Risking House and Home: Disasters, Cities, Public Policy

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Cover: Loma Prieta Earthquake, October 17, 1989. San Francisco, California. Collapsed and burned buildings at Beach and Divisadero streets in the city's Marina District.
Photograph: C. E. Meyer, US Geological Survey

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Macroeconomic Impacts of Catastrophic Events: The Influence of Resilience 6

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A number of recent studies claim that regional and national economies are resilient to disasters. However, very few of these examinations have defined resilience or provided metrics by which to measure it. This paper presents an operational definition of resilience at the levels of the individual firm, market, and macroeconomy It also indicates how various resilient actions (e.g., conservation of critical supplies, use of distributed electricity generation, reliance on price signals to allocate scarce resources) can be modeled. The paper also indicates how resilience varies according to the size and magnitude of an event, and how resilience can be significantly eroded by catastrophes..

I. Introduction

In the past few years, nearly every analysis of the impacts of a catastrophe in the US has highlighted the "resilience" of the economy (see, e.g., Chernick, 2005; FRB, 2005). 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. Mostly, however, the term is either poorly defined or defined so broadly as to be meaningless.[1] Is resilience simply a vacuous buzzword, or is it a concept with substance that can provide insight into the impact and recovery

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[1] For example, none of the authors in Chernick (2005) define resilience, nor is the term even included in the index of that collection of papers. This and several other recent studies appear to be using the term in the vernacular and appear to be unaware of three decades of formal refinement of the term in several different disciplines.

from a disaster? Can resilience be quantified? Perhaps most importantly, is resilience a constant, or can it be enhanced or depleted?

This paper addresses all of these questions. The analysis builds on work by the author and several other researchers in the fields of economics, geography, ecology, natural hazards, engineering, and organizational behavior. I will first discuss the relative strengths and weaknesses of alternative approaches to evaluating the economic impacts of disasters. I will next propose a set of definitions of various aspects of resilience that reconcile diverse perspectives. I will then analyze the definitions and estimated extent of resilience posited in several studies in the aftermath of the September 11 terrorist attack on New York City and of Hurricane Katrina in the New Orleans area. I will also offer an operational measure of resilience and provide estimates of its strength. Finally, I will explore how resilience differs between ordinary disasters and catastrophes.

II. The Standard Methodologies for Evaluating Disaster Impacts

Two branches of economics are typically applied to estimating the regional or national economic impacts of a disaster. The first is macroeconomics, or the study of the workings of the overall economy. This inquiry is often formally approached with the use of comprehensive econometric models of regional or national economies based on extensive time series data. Since their inception, these models have improved from consisting of amorphous aggregates to including basic behavioral considerations and sectoral detail. These models have the capability of forecasting future baseline economic conditions to serve as a reference path for the deviation of an economy due to a disaster. They are consistently estimated and have formal statistical properties.

In comparison to other types of models discussed below, macroeconometric models have stronger capabilities to analyze financial variables, fiscal operations, housing stocks, and real estate markets. Some major drawbacks of macroeconometric models relate to the fact that they are based on time-series data, which means they have a bias toward extrapolating the past, i.e., business-as-usual behavior. Their consistent (simultaneous equation) estimation also makes it more cumbersome to incorporate modified conditions relating to a disaster.

The second relevant branch of economics is called impact analysis. Here, the scope is not as broad nor comprehensive as macroeconomic models, and the emphasis is on a counterfactual experiment (i.e., testing an "if-then" proposition) rather than a forecast. In fact, the prevailing approach, input-output ("I-O") analysis, has been strongly criticized for its oversimplification of the economy. For example, I-O models do not include the explicit workings of markets and prices, and where they do include the latter, the price-quantity interactions are stunted. Such models omit financial variables and lack behavioral content. At the same time, I-O models have extensive sectoral detail, make a comprehensive accounting of all inputs, are able to capture quantity interdependence (through multipliers), are inexpensive to construct, and represent a practical way to model the economy in the context of a larger systems model (see, e.g., Gordon et al., 2005).

More recently, computable general equilibrium (CGE) models have come to supplant I-O models for impact analysis. CGE models are comprehensive and multisector but are nonlinear, mimic the role of markets and prices, and have behavioral content. CGE models to date do not adequately incorporate financial variables, and the standard versions assume the economy is always in equilibrium. In essence, CGE models contain the best features of I-O models and overcome most of their limitations (see, e.g., Rose, 1995), though they have some unique shortcomings of their own.[2] Relative to macroeconometric models, however, in both I-O and CGE, it is easier to change key parameters to include considerations relating to disaster situations.

There are some notable differences between both macroeconometric and impact-analysis models at the national and regional levels, the latter being arguably the more relevant context for the analysis of most disasters. At the regional level, data are less readily available, so it is relatively harder to construct both types, but especially econometric models. At this level, many key variables (e.g., the money supply, interest rates) can be taken as given. Thus, some of the relative advantage of econometric models wane in this context.

