Advances in Analyzing and Measuring Dynamic Economic Resilience

Adam Rose[i*] and Noah Dormady[ii]

Keywords: Dynamic economic resilience, disaster recovery, resilience, definition

[*]Corresponding author: Adam.Rose@usc.edu

This paper places into the broader context of an analytical framework recent research findings and policy initiatives relating to dynamic economic resilience, which is usually defined as speeding up and/or shortening the duration of recovery from disasters. Our purpose is to offer insights into the operation and implications of both of these innovations. The first pertains to research that indicates that accelerating the pace of economic recovery has much greater potential for reducing disaster losses than does compressing its duration. The second pertains to supplementing the constructing and protecting of the built environment with the resilience strategy of embedding ways of repairing and reconstructing it more quickly in the aftermath of a disaster.

Basic definitions

The concept of *economic resilience* to disasters is often construed broadly to include actions taken both before the event, as well as after the disaster strikes, in order to reduce losses in an overall risk management strategy (Bruneau et al., 2003; Rose, 2016; Rose, 2017a).[iii] We find it useful to make the distinction between *mitigation*, which is generally undertaken before the disaster and to define *resilience* more narrowly to include actions implemented after the disaster strikes to promote *recovery*.[iv] However, we emphasize that resilience is *a process.* Overall resilience capacity can be enhanced prior to the disaster for implementation once it is needed (Tierney, 2007; Cutter, 2016; and Rose, 2017a). Examples of such resilience capacity-enhancing actions include the purchase of back-up electricity generators, stockpiling critical materials, and informational/learning actions such as disaster resource planning emergency drills. These examples apply to the microeconomic level (i.e., individual enterprises or organizations), but analogous pre-disaster resilience actions are also applicable at the mesoeconomic, or industry/market level (e.g., the workings of markets through price signals that reallocate scarce resources to their highest value use), and at the macroeconomic level (e.g., importing goods that are in short supply within the affected region, reserve margins and ancillary services markets in regional power grids).

---

[i] University of Southern California Sol Price School of Public Policy; USC Center for Risk and Economic Analysis of Terrorism Events (CREATE); Critical Infrastructure Resilience Institute (CIRI) at the University of Illinois
[ii] The Ohio State University John Glenn College of Public Affairs; USC Center for Risk and Economic Analysis of Terrorism Events (CREATE); Critical Infrastructure Resilience Institute (CIRI) at the University of Illinois
[iii] For example, the U.S. National Academies of Science defines resilience very broadly as: "Resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events."
[iv] The investment in dynamic economic resilience can also involve technological change and other forms of adaptation that lower the vulnerability of the system to future disasters.

Suggested citation: Rose, A., & Dormady, N. (2018). Advances in analyzing and measuring dynamic economic resilience. In Trump, B. D., Florin, M.-V., & Linkov, I. (Eds.). *IRGC resource guide on resilience (vol. 2): Domains of resilience for complex interconnected systems.* Lausanne, CH: EPFL International Risk Governance Center. Available on irgc.epfl.ch and irgc.org.

Another important distinction is the difference between *static* and *dynami*c economic resilience. The former refers to using remaining resources efficiently to maintain function (producing as much as possible), while the latter is often characterized as investing efficiently in repair and reconstruction in order to reestablish productive capacity as quickly as possible to regain function. It is dynamic because it involves an active decision with a real opportunity cost that requires foregoing the current use of resources in order to attain a higher level of future production capacity (Rose, 2017a).[v] Overall, static economic resilience works primarily within the existing system structure with limited potential to promote full recovery, while dynamic resilience is intended to promote full recovery through investment that can capitalize on revolutionary and evolutionary changes.

Yet another important distinction is between *inherent* and *adaptive* resilience. The former pertains to resilience that is naturally-occurring or otherwise already in place prior to the disaster (e.g., excess capacity, the operation of markets), and the latter pertains to deliberate enhancement (e.g., purchase of back-up generators and stockpiling). Adaptive resilience refers to improvisations made after the disaster strikes (e.g., relocation, finding new substitutes for critical materials in short supply). Practically all analyses to date have confined inherent resilience to the static version.[vi] However, there is increasing awareness that it can also apply to dynamic economic resilience. A major example is rethinking building materials and design considerations so that structures can be repaired more quickly and cheaply.

