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Anne Wein

Adam Z. Rose
*University of Southern California*, adam.rose@usc.edu

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# Economic Resilience Lessons from the ShakeOut Earthquake Scenario

**Anne Wein,[a] and Adam Rose[b], M.EERI**

Following a damaging earthquake, "business interruption" (BI) -- reduced production of goods and services -- begins and continues long after the ground shaking stops. Economic resilience reduces BI losses by making the best use of the resources available at a given point in time (static resilience) or by speeding recovery through repair and reconstruction (dynamic resilience), in contrast to mitigation that prevents damage in the first place. Economic resilience is an important concept to incorporate into economic loss modeling and recovery and contingency planning. Dimensions of a refined economic resilience framework include applicability of resilience strategies to inputs and output, demand and supply side effects, inherent and adaptive abilities, and levels of economies. It provides a means to organize and share strategies that enhance economic resilience; identify overlooked resilience strategies; and present evidence and structure of resilience strategies for economic loss modelers. Numerous resilience strategies are compiled from stakeholder discussions about the ShakeOut Scenario (Jones et al., 2008). Modeled results of ShakeOut BI losses reveal variable effectiveness of resilience strategies across sectors given lengthy disruptions caused by fire-damaged buildings and water service outages. Resilience is a complement to mitigation and may, in fact, have cost and all-hazards advantages.

## INTRODUCTION

The ShakeOut Scenario (Jones et al., 2008) was constructed and exercised to identify the physical, social and economic consequences of a major earthquake in eight southern California

[a] Anne Wein . U.S., Geological Survey, 345 Middlefield Rd, Menlo Park, CA 94025

[b] Adam Rose, University of Southern California, 310 RTH, 3710 McClintock Ave, Los Angeles, CA 90089

counties; Imperial, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura. The scenario analyzed a magnitude 7.8 earthquake on the southern San Andreas Fault. The economic consequences amounted to $213 billion of physical damages due to shaking and fire and business interruption losses (the reduced production of goods and services). The study concludes that the economic loss "is as low as it is because of aggressive retrofitting programs that have increased the seismic resistance of buildings, highways and lifelines in Southern California and it is as high as it is because more retrofitting could be done to reduce this number". However, the reality is that not all economic losses can be mitigated at the outset. Some property damage is always likely to occur. Moreover, losses in the form of "business interruption" -- reduced production of goods and services-- actually begins and continues after the ground shaking stops. There are ways to reduce these negative effects of earthquakes because individuals, institutions, and communities have the ability to deflect, withstand, and rebound from such serious shocks to the economy through the course of their ordinary activities or through ingenuity in the face of a crisis (see, e.g., Rose, 2007). Moreover, this "economic resilience" is often implemented in a relatively costless manner, such as conserving resources in short supply, reallocating resources in response to market signals, recouping lost production at a later date, or speeding up the recovery process. Consistent with the etymology of resilience (*resilio* means rebounding), economic resilience refers to post-disaster conditions and response in contrast to pre-disaster activities that reduce potential losses through structural mitigation (cf., Bruneau et al., 2003). Some forms of economic resilience were modeled in the ShakeOut business interruption analysis to produce plausible estimates of loss (Rose et al, 2010). Throughout the construction of the ShakeOut scenario and emergency management exercises, panels and workshops were held with southern California stakeholders (see below for more details). Participants were prompted for and volunteered loss reduction strategies, By count, most of these suggestions related to resilience (post-disaster) versus mitigation (pre-disaster) strategies. This paper compiles all these economic resilience suggestions within a framework and reports on the effectiveness of the strategies modeled for the ShakeOut scenario BI loss analysis.

Economic resilience pertains to ways for economic activity, post-disaster, to rebound by absorbing losses (static resilience) and speeding recovery (dynamic resilience) (Rose, 2004b; Rose, 2007). S*tatic* economic resilience refers to making the best of the resources available at a

given point in time to maintain function, as distinct from the *dynamic* considerations of repair and reconstruction that affect the time path to recovery.