Both of these branches of economics were developed for general purposes such as analyzing economic growth or decline, the entrance or exit of new businesses, or the impacts of public policy decisions. In the context of disasters, I-O models were first used to analyze the economic impacts of military attacks in the 1940s (US Strategic Bombing Survey, 1945), and econometric and CGE models were used to analyze the effects of the oil embargo in the 1970s. The first application to natural disasters was the I-O application by Cochrane (1974), followed by

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2 I thank Stuart Gabriel for prompting me to make explicit the various limitations of CGE modeling. Here, I note several limitations, along with efforts others and I have made to rectify them. Adjustments relating more explicitly to resilience (e.g., recalibrating models to reflect emergency situations rather than business-as-usual conditions) are discussed further in Section VI.

a. CGE models are intended for long-run equilibrium analysis. Various types of disequilibria relating to imbalances in labor and capital markets, trade, and the fisc have been incorporated into CGE models (see, e.g., Rose et al., 2007a). Similarly, parameter values (most notably elasticities) can be modified to reflect the very short run (Rose and Liao, 2005).

b. Adjustments to new equilibria are assumed to be costless. Actually, there is some cost penalty associated with substitution, as reflected in substitution elasticities less than infinity.

c. CGE models omit considerations of uncertainty, which makes adjustment more costly. This, however, is true of all basic models.

d. CGE models omit considerations of unpriced goods and services. This is overcome by the formulation of household production functions or treating some public services as marketed goods to calculate their efficiency prices (see Rose and Oladosu, 2005).

more sophisticated I-O applications (see, e.g., Rose et al., 1997; Okuyama et al., 2004; Gordon et al., 2004), CGE analyses (see, e.g., Rose and Liao, 2005), and econometric analyses (see, e.g., Ellson et al., 1984). Recently each has also been applied to the analysis of the impacts of terrorist attacks (Gordon et al., 2005 and Haimes et al., 2005 [I-O]; Rose, 2005 and Rose, Oladosu, and Liao, 2007a [CGE]; and Haughwout, 2005 [econometric]).

Despite applications to these new areas, each of the modeling approaches discussed above has remained relatively standard. Still, differences in underlying conditions warrant some major changes. For example, in contrast to the single-sector focus of opening a new copper mine or closing an automobile plant, the initial stimulus in the case of disasters is typically much more widespread, as it involves extensive destruction of physical as well as human capital. A crisis situation warrants reconsideration of the postulate of rational behavior and of equilibrium outcomes.[3] But perhaps the area in most need of refinement is that of resilience. It is a contention of this chapter that this aspect of disaster impacts cannot be adequately addressed in standard applications of the models at hand.[4] A discussion of modeling advances on this score is presented in Section VI below.

Several researchers have identified major factors influencing economic losses from disasters and have explored how to model them (see, e.g., West and Lenze, 1994; Rose, 2004a). Most of these factors relate to the normal workings of the economy and need not be repeated here. Instead, we take note of three considerations that are often overlooked, all of which have a bearing on resilience.

The first is the importance of flow measures of disaster losses, such as output, income, and employment. For decades, hazard loss-estimates were dominated by attention to stock measures, i.e., property damage. However, it is the flow of goods and service from these assets that contributes to well-being.[5] Moreover, these flows include not only direct losses, but rather "higher order" losses due to multiplier, general equilibrium, or broader macroeconomic effects. The value of a capital asset is the discounted flow of its future earnings, so it may at first appear to be double-counting to include both property damage and business-interruption

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3 My research has attempted to rectify some of these issues by, for example, incorporating disequilibria into a CGE model. The next phase of my research will explore broadening the range of the behavioral responses through the use of bounded rationality.

4 There is some disagreement about whether the random element of natural hazards or terrorist attacks makes a difference in their modeling. It should be emphasized that the models discussed above need not be able to predict where the damage will occur (i.e., they only need to be supplemented by models able to do so). Damage is not as random as one might first imagine, since terrorist attacks are often targeted for maximum damage. Moreover, mitigation actions such as the adoption of building codes and floodplain management reduce the randomness of the impacts of natural hazards. Finally, the models discussed in this section are also currently being used to predict terrorist targets (i.e., those that are likely to result in the greatest direct and indirect economic losses) to help in allocating funds to protect potential targets.

5 Formal "welfare" measures of the impacts, typically approximating consumer-surplus losses, are also related to flow measures.

losses. However, in the case of the destruction of the capital asset it is legitimate to include aspects of both. This is because any loss in net earnings while the capital stock is being repaired or replenished represents a lost opportunity to society as a whole. In addition, many flow losses may not even accompany property damage directly, e.g., broad-based business shutdowns due to electricity-service disruptions caused by terrorist damage to generating stations or transmission lines, when factories themselves are otherwise unscathed.

The second consideration is the limitation of ordinary indicators of either macroeconomic performance or market values. This pertains to the omission of losses of various unpriced services (e.g., environmental, infrastructure, and household services), historical and cultural sites, and the economic value of social and psychological disruption. Broadening macroeconomic indicators through the use of enhanced accounting measures, such as "net economic welfare," or more recently, green accounting, is a conceptual step forward in avoiding the understatement of losses. Recent advances have been made in modeling some other loss aspects, such as highway services (Cho et al., 2002) and the value of household time (Rose and Oladosu, 2005).

Third is the difficulty of isolating impacts of disasters from other ongoing phenomena in the economy. The often dominating effect of national or regional economic cycles is typically acknowledged. Less frequently acknowledged is the influence of public and private decisions during the course of recovery and reconstruction. Since these do not apply to the estimation of property losses, they have thus often been neglected. However, flow losses are highly sensitive to decisions that are able to mute them on a day-to-day basis and limit the period during which they take place (both being aspects of resilience to be discussed in more detail in the following section). Also relevant is the conceptual issue of whether disaster losses should be measured in gross terms, evaluating an economy left to its own devices, or in net terms, subtracting the influence of insurance payments and outside aid. All too often the latter perspective leads to the conclusion that disasters have minimal economic impacts in the directly affected regional economy, disregarding how the geographical transfer of dollars always leaves the nation as a whole worse off.

