for adaptive substitution. Both inherent and adaptive import substitution are highly vulnerable to damage to the transportation system. Adaptive conservation is weakened by property damage. Resource inventories are also likely to be weakened by damage to structures and containers. Resource importance is unlikely to be affected in any other than a random way. Production rescheduling is also weakened by property damage, as well as by decreased availability of needed inputs and cancellation of customer orders (loss of market share).

Overall, the brief analysis here indicates that catastrophes are likely to lower resilience significantly. This will stem from a combination of damage to physical aspects of the business enterprise, as well as damage to the remainder of the economy on which it is dependent. Catastrophes will also weaken decision-making ability.

*See also Rose et al. (2007a) for a counterpart assessment of electricity service disruptions.

TABLE 6. EVALUATION OF INDIVIDUAL BUSINESS RESILIENCE ACTIONS

Action	Example	Ordinary Effectiveness	Effectiveness Time Trend	Potential Effectiveness	Effectiveness in Catastrophe
Inherent Resource Substitution	Bottled water for piped water	Minor	Constant[a]	Limited by cost	Lowered because substitutes less available
Adaptive Resource Substitution	Drilling new water wells	Minor to moderate[b]	Increases w/ learning	Increases w/ planning	Lowered by limited substitution options
Inherent Import Substitution	Importing bottled water	Minor	Constant[a]	Limited by cost	Lowered if transport network damaged
Adaptive Import Substitution	Importing trucked water	Moderate	Increases w/ re-contracting	Increases w/ planning	Lowered if transport network damaged
Adaptive Conservation	Using less water by recycling	Minor to moderate[b]	Increases w/ learning[c]	Increases w/ technology	Weakened by property damage
Resource Inventories	Using stored water	Minor	Decreasing	Limited by capacity	Weakened by property damage
Resource Importance	Portion of operation not requiring water	Moderate to large[b]	Constant	Increases w/ technology	Unlikely to be affected
Production Rescheduling	Making up lost production afterward	Moderate to immense[b]	Decreases w/ length of disruption	Improvements unlikely	Weakened by property damage[d]

[a]Increases are associated with the adaptive version of this action.
[b]Depends significantly on sector.
[c]Draconian measures are likely to be sustainable for only short periods, however.
[d]Also weakened by decreased availability of other inputs and cancellation of customer orders.

One other consideration that is critical in the context of catastrophes is the baseline from which we measure resilience. Earlier, I used a linear damage function as this reference point, but it is likely there are complexities and interactions that make damages exponential in the context of catastrophes (i.e., an *X*% loss of a critical input will yield a loss of output larger than *X*%). At the extreme there are irreversibilities or "flips" that can lead to a state of decay in an ecosystem [see, e.g., Perrings (2001)], which are applicable to human catastrophes as well. These various factors make resilience all the more important, while at the same time posing an even greater challenge to its effectiveness. Note, however, that a total absence of static resilience would result in only a linear reduction in economic activity. The damage states exceeding the linear outcome would appear to be related to aspects of dynamic resilience in reverse—decay versus rebuilding.

9. THE COST OF RESILIENCE

Many resilience tactics are low cost and some are even cost saving. Conservation often more than pays for itself, the exception being the few instances where, for example, energy-saving equipment must be purchased and where these costs cannot be recouped from the savings. However, the case of adaptive conservation in a crisis is likely to be a more straightforward example of doing more with less.* Other tactics are relatively inexpensive. Input substitution imposes a slight cost penalty; as in most cases the substitute was not the cheapest alternative in the first place. For import substitution, the penalty may simply be additional transportation costs. Production rescheduling only requires overtime pay for workers. Relocation costs may only involve moving costs or additional travel cost for workers; also some of the costs may be offset by lower rents in the new location as in the case of the relocation after the September 11 attacks [see Rose et al. (2009b)]. The market mechanism itself, to the extent it is not damaged, is a relatively costless contributor to resilience by signaling changes in scarcity.