In practice, economic resilience has been promoted by disaster recovery and business continuity industries that offer specialized services to help firms prepare for various aspects of disasters, especially power outages (see, e.g., Salerno, 2003, Business Continuity Institute, 2002). Key services include the opportunity to outsource communication and information aspects of the business to an alternative site. Recent toolkits (e.g., Disaster Resistant Business, 2009) facilitate in-house disaster planning including identification of business continuity strategies. The growing realization that firms are only as resilient as the firms they rely on (e.g., Corcoran, 2003; p. 28) emerged with the new emphasis on supply-chain management (Hill and Paton, 2005; Sheffi; 2005). Experience with Y2K, 9/11, natural disasters, and technological/regulatory failures, as well as simulated drills, have sharpened utility industry and business resilience (Eckles, 2003). Similar activities of public sector agencies have improved community disaster resilience (Godschalk, 2003).

This paper brings together theory and practice by aligning stakeholder resilience strategies with an economic conceptualization of resilience. Our purpose is two-fold: 1) to develop an economic resilience framework to improve understanding of economic resilience and to share strategies among the southern California community and beyond, and 2) to collect practical economic resilience suggestions to improve economic loss modeling. The motivation for the first purpose follows from witnessing the fruitful exchanges and transmission of resilience ideas among utilities, large and small businesses, hospitals, emergency responders, and local government during the ShakeOut community workshops. The compilation of ideas should be useful to public and private decision-makers forming judgments about the promotion, safeguarding, and implementation of economic resilience. The second purpose corresponds to the critical role of economic resilience in disaster loss assessments and in the evaluation of mitigation benefits including the prevention of damage to avoid business interruption losses. Disaster loss estimation is still less than fully developed, and many economic impact models in current use are too rigid in the economic responses they allow, while others are overly flexible structures (see the review by Rose, 2004a). Also, these models underestimate the effectiveness of

common sense responses by individuals, as well as the professionalization of this strategy through the formation of the new business continuity service industry. Accurate estimates of disaster losses at the level of the individual firm, the market, and the macro economy are critical to the evaluation of risk-management strategies. Under-estimation of losses will result in too few resources applied to the problem, while over-estimation of losses will lead to excess resources being applied. Therefore, the findings are intended to be helpful to academic researchers in several disciplines to understand the nature and role of economic resilience. It should be useful to those involved in economic loss estimation in more accurately assessing the net economic impacts of disasters. It will also be useful to practitioners.

We refine a conceptual framework for economic resilience while populating it with the approximately eighty (sixty unique) resilience strategies gleaned from stakeholders during ShakeOut workshop and panel discussions (logged in Chapters 4 and 7 of Jones et al., 2008) and subsequent ShakeOut community studies and Golden Guardian 08 exercise planning meetings. (Golden Guardian 08 was a regional and State emergency response and recovery exercise based on the ShakeOut scenario.) We begin by categorizing tangible actions that operate on inputs and outputs of economic activity to enhance static and dynamic resilience at the microeconomic level. We identify examples of economic resilience at the meso and macro levels of the economy. We distinguish between inherent and adaptive abilities and demand and supply side effects. The ShakeOut resilience strategies are listed and characterized according to these various dimensions. Next, we report on the effectiveness of production recapture – recouping lost production – as estimated by the ShakeOut economic impact analysis. We conclude with a comparison of the advantages and disadvantages of mitigation and resilience and insights for business interruption loss modelers and practitioners.

## ECONOMIC RESILIENCE STRATEGIES

Economic resilience resides in three levels of the economy: the *microeconomic level* of individual firms, households, or organizations; the *mesoeconomic* level of economic sector, individual market, or cooperative group; and the *macroeconomic* level of all individual units and markets combined, including interactive effects. The ideas of Tierney, 1997; Rose and Lim,

2002, Foster,1997; Godschalk (2003), were incorporated into the static and dynamic economic definitions of Rose (2004a, 2007). In this paper, the strategies are further refined by Stakeholder suggestions to produce a comprehensive list of possibilities. .The dimension of inherent versus adaptive resilience is retained and a new dimension of production input and output applicability is added.