III. Defining Economic Resilience

I define static economic resilience as the ability or capacity of a system to absorb a shock so as to maintain function (see Rose, 2004b). A more general view incorporating dynamic considerations, including stability, defines economic resilience as the ability of a system to recover from a severe shock and achieve a desired state. I also distinguish two types of resilience:

> Inherent resilience is recovery ability under normal circumstances (e.g., 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).
>
> Adaptive resilience is recovery ability in crisis situations due to ingenuity or extra effort (e.g., increasing input-substitution possibilities in individual business operations, or strengthening the market by providing information to match suppliers with customers).

Resilience emanates both from internal motivation and the stimulus of private or public-policy decisions (Mileti, 1999). Resilience, as defined in this chapter, refers to postdisaster conditions and response (see also Comfort, 1994), which are distinguished from predisaster activities to reduce potential losses through mitigation (cf., Bruneau et al., 2003). In disaster research, resilience has been emphasized most by Tierney (1997) in terms of business coping behavior and community response, by Comfort (1999) in terms of nonlinear adaptive response of organizations (broadly defined to include both the public and private sectors), and by Petak (2002) in terms of system performance. These concepts have been extended to practice. Disaster recovery and business-continuity industries have sprung up, offering specialized services to help firms during various aspects of disasters, especially power outages (see, e.g., Business Continuity Institute, 2002; Salerno, 2003). Key services include the opportunity to outsource communication and information aspects of the business at an alternative site. There is a growing realization of the broader context of the economic impacts, especially with the new emphasis on supply-chain management (Hill and Paton, 2005).

Resilience can take place at three levels:

- Microeconomic—individual behavior of firms, households, or organizations.
- Mesoeconomic—economic sector, individual market, or cooperative group.
- Macroeconomic—all individual units and markets combined, including interactive effects.

Examples of individual resilience are well documented in the literature, as are examples relating to the operation of businesses and organizations. What is often less appreciated by disaster researchers outside economics and closely related disciplines is the inherent resilience of markets. Prices act as the "invisible hand" that can guide resources to their best allocation, even in the aftermath of a disaster. Some pricing mechanisms have been established expressly to deal with such a situation, as in the case of noninterruptible service premia that enable customers to estimate the value of a continuous supply of electricity and pay in advance for receiving priority service during an outage (Chao and Wilson, 1987).

The price mechanism is a relatively costfree way of redirecting goods and services. Price increases, though often viewed as gouging, serve a useful purpose of reflecting highest value use, even in the broader social setting (see also Schuler, 2006). Moreover, if the allocation violates principles of equity and fairness, 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: (1) substitute centralized decree or planning, though at a significantly higher cost of administration; or (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 or unrelated to resilience in another, making it all the more difficult to measure or 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 noninterruptible 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, ignoring benefits to their direct or indirect suppliers and customers.[6]

A related perspective on resilience at the macro level stems from research in the areas of planning and sociology. Here, the pronounced goal has been to create hazard-resilient communities as a key step toward achieving sustainability (see, e.g., Mileti, 1999; Burby et al., 2000). Interestingly, most of the policies suggested relate to hazard mitigation. Godschalk (2003:137) suggests that "Traditional hazard mitigation programs have focused on making physical systems resistant to disaster forces." Geis (2000) has stated a preference for the term "disaster resistant" with respect to planning themes and practices in this area, concluding it is more fitting and marketable than "disaster resilient." However, this perspective neglects the important pre- versus post-disaster distinction of the two terms.

Overall, the goal is to reduce losses from disasters and to weigh tradeoffs between allocating resources to resilience versus resistance. Two of the points to be made below are that resilience options are often relatively inexpensive and have

[6] As in many other fields, some resilience researchers have reinvented the wheel narrowly in their own discipline, rather than looking carefully for precedents or at the big picture. Ecologists have pioneered a useful, broad definition of resilience relating to the survival of complex systems. Holling (1973:17) 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." It would appear that some analysts, such as Mileti (1999) and Bruneau et al. (2003), 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 including mitigation. However, this broad usage is inconsistent with the etymology of the term in general (*resilio*, meaning rebounding), its use in ecology, and its use in other areas of hazards research. Ideally, another term can be found to modify this ideal community, so that the term "resilience" can be applied to the subset of characteristics to which it is well suited.

typically been overlooked. Thus, I conclude that policymaking has been biased in the direction of mitigation, or resistance.[7]

Still another issue is the extent to which market forces will bring about the desired level of resilience. As in the case of mitigation (i.e., resistance), there are likely to be market failures in the case of resilience (in addition to the problem concerning noninterruptible service contracts noted above), which warrant government involvement in market-strengthening, regulating, providing incentives, or providing certain types of resilience directly. Business survival is a strong impetus to adopting resilience, but uncertainty, myopia, and the disincentive effect of government disaster relief are strong reasons for hypothesizing that it will not occur in a socially optimal manner (see also Rose, 2007b).

IV. Review of Economic Resilience Associated with Recent Catastrophes

I now summarize some recent assessments of the macroeconomic impacts of two major catastrophes—terrorist attacks on the World Trade Center and Hurricane Katrina. The focus is primarily on studies that purport to address resilience. Ideally, the analysis of resilience would first include a formal definition, followed by a discussion of ordinary causal factors that bear on the macroeconomic effects and then on the resilience influences that uniquely mute these effects. The problem in most of these studies is not the lack of conformance with the definition of resilience presented in the previous section, but rather the lack of any definition at all. There is a lack of formal analysis of resilience, as well as an absence of testable hypotheses. Several of the studies identify red herrings as sources of resilience or draw erroneous implications.

