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The Emergence of Global Systemic Risk

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Abstract

In this article, we discuss the increasing interdependence of societies, focusing specifically on issues of systemic instability and fragility generated by the new and unprecedented level of connectedness and complexity resulting from globalization. We define the global system as a set of tightly coupled interactions that allow for the continued flow of information, capital, goods, services, and people. Using the general concepts of globality, complexity, networks, and the nature of risk, we analyze case studies of trade, finance, infrastructure, climate change, and public health to develop empirical support for the concept of global systemic risk. We seek to identify and describe the sources and nature of such risks and methods of thinking about risks that may inform future academic research and policy-making decisions.

INTRODUCTION

The processes and outcomes of globalization are a core concern of social science scholars who have studied its social, political, and economic causes and implications (Centeno & Cohen 2010, 2012; Dicken 1986; Guillén 2001; Held & McGrew 2007; Ritzer 2012; Sassen 1991). Many studies have centered on the distributional aspects of globalization, with some focusing on its benefits (Bhagwati 2004, Dornbusch 2000, Masson 2001) and others taking a more critical approach (Rodrik 2011, Stiglitz 2002). Within sociology, researchers have contributed insights into the structure and dynamics of the global system as series of networks and the flows they facilitate (Castells 1996; Gereffi & Korzeniewicz 1994; Wallerstein 1975, 2000).

This article takes an alternative and largely unexplored perspective on the increasing interdependence among societies, focusing specifically on issues of systemic instability and fragility generated by globalization (Fouque & Langsam 2013). Although questions of sustainability and instability of physical systems have long been central concerns of ecological analysis (e.g., Levin 1999, May 1973, Meadows et al. 2004, Ponting 1991), the relationship between global social organization and risk has been understudied. In focusing on this relationship, we follow recent contributions regarding the theoretical and empirical linkages between complexity, globalization, and fragility (e.g., Goldin & Mariathasan 2014, Urry 2002). To these, we add the insights of sociologists of risk, who have argued that modernity reflexively relies on increasing complexity to manage the very risks it creates (Beck 1992, 1999; Luhmann 1993; Giddens 1991) and that the causes of catastrophes are often embedded in the very construction of social organization (Clarke 2005; Perrow 1984; Vaughan 1996, 1999).

In the following section, we focus on three general concepts, which we seek to integrate into an explanatory schema for global systemic risk. The first concept is the notion of globality and its complexity. The second concept is the nature of risk. The third concept, networks, integrates the first two. We find empirical support for this schema of global systemic risk in case studies of trade, finance, infrastructure, climate change, and public health, which we explore in the final section of the article.

CONCEPTUAL TOOLS

A Complex Global System?

Why focus on the global? Many areas of the world are now connected across myriad domains. In the context of the global system, we focus on the patterns of relationships between societies, such as those created by trade, capital transfers, and migration flows, and on the infrastructure, such as shipping lanes, electricity grids, and computer networks, that make these relationships possible. In doing so, we define the global system as a set of tightly coupled interactions that allow for the continued flow of information, money, goods, services, and people.

Although these connections themselves are not new, the level of interdependence, the tight couplings between many of these domains, and the speed and scale of interactions have created new configurations of opportunity and risk. Modern systems are built to exploit the benefits and efficiencies resulting from specialization of labor, economies of scale, collective knowledge, and information sharing. These same systems that underwrite our way of life also expose us to catastrophic outcomes that may derive from the characteristics of the relationships themselves (Helbing 2013). Consider global food production (Puma et al. 2015). The Green Revolution of the 1950s has certainly reduced global hunger and increased life expectancy and population rates over the past 50 years (Evenson & Gollin 2003). However, these benefits come not only with sustainability concerns over energy and water (Rockström et al. 2007, Welch & Graham 1999) but also with an increased reliance on a small number of crop varieties and a decline in food self-sufficiency. The global diffusion of agricultural innovation has therefore solved the immediate problem of food production at the expense of resource unsustainability and reduced robustness to a low-probability but high-impact crop disease outbreak or trade disruption. One might be tempted to deal with the issue of disease simply by further innovating and developing disease-resistant crop strains. However, what if increasing reliance on GMO crops simply delays an inevitable disease outbreak that is then made more extreme by relying on GMO innovations to begin with? This conundrum begs further exploration of two questions: How does vulnerability arise endogenously in global systems? How might these systems tip from vulnerability to catastrophe?

The theory of complex adaptive systems (CAS) is ideally suited to such questions. CAS arise endogenously out of the interactions of components and have collective behaviors that cannot be reduced to those of their components (Holling 2001, Miller & Page 2007, Mitchell 2009). Such systems can often give the appearance of stability even as their fragility increases (Perrow 1984, Scheffer 2009). Fragility results from complex systems gradually becoming susceptible to small perturbations that have catastrophic results. In drawing on CAS theory, we hope to contribute to a small but growing body of work that incorporates complexity and systems theory into the study of globalization (Goldin & Mariathasan 2014, Urry 2002) and the fragility and control of complex socioeconomic systems (Levin et al. 2013; Scheffer et al. 2009, 2012). In doing so, we draw on core insights from CAS theory that help extend key insights of sociological theory to the terrain of systemic risk.