At the microeconomic level, static and dynamic resilience strategies in Table 1 have some commonality, but they are distinguished by their applicability to inputs and outputs for normal production operations (static) versus inputs and outputs for restoration, repair, and reconstruction (dynamic). Each of the resilience strategies may be able to operate on one or more inputs of economic activity including physical (plant and equipment) and working (financing) capital (K), labor (L), infrastructure (I), and materials (M). For example, the resilience strategy of management training to continue operations or manage restoration and repair pertains to labor (only), but input substitution is more generally applicable to K (e.g., substituting portable trailers for office space), L (e.g., substituting labor that has been cross-trained), I (e.g., substituting back-up power generation for electricity), and M (e.g., substituting coal for gas). While production recapture and export substitution apply only to Q (output), inventories can be held for all four types of inputs and output. Business resilience has two sides to it. Demand-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, i.e., static resilience, in general. In contrast, supply-side resilience is concerned with delivering outputs to customers, and could be achieved by establishing system redundancy and inventories, but usually requires the repair or construction of critical inputs (i.e. dynamic resilience).

**Table 1.** Static and dynamic resilience strategies at the microeconomic level involving capital (K), Labor (L), Infrastructure, (I), Materials (M) and Output (Q).

| **Resilience strategy** | **Static resilience** | **Dynamic resilience** |
|---|---|---|
| Conservation of K,L,I,M | Maintain production with fewer inputs (cut nonessential uses) | |
| Production recapture of Q | Arrange to catch up on lost production (e.g., by working overtime or extra shifts) | |
| Relocation of K,L,I,M | Arrange for changing the site of business activity | |

| | | |
|---|---|---|
| Resource unimportance of K,L,I,M | Reduce dependence on critical inputs to increase proportion of business operation that can continue without it | |
| Excess capacity of K | Build and maintain idle facilities and equipment and/or redundancy | |
| Export Substitution of Q | Sell goods to other regions that cannot be sold otherwise to the usual customers | |
| Import substitution of K,L,I,M | Broaden supply chain to import ordinary production inputs from other regions | Arrange to import recovery resources from other regions (e.g., mutual aid) |
| Input substitution of K,L,I,M | Enhance flexibility to shift ordinary input combinations to achieve the same function/productivity | Shift input combinations to achieve more efficient repairs |
| Technologic solutions for K,L,I,M,Q | Increase flexibility to change production in response to altered inputs and/or product demands | Increase flexibility to restore function |
| Inventories of K,L,I,M,Q | Maintain and protect stockpiles of emergency supplies and inputs for and outputs from ordinary production | Maintain and protect stockpiles of repair parts |
| Management effectiveness of L | Train managers to promote more efficient utilization of resources, project demand changes, prioritize the supply of services and goods | Train mangers to manage and prioritize restoration, repair, and reconstruction |
| Accelerate removal of operational impediments of K,L,I,M,Q | Facilitate delivery logistics. e.g., clear debris | Recovery planning and exercising (e.g., streamline disaster paperwork) |
| Speed restoration (Q) | | Adopt a range of options such as alternative means of access to repair sites and incentive contracts |

Resilience at the mesoeconomic (sector or market) level is implemented as *pricing mechanisms, industry pooling of resources and information* and *infrastructure that serves many customers.* 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" 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 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).

At the macroeconomic level, there are a large number of interdependencies through both price and quantity interactions that influence resilience (Rose, 2008). That means resilience in one sector can be greatly affected by activities related to or unrelated to resilience in another. In this context, macroeconomic resilience is not only a function of individual business or household actions but also all the entities that depend on them or that they depend on directly or indirectly. Resilience of macroeconomic structure refers to features such as economic diversity, which reduces the vulnerability of the economy. The resilience of geographic proximity to other economies facilitates importation of goods and aid from neighboring communities for both continuity of operations and restoration and recovery.