Many of these options are much cheaper than mitigation measures, which generally require widespread interdiction or "hardening" of many and massive targets (e.g., electric power plants, steel mills, major bridges). Moreover, a major cost advantage that resilience offers over mitigation stems from the fact that resilience is implemented after the event is known to occur, thereby allowing for fine-tuning to the type of threat and character of a particular event, rather than being a "one-size-fits-all" approach. The major cost advantage of resilience, however, comes from the fact that it need not be implemented until the event has actually occurred. Thus the risk factor need not involve the multiplication of the benefit term by the probability of occurrence, which reduces the potential benefits in the case of mitigation for major events in the range of 10^{-2} to 10^{-3} (Rose et al., 2007c).†

One way to lower the cost of resilience, as well mitigation, is to make it multipurpose, so it applies to a broad range of hazard threats. Emergency planning drills are amenable to this, as are inventory-buildup and back-up information technology systems.

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*Note that the monetary cost may be negative on net, but that there may be a personal welfare cost in terms of inconvenience or distress. A prime example would be factories or home owners turning off their air conditioner/heating systems to conserve energy. Cost evaluations usually only include out-of-pocket expenditures, but a more complete "welfare" analysis should factor in the non-monetary cost.

†Inventories need to be built up ahead of time, but they are not actually used until after the event. Here the cost is only the opportunity cost (interest payment on the set-aside for the stockpile rather than the value of the inventory itself).

Costs have another important dimension in the analysis of economic resilience. Our metrics have focused entirely on the benefit side of resilience—avoided losses. However, two resilience options may yield the same percentage reduction in losses but may differ significantly in terms of their implementation cost or any negative (or positive) externalities (Ehlen et al., 2009). The favored resilience option would then be the lower cost one, all other things being equal. This applies to both static and dynamic resilience. In the latter case, it involves a complicating factor known as "demand surge." This refers to the fact that post-disaster recovery and reconstruction greatly increase the demand for construction and building materials, and therefore raise their prices. This is exacerbated by any damage to construction equipment and factories producing necessary inputs. This combination of factors greatly raises the cost of reconstruction undertaken soon after the event. There exists a trade-off between rebuilding now and reducing BI vs. incurring greater BI by waiting but saving on reconstruction costs [see, e.g., Rose and Liao (2009)].

Yet another dynamic aspect of resilience bears mention. This is the fact that costs may decrease over time due to experience and learning. To maintain the distinction in the definition of resilience above, I suggest that we refer to the influence of learning as a change in static resilience when it pertains to cheaper ways to maintain function and refer to it as another aspect of dynamic resilience when it pertains to speeding recovery.

Many economists are inclined to suggest that market forces are the most effective mechanism to ascertain the least cost action for both mitigation and resilience [see, e.g., Horwich (1995) and Boettke et al. (2007)]. However, many market failure considerations have been identified in the case of mitigation, stemming from public goods characteristics of infrastructure or perception problems (Mileti, 1999); this also holds for related strategies such as insurance (Kunreuther et al., 1980). This aspect of resilience has hardly been studied. We can, however, glean some insight from the general literature. Typically, private businesses can be counted on to identify their optimal inventory holdings or back up equipment. Competitive pressures will cause them to conserve resources in a crisis and to substitute or relocate as appropriate. Where economies of scale or scope exist we note the emergence of the business continuity industry (Rose et al., 2009a). Still, market failures do exist in the area of resilience. Some are caused by the crisis situation itself, which does not always lend itself to rational decisions. Other problems may stem from the breakdown of institutions, especially markets. Still others may stem from the divergence of private and socially optimal behavior. A good example is the case of the non-interruptible service contracts noted in Section 2.

The final cost to consider is the concept of *opportunity cost*. This refers to the amount of one pursuit that has to be given up to obtain one more unit of another. In effect, this is a determinant of value that underlies exchanges for dollars, but it provides even greater insight when dollar exchanges are not present. In effect, it is the underlying idea for the "guns vs. butter" or "economic growth vs. the environment" trade-offs. Here we note the trade-off between attention to resilience in a given period after disaster and all future periods, in other words, the trade-off between static and dynamic resilience. This manifests itself if we chose to expand resources in promoting resilience that apply only to reducing BI losses in a given period vs. expending resources that reduce BI losses in the future--essentially the investment problem. Advanced tools are required to address this trade-off, as in the current research by Vugrin et al. (2009) that applies optimal control theory to the analysis of resilience.