A core idea found in both CAS theory and sociology is emergence—the spontaneous formation of a self-organized order out of chaos (Kauffman 1993, Prigogine & Stengers 1984). From an emergence perspective, the behavior of a system cannot be reduced to the behavior of its constituent components. The complex interactions of components create new dynamics that cannot be explained solely by the behavior of constituents, whether intended or not (Merton 1936). For example, weather cannot be explained simply by understanding the behavior of the various elements in the earth's atmosphere. The complex interactions of the earth's atmosphere can yield chaotic nonlinear dynamics in which a small perturbation at one location on the earth can have massive repercussions on the opposite side of the planet. Emergence posits the idea that orders spontaneously arise from the relationships between components. Thus, complex and relatively functional phenomena such as our atmosphere or the global system can emerge and self-organize spontaneously through the individual interactive behaviors of the component parts without any centralized control, direction, or planning. In emergence, much like globalization, there is no single architect, no single regulator.

An emergence perspective respects that the relations between components yield their own dynamics, which cannot be predicted solely from the actions of individuals. This idea is no surprise to the Durkheimian tradition, which embraces the idea that the realm of social interaction can be considered on its own terms, separate from the consciousness and agency of individuals (Durkheim 1973). In a contemporary setting, the relational turn in sociology is also sympathetic to emergence, given Zelizer's (1994) argument that the construction of complex and stable norms of economic exchange can be understood by analyzing the noneconomic relationships formed between actors. Padgett & Powell (2012) further develop a sociological conception of emergence in an organizational context by emphasizing how interaction in social networks changes the properties of the people, things, and ideas that flow through social networks.

Previous scholarship (Sawyer 2001) has noted how emergence cuts to the core of debates about the micro-macro link and the role of agency and structure in explaining social phenomena (Elder-Vass 2010, Hedström & Ylikoski 2010). Without engaging in that debate, we instead note that emergence can refer not only to structures but also to the qualities of those structures. We draw on risk theory to note that, just as social organization emerges from interactions, systemic fragility can also emerge from the normal functioning of complex global systems (Perrow 1984). We then discuss this aspect of emergence in greater detail (see Risk, below).

One of the most important insights of CAS theory is that emergent systems tend to evolve through adaptation to a critical zone that lies at the border between order and chaos (Bak 1996, Kauffman 1993). Systems that reach this threshold at the "edge of chaos" (Langton 1990) are particularly prone to sudden, nonlinear transitions from one state to another. Such critical transitions can result from either external perturbations or the endogenous functioning of the system itself, and are both difficult to forecast and potentially irreversible (Scheffer 2009). Systems that are both complex and densely interconnected are especially prone to "complexity catastrophe" (Kauffman 1993).

Although they go by different names, threshold effects in social organization are a well-established and well-studied phenomenon in sociological domains including social movements (Marwell & Oliver 1993), riots (Granovetter 1978), and contagion and cascades (Centola & Macy 2007; Rogers 1962; Watts 2002, 2004). Although these studies provide deep insights into the dynamics produced by direct social interaction, applying them at a global scale involving social, technological, environmental, and other forms of interdependence threatens to extend them beyond their scope. We argue that the critical transitions framework of CAS provides a basis for such an extension.

CAS also allows us to incorporate feedback as a source of instability. As Robinson (2007) notes, systems theory in sociology (Parsons 1951, Parsons & Shils 1951) identified negative feedback loops as a regulating mechanism that creates and maintains equilibrium and thus order. By contrast, mathematical ecologists have established that nonlinear feedback is a driver of critical transitions, from order to collapse, in CAS (Levin et al. 2013, Staver et al. 2011). Although positive feedback loops are familiar to the discipline in the form of Merton's (1968) Matthew effect, the possibility for positive and/or nonlinear feedback to trigger catastrophic outcomes is a necessary addition to our theoretical toolkit if we are to understand the emergence and dynamics of this new form of risk.

CAS may also provide a heuristic for the new level of analysis required by a globalized world. We are living with a new and unprecedented level of aggregation of social space. The sheer quantity and breadth of interactions may require a shift in our analysis of interdependence. Such interdependence has produced myriad benefits, but potential instability may be an endogenous characteristic of a system as complex as the one we have created.

Risk[1]

In the context of the global system, systemic and emerging risks are the key factors in our analysis. We define systemic risk as the threat that individual failures, accidents, or disruptions present to a system through the process of contagion. This is the risk that unexpected and unlikely interactions may lead to unpredicted threats to system survival. We define emerging risk as the danger that arises from new technologies or interdependencies—disasters that we have not experienced yet are expected to increase in both frequency and magnitude, such as terrorist attacks or natural disasters.

[1]We are not referring to the pure Knightian definition of risk as a calculable "measurable uncertainty" (Knight 1921). Uncertainty is a ubiquitous concept in the physical world, in human behavior, and in social, economic, and financial outcomes, yet these uncertainties will always continue to be commonly referred to as risk. In this article, we proceed under the assumption that systemic risks we discuss are necessarily unquantifiable uncertainties, in the sense of Knightian uncertainty.

Emergent risk is the endogenous threat to the individual parts produced by their participation in and interaction with the system itself. The emergence of these risks may reflect both systemic causality and limitations of available information and human analytical ability—they are inevitably caused by the nature of the system, yet we do not have the capacity to foresee them. Although many of the global system's emergent properties are benign or even beneficial, this article is concerned particularly with analyzing the potential for significant negative consequences of such systems.

Theories of risk can be arranged along a realist-constructivist continuum more broadly in the social sciences (Lupton 1999). Realist models begin from the assumption that it is possible to probabilistically assess the likelihood and impact of any specified risk given its inherent characteristics (Slovic et al. 1979). On the other side of the continuum lie social constructivist theories of risk. In this view, the existence and nature of a risk derive from its political/historical/social context (Brenot et al. 1998, Lidskog et al. 2009). Douglas (1966), for example, sees the very notion of a risk as tied to a particular culture's taboos, which are defined in the context of cultural notions of purity and pollution. Douglas & Wildavsky (1982) argue that the risks that people find salient are those that threaten their current social and institutional arrangements. Dean (1999) has extended Foucault's idea of governmentality as it applies to risk. In Dean's framework, populations that are a threat to the state are thought of as risks. Power is wielded not through force, but through the construction of social norms that transform incalculable dangers into calculable risks. Risks therefore do not exist independently from society, but are created socially in response to the need to regulate populations and interactions.