The first study reviewed is the edited volume, *Resilient City: The Economic Impact of 9/11* (Chernick, 2005). I do not take issue with the overall high quality of the several chapters of this volume, but rather the failings with respect to the book's theme. The impacts of 9/11 on New York City's economy are measured in terms of $50 billion of annual gross city product losses by the fourth quarter of 2004, or less than two percent of the city's total economic activity. The overall assessment is as follows: "There is no question 9/11 was spectacularly successful in disrupting the social and economic fabric of a great city" (op. cit., p. 3). The forward to the volume seems to set the tone, implicitly defining resilience in a

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[7] I thank Chris Redfearn for suggesting that this issue, and a related one in the following paragraph, be addressed in this chapter. Redfearn suggests that the combination of resilience and resistance be termed "robustness." Unfortunately, the term "robustness" already has a more narrow meaning in the hazards-engineering literature, ironically equivalent to the concept of static resilience defined in this paper (see, e.g., Bruneau et al., 2003; Haimes et al., 2005). To avoid overlap in meanings and a proliferation of terms, I suggest that combining resilience and resistance be related to promoting a "sustainable community," until a better term is offered.

nebulous and almost circular fashion: "By and large the book tells a remarkable story of recovery" (op. cit., p. ix). Resilience is then gauged in terms of lack of deterioration of the city's competitive position and the ability to absorb firms forced to relocate from their downtown locations. Other characteristics of resilience are related to the strength and flexibility of the economy. However, not faring as well were the city's labor force and tax base.[8]

The Chernick study further suggests that the major reason for resilience is the presence of agglomeration economies in the city, consistent with studies that have found high density to lead to major productivity increases. The major aspect of agglomeration is related to spillovers of knowledge across industries and occupations. Apparently, a major terrorist attack did not cause a permanent tear in this economic fabric. Similar results were found for cases of external shocks by Glaeser and Shapiro (2002) and Harrigan and Martin (2002) in other contexts. However, agglomeration economies are difficult to measure, and city size and economic diversification may be poor proxies for measuring the resilience aspect.

The first analysis of Hurricane Katrina reviewed is that of Cashell and Labonte (2005 [Congressional Research Service]). The authors begin by stating that: "Hurricane Katrina will have substantial and long-term effects on the economies of Southern Louisiana and Mississippi. But, given that those two states account for just 2% of total US gross domestic product [GDP], the effects on the national economy will be much less dramatic than the effects on the region" (op. cit., p.1). The authors then characterize the shock of Hurricane Andrew and 9/11 as previous examples of overall minor intrusions on the national economic scene. Moreover, their emphasis on impacts is in terms of whether these various events effectively halted economic growth, not just whether they affected its rate. They suggest that storm-relief funds flowing into the region following Katrina will offset some of the losses due to the catastrophe. They curiously state that: "Although damage to the capital stock does not reduce measured GDP, rebuilding increases it" (op. cit., p. 3). The first part of the passage clearly ignores business interruption losses.

This analysis by Cashell and Labonte gives rise to two criticisms relating to the geographic unit of analysis. The first is that the major focus be the economy hardest hit and that regional economies are distinct entities. Evaluating the overall impact of the shock in relation to the national economy marginalizes the region and trivializes the impact. The second point pertains to the misguided implication that regional economies are better off after a disaster because of the inflow of aid and insurance dollars from the outside and the utilization of savings internally. This overlooks lost production in the meantime, the likelihood of higher insurance rates affecting business competitiveness thereafter, and the subsequent need to

[8] Interestingly, while New York City's economy receives a positive characterization as "resilient," two companion volumes, also sponsored by the Russell Sage Foundation, conclude that other dimensions did not perform as well. These include a volume entitled *Wounded City: The Social Impact of 9/11* (Foner, 2005), which indicates that vulnerable neighborhoods and workers were disproportionally adversely affected, and *Contentious City: The Politics of Recovery in New York City* (Mollenkopf, 2005), which characterizes post-recovery politics as byzantine.

replenish withdrawals from savings. It also fails to acknowledge that for the US as a whole, the interregional transfer of funds may be a boon to the regional economy, but the disaster is always a net loss to the nation.

Another analysis of Katrina is by the Joint Economic Committee Democrats (JECD) (2005). It is similar to Cashell and Labonte (2005) in terms of (1) focusing on impacts on the national economy, (2) emphasizing that the recovery will be a boon to the regional economy, and (3) failing to mention resilience explicitly. The JECD study quotes the Congressional Budget Office (CBO) analysis of the impacts of Katrina as being about $100 billion and the negative effect on US growth to be between one-half and one percent in the second half of 2005.[9] Again, as in the previous study, JECD (2005) emphasizes that the affected region is only a small portion of US economy. There is some assessment of impacts on individual sectors, primarily labor and energy. However, there is no discussion of resilience considerations such as inventories, substitution, and conservation in particular, or human ingenuity in general. At the same time, the study emphasizes positive impacts on the economy during recovery and cites two consulting studies as predicting positive effects on projected GDP growth beginning during the first half of 2006 and continuing throughout the remainder of that year.

A good deal of the JECD report is devoted to making a case against large amounts of federal aid to the affected areas. However, there is little mention of resilience, which would have helped make the case that the economy is not as adversely affected as might first be believed. Only a passing reference is made to this concept: "Although the supply of energy from the Gulf region has been reduced, policy actions and market responses have mitigated the effects of that disruption" (JECD, 2005:1). Instead, the analysis emphasizes that "[t]he substantial necessary direct spending on relief and reconstruction should by itself provide considerable short-term stimulus that will cushion the macroeconomic shock from Katrina" (op. cit., p. 2).