At the time of crisis, the ability to absorb losses or speed recovery can already be operational (inherent) or it can be acquired (adaptive). *Inherent* resilience includes 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 they are not damaged or eroded (e.g., when inventories drawn down). The act of emergency response and recovery planning increases the pool of inherent resilience strategies. *Adaptive* resilience refers to the ability 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 and resource unimportance can be increased after the shock through improvements in technology. Most resilience strategies can be inherent and adaptive, but there are exceptions. For example, it is not economically prudent to permanently increase productive capacity to make up lost production if this additional capacity is needed only sporadically, although planning drills to facilitate re-starting production lines is a worth while strategy.

These economic resilience concepts apply to households and government because they are purchasers and providers of goods and services. Microeconomic strategies of emergency inventories and conservation are obvious candidates for households providing labor. Government at various levels plays a key role in economic resilience via improvements in the quality and quantity of emergency services, financial or in-kind disaster assistance (inventory of K), and managing the prioritization of resource use for recovery. However, the provision of aid can have disincentive effects on resilience, just as it does for mitigation in the "bail-out" sense.

## CHARACTERIZATION OF SHAKEOUT STAKEHOLDER RESILIENCE STRATEGIES

During the development of the ShakeOut scenario numerous panels and workshops were held to verify damages and losses and/or identify recovery issues. Meetings were assembled around infrastructure (e.g., water, power, highways, banks) damages, goods movement disruption, implications for regional government, and community recovery (see Jones et al., 2008 and Wein et al., 2010). In the context of each meeting, participants were asked for a couple of loss reduction ideas, but often they voluntarily shared or proposed them throughout discussions. Recorded static and dynamic economic resilience suggestions were extracted (i.e., mitigation suggestions were excluded) and listed and categorized in Tables 2 and 3, respectively. Each record specifies a ShakeOut stakeholder resilience strategy, its applicability to production inputs (K, L, I. M) or output (Q), its inherent or adaptive ability, its relation to the demand or supply side, and its resilience strategy category under the stakeholder perspective of business/government micro, meso, and macro economic levels. Household is not included because it was not the focus of our discussions. The tables succinctly summarize stakeholder resilience suggestions that are briefly described in context along with any noted implementation obstacles.

Economists recognize that the size, diversity, and geographic proximity of the Southern California regional economy enhance the resilience of the macro level economy. At the meso level, water utilities propose pooling resources, but not without limitations: adaptive sharing of liquid chlorine depends on compatible water system purification methods and moving supplies within stricken zones and the sharing of water between systems requires inherently redundant and

interconnected systems. The California trucking industry saw the potential to partner with the American Trucking Association to move food and water, and provide emergency dispatch centers (representing an adaptation of technology to a demand change). Port management predicts the need for inter-organization agreements (centralized planning) among competing cargo unloading companies during recovery with government intervention to expedite the agreements.

Most stakeholder static resilience suggestions and cautions relate to the microeconomic level. Water conservation is assumed in estimates of emergency water supplies (inventories) during the recovery period. High levels in gas fields in November (the month of the ShakeOut drill) provide fuel inventories, although this ability is seasonal. Manufacturers' material inventories are held in local warehouses, but this strategy may be eroded by damage to warehouse districts and intervening transportation systems. Electric power is more difficult to store, but it can be rationed using rotating outages, and managed according to priority needs to force conservation. Input substitution of back up generators for power is also a viable option, but environmental regulations limit the run time of generators before imposing a fine. Technological innovation looks promising for marine power ships to reverse power back into the grid and restore power in the port. Banking institutions plan to substitute damaged building capital with mobile facilities and relocate business sites according to damage and demand. Geographically dispersed data centers allow the banking industry to relocate this function. Also, the industry has the technology to respond to changed demands and alter their services and products (e.g., provide more cash). Banking and water operations reported the ability to substitute labor inputs by cross training the labor force in high priority jobs across systems. A supply-side resilience strategy for highway segment closures is redundancy in the highway system while the demand-side strategy involves management solutions to reallocate labor to priority sites to alleviate commute problems and to schedule the movement of goods, day *and night* to take advantage of excess capacity. City purchasing departments discover they could enhance resilience by geographically diversifying away from the concentration of suppliers in the one area (import substitution). Utilities and businesses manage employee focus and labor productivity by helping families prepare for disasters, or even setting up facilities and stockpiles for employee families to shelter in their place of work. Utilities expect to import contractors to substitute personnel. There is a general consensus that management trained for a disaster of ShakeOut proportions is critical to