The social construction of risk is particularly important for the study of the global system. First, identifying the sources of risk is an inherently political act and often involves conflicting agendas. Thus, the identification of an activity as risky is often difficult to separate from the interests of those who benefit from it and the interests of those who would bear the possible costs. Second, the distribution of these sources of risks is not symmetrical, as the wealthy parts of the world play a more significant role in generating the possible dangers. The policing of the system therefore often depends on those very same actors who are endangering it. Conversely, the costs of failure are also asymmetrically distributed and are often the mirror image of those bearing responsibility. Finally, assessing and addressing these risks are especially difficult given the absence of any central coordinating mechanism or governance process.

Other authors focus more on the organizational origins and dynamics of risk, particularly on the paradox that systemic risks can arise from the very organizational structures and processes used to control other risks. Perrow (1984, 2002) argues that organizational structures with tight coupling and high interactional complexity are beyond the full control of their operators, and that these structures allow for small issues to concatenate and expand in unforeseen ways to create normal accidents even under seemingly normal operating conditions. In her analysis of the space shuttle *Challenger* disaster, Vaughan (1996) notes how organizations come to ignore signals of disaster though the normalization of deviance, in which minor deviations from formal operating procedures are redefined as acceptable risks. Vaughan also finds that the technologies of control—the bureaucratic rules and procedures for creating risk assessments—can desensitize risk managers to potential catastrophes. Both Vaughan (1999) and Perrow (1984) note that complex organizational structures that rely on large numbers of interacting components are particularly prone to failure given the impossibility of effectively monitoring those interactions.

Social theorists of risk find a similar paradox at the macroscale. Luhmann (1993) is concerned with the production and reproduction of social systems. Risks are threats to the functioning of social systems and functionally specialized subsystems, which must either absorb and transform environmental perturbations or divert them to other subsystems. Luhmann's perspective shows how the operating logic of a social subsystem may make it incapable of conceiving of risks, let alone protecting the needs of dependent populations. Luhmann also identifies a reflexive pattern similar to that of Vaughan and Perrow, as social subsystems constantly create new risks in the attempt to manage existing risks. These paradoxes profoundly complicate the taken-for-granted status of Knight's (1921) classic distinction by linking the proliferation of unknown risks, or uncertainty, to the very calculations we rely on to manage knowable risks.

In part because of the sheer speed of global transformations, risk theorists have also noted the increasing importance of systemic risk as an inherent element of modernity. Beck (1992) posits that risk has become a central concern of modernity, as ideas of science, rationality, and increased human agency have come to replace prior concepts of fortune and fate. Our current age is one in which modernity itself is ending and being replaced by a risk society, in which science and progress are under question. The work of Giddens (1991) aligns with Beck's work. Both scholars also embrace the idea of a global cosmopolitan society that shares consciousness of global risks while maintaining reflexivity that maintains doubt and skepticism in the modernist project.

One hundred fifty years ago, Karl Marx appropriated Goethe's image of the sorcerer's apprentice as a metaphor for the capitalist. We propose that the insights from the study of risk can provide an important heuristic with which we can analyze the functioning of the global system. This analysis requires us to identify structural weaknesses in the system and to determine the costs and benefits of maintaining the global status quo for both the whole and its different parts. This understanding and appreciation of risk can therefore allow an improved comprehension of the risks associated with our contemporary prosperity (Willke & Willke 2012).

Networks

Perhaps the most intuitive way to conceptualize both the abstract characteristics and the structural features of the global system, as well as its inherent risks, is as a complex web of networks (Fouque & Langsam 2013). Indeed, the field of social network research has recently begun to expand network theory from the study of the dynamics of single networks to multilayer networks such as the ones we study in this article (Kivelä et al. 2014). From this perspective, a significant and evolving body of research emphasizes the relationship between interdependent scale-free networks, in particular, and systemic instability.

In many large networks, including "the Internet, the World Wide Web, social networks representing the relations between individuals, [and] infrastructure networks such as those of airlines" (Gao et al. 2012, p. 40), the connectivity of the various nodes often follows a scale-free or power-law distribution (Cohen et al. 2000). As Barabási & Albert (1999) explain, this feature is a consequence of two dynamics: Networks tend to expand continuously and links "attach preferentially to sites that are already well connected" (p. 509). Scale-free networks are distinguished by their relative stability to random shock, and it is precisely this property that makes them so valuable and critical to developments such as the Internet. Independently, these networks are therefore typically endogenously stable, though they are highly vulnerable to deliberate exogenous attack (Albert et al. 2000).

More important, as various scale-free networks within the global system are connected, the vulnerability of the resulting network is significantly greater than that of constituent parts observed independently (Buldyrev et al. 2010). Recent research by Zhou et al. (2013) extends such analysis to partially interdependent scale-free networks under random attack, confirming the findings of Buldyrev et al. (2010). Following these discoveries, Parshani et al. (2010) initially questioned the assumptions undergirding the previous work. Within "real interdependent networks such as. . .power network and the communication network. . .we observe that in practice not all nodes of network A depend on network B and vice versa" (Parshani et al. 2010, p. 2). Yet even after developing an alternative model, they too found that "the system still disintegrates in an iterative process of cascading failures unlike a regular second order percolation transition in a single network" (Parshani et al. 2010, p. 2). Moreover, researchers have recently shown that coupled scale-free networks are highly sensitive not only to random shock but also to deliberate attack. Huang et al. (2011), for instance, find that "interdependent networks are difficult to defend by strategies such as protecting the high degree nodes that have been found useful to significantly improve robustness of single networks" (p. 1). The analysis of the global system as a complex array of intercoupled networks provides new theoretical lenses through which to understand the behavior of the structure as a whole and to better appreciate the consequences of disruptions.