Mitigation is the major strategy to reduce property damage from disasters. This refers to reducing the frequency and magnitude of disasters by reducing the root cause(s) and “hardening” the target. The outcome of the latter is often referred to as improving the robustness of the system. However, it is important to note that mitigation also reduces lost production associated with property damage. This is a major consideration for both individual businesses and the economy as a whole. The magnitude of disasters is increasingly measured by the economic losses they cause. Most of the attention to mitigation is on the destruction of buildings and infrastructure, but lost economic output, often referred to as “business interruption” (BI), can be even larger than property damage in major disasters. This is because supply-chain reactions radiate outward from the site of the disaster and accumulate over the course of a protracted recovery. This was the case, for example, for Hurricane Katrina, and the Wenchuan Earthquake. Mitigation reduces potential BI as a joint product along with its protection of the capital stock, but the potential of dynamic resilience to reduce some of the remaining BI losses has rarely been quantified.

Inherent dynamic economic resilience has important implications for risk, because it requires investment prior to the occurrence of any disaster. This is in contrast to adaptive dynamic resilience, which has been the subject of most of the literature (such as hastening the pays of insurance payments from government assistance for repair and reconstruction of damaged), and which does not require investment until after the disaster strikes. Hence, the benefits of the insurance dynamic resilience require adjustment for the probability of occurrence of the disaster, while adaptive dynamic resilience is implemented with perfect knowledge of the disaster having actually taken place. Moreover, there are additional uncertainties pertaining to inherent dynamic resilience than in

[v] The more general versions of static and dynamic resilience are usually ascribed to ecologists Holling (1973) and Pimm (1984), respectively.

[vi] See, e.g., Hosseini et al. (2016), who provide a current comprehensive survey of related resilience research for the interested reader.

the case of inherent static resilience in terms of the effectiveness of the resilience tactic. This is more the case in the dynamic realm, as opposed to static inherent resilience (such as stockpiling or purchasing backup generators), because various dynamic inherent resilience tactics to be discussed below are relatively new and untested.

Dynamic economic resilience and the time-path of disaster recovery

Recovery from disasters is usually measured in terms of the time it takes the system to return to a pre-disaster level, to a projected baseline level, or to what is now referred to as a "new normal" - a sustainable post-disaster level of economic activity, such as the downsized economy of New Orleans in the aftermath of Hurricane Katrina. On the one hand, economic recovery from disasters is about the repair and reconstruction of buildings and infrastructure, along with social and political institutions and the rehabilitation of the workforce. It is helpful to conceptualize this in terms of *stocks* and *flows*. The major categories of economic inputs available for production (capital, labor, and institutions) are fixed quantities, or stocks. What is variable, however, is the lost flow of economic activity between the point at which the disaster strikes and the point at which it recovers. This is determined primarily by the duration and time-path of the recovery. Recovery from disasters and its time-path are linked through the concept of *resilience*. What has not been analyzed adequately to date is the connection between the variability of disaster recovery and disaster flow losses in terms of such indicators as economic output and employment, in contrast to property damage. Dynamic resilience pertains to the reduction in these flow losses during the recovery period by investment in repair and reconstruction so as to enhance future productive capacity, as opposed to static resilience actions of efficiently reallocating resources to increase current production.

Referring again to Rose (2017a), dynamic economic resilience has two aspects:

- the ability to recover
- the ability to recover rapidly

The first aspect is typically straightforward and can readily be observed and measured; it is simply a binary "yes" or "no." The second aspect is more complex than might appear. Initially it is important to distinguish resilience and recovery—they are not the same thing (Chang & Rose, 2012). Dynamic resilience represents the possibility of both an acceleration in recovery and reduction in its duration (the "recovered rapidly" aspect of the definition above). The measurement of dynamic economic resilience thus requires a reference base, or baseline, recovery time-path to compare with the accelerated, or more rapid, recovery path.[vii] The difference between the two, in terms of GDP or employment, is the measure of BI losses averted by dynamic economic resilience during recovery.

Recent research by Xie et al. (2018) on the macroeconomic impacts of the Wenchuan Earthquake indicates that jump-starting the disaster recovery will reap far greater BI loss reductions than shortening its duration. This conclusion holds for recovery time-paths for disasters in general that are linear, logistic (S-shaped), or exponential (i.e., most recovery paths), because relatively little of the recovery is left to perform in the final year(s).