continuing operations effectively and efficiently under adverse conditions. Most of the Stakeholder static resilience suggestions are inherent abilities rather than adaptive. Adaptive static resilience strategies include stretching chlorine usage when there is a boil/disinfect water order, using non-potable wells for fire fighting, and adapting normal distribution operations to changed emergency demand (e.g., the distribution of bottled water and emergency supplies).

Stakeholders contributed numerous dynamic resilience suggestions to speed recovery. As a means to remove recovery impediments, federal agencies stressed fast-tracking disaster assistance by expeditious communication of need and preparation of documentation of damages and expenses that are essential to the accountability and transparency of government assistance. In particular, debris removal can be impeded by time consuming documentation, a lack of contractual agreements, and right of entry (on to private lands). Disaster planners advocated for recovery planning before a disaster, affording the time to consider best practices of existing plans and expand ideas, comprehend and prepare for federal procedures, coordinate with local agencies and understand roles. Planning across functional areas avoids turf battles over the use of facilities and land for temporary recovery solutions. Coordinated planning across communities within the region avoids reliance on and conflicts over the same resources. Strategies to speed restoration include incentive contracts (e.g., Caltrans incentive contracts after the Northridge earthquake.) Use of railroad maintenance roads (on railroad right of ways) to access utility sites for emergency repairs to speed restoration should be explored in advance because of liability policies.

Input substitution, import substitution, inventory, and management strategies apply to speeding rebuilding and reconstruction, as well as to maintaining normal operations. Dynamic resilience examples of input substitution include using helicopters to access sites when the highway system is blocked, portable water labs to conduct water quality tests and/or treatment, and cross-trained employees for recovery tasks (e.g., building inspection). Import substitution of labor is available in the form of mutual aid for utilities, but may be hindered by lack of local knowledge, training, paperwork, management issues. Contractors will supplement local building inspection capacity. For a state organization like Caltrans contractors can be reassigned from other maintenance projects, but contractor agreements set in place beforehand will speed the reassignment. Import substitution of materials for repair and reconstruction requires

geographically dispersed suppliers and delivery logistics. Carrying inventories of the cheaper repair parts will enhance dynamic resilience. If an organization manufactures its own parts then inventories of raw materials would also speed reconstruction efforts. Carrying commercial insurance or self-insurance (financial inventories) speeds repair and reconstruction. Management is critical to dynamic resilience and the challenges include directing crews with interdependent tasks, managing distressed employees, and prioritizing resource use. Facilitation of family communications (e.g., distribution of notes by other employees in the area) are designed to keep repair and restoration labor focused.

Overall, ShakeOut stakeholders, collectively, touched on many categories of static and dynamic resilience, related to all three levels of the economy although predominantly microeconomic, and involved all four types of inputs and output. Across the board, the most popular advice to enhance resilience, in response to the ShakeOut scenario, is business continuity and recovery planning, training, and exercising. Ultimately, this activity should encapsulate all categories of resilience strategies and the implementation of them. The ShakeOut scenario was received as an opportunity to test business local government continuity and recovery plans, or even begin to create them. It was evident that, today, large businesses, critical infrastructure and/or utilities in southern California are enhancing economic resilience through business continuity and/or disaster recovery planning. Some used the scenario to take planning to the next level – to the meso level; water utilities identified issues and explored strategies as a sector. Across utilities, a suggestion to reduce restoration and reconstruction conflicts among collocated life line providers entails management by area rather than function. At higher levels of regional and State government, the ShakeOut scenario facilitated inter-agency coordination that would affect the recovery time path. Next, we switch our attention to the modeling of economic resilience in ShakeOut business interruption loss estimations.