THE EMERGENCE OF GLOBAL RISKS: CASE STUDIES

Combining and integrating the conceptual tools discussed above, we now summarize how these principles may play out in three different areas: the continued flow of goods and money, the maintenance of a global infrastructure, and the interaction of the entire system with nature. Obviously these are not the only domains relevant to our discussion, but they serve as empirical examples of the broader phenomenon we are studying.

Global Trade

The system of global trade combines technological and physical system dynamics to produce a highly effective yet potentially vulnerable system. The globality of the dense network of global trade is a defining characteristic motivating a growing literature in the social sciences. Within the sociological literature, scholars working in the world systems tradition of Wallerstein (1975, 2000) have used network analysis to examine the structural characteristics of the global network of trade between countries. Using data on exports and imports (Kim & Shin 2002, Snyder & Kick 1979) and commodities (Smith & Nemeth 1988, Smith & White 1992), these scholars find support for a densely connected but hierarchically partitioned system of states with a core, a periphery, and an intermediate range of positions (for a review of this literature, see Lloyd et al. 2009).

A line of inquiry has emerged at the intersection of economics and physics and examines the world trade web as a complex, interdependent network in order to identify its structure and dynamics. The earliest publications within this body of work analyzed the topology of the trade system as a network and identified its central features as a combination of global disassortativity (a pattern in which nodes link to nodes unlike themselves), hierarchy, and a local tendency for preferential attachment among well-connected states (Garlaschelli & Loffredo 2005, Serrano & Boguñá 2003), echoing some of the key structural findings about the topography of the world trade web from studies on world systems. More recent articles have refined this analysis by incorporating the volume of trade into weighted (as opposed to binary or unweighted) network analyses (Fagiolo et al. 2008, 2010). These studies have generally confirmed the hierarchical structure and clustering among wealthy countries identified in the earlier papers, though they have found weaker disassortativity at the macro level once weightings are taken into account. Other analyses have identified significant heterogeneity in the structure of trade webs for individual commodities that is masked by the aggregate structure, though these individual webs retain the disassortative character of the macroweb (Barigozzi et al. 2010).

Other network papers have begun to build on these insights to examine the dynamics of diffusion across the trade web in ways that point to possible sources of systemic risk. Much of this work emphasizes the intersection of trade and finance. For example, Serrano et al. (2007) analyze the trade web first as a structure, and then as a series of financial flows moving across that structure, in order to identify the role of trade links as potential pathways for the diffusion of risk in crisis episodes. Their work indicates that focusing on direct trade ties can often yield a less complete analysis than an approach that takes into account distributed interdependencies. In a similar vein, Kali & Reyes (2010) examine the relationship between integration into the world trade web and vulnerability to financial crisis. The authors proceed from the assumption that trade and credit funding relationships are linked, and that credit creates leverage that can magnify crisis effects. Their analysis indicates that crisis effects (which they identify by stock market performance) are amplified if the country where the crisis originated is tightly integrated into the trade web, and that more densely connected countries tend to suffer less from crisis effects overall, perhaps due to their ability to diffuse those effects over their trade links.

Although a network depiction of trade between states reveals a densely interconnected web of transactions, the physical network of trade routes is far more concentrated into a set of vitally important shipping lanes, which today account for more than 80% of global trade by volume (UNCTAD 2012). Local geography and politics have rendered many of these lanes acutely vulnerable to piracy and other disruptions, making them a primary source of systemic fragility. The US Energy Information Administration (EIA 2012) has identified seven shipping channels around the world as "transit chokepoints" that could pose a threat to the global economy in the case of a disruption. One example is the Strait of Malacca in Indonesia, a narrow channel that serves as the primary shipping lane connecting the Indian and Pacific Oceans, linking the Middle East and Africa to Asia. By some estimates, the Strait of Malacca accounts for roughly 40% of world trade, including the bulk of Asia's oil imports (Reuters 2010).

Managing shipping risk has been a central preoccupation of societies since the earliest recorded moments of human history, with the first extant record of maritime insurance laws appearing in the Code of Hammurabi in the eighteenth century BCE (Bernstein 1998). The practice of insuring against the loss of ships and cargo was similarly widespread in Greek and Roman times and, after a lull, reappeared in the Middle Ages. Lloyd's, the world's oldest insurance company, was formed in a coffee shop in London in the seventeenth century and grew to its current form in concert with the mercantile expansion of the British Empire (Kingston 2007). Over the past three decades, the shipping industry has benefited from an increasingly sophisticated array of risk management tools. The first generation of these tools appeared in 1985, with the creation of standardized forward derivatives contracts based on the Baltic Freight Index that allowed shipping companies to hedge against fluctuations in shipping costs, a crucial component of their business. Although the initial format proved unpopular, other exchanges and formats emerged and grew in prominence, in part by moving beyond the initial contract's use of a single, global index to allow firms to hedge costs on specific shipping routes over specific time horizons (Kavussanos & Visvikis 2006b). These contracts joined a growing array of contracts that allowed firms to hedge bunker fuel rates, interest rates, currency, and other important costs (for a full description, see Kavussanos & Visvikis 2006a).