The last analysis of Katrina reviewed here is that of the Federal Reserve Bank of Atlanta, in whose jurisdiction New Orleans and the other affected parts of the Gulf Coast hit by Katrina reside. In the fourth quarter issue of its *EconSouth* publication, its president and CEO of the Atlanta Fed offers an editorial entitled, "Witnessing the Resilience of a City and an Economy" (Guynn, 2005). Again there is no definition of resilience here nor in the remainder of that edition of the quarterly, which is almost entirely devoted to Katrina. In this publication, the Atlanta Fed evaluates impacts primarily in terms of the effect on national economic growth, though subsequent sections of the report do consider the broader region and its individual states. The implicit analyses of resilience focuses on those sectors likely to be hardest hit and those that are being positively affected. The only sources of resilience mentioned are from "offsetting" sectors (like gambling) (FRB, 2005:7) and other ports in the region able to take up the slack after the devastation of New Orleans and Biloxi. Interestingly, the rising price of oil is given as a reason for

9 These results are similar to those presented by Cashell and Labonte (2005), as well as those of several brokerage houses and consulting firms.

future increases in investment in this industry, though little mention is made of the impact of higher energy prices on the regional or national economy.[10]

V. Quantifying Resilience

In this section, I provide admittedly crude mathematical definitions of resilience at two levels. Direct economic resilience refers to the level of the individual firm or industry (at the micro and meso levels) and corresponds to "partial equilibrium" analysis concerning the operation of the entity itself. Total economic resilience refers to the economy as a whole and corresponds to "general equilibrium" or macro analysis, which includes all of the price and quantity interactions in the economy. In terms of actual measurement of resilience, I-O models of disaster impacts capture only quantity interdependence, often referred to as indirect or multiplier effects. CGE and macroeconometric models capture both price and quantity interaction through the explicit inclusion of market forces (see Rose, 2005).

An operational measure of direct economic resilience (DER) 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:

$$DER = \frac{\%\Delta DY_m - \%\Delta DY}{\%\Delta DY_m},$$

where $\%\Delta DY_m$ is the maximum percent-change in direct output, and $\%\Delta DY$ is the estimated percent-change in direct output.

The major issue is what indicator 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. This would be consistent with the context of an I-O model, which is inherently linear. The application of a simple version of this type of model implicitly omits the possibility of resilience.[11] Note that while a linear reference point may appear to be arbitrary or a default choice, it does have an underlying rationale, because a linear relationship connotes rigidity, the opposite of the "flexibility"

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[10] Cashell and Labonte (2005) note that the last four recessions were accompanied by sharply rising oil prices. A case could be made that at least two of them were in fact *caused* by these higher prices.

[11] Resilience can be incorporated into I-O models in the manner of Rose et al. (1997) and Rose and Lim (2002). See the analysis below for results of the latter study.

connotation of static resilience defined in this chapter. Aspects of nonlinearities in the context of an extreme disaster, or a catastrophe, are discussed below.[12]

The measure of total economic resilience (TER) to input-supply disruptions is the difference between a linear set of general equilibrium effects, which implicitly omits resilience, and a nonlinear outcome, which incorporates the possibility of resilience. From an operational modeling standpoint, this is the difference between linear I-O multiplier and CGE (or other comprehensive, nonlinear model) impacts, as follows:

$$TER = \frac{\%\Delta TY_m - \%\Delta TY}{\%\Delta TY_m} = \frac{M(\%\Delta DY_m) - \%\Delta TY}{M(\%\Delta DY_m)},$$

where M is the economy-wide input-output multiplier, $\%\Delta TY_m$ is the maximum percent-change in total output, $\%\Delta TY$ is the estimated percent-change in total output, and other terms have the meanings assigned above.

My definitions of economic resilience have been stated in flow terms in relation to economic output at a given period in time. 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 steps. Even if "dynamics" are the focal point, it is important to understand the underlying process at each stage: why a production level is achieved (or why the economy functions at a given level), and why that level differs from one time period to another. As presented here, resilience helps explain the first aspect and changes in resilience, along with repair and reconstruction of the capital stock, help explain the second.

Repair and reconstruction of the capital stock is most often mentioned as the source of economic recovery. However, I define resilience as making the best use of resources in hand, i.e., as a productivity measure. Thus, the flow of goods and services can be increased without an increase in the capital stock. Of course, the flow and stock considerations are interactive as well. Repair and reconstruction will enable further increases in output. At the same time, maintaining function will help avoid losing customers or market share permanently and thus will serve as a significant force justifying rebuilding (see Rose, 2007b).

VI. Measuring Resilience

To date the only efforts to measure economic resilience formally in the face of disasters pertain to business interruption associated with utility lifeline disrup-

[12] Note that the definition presented here (based on Rose, 2004b) is couched in deterministic terms. Though their definition of resilience (an offshoot of that suggested 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.

tions. The initial question posed is: will an x-percent loss of electricity result in that same x-percent direct loss in economic activity for a given firm? The answer is definitely no if economic resilience is present. One of the most obvious resilience options for input-supply interruptions in general is reliance on inventories. Electricity outages have hence been especially problematic, since this product cannot typically be stored. However, the increasing severity of the problem has inspired ingenuity, such as the use of noninterruptible power supplies (capacitors) in computers. Other resilience measures include backup generation, conservation, input substitution, and rescheduling of lost production. In many business enterprises, these measures are adequate to substantially cushion the firm against some losses of a rather short or moderate duration.

Next, the question is extended: will a y-percent loss in direct output yield much larger general equilibrium losses? Here both individual business and market-related adjustments suggest some muting of general equilibrium effects. Adjustments for lost output of goods and services other than electricity include inventories, conservation, input substitution, import substitution and production rescheduling, at the level of the individual firm, and the rationing feature of pricing and "recontracting" among suppliers and customers, at the level of the market.