In effect, the earlier start and steepening of the recovery path has a compounding, or cumulative, positive effect on loss reduction that increases with the rate of acceleration. This is particularly the

[vii] In this brief essay, we do not address how to define this reference case and instead refer the reader to Pant et al. (2012) and Xie et al. (2018).

case for flows rather than stocks. Whereas stock losses are typically damaged plant and equipment with a known, fixed replacement cost, flow losses early in a firm's recovery period can also have an additional adverse "snowball" effect over the duration of a recovery period with the potential for significant secondary and tertiary losses in the future. For example, middle-size firms (firms with annual revenues between $10 million and $1 billion, often referred to as the "middle market"), which make up the bulk of the U.S. economy (Young, Greenbaum & Dormady, 2017), are in many cases reliant upon contracts with larger firms (e.g., a machine shop contracted to make injection molds for a multi-national electronics manufacturer). It behooves a small- or medium-sized business to recover quickly so it does not lose its competitiveness for future contracts with current and prospective customers.

The general time-path analysis and individual business example prompt us to reiterate the importance of modifying standard definitions of dynamic economic resilience. The reference to speed is too vague. It behooves analysts and decision-makers to distinguish between shortening the duration of recovery and accelerating its time-path.

We offer one major caveat with respect to potential downsides of inherent dynamic economic resilience. For example, in the haste to accelerate recovery, there is the possibility of giving an adequate attention to tactics that can make the system (business, market, entire economy) less vulnerable to future disasters. This also relates to promoting long-term considerations of adaptation and sustainability. Therefore, assessment of the benefits of dynamic economic resilience of all forms requires a careful examination of trade-offs between reducing current and future losses.

Inherent dynamic resilience tactics

Tactics to improve dynamic economic resilience are typically represented by: hastening debris removal, reducing delays in the dispensation of insurance payments and government aid, increasing the level of these investment funds for recovery, and technological change during the reconstruction process. However, all of these examples are those of adaptive dynamic economic resilience, i.e., for the most part, improvised after the disaster has struck and the rebuilding process has begun. Of course, each of them can be enhanced prior to the disaster by having heavy equipment for debris removal in place, reducing paperwork needed to obtain insurance payments and government assistance, and having automatic triggers for government assistance to disaster areas. However, the more prevalent approach in research and practice on this strategy is on improvising to increase and accelerate each of these tactics, which pertains to the adaptive aspects.

Yet another strategy to improve dynamic economic resilience is via inherent resilience, exemplified by modifying building materials and design, not only to make structures more robust, or disaster-resistant, but also to make their restoration more rapidly forthcoming, and, ideally less expensive. This goes beyond trying to make structures more durable toward the goal of making those that are damaged capable of becoming operational again much faster. Examples would include materials less likely to cause debris problems and more modular construction that facilitates repair (Benedetti, Landi & Merenda, 2014; Jones, 2018).

Public policy can provide an additional stimulus to an inherent dynamic resilience strategy. There are an increasing number of examples of local government regulations to establish target dates for buildings and infrastructure to become habitable and operational more quickly following an earthquake. Buildings and infrastructure provide the capacity for producing goods and services, and providing jobs, upon which human well-being depends. This strategy is also being touted as a way to promote recovery by preventing a protracted or even permanent mass exodus from a disaster area (Rose, 2017b; Jones, 2018). Leadership in this initiative came from the San Francisco Planning and Urban Research Association (SPUR) (SPUR, 2016). This was followed by similar efforts in Oregon and Washington, and the attempt to standardize this in practice by the National Institute of Standards and Technology (NIST, 2016; see also the comparison of approaches by Miles, 2018). Essentially, this represents the setting of performance standards for recovery linked to time. The premier instrument was building codes. However, the emphasis is not on reducing property damage for its own sake but for reasons related to dynamic inherent economic resilience to promote recovery – stronger structures are easier to repair. Over time, this will merge with the rationale in the previous paragraph – more flexible structures are easier to repair.

Measuring dynamic economic resilience

We briefly summarize some aspects of our recent efforts to measure dynamic economic resilience (Rose et al., 2017; Dormady et al., 2018). We are utilizing a survey instrument of disaster-affected firms to pose questions such as:

1. How long did it take your business to recover?
2. How long did you originally expect it would take your business to recover?
3. What factors delayed recovery?
4. What factors expedited recovery?
5. Was the trend of your business' time-path linear, logistic or exponential in shape?
6. What was your total business interruption (BI) loss during your recovery period?
7. What was your expected total business interruption loss during your recovery (assuming no delays or expedited effort)?

Question 2 addresses the baseline or reference point. The difference between responses to Q1 and Q2 provide the speed of recovery, a first step in measuring dynamic resilience. The difference between Q6 and Q7 gives us a first approximation of the dollar value of dynamic economic resilience. However, it is important to control for static economic resilience efforts that would also affect avoided BI.