In spite of these innovations, commercial maritime risk management remains focused at the level of the physical ship and aggregated at the level of the individual shipping firm. There is currently no single body with the authority and resources to impose order on the global network of shipping trade. States have stepped into this void through a series of treaties coordinated by the International Maritime Organization, as well as (in extremis) military interventions in cases in which their economic and security interests have been threatened. In 2009, the US military intervened to rescue the crew and cargo of the *Maersk Alabama*, a cargo ship seized by Somali pirates off the coast of East Africa. The rise of similar incidents led to calls by legislators for more extensive and formal involvement by the US military to protect American-flag ships off the coast of Africa and around the world (US Senate Committee on Commerce, Science, and Transportation 2009).

Finance

Crises in the financial system have been with us for centuries and have typically involved some combination of credit threats to the banking system and turmoil in stock and bond markets, though not necessarily at the same time. What makes our current financial system particularly vulnerable to crises is the number of linkages between the banking system and financial markets through the securitization of credit, as well as linkages between markets and the broader economy through financialization (Krippner 2011). These linkages make financial volatility a social, political, and economic problem in a way that it has not been historically.

Financial volatility is hardly new to the United States, whose financial system experienced shocks roughly every 15 years between the late eighteenth century and the early decades of the twentieth century (Moss 2009). The last of these shocks was the Great Depression, during which both the banking system and the financial markets collapsed. The Roosevelt administration and Congress responded with a series of New Deal regulatory measures such as the Banking Act of 1933, which established a regulatory structure for banking that persisted for decades. The Act included an array of measures, three of which were particularly important. The first measure was the creation of a federal deposit insurance system in order to stabilize banks' deposits and protect depositors. The second measure sought to protect banks from fluctuations in interest rates by imposing a cap on interest rates for savings and demand accounts (through so-called Regulation Q). With the third measure, through the provisions collectively called the Glass-Steagall Act, Congress mandated the separation of investment and commercial banking to limit the impact of market volatility on banks holding federally insured deposits.

These reforms are widely seen as having played a central role in the decades of financial stability that followed their enactment in the 1930s. The resulting separation of financial activities created a modularized financial system that prevented concentration of activities and risks (Krippner 2011), a perspective echoed by many others (see, e.g., Moss 2009). In addition, the interest rate caps set by Regulation Q functioned as an automatic regulator for the financial system that limited credit from overheating during expansions (Krippner 2011, p. 62). It is equally true, however, that the appearance of stability concealed mounting pressures that ultimately led to the breakdown of much of the New Deal regulatory framework, in some cases due to crises caused by the measures themselves. In the case of Regulation Q, the reform went from successful to volatile when the economic and financial environment changed. In the case of the Glass-Steagall Act, the appearance of stability created by the rules' persistence until the late 1990s belied the reality of proliferating linkages between institutions and markets once deregulation gathered steam.

The evolution of systemic risk in finance is evident in the progression of two crises that began with the savings and loan (S&L) crisis of the late 1970s and early 1980s. Rising interest rates in the late 1960s and 1970s made bank deposits under Regulation Q increasingly uncompetitive with innovations such as the money market account (Wallach 2014). The resulting pressure on savings and loans—the primary source of home mortgage finances at the time—led to significant deregulatory policy changes in the early 1980s, key among which was the relaxation of both Regulation Q and constraints on bank portfolios. The joint result of these policies was a significant decline in underwriting standards and a boom in speculative real estate lending by savings and loan associations (SLAs), just as a long-running bull market in commercial real estate was nearing its peak. As many as one-third of all SLAs failed in the resulting S&L crisis, creating risk to the US banking system that necessitated a resolution program with a final cost estimated to be as high as $500 billion in 1990 dollars, or more than $900 billion in 2013 dollars (CBO 1992).[2]

[2] Bureau of Labor Statistics, CPI Inflation Calculator: **http://www.bls.gov/data/inflation_calculator.htm**.

The next crisis arrived in the late 1990s, when currency speculators triggered runs on a series of currencies and markets in Asian countries whose governments had encouraged a surge in reckless lending through their implicit support of national banks. The resulting wildfire appeared to jump at random from one country's currency and credit market to the next, and reached its climax in October 1998, when Russia opted to conserve its dwindling stores of rubles for domestic use rather than pay foreign lenders. At that point, what had appeared to be an unwelcome but traditional pattern of financial problems at the country level was transformed into a global financial problem, as the shockwave from Russia's default was transmitted across stock, bond, commodity, and other markets around the world. The linkages that allowed this transmission were created in large part through the use of swaps and other derivatives contracts, which allowed large financial institutions unprecedented flexibility to make bets in markets around the world without needing to hold the underlying securities. Operating outside the purview of most regulation (Funk & Hirschman 2014), these contracts created unseen linkages between institutions whose activities were nominally separated by the Glass-Steagall Act, as well as between the markets in which those institutions operated. The scale and danger of those linkages were evident in the collapse of the US-based hedge fund Long-Term Capital Management, which borrowed aggressively to create a portfolio so large that its failure threatened the viability of global capital markets. Only the aggressive intervention of the Federal Reserve Bank of New York and the cooperation of the world's largest investment banks were able to contain the fallout (Lowenstein 2000). Interest in this new pattern of behavior in finance led to a stream of research on financial contagion that continues today (Allen & Gale 2000).