Table 6.1 summarizes loss estimates from utility service disruptions and the role of resilience.[13] The number of studies is rather sparse because I have included only those studies that used customer lost output as the unit of measure and explicitly or implicitly included indirect (either ordinary multiplier or general equilibrium) effects. 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. A brief summary of the methodologies used in these studies provides some additional insight into the estimates. Primary data collection is typically considered a superior approach to ex post evaluations, though some underlying conceptual framework for data collection is key to analyzing the intricate workings of resilience.

Various ad hoc adjustments have been suggested for incorporating resilience into I-O models with respect to increased reliance on imports (see, e.g., Cochrane, 1997) and for other types of resilience (see Rose and Lim, 2002). This typically involves changing I-O coefficients according to a demand-supply balancing algorithm or use of side equations. For example, production rescheduling can readily be separated from other types of resilience in ordinary disasters and its effects represented as additive to those of other resilience types.

A stronger theoretical foundation is possible in the context of CGE models. My associates and I have utilized nested constant elasticity of substitution production functions to represent the hierarchy of decisions business managers

[13] Nearly all studies of power outages exclude resilience (see, e.g., Caves et al., 1992; Lave et al., 2006), except for those that use a resilience response as a proxy value of service continuity, as in the case of back-up generators (see, e.g., Bental and Ravid, 1986).

Table 6.1. Summary of Loss Estimates from Utility Service Disruptions

(1) Study	(2) Event	(3) Utility: Duration	(4) Method or Model	(5) Loss of Utility Services	(6) Direct Output Loss
Tierney (1995)	Northridge Earthquake	Electricity: 36 hrs	Survey	8.3	1.9[a]
Rose Lim (2002)	Northridge Earthquake	Electricity: 36 hrs	I-O	8.3	0.42[c]
Rose-Guha (2004)	Memphis Earthquake	Electricity: One week	CGE	44.8	—
Rose-Liao (2005)	Portland Earthquake	Water: One week	CGE	50.5	5.7[f, g, h, i]
Rose-Liao (2005)	Portland Earthquake	Water: One week	CGE	31.0	3.5[f, g, h, j]
Rose et al. (2007a)	Los Angeles Terrorism	Electricity: Two Weeks	CGE	100.0	9.4[g]
Rose et al. (2007b)	Los Angeles Terrorism	Water: Two Weeks	CGE	100.0	10.2[g]

[a]Survey response incorporates various undefined direct resilience practices.

[b]Explicitly includes only direct effects, though it is likely that some indirect effects are included.

[c]Resilience adjustments limited to time-of-day use, importance factor, and production rescheduling.

[d]Model not able to incorporate very short-run elasticities; hence, flexibility of response is exaggerated.

[e]Numerator is total-output loss, since direct and indirect-output losses could not be distinguished in this model.

[f]Does not include production rescheduling.

[g]Production rescheduling (recapture) factors from Rose-Lim (2002) were applied to study results.

[h]In addition to production rescheduling, the remaining resilience is attributed to conservation and input substitution for water, though other factors are implicitly present.

[i]Prior to any mitigation.

[j]After mitigation.

Note: All numerical entries are percentages. All events other than Northridge Earthquake are hypothetical.

Table 6.1. cont.

(7) Total Output Loss from Adjusted Direct	(8) Direct Loss/Loss of Utility Services	(9) Individual Business Resilience	(10) Total Loss/ Direct Loss	(11) Market Resilience
1.9[b]	22.9[b]	77.1	—	—
0.6	5.0	95.0	131	79.3
2.3[d]	5.1[e]	94.9	—	—
7.0	11.3	88.7	122	75.6
5.0	11.4	88.6	143	52.2
13.0	9.4	90.6	138	84.8
13.5	10.2	89.8	132	87.2

make in ordinary circumstances and crises (with the possibility of different rationality postulates for each context). Parameters of these production functions are first adjusted to both very short-run and short-run levels and then linked to individual types of resilience, most notably inherent and adaptive input substitution, import substitution, and conservation. Rose and Liao (2005) and Rose, Oladosu, and Liao (2007a, 2007b) illustrate this approach. A cornerstone of the analyses is an optimizing algorithm for utilizing survey and simulation data to recalibrate ordinary CGE parameters for crisis situations, i.e., formally factoring in adaptive resilience associated with key parameters of the model. Other types of resilience such as inventories are incorporated through the relaxation of resource constraints, and market resilience is analyzed by comparison of flexible-pricing results with fixed-price or linear model results.

The first study in Table 6.1 is that of Tierney (1997), who collected responses to a survey questionnaire from more than a thousand firms following the Northridge earthquake. Note that maximum electricity service disruption following this event was 8.3 percent and nearly all electricity service was restored within twenty-four hours. Tierney's survey results indicate that direct-output losses attributable to the electricity outage amount 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.

A study by Rose and Lim (2002) of the aftermath of the Northridge earthquake uses a simple simulation model of three resilience options to estimate adjusted direct-output losses at 0.42 percent, and uses an I-O model to estimate total regional losses of 0.55 percent. Although this study does not include the full range of resilience tactics inherent in the Tierney study, it is likely that the effects of production rescheduling are underreported in that prior study because not all businesses attribute activities undertaken long after the event to the effects of the disaster. This helps explain the relatively higher level of resilience in the analysis by Rose and Lim.

A CGE analysis by Rose and Guha (2004) of the impacts of a hypothetical New Madrid fault earthquake on the Memphis, Tennessee economy indicates that a 44.8 percent loss of utility services would result in only a 2.3 percent loss of regional output. However, this model does not explicitly include many resilience options and is constrained by computational limitations from reducing major parameters, such as elasticities of substitution, to levels that reflected a very short-run crisis situation.