**Table 2**: Static ShakeOut Resilience Strategies for Normal Operations with applicability to Capital (K), labor (L), Materials (M), and infrastructure (I) inputs and output (Q); Inherent (I) or Adaptive (A) ability; and Demand (D) or Supply (S) side

| ShakeOut Static Economic Resilience Strategy | Applic ability | Abil -ity | Side | Strategy Category by Level of Economy | | |
|---|---|---|---|---|---|---|
| | | | | Micro Business | Micro Government | *Macro* Meso |
| Inherent in size and diversity of regional economy | K,L,I, M,Q | I | | | | *Economic Structure* |
| Inter-organization agreement & government intervention for cargo handling | I | A | S | | | Centralized planning |
| Share scarce inputs (e.g., chemicals, water) | M,I | A,I | D | | | Resource Pooling |
| Reduce water use | I | I,A | D | Conservation | | |
| Stretch chemical inputs | M | A | D | Conservation | | |
| Ration power | I | I | S | Conservation | | |
| Use mutual aid agreements for normal operations | L,M | I | D | Import Substitution | Import Substitution | |
| Set up contractor agreements (to replace & increase staff) | L | I | D | Import Substitution | Import Substitution | |
| Use geographically dispersed suppliers | M | I | D | Import Substitution | Import Substitution | |
| Build in redundancy (e.g., highways, pipelines) | I | I | S | Excess capacity | | |
| Respond to demand changes | Q | I | S | Management | | |
| Train managers for disasters | L | I | D | Management | Management | |
| Support family situation | L | I,A | D | Management | | |
| Prioritize lifeline service | Q | A | S | Management | | |
| Cross-train employees | L | I | D | Input Subst. | Input Subst. | |
| Use other fuel (natural gas) | M | I | D | Input Subst. | | |
| Bring in mobile facilities | K | I | D | Input Subst. | | |
| Use backup generators | I | I | D | Input Subst. | | |
| Use bottled water | I | I | D | Input Subst. | | |
| Design flexible processes (e.g., 2-way power supplies) | I | I | D | Technologic solution | | |
| Design flexible products (e.g., cash availability) | Q | I | S | Technologic solution | | |
| Set up alternative sites | K | I,A | S | Relocation | | |
| Reassign employees to accessible locations | L | A | D | Relocation | | |
| Store fuel (e.g., gas fields) | M | I | D | Inventories | | |
| Store emergency supplies & shelter for employee & families | L | I | D | Inventories | | |
| Maintain emergency water | M | I | S | Inventories | | |
| Maintain emergency funds | K | I | D | Inventories | | |

**Table 3**: Dynamic ShakeOut Resilience Strategies for Recovery. Capital (K), labor (L), infrastructure (I), and materials (M) inputs and output (Q); Inherent (I) and Adaptive (A) ability; Demand (D) and Supply (S) side