By the time of the financial crisis of 2007–2008, the financial system had become still more interconnected even as the derivatives contracts driving those connections remained largely outside the regulatory framework. As a result, the financial system had the characteristics of a complex, dynamic system (May et al. 2008), including the potential for tipping points and system-wide cascading failures (Battiston et al. 2012, Gai & Kapadia 2010). These system dynamics were a necessary condition for the transformation of a collapsing, debt-fueled bubble in residential real estate into the rapid spread of credit problems across institutions and markets in a pattern that echoed the most dangerous aspects of the S&L and Asian and Russian financial crises. This time, subprime mortgages provided the links connecting households (as borrowers), commercial banks (as lenders), investment banks (as securitizers), and financial institutions around the world (as holders of mortgage-backed securities). Moreover, by using subprime bonds as collateral backing long chains of interbank borrowing through derivatives, investment banks unwittingly created powerful feedback loops that brought down major institutions and again threatened the viability of global markets (Gorton & Metrick 2012). The complexity of the system is also evident in the inability of policy makers and academics to arrive at a consensus over a single causal explanation for the crisis, with one best-selling book arguing strongly that as many as seven causal factors and processes necessarily contributed to the crisis and that no single factor or process was causally sufficient (Blinder 2013).

The severity of the crisis has triggered intensive study in both academia and regulatory policy. Many academic researchers in finance and economics are focused on identifying the structural characteristics of the financial system both in its normal behavior and in crisis, largely through the development of abstract models (for a review of economic models and literature on financial crises and systemic risk, see Brunnermeier & Oehmke 2013). Economists and physical scientists have also begun to work more closely together to apply insights from complexity science to the modeling and oversight of the financial system (Kambhu et al. 2007). Some of the more useful work for sociologists focuses on the relational structures and organizational processes that create systemic fragility. Within economics and finance, the work of Gorton and colleagues (Gorton

2008, 2009, 2010; Gorton & Metrick 2012) provides a detailed view into the complex workings of the generally invisible but vitally important interbank lending markets that enable the daily functioning of the financial system. Within sociology, MacKenzie (2005, 2009, 2011a,b, 2012, 2014) has conducted a series of studies in both academic articles and the popular press that have provided unique insights into the interplay between knowledge, technology, and material practices in securitization, derivatives markets, and high-frequency trading, among other areas.

Regulatory policy has proceeded broadly along two paths. The first path is the identification and control risk at the level of the organization and is embodied most clearly in the so-called Volcker Rule, which seeks to reduce moral hazard in the banking system by encouraging banks that benefit from deposit insurance to exit speculative trading activity. The second path is often described as macroprudential given its focus on risk at the aggregate level of markets (for a review of the related literature, see Galati & Moessner 2013). The balance between organization-level and macroprudential policy is one of the most active debates in both academia and the policy world and is likely to remain so given the newfound awareness of the complexity of the financial system and our limitations in understanding potential effects on its stability. The possibility of effective macroprudential policy is still challenged, however, by the difficulty in coordinating across national bureaucracies. As Beck's (1992) theory would predict, these challenges result partly from the difficulty in agreeing on the risks to be addressed, as well as who is to be held accountable.

Critical Infrastructure

Critical infrastructure refers to the physical systems required to facilitate the flows upon which the global system depends. These networks of communications, energy, vital resources, and transportation are complex when considered individually, but are rendered even more so by two patterns. First, the rise of global information technology has accelerated the development of systems that couple information technologies with critical physical infrastructure (Rinaldi et al. 2001). Second, all other global systems rely on the coupling of information technology systems and critical infrastructure. As a result, all global systems are subject to the stability of the critical infrastructure on which they depend.

An example of the coupling of information technology and physical infrastructure can be found in global telecommunications networks. Rinaldi (2004) notes that these systems rely on the electric grid as well as transportation networks to support operations. In turn, the generation of electricity relies on global fuel networks, and transportation networks often rely on sophisticated computerized control via logistics systems. However, modern systems are not only interconnected but also often simultaneously interdependent. Buldyrev et al. (2010) note that power and communications networks are simultaneously interdependent, as power networks rely on communications networks for coordination while the communications networks depend on electricity for their basic functioning. Understanding the impact of this simultaneous interdependency is a critical issue for infrastructure research; there is much to learn about the depth of the systems' interdependencies, and how failures in one system may propagate across other systems (Gao et al. 2012, Little 2005).

These tightly coupled and interdependent infrastructure networks may be vulnerable in ways that cannot be predicted on the basis of the properties of the constituent networks themselves. Laprie et al. (2007) create a typology of failures that must be addressed when considering interdependent infrastructure systems. Among these failures are cascading failures, in which a failure in one infrastructure system triggers failures in other infrastructure systems, and escalating failures, in which a failure in one system worsens an independent failure in another system, thereby increasing the impact of each individual failure and increasing the resources required to recover from each failure. In addition, coordinated, intentional attacks on interdependent infrastructure systems can also have magnified effects. For "networks where loads can redistribute among the nodes, intentional attacks can lead to a *cascade* of overload failures, which can in turn cause the entire or a substantial part of the network to collapse" (Motter & Lai 2002, p. 1; italics in the original).

The loss of the telecommunications satellite PanAmSat Galaxy 4 in 1998 illustrates cascading failures in critical infrastructures (Zuckerman 1998). In addition to disrupting television and radio transmissions, the event affected roughly 80% of pagers (a.k.a. beepers) throughout the United States, resulting in a number of follow-on disruptions in the banking and financial services sectors. Credit cards and ATM machines failed, as did important communications links for doctors and emergency workers (Rinaldi et al. 2001). An example of escalating failures occurred in Italy in 2003, when an electricity outage induced a large failure of the railway, healthcare, financial services, and communications networks. The outage disabled the SCADA (supervisory control and data acquisition) network, which is used to manage the electrical grid, thus making it difficult to restore electricity (Rosato et al. 2008).