A study by Rose and Liao (2005) for a hypothetical earthquake in Portland, Oregon, based on water rather than electricity utilities, incorporates engineering-simulation estimates of direct-output losses into a CGE model. The first simulation, which represents a business-as-usual scenario, indicates that a 50.5 percent loss of utility services would result in a 33.7 percent direct-output loss, factoring in some resilience measures. Further adjustment for production rescheduling reduces this estimate to 5.7 percent. A second simulation, representing the case of $200 million capital expenditure for replacing cast-iron pipes with modern materials, indicates that a thirty-one percent loss of utility services would result in a 3.5 percent loss of direct output in the region. Direct resilience declines following mitigation (i.e., direct-output losses as a proportion of utility-outage levels increase) because mitigation reduces initial loss of service and hence ironically narrows the range of resilience options that can be brought into play.

More recently, Rose, Oladosu, and Liao (2007a, 2007b) perform simulations for hypothetical terrorist attacks on the power and water systems of Los Angeles. They simulate total supply disruptions for the entirety of Los Angeles County for a two-week period. Their analysis incorporates an extensive set of resilience options and finds direct resilience to be over ninety percent for the case of the power outage and slightly less than ninety percent for the water disruption. Market resilience is found to be almost as high. As noted in the following section, the 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, and related factors.

Individual business, or direct resilience is presented in column 9 of Table 6.1. This measure is simply the complement of the figure in column 8 (i.e., the column-8 figure subtracted from one-hundred percent). The results of the several studies, using several alternative methods, indicate that individual business resilience is quite high and that results of analyses that included this factor would be between 77 percent and 95 percent lower than for analyses that neglected it (e.g., purely linear models).[14]

General equilibrium effects are presented in column 10 of Table 6.1, and they indicate a moderate increase over direct (i.e., partial-equilibrium) effects, ranging from 122 percent to 143 percent. The I-O model of the Rose and Lim (2002) study does not allow for ordinary multiplier effects, because of the assumed adequacy of inventories for goods other than electricity for the thirty-six-hour outage period, and thus consider only "bottleneck effects" (see also Cochrane, 1997). Interestingly, the first simulation by Rose and Liao (2005) yields general-equilibrium effects on the order of twenty-two percent of direct effects, while the second simulation yields a result of forty-three percent for the same proportion. This means that mitigation not only lowers direct business resilience but makes the regional economy as a whole less resilient, thus offsetting some of this strategy's benefits.

While I have stressed the importance of including general-equilibrium effects, it is equally likely that they might be overestimated, especially if a linear model is used. The extent of this problem can better be appreciated by examining market resilience, which is based on factors such as the ability of price changes to guide resource reallocation and changes in interregional trade. It is measured as the percentage deviation between an analysis that takes the workings of the market into account and one that does not. Some aspects of market resilience can, however, be taken into account in a linear model like I-O analysis, as in the work of Cochrane (1997), Rose et al. (1997), and Rose and Lim (2002). In the former case, the solution algorithm allows for market resilience by changing the pattern of imports and exports. In the latter two studies, customers without suppliers will find new suppliers without customers in a type of recontracting arrangement. Indirect effects under both these approaches are thus limited to bottleneck effects, where one sector is so extensively disrupted that it limits the smoothing effects on supply and demand throughout the economy. Otherwise, if the standard I-O formulation is used, multiplier effects (as a proxy for general equilibrium effects) can be quite large. In the studies listed in Table 6.1, the Los Angeles County multiplier is about 2.5 and the Portland metropolitan area multiplier is 1.9. Column 11 represents a measure of market (i.e., net general equilibrium) resilience as a percentage devia-

[14] It should be noted that the various studies listed in Table 1 are not entirely independent. For example, Rose and Liao (2005) used some of the Tierney survey findings on resilience to recalibrate their production function parameters. In addition, the same production rescheduling (recapture) factors used in the Rose and Lim study (2002) are applied in all of the other study results by myself and my research team. It should be kept in mind, however, that these are only a few of several considerations that influence the numerical value of the results. In addition, sensitivity analyses in most of the studies summarized in Table 1 indicate the results are robust.

tion from the purely linear results, based on these multiplier values. However, even with the overestimation resulting from a standard I-O model, direct resilience appears to be the more dominant of the two effects.

Two limitations of our definition of resilience and its measurement should be noted. First, I have used a common denominator of economic output to define resilience. Although I have not done so in my own research, and neither has anyone else, I have indicated how the standard measures of gross output, gross regional product, and value-added can be extended to include the value of unpriced or underpriced goods and services as well. Still, the single measure—while being additive, reasonably comprehensive, and readily measurable—tends to obscure specific elements of an economy, such as its relative competitiveness or equity.

Second, most of the simulation studies performed on this subject come closer to measuring potential resilience 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 (as discussed more extensively below). Also, damage to one utility-service provider may lead to a series of cascading failure in others. Finally, the existence of coping measures does not mean they will be optimally used given the likelihood of the situation of bounded rationality, market failures, and extreme uncertainty. At the same time, most analysts on the subject may have underestimated human ingenuity. Overall, however, the estimates of resilience presented in Table 6.1 are likely biased toward the high side.

VII. Contextual Insights into Resilience

Additional insight into resilience can be gained by examining the context in which it operates and how changes in this context affect the concept. Context refers to internal and external conditions affecting a phenomenon. Internal conditions include 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 include a business's connection to the supply chain and the competitiveness of its market. 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 I examine how resilience changes in relation to two of the external factors: the duration and severity of the disaster. More specifically, I examine the time trend and effectiveness of different resilience responses. Further, I consider how effectiveness at a given point in time, and over a period of time, differs between an ordinary disaster and a catastrophe.[15]

[15] Note two considerations. First, duration and magnitude are not independent. Larger magnitude events are likely to have longer durations. Duration here is defined from

Table 6.2 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 provides a concrete example. Column 3 lists the current effectiveness, based on a study by Rose, Oladosu, and Liao (2007b).[16] The conclusion from this study is that most types of resilience reduce potential losses by only a few percentage points each. The major exception is production rescheduling, which ranges from thirty to ninety-nine percent 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 indicator ranges from zero to eighty-five percent, depending on the sector.