| ShakeOut Dynamic Economic Resilience Strategy | Applic ability | Abil-ity | Side | Micro Strategy Category | |
|---|---|---|---|---|---|
| | | | | Micro Business | Micro Gov't |
| Expedite communication of needs for disaster assistance | I,M,K, L | A | | | Remove operating impediments |
| Prepare documentation for financial assistance | K | I | D | | Remove operating impediments |
| Adopt emergency waivers & ordinances | I | I | S | | Remove impediments |
| Prepare documentation for private right of ways | I | I | | | Remove operating impediments |
| Plan redevelopment | K | I,A | S | Remove operating impediments | Remove operating impediments |
| Implement incentive contracts | I | I,A | S | | Speed restoration |
| Install instrumentation to speed restoration (reduce access and labor issues) | I | I | S | Technologic solutions | |
| Use mutual aid for inspect-tion,, repair, & rebuilding | L | I | S | Import Substitution | |
| Maintain contractor lists and agreements for inspection, restoration, repair, rebuilding | L | I,A | S | | Import Substitution |
| Maintain geographically dispersed suppliers of repair & reconstruction materials | M | I | D | | Import Substitution |
| Use alternative communica-tion devices and mediums | I | I | S | Input Substitution | Input Substitution |
| Find alternative access to sites for inspection & repairs | I | I,A | S | Input Substitution | |
| Use portable recovery facilities (e.g. water labs) | K | I,A | S | | Input Substitution |
| Cross train employees for inspection and repairs | L | I | S | Input Substitution | |
| Maintain volunteer list | L | I | S | Inventories | |
| Stockpile repair parts | M | I | | Inventories | |
| Buy insurance | K | I | S | Inventories | |
| Train managers for recovery | L | I | S | Management | Management |
| Assist employee families | L | I,A | D | Management | |
| Maintain repair part supplier relations | M | I | D | Management | Management |

## SHAKEOUT RESILIENCE EFFECTIVENESS

One resilience strategy that did not surface during stakeholder discussions is production recapture – recouping lost production at a later date. Ironically, this overlooked strategy was the main form of resilience incorporated into the ShakeOut business interruption loss estimation input-output model (see Rose et al. 2010) because production recapture has exhibited the greatest potential for loss reduction in previous resilience studies (Rose et al., 2007a; 2007b). The ability for a producer to recapture lost production differs across sectors and depends on the time of implementation; it is higher for manufacturing sectors and lower for service industries that cannot permanently defer some purchases of such things as restaurant meals, movies, dry cleaning, etc. It is higher during the first few months, but the ability reduces as time passes and customers seek replacement suppliers. For example, the time to clear the backlog of hundreds of ships waiting in Los Angeles and Long Beach harbors will weaken the potential to recapture over time. That is, customers who have not had their orders filled may be patient for a few weeks, but may be much less so after several weeks or months, and the producer may end up losing market share. Table 4, presents ShakeOut recapture resilience effectiveness for selected sectors and for the four biggest sources of economic shock (shaking and building damages, water and power outages) using estimates from Rose et al., 2010. Production recapture resilience is avoids 17 to 98% of the output losses across the selected sectors. Direct recapture resilience is greater for manufacturing than for the service industries but, total resilience (direct plus indirect or ripple effects) can vary because sectors with less and more recapture resilience are linked to them. Production recapture resilience is 2-4 times greater for shaken building damage than fire damage because longer reconstruction times for fire damage erode the ability to recoup lost production.

**Table 4**. Illustrative Resilience Results From Shakeout Economic Analysis (see Rose et al., 2010) for the Four Biggest Sources of Economic Shock (shaking, fire, power and water outages) for Various Sectors. Production recapture resilience is measured as the percentage of direct and total output loss avoided (relative to estimates of BI output loss when no resilience strategies are in place).

| | Production Recapture Resilience given each Economic Shock | | | |
|---|---|---|---|---|
| Sector | Building Shaking (Direct, Total) | Building Fire (Direct, Total ) | Power Outage Direct, Total | Water Outage Direct, Total |
| Heavy Industry | 98%, 95% | 41%, 39% | 98%, 93% | 75%, 74% |
| Water Utility | N/A, 77% | N/A, 90% | 90%, 80% | 71%, 70% |
| Health Services | 54%, 62% | N/A, 26% | 60%, 68% | 52%, 57% |
| Entertainment & Recreation | 60%, 60% | 25%, 27% | 60%, 66% | 47%, 53% |
| Regional economy | 78%, 79% | 17%, 30% | 75%, 74% | 63%, 63% |

## DISCUSSION AND CONCLUSION

Economic resilience is an important means to reduce business interruption losses from disasters. Static resilience absorbs losses by making the best use of what is available at any one time and dynamic resilience speeds recovery and determines the time path of recovery. Economic resilience resides in demand and supply sides of businesses, in government roles, and households at the microeconomic level, as well as at the meso (market or sector) and macro levels of the economy. Klein et al. (2003; p. 41) concluded that decades of research have not been able "to transform the concept [of resilience] into an operational tool for policy and management purposes." This paper is intended to strengthen the conceptual foundation and to provide empirical findings toward this goal.