Several factors have hampered efforts to develop policy to forestall such vulnerabilities. A key factor is that both research and policy regarding critical infrastructures have dealt largely with single systems such as telecommunications or transport, even though the interaction between differently located failures may have still greater implications (Buldyrev et al. 2010, Rosato et al. 2008, Vespignani 2010). Government efforts to protect infrastructures have been guided in large part by fear of deliberate attacks, not of cascading failures endogenous to the system. Governments have erred on the side of attempting "to protect people and assets from what could happen rather than what is likely to happen" (Little & Weaver 2005, p. 264). Even governments that focus on the problems of interdependence lack an established and widely accessible analytical model for understanding complex dynamics in infrastructure (Buldyrev et al. 2010, Gao et al. 2012).

Effective policy responses to infrastructure vulnerability are themselves subject to risk. One means of mitigating network collapse may involve "partially decoupling the networks by the creation of autonomous nodes" (Parshani et al. 2010, Schneider et al. 2013). However, such an approach threatens the functionality of the interdependent system. That is, it may be difficult if not impossible to obtain the benefits from interdependence without accepting a decline in system robustness. Another approach might involve creating ever more complex regulation systems to predict and prevent catastrophes, as per cybernetics theorists Conant & Ashby (1970). However, such an approach faces obvious time and resource limitations that increase at the same pace as technological advancement.

A separate source of concern is the widespread adoption of just-in-time inventory discipline and underengineering practices by many multinational firms. As such firms have sought to decrease costs, they have often adopted operating procedures that, although highly efficient, are vulnerable to unexpected supply chain disruptions (AIG & Advisen 2013, Fiksel et al. 2015). Following the September 11, 2001, terrorist attacks, for instance, both Ford and Toyota idled assembly lines because supplies could not arrive and inventories were insufficient (Sheffi & Rice 2005). Similarly, a growing number of firms have adopted engineering and production techniques resulting in goods that function or remain durable for specific (and often short) periods of time (Koehler & Weissbarth 2004, Roos 1990). One concern is that underengineering practices will interact with low reserves and emergent network properties and will ultimately result in unexpected system failures.[3]

[3] A parallel concern in finance is the increasing use of leverage to avoid having too much reserve capital. This produces greater profits but also makes financial institutions more vulnerable to disruption.

Climate Change and Public Health

Despite the considerable debate in American politics, there is a scholarly consensus on the transformation of the globe's climate (IPCC 2014, NRC 2012, Urry 2010) and the existence of a causal relationship between the development of the global system and climate change. More important for our analysis, changes in global climate have had and will increasingly have an effect on the viability of the global system.

Climate change will directly disturb the global system through a variety of potentially significant changes in surface and ambient temperatures, sea levels, and meteorological patterns (Arnell 2010, NRC 2012). We argue for less emphasis on obviously catastrophic events, such as Hurricane Sandy, and more on the unforeseen consequences of even small perturbations in the system, which can lead to declines in agricultural productivity or drastic disruptions to human habitats. The 2010 explosion of the Eyjafjallajökull Volcano in Iceland is one example of how a relatively small incident could have significant effects on the global transport network (Hutter & Lloyd-Bostock 2013). The climactic equivalent of such events could disrupt the global system in unforeseen ways.

Climate itself may be considered a complex system that, upon interaction with the global system, becomes increasingly complex and fragile (Daily et al. 2000, Nordhaus 2013, Sinnott-Armstrong & Howarth 2006). Climate change exhibits the defining characteristics of any complex system: emergence, path dependence, and nonlinearity. The central concern here is not absolute changes in one climatic measure or another, but the existence of tipping points after which our ability to predict future outcomes would decline precipitously (Lenton 2011). Recalling Weber's (1946) emphasis on predictability as central to modernity, any increase in uncertainty or potential variance would significantly challenge the maintenance of the global system.

For example, changes in climate will eventually cause irreversible changes to ecosystems, particularly among sea life. Scientists have observed that changes in temperature affect the world's oceans, and predictions suggest further change. Climate change poses risks to biodiversity in general (Chapin et al. 2001). Specifically, meteorological pressures combined with other stressors will leave the world's oceans irreversibly altered (European Environment Agency 2014).

Evidence exists for the significant consequences of small changes in climate and indicates that complex human societies are vulnerable to even small changes in the natural contexts in which they operate (Brooke 2014, Cline 2014, Diamond 2004, Fagan 1999, Parker 2013, Tainter 1988, Wood 2014, Wright 2004). From this perspective, complexity is an "adaptive problem-solving strategy" with significant costs (Tainter 1988, p. 8). These costs include ever-rising energy requirements and possible declines in the marginal return of organizational and technological advances.

The dangers of coupling two critical complex systems—global humanity and climate—are equally apparent in another source of potential catastrophe: infectious diseases. As in the case of climate, we have considerable evidence of the extremely rapid and disastrous consequences of appearance and diffusion of disease in complex societies (McNeill 1976, Rosen 2007). The increasing interconnectedness of the global system has created the coupling of social and biological contagion (Bauch et al. 2005, Butler & Weinstein 2011). Globalization has brought with it obvious medical benefits for many, but it also presents new challenges to basic human health (Lloyd-Smith et al. 2009). This is the result of several dynamics.