The effectiveness of the various options over time is presented in column 4 of Table 6.2. 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 recontracting. Inventories (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 (or 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 near their productive-capacity limits or lose market share permanently.

Column 5 of Table 6.2 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 the event (via "capacity building"). This is also the case for inventories using increased 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 for 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., after 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, as summarized in column 6 of Table 6.2. In the case of inherent substitution, a catas-

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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, I offer no specific definition of the threshold at which a disaster becomes a catastrophe. I simply point to clear-cut examples I have in mind, such as Hurricane Katrina, the Indian Ocean tsunami, and the World Trade Center attacks.

[16] See also Rose, Oladosu, and Liao (2007a), for a counterpart assessment of electricity service disruptions.

Table 6.2. Evaluation of Individual Business Resilience Actions

(1)	(2)	(3)	(4)	(5)	(6)
Action	Example	Ordinary Effectiveness	Effectiveness Time Trend	Potential Effectiveness	Effectiveness in Catastrophe
Inherent Resource Substitution	Bottled water for piped water	Minor	Constanta	Limited by cost	Lowered because substitutes less available
Adaptive Resource Substitution	Drilling new water wells	Minor to moderate[b]	Increases with learning	Increases with planning	Lowered by limited substitution options
Inherent Import Substitution	Importing bottled water	Minor	Constanta	Limited by cost	Lowered if transport network damaged
Adaptive Import Substitution	Importing trucked water	Moderate	Increases with recontracting	Increases with planning	Lowered if transport network damaged
Adaptive Conservation	Using less water by recycling	Minor to moderate[b]	Increases with learning[c]	Increases with technology	Weakened by property damage

Table 6.2 cont.

(1)	(2)	(3)	(4)	(5)	(6)
Action	Example	Ordinary Effectiveness	Effectiveness Time Trend	Potential Effectiveness	Effectiveness in Catastrophe
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 with technology	Unlikely to be affected
Production Rescheduling	Making up lost production afterward	Moderate to immense[b]	Decreases with 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.

trophe, 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 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 weakened by property damage, as well as by decreased availability of needed inputs and cancellation of customer orders (resulting in 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.[17]

In relation to some concepts mentioned earlier, there is 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 operative 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 backup electricity generators after the Northridge earthquake in 1994, and after the rolling blackouts (caused by poorly designed deregulation) in 2000 and 2001, makes them less vulnerable to the possibility of a terrorist attack on the electric power system.

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 damage exponential (i.e., an x-percent loss of a critical input will yield a loss of output larger than x-percent). At the extreme, there are irreversibilities, or "flips," that can lead to a state of decay in an ecosystem (see, e.g., Perrings, 2001) that are applicable to human catastrophes as well. These various factors make resilience all the more important, while 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.

Data being collected in the aftermath of Hurricane Katrina should prove useful in recalibrating various macro impact models to analyze the disaster and the role that resilience did or did not play in it. Rose, Oladosu, and Liao (2007a,

[17] This analysis has overlooked another dimension that affects resilience but is beyond the scope of this chapter—the level of economic development. Intuitively, it is likely that an industrialized economy is likely to be more resilient than a developing one, since managerial talent, structures, and markets are typically stronger in the former.

2007b) have formally decomposed the results of analyses of hypothetical shocks, through a set of comparative-static computations, in order to ascertain the relative prominence of various resilience adjustments. Application of this methodology to Katrina can yield insight into what worked and what did not in this catastrophic context. The relatively successful resilience options can then be touted as "best practices" and disseminated to business and government. The extent of the adoption of various resilience options can subsequently be evaluated as to its sufficiency, with remedial actions taken if necessary. Examples of such actions include (1) more targeted information campaigns on the advantages of increasing inventories, (2) having offsite backups for communication systems, or (3) price adjustments warding off the temptation to impose price controls, except where equity considerations dominate and cannot be addressed by other means.

VII. Conclusion

In this chapter, I have developed a formal approach toward analyzing economic resilience to extreme events. This has included explaining and illustrating definitions of the concept, offering metrics by which to gauge it, identifying the limitations of recent studies in explicitly addressing it, summarizing other studies that have formally tried to measure it, and discussing ways that resilience might differ between ordinary disasters and catastrophes. This paper has focused on a limited number of the possible dimensions of economic resilience. One purpose is to inspire additional research on more formal analyses of this important topic in broader scope. Without further such work, it will be impossible to accurately assess the potential of resilience in reducing economic losses from disasters.

Resilience has several attractive features. It is an extension of many of the best qualities of the human spirit, an indication of human ingenuity, and a way to hone our survival skills. In many cases, resilience represents a low-cost way to reduce losses from disasters (e.g., conservation, production, rescheduling, and use of market signals). However, major catastrophes may really challenge resilience. Estimates of high levels of resilience for disasters such as the Northridge earthquake or 9/11 may not be applicable to widespread devastation such as that left by Hurricane Katrina. An accurate assessment of the cost and potential of resilience for each context is needed to accurately factor this set of tactics into an overall risk-reduction strategy.

Although the emphasis of most policymakers since 9/11 has been on mitigation, we must realize that we cannot always prevent catastrophes. When they do occur, resilience is a most valuable second line of defense.