10. RECAPITULATION

"Resilience" has become a popular term that is often used carelessly without regard to its precise meaning. It is going through a phase much like the terms "dynamic" in the 1950s and "sustainability" in the 1990s, in which it has become a vague buzzword that undercuts its substance. In all of these cases, there is some consensus about the core meaning, but a precise definition is needed to capture its essence and to establish some boundaries. Only then will we have a sound basis for actually measuring resilience and applying this metric to benchmark improvements in the way we cope with disasters.

Consider the following definitions which have gained a great deal of recent attention:

> The capability of an asset, system, or network to maintain its function or recover from a terrorist attack or any other incident (U.S. Department of Homeland Security, 2006).
>
> The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures (UN ISDR, 2006)
>
> The ability of social units (e.g., organizations, communities) to mitigate risk and contain the effects of disasters, and carry out recovery activities in ways that minimize social disruption while also minimizing the effects of future disasters. *Disaster Resilience* may be characterized by reduced likelihood of damage to and failure of critical infrastructure, systems, and components; reduced injuries, lives lost, damage, and negative economic and social impacts; and reduced time required to restore a specific system or set of systems to normal or pre-disaster levels of functionality (Multidisciplinary Center for Earthquake Engineering Research, 2006).

The NIPP definition is potentially narrower in scope than the MCEER definition, based on Bruneau et al., 2003, though the concept of maintaining function is somewhat vague in the former. It could include maintaining as high a function as possible at the point of the shock (natural or man-made disaster) itself. This ability to continue to function is brought about by mitigation and usually referred to as *robustness*. Alternatively, it could refer only to activities undertaken after the event, and hence would not necessarily include pre-event mitigation. This focus on post-shock adaptation and the emphasis on recovery as both objective and process are more consistent with the origins of the term resilience. The United Nations International Strategy for Disaster Reduction (ISDR) definition, in contrast, departs further from these origins and appears to emphasize pre-disaster mitigation and preparedness, with the only allusion to the idea of rebounding from a disaster relating to the speed of recovery.* The MCEER definition explicitly mentions mitigation and would seem to cover all actions that would reduce disaster risk. Moreover, the definition is extended to even cover recovery actions that not only minimize

*The National Earthquake Hazard Reduction Program (NEHRP) Strategic Plan (NIST, 2008) has adopted the MCEER definition, which places a major emphasis on mitigation, as well as the NIPP definition.

disruption from the current disaster but also reduce losses from future ones as well (a further extension of the emphasis on mitigation—in this case in the post-event context).

No short definition of resilience, however, can do justice to the concept. Some useful dimensions are missing or insufficiently emphasized in all these definitions, especially with regard to *Economic Resilience*. These include the following.

a. The need to distinguish between *stock* (property damage) and *flow* (production of goods and services) dimensions of assets, systems, economies, and communities. Property damage takes place at a given point in time, but the service flows (to which maintaining function applies) are disrupted until recovery is completed, and are thus more central to the idea of rebounding after a disaster.

b. The fact that resilience has *behavioral and policy* dimensions. That is, the length of the recovery following disasters is not some constant that can be known beforehand but an outcome that depends critically on decisions and activities undertaken by private and public sector decision makers.

c. The bifurcation of *temporal* aspects. *Static* resilience refers to the ability of an entity or system to maintain function when shocked. This is related in turn to a fundamental economic problem—how to efficiently allocate the resources remaining after the disaster. It is static because it can be attained by various means, such as conservation, input substitution, relocation, etc., that increase capacity to produce in subsequent time periods. Such efforts can be undertaken both without and independent of any restoration or recovery activities. *Dynamic* resilience refers to the speed at which an entity or system recovers from a shock. This subsumes the concept of mathematical or ecological system stability because it implies the system *is* able to bounce back. This is a relatively more complex problem because it involves a long-term investment associated with repair and reconstruction.