Declining transport costs of both humans and trade goods have rapidly expanded the networks through which disease may travel. In addition, shorter travel times have allowed diseases to be transported and transmitted before their symptoms are recognized (Brockmann & Helbing 2013, Hufnagel et al. 2004, Kilpatrick & Randolph 2012, McMichael et al. 2006, Tatem et al. 2006). This same global interconnectedness has also increased the potential for catastrophic effects from the spread of zoonoses, i.e., diseases transmitted from animals to humans (Jones et al. 2008, Kahn 2006, Morse et al. 2012, Woolhouse et al. 2005).

The very public health advances made possible by the human global system may also represent a danger to the system. In the late 1970s, for example, the sourcing of most of the world's blood plasma in the United States made its delivery more efficient while it laid the groundwork for the global spread of blood-borne pathogens (Starr 1998). Increasing use of antibiotics today, especially when combined with nonoptimal use protocols and lax compliance, may lead to drug-resistant diseases dangerous both to humans directly and to the sustainability of the earth's life-support system (Levin 1999, Van Boeckel et al. 2014). Decreasing variety of nutritional baskets and the broad adoption of a Western diet have had direct consequences on nutritional health, as well as critical implications for immune systems (Myles 2014). Similarly, as the genetic heterogeneity of our agricultural products declines, the susceptibility to a single catastrophic disease increases (Fineberg & Wilson 2009). In perhaps the most obvious causal feedback system, the climate change produced by the human global system might produce environments in which new diseases can develop (Altizer et al. 2013, Daszak et al. 2001).

CONCLUSIONS

Perhaps the most important sociological development associated with globalization is the tightly coupled and interdependent system of flows that defines modern life. This makes necessary a new unit of analysis at a planetary scale. Although aspects of these characteristics have been studied in research settings operating at various levels of social organization, the scale of interdependence calls for an approach that maximizes the level of analysis and minimizes assumptions about what can be treated as exogenous. The analysis of systemic risk is a promising point of entry for research at this new level of aggregation.

Such an approach raises questions about theoretical framing. Complexity theory offers potentially productive heuristics with which to understand this global system. Three key characteristics are particularly relevant when analyzing risk on a global scale: self-organization, or emergence; feedback loops; and nonlinear responses to changes. Each of these contributes to the development of a new level of systemic fragility, and together they point to ways in which risk can arise endogenously within the global system. The analysis of this new level of structural fragility can be understood best through the application of theories of risk. In analyzing this structural fragility, we must appreciate how social problems are constructed and how responses to these problems reflect social hierarchies. Moreover, risk analysis also teaches us that it may be the very structure of—and protocols followed by—an organization to manage local risks that ultimately produces the larger systemic risks. We believe this endogeneity of risk within global systems may represent the most important sociological lesson from this analysis.

We apply this perspective to three different forms of global interaction. First, in the analysis of critical infrastructure we apply principles from network theory to suggest that the system as a whole may exhibit vulnerabilities not predictable on the basis of the properties of the constituent networks. The vulnerability of the global infrastructure, along with the coupling of previously autonomous networks, may dramatically increase. Second, in the discussion on trade we again note the centrality of network literature. The financial and logistical support structures required by the global trade web may be subject to unexpected failures that could cascade through the entire system. For example, despite the centrality of the food trade—where many parts of the world have less than one month's supply of food domestically available—our governance structures and authorities largely neglect the systemic properties associated with it. In the world of finance, the securitization of risk has further enhanced tight coupling between various parts of the economy. Last, the human global system interacts with an even more complex natural climatic and epidemiological space. As our actions transform the underlying global environment, we will witness greater variance and unpredictability in natural events. As the system requires ever more predictability to function, tipping points may arise that will make its functioning impossible. Similarly, the construction of the global system has reduced the barriers that once kept ecosystems of disease separate from one another. Interconnectedness and the frequency and speed of travel have drastically reduced the possibility of quarantining disease and preventing pandemics.

The topographical characteristics created by these interdependencies can enable cascading failures that together make a system more fragile than any single set of relationships could. With relevant networks of thousands behaving autonomously, how do the sheer numbers of possible interactions define social outcomes? Moreover, how have our institutional efforts to regulate disaster and harm produced the very conditions behind the fragility?

The current response to these dangers tells us a great deal about the problems of addressing systemic risks. We suggest that three common policy dilemmas make the resolution of global risk particularly difficult. First, there is the dilemma of using the appropriate future discount rate on the consequences of current actions (or lack thereof). Second, our very management tools prize productive efficiency over sustainability and fail to appropriately price resulting fragility. Third, global systemic risks suffer from all the standard problems of collective goods that require coordination among and compromise between individual preferences. Across a broad set of issues we face concerns with externalities, the globalization of costs of actions taken on by the few, and the manner and degree to which we wish to discount our medium- to long-term futures. Over and above this, resolutions to these dilemmas highlight the absence of global governance institutions and the difficulties in managing these risks on a global scale.

What are the next steps? Rather than simply import a complexity perspective wholesale from other disciplines, sociologists have a unique opportunity to combine deep insights about social context with new analytical methods. This opportunity exists for both quantitative and qualitative researchers. The foundational assumption of independence makes traditional regression analysis a limited tool in the context of interdependent systems. More recent developments in agent-based modeling and computational social science are taking sociology beyond those limitations in exciting ways that lend themselves particularly well to the study of system dynamics and "networked threats" (Erisman et al. 2015). Some of the deepest insights about complexity continue to come from historical, ethnographic, and other qualitative researchers, whose fine-grained analyses of specific contexts and situations can be applied to identify which aspects of complexity are at work in a given setting, how those aspects arose, and how they interact. Such work would also help us limit the risk of using complexity as another vague metaphor. Taken together, these opportunities indicate that sociology can contribute significant insights into this new level of social aggregation.

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