Our resilience analysis has been bidirectional; ShakeOut suggestions were used to corroborate some of the economic resilience framework and concepts, which in turn, provided a means to compile and examine a collective understanding of economic resilience among stakeholders in Southern California. The framework offers a checklist for resilience strategies relative to production inputs and outputs. A comparison of the conceptual with the practical suggestions reveal some underappreciated potential at the microeconomic level, namely, resilience strategies including export substitution, resource unimportance, and production recapture. Only a few of the suggestions addressed meso and marco economic resilience, but emerging coordination within the water sector was evident. Regarding the macro level, the most commonly expressed concern, and perhaps least resolvable, involved prioritization of scarce resources: prioritization of lifeline restoration and prioritization of limited resources across functional needs relating to dynamic and static resilience, respectively. The economically oriented stakeholders suggested that prioritization be done in accordance with economic impact.

The challenge for business interruption loss modeling is incorporating resilience. ShakeOut stakeholder examples provide a reference set for modelers, and they pinpoint data and model structure needs. The value of loss modeling is the revelation of the biggest contributors to business interruption losses and investigation of the effectiveness of different resilience strategies. We demonstrate the effectiveness of production recapture, a static resilience strategy, but are unable to do so for dynamic resilience because we obtained only one spatially sensitive

restoration time path for buildings and each disrupted lifeline service. Essentially, the lifeline restoration expert opinion (see Ch. 7 of Jones et al, 2008) implicitly factored in inherent dynamic resilience into their estimates, with caveats around multi-agency cooperation and prioritization of limited resources.

When it comes to cost-effectiveness, the relative roles of mitigation and resilience to reduce losses come into play. Undoubtedly, mitigation of structures before the event prevents damage and associated business interruptions losses and, hence, need for resilience. When mitigation fails or cannot be implemented, we resort to resilience to reduce business interruption losses, but the two are not pure substitutes. A business can mitigate by building stronger, but it can still be affected indirectly by damage to its customers or suppliers, such that its resilience will still be tested. Furthermore, it is not cost-effective or even possible to mitigate all damages. Post-disaster resilience initiatives have a cost advantage because they involve targeting of resources when they are actually needed (e.g., overtime) rather than probabilistically anticipated. Mitigation has to be put in place before one knows that the event will even take place. Of course, resilience can be enhanced before a disaster, as in the design of more flexible production processes, stocking of inventories, and by holding emergency planning drills, but these investments are rather modest, and resilience may even be cost saving (in the case of conservation). Although, generally more expensive, mitigation has a relative advantage if society requires an initial target level of safety (i.e., if saving lives is the priority or if there is a maximum level of economic disruption that can be tolerated). Mitigation is also more permanent. For example, some emergency inventories set up after the Northridge earthquake have been removed by subsequent management.

On the other hand, resilience has another advantage of avoiding business interruption losses from *all* hazards. Most resilience strategies are broadly applicable, while building strengthening more narrowly targets particular hazards such as earthquake and wind. Some mitigation strategies may even be counter-productive for other hazards, e.g., elevating buildings to avoid flooding in an earthquake zone. Dynamic resilience and mitigation are potentially trade-offs in the case of hasty reconstruction compromising mitigation opportunities leaving businesses or the economy more vulnerable to future disasters. Ideally, the recovery planning process begins earlier to promote the building of mitigation into repair and reconstruction. Static and dynamic

resilience and mitigation play different roles in reducing disaster losses, but they do not operate independently, and the challenge is to create positive synergies.


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