d. The *contextual* dimension. The level of function of the system at any point in time has to be compared to the level that would have existed had the ability been absent. The means a reference point or type of worst case outcome must be established first.

e. The *capability* dimension. *Inherent* resilience refers to the ordinary ability to deal with crises (e.g., use of inventories, response to price signals reflecting greater scarcity). The ability already in place can be enhanced prior to a disaster through appropriate planning strategies, and, if not damaged or eroded, can be implemented in the disaster aftermath. *Adaptive* resilience refers to ability in crisis situations to maintain function on the basis of ingenuity or extra effort (increasing substitution possibilities, imposing conservation measures, mobilizing resources through the formulation and implementation of new policies, strengthening markets).

f. The *market* dimension. All markets function according to supply and demand. The concept of *supply-side* resilience encompasses actions are those undertaken to maintain the function of assets, enterprises, systems, communities and economies. *Demand-side* resilience refers to the actions that customers of these entities undertake to minimize the disruption of services. For purposes of this discussion, "customers" can be either private or public entities. This concept implies an active role for all members of society in achieving a resilient nation (see also Flynn, 2008).

g. The *cost* dimension. Resilience essentially represents a measure of benefits of various actions. However, two actions may result in the same benefits but differ significantly in terms of costs (Vugrin, 2009). Tierney (1997) and Rose and Liao (2005) have identified a broad range of relatively low-cost and even cost-saving resilience actions following disasters.

h. The *process* dimension. Resilience is not just about actions and targets; the manner in which these are achieved is a critical aspect. This has best been emphasized by Norris et al. (2008) in the context of developing and applying a set of adaptive capacities.

i. The *fairness* dimension. Resilience should be applied in an *equitable* manner, such that it is sensitive to the needs of the most disadvantaged groups in society and such that no group is severely disadvantaged by its implementation.*

I have previously emphasized the narrower definition of *economic resilience* as referring to actions implemented after a disaster, though it includes the possibility of enhancing the capability beforehand. There is already an excellent term that applies to actions taken before the event to reduce losses--mitigation. What is lacking is an umbrella term to refer to both the pre- and post-disaster actions. However, it should be emphasized that most of the dimensions listed above are applicable to the concept of resilience whether one favors the narrow or broad definition.

To capture many of the above dimensions I offer the following definition of economic resilience:

> The process by which a *community* develops and *efficiently* implements its *capacity* to *absorb* an initial shock through *mitigation* and to *respond* and *adapt* afterward so as to *maintain function* and *hasten recovery*, as well as to be in a better position to reduce losses from *future disasters.*

In the final analysis, a broad definition of resilience in general, and even economic resilience in particular, may be preferable to capture all of the potential ways to reduce losses from disasters.† My emphasis on the post-disaster stage and reduction of business interruption losses should not be taken as suggesting these considerations are the most important but rather that they have been relatively neglected in comparison to the mitigation of property damage and deaths and injuries.

Therefore, my definition and interpretation of economic resilience is consistent with the Community and Regional Resilience Institute (CARRI) developed by Kates and Wilbanks (2008):

> A resilient community anticipates problems, opportunities, and potentials for surprises; reduces vulnerabilities relative to development paths, social economic conditions, and sensitivities to possible threats; responds effectively, fairly and legitimately in the event of an emergency; and recovers rapidly, better, safer, and fairer.

*Note that the above dimensions apply to more conventional natural disasters and terrorism. We have omitted dimensions of resilience in the literature related to vulnerability and adaptation to long-term climate change [see, e.g., Thomalla et al. (2006) and Heltberg et al. (2009)].

†I was recently involved in the development of a definition for system resilience for the U.S. Department of Homeland Security (2008). This definition is as follows: Given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is the ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels (Vugrin et al., 2009). This definition is somewhat narrower than the final one just presented, but it is consistent with its main themes.

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