There are four main motivations for investment that have major implications for measurement:

1. *Restoration/Replacement/Repair/Reconstruction* of previous productive capacity. All of the following have the goal of reestablishing original functionality:

- *Restoration* refers to efforts made in reinstating the equipment or facility to its original character. This would be especially important if the original had historical, sentimental, or special marketing value, but is not always possible.

- Replacement refers to obtaining or rebuilding a comparable piece of equipment or building. However, in most cases one would be replacing equipment or facilities put in place in previous years, and it is likely that the replacement goods would be more productive, even if that were not the original intent.

- *Repair* refers to the range of patching up to overhauling damaged equipment or facilities to reestablish their functionality.

- *Reconstruction* refers to extensive actions in rebuilding or re-fabrication.

2. *Productivity Enhancement*. This refers to explicit efforts to increase the level of output of goods or services per unit of equipment/facility input. As noted above, it may not be intended, but is likely in terms of replacing equipment. In other cases, it is an explicit decision. It may be attractive because it affords an opportunity to achieve a goal that would not otherwise be economically viable if the original equipment were still in place and did not actually need to be replaced.

3. *Vulnerability Reduction* in relation to future disasters. This is far from an automatic outcome. In fact, many experts suggest that, as economic activity becomes more advanced, it becomes more complex and less flexible, and hence more vulnerable within the firm and with respect to the supply chain (e.g., Zolli & Healy, 2012). In one way, the situation is similar to productivity enhancement in terms of the investment decision, whereby the disaster affords an opportunity, as well as the realization of the worthiness, of reducing losses from future disasters.[viii]

In terms of obtaining data necessary to measure the cost-effectiveness of various types of investment on avoided BI losses, caution is advised. Subtleties in the distinction between motivations for investment often overlap or exist in complementarity on the effectiveness side. The estimation of property damage represents a start as a reference point for quantifying the cost of investment expenditures. However, investment need not equal standard damage estimates at original cost minus depreciation, because the best estimate of the value of an asset (intact or damaged) is replacement cost. The situation is also complicated by "demand surge," which refers to an oft-observed condition of increased construction cost following disasters due to a spike in demand and damage to construction equipment and materials, as well as a shortage of construction labor due to death, injury, or outmigration.

Conclusion

This paper has made the case for enhancing the standard definition of economic resilience, and resilience in general. Dynamic resilience does in fact have an inherent aspect. In addition, the vague reference in many definitions of dynamic economic resilience, and dynamic resilience in general, to increasing the speed or reducing the duration of recovery is far too vague and actually emphasizes the wrong attributes, where the more important one is jump-starting the process. A greater emphasis needs to be placed on the time-path of the recovery and its shape. Both of these features lead us to a revised definition of dynamic economic resilience as: *inherent and adaptive efficient tactics related to investment to reestablish functionality of the built environment so as to accelerate and shorten the time-path of disaster recovery*.

Acknowledgements

The authors wish to thank Igor Linkov and Ben Trump for their helpful suggestions for improving the paper.

[viii] We have omitted discussion of the expansion of productive capacity, which refers to the extension or enlargement of equipment or facilities of the same type or nearly the same as the original during recovery. We set this aside because it goes beyond recovery. One might say that this also applies to motivations 2 and 3 above, but they are part of the *replacement* process, even if they are intended for joint or other purposes. Expansion investment is not.

Annotated bibliography

Benedetti, A., Landi, L. & Merenda, D.G. (2014). Displacement-Based Design of an Energy Dissipating System for Seismic Upgrading of Existing Masonry Structures. *Journal of Earthquake Engineering 18*(1), 477-501. Analysis of major technique to install in original building construction or retrofit to reduce vulnerability to earthquakes and also to facilitate the repair and reconstruction following an earthquake.

Bruneau, M., Chang, S., Eguchi, R., Lee, G., O'Rourke, T., Reinhorn, A., Shinozuka, M., Tierney, K., Wallace, W., & von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance seismic resilience of communities. *Earthquake Spectra, 19*, 733–52. Classic paper on multiple dimensions of community resilience, though only a perfunctory treatment of the economic dimension.

Chang, S., & Rose, A. (2012). Economic recovery to disasters. *International Journal of Mass Emergencies and Disasters, 30*(2), 171-81. Synthesis of the literature on disaster recovery.

Cutter, S. (2016). The landscape of disaster resilience indicators in the USA. *Natural Hazards, 80*, 741-58. Major insights into resilience, primarily from a geography perspective.

Dormady, N., Rose, A., Rosoff, H., & Roa-Henriquez, A. (2018). Estimating the cost-effectiveness of resilience to disasters: Survey instrument design & refinement of primary data. In M. Ruth & S.G. Reisemann (Eds.), *Handbook on resilience of socio-technical systems*. Cheltenham: Edward Elgar. Design of a survey to measure static economic resilience and a presentation of some initial results from businesses affected by SuperStorm Sandy.

Holling, C. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4,* 1–23. Classic article on resilience focused on maintaining functionality.

Hosseini, S., Barker, K., & Ramirez-Marquez, J. (2016). A review of definitions and measures of system resilience. *Reliability Engineering and System Safety, 145*, 47-61. Provides one of the best and most comprehensive literature surveys on recent resilience research from engineering, economics, and supply-chain management.

Jones, L. (2018). *Big ones: How natural disasters have shaped us*. New York: Doubleday. Lessons from case studies of major disasters world-wide over the course of history.

Miles, S. (2018). Comparison of jurisdictional seismic resilience planning initiatives. *PLOS Disasters*, March. Evaluation and comparison of seismic resilience initiatives focused on establishing performance standards for returning structures to operational capabilities.

National Research Council (NRC). (2011). *National earthquake resilience: Research, implementation and outreach*. Washington, DC: National Academy Press. Evaluation of the status of research and practice on earthquake resilience and recommendations for the future of both.

National Research Council (NRC). (2012). *Disaster resilience: A national imperative*. Washington, DC: National Academy Press. Authoritative and comprehensive assessment of research and practice on resilience broadly defined.

National Institute of Standards and Technology (NIST). (2016). *Community resilience planning guide for buildings and infrastructure systems volume II*, Special Report 1190. Washington, DC: National Institute of Standards and Technology. A template for standardizing post-disaster returned the functionality of buildings and infrastructure.

Pant, R., Barker, K., & Sobel, B. (2012). Static and dynamic metrics of economic resilience for interdependent infrastructure and industry sectors. *Reliability Engineering and System* Safety, 125, 92-102. Analysis of the time-path of recovery of infrastructure in relation to supply-chain linkages.

Pimm, S. L. (1984). The complexity and stability of ecosystems. *Nature, 307*(26), 321–26. Classic article on resilience emphasizing rapid return to equilibrium.

Rose, A. (2004). Defining and measuring economic resilience to disasters. *Disaster Prevention and Management, 13*(4), 307-14. Provides basic economic principles underlying resilience.

Rose, A. (2016). Private sector co-benefits of disaster risk management. In E. Surminski & T. Tanner (Eds.), *Realising the triple resilience dividend: A new business case for disaster risk management*. Heidelberg: Springer. Analysis of the direct and co-benefits of mitigation and resilience for disaster risk management.

Rose, A. (2017a). Benefit-cost analysis of economic resilience actions. In S. Cutter (Ed.), *Oxford research encyclopedia of natural hazard science.* New York: Oxford. Comprehensive analysis of many aspects of economic resilience.

Rose, A. (2017b). *Defining and measuring economic resilience from a societal, environmental and security perspective*. Heidelberg: Springer. A primer on economic resilience from several perspectives.

Rose, A., Tierney, K., & Dormady, N. (2017). *Measuring dynamic economic resilience to disasters*. Final Report to the US National Science Foundation.

San Francisco Planning and Urban Research Association (SPUR). (2016). *The Resilient City,* San Francisco, CA: San Francisco Planning and Urban Research Association. Retrieved from http://www.spur.org/featured-project/resilient-city. The pioneering plan to promote economic recovery by establishing performance standards for returning structures to functionality according to timetables.

Tierney, K. (2007). *Businesses and disasters: Vulnerability, impacts, and recovery*. Handbook of Disasters. Heidelberg: Springer. Summary of classic surveys to measure business interruption losses, with some consideration of resilience

Xie, W., Rose, A., Li, S., He, J., Li, N., Ali, T., & Wei, W. (2018). Dynamic economic resilience and economic recovery from disasters: A quantitative assessment. *Risk Analysis*, forthcoming. One of the first attempts to measure dynamic economic resilience at the macroeconomic level and then to use the results to clarify the definition of dynamic economic resilience.

Young, K. A., Greenbaum, R. T., & Dormady, N. C. (2017). Sex, gender, and disasters: Experimental evidence on the decision to invest in resilience. *International Journal of Disaster Risk Reduction 24*: 439-450. Provides a decision sciences resilience experiment using CEOs and COOs of middle market businesses as subjects.

Zolli, A. & Healy, A. M. (2012). *Resilience: Why things bounce back*. New York: Free Press. Treatise on the concept that flexibility is a core consideration in resilience.