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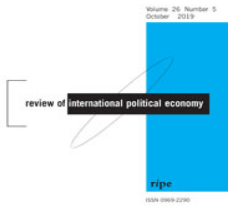
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Finding fault lines in long chains of financial information

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ABSTRACT

IPE has usefully identified numerous contributors to financial crises. Considerably less attention however has been granted to the roles of financial infrastructures, considered in this special issue as the socio-technical systems enabling basic yet crucial financial functions to be carried out, but that tend to be taken for granted and assumed. This article argues that vulnerabilities in information flows enabled through connections between globally dispersed human actors and non-human objects have shaped the types of events triggering crises, how such periods of instability unfold, and their eventual resolution. Building on insights from actor-network theory, we illustrate how fault lines in ‘long chains’ of financial information conditioned three financial earthquakes between the 1980s and the present. Our analysis bridges insights from accounts that tend to separately emphasize material and ideational roots of crises. It also points to the importance of supplementing the stress on quantitative indicators with efforts to identify and address vulnerabilities in the quality of connections between disparate actors and objects that enable or disrupt flows of information facilitating global financial markets.

KEYWORDS

Actor-network theory; governance; finance; crisis; information; infrastructure

Introduction

A flurry of recent studies underline the extent to which the theoretical and empirical investigation of crisis has become a central value-added feature of International Political Economy (IPE) (e.g. Barder, 2016; Bell & Hindmoor, 2014; Best, 2016; Cafruny & Schwartz, 2012; Gamble, 2014; Helleiner, 2011; Hozic & True, 2016; Langley, 2014; Mikler, Rajendra, & Elbra, 2016; Nelson & Katzenstein, 2014; Nesvetailova, 2015; Palan, 2015; Samman, 2015). These and earlier studies (e.g. de Goede, 2005; Nesvetailova, 2007; Underhill, Blom, & Mügge, 2010) usefully identify numerous contributors to financial crises that have been increasing in frequency and severity over the past half-century. Such contributors range from endogenous

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factors such as monetary imbalances or forms of ‘regulatory capture’ to exogenous factors like inequality, technological change and the distribution of power within the wider international system.

Yet IPE is only beginning to explore how the infrastructural character of specific assemblages of ideas, practices, and technical objects distributed globally across diverse locations and types of actors also contribute to crises and shape responses to them. In line with the wider intention of this special issue to bridge complementarities between IPE and Science and Technology Studies (STS) for understanding technological change in global finance, this article harnesses insights from actor-network theory and social studies of finance (SSF) to advance our understanding of financial crises. We demonstrate how vulnerabilities in the specific manners through which disparate humans and non-humans are connected into ‘long chains’ (Latour, 2005, p. 173) of financial information infrastructures (‘infostructures’) critically shape the events triggering outbreaks and unfolding of crises. In doing so, we contribute to the aims of this special issue, highlighting the insights derived by foregrounding financial infrastructures that tend to only become visible in tumultuous times of crisis or during the construction of new markets.

Our argument is that the occurrence, scope and management of financial crisis are significantly conditioned and shaped by the form and varying composition of both material and ideational mechanisms involved in producing, transmitting and analyzing financial information. How specifically such information is stored, transmitted and incorporated into financial activities impacts the types of events contributing to financial crises, how they unfold once they begin, as well as the kinds of governance strategies that can be deployed to resolve them. The myriad factors identified in existing studies as contributing to financial instability, such as a reckless pursuit of profit and power or pathologies associated with information asymmetries, often play out through financial infrastructures that shape crises through an identifiable pattern in which ‘long chains’ decouple. Crises, to be clear, tend not to be triggered by one sole factor, but disruptions in information flow form critically under-recognized elements of these events that a focus on infrastructures can help to understand. The kinds of processes understood to cause financial crises are closely connected to the specific composition of long chains enabling flows of information. Further, the specific composition of a financial infrastructure can alter the terrain in which states and other governance actors seek to resolve and prevent crises. Drawing inspiration from French econophysicist Didier Sornette (2009), we liken specific flaws in informational infrastructures, or infostructures, to the fault lines and stresses that condition how earthquakes occur and unravel. While recognizing the perils of transposing natural metaphors to socio-technical systems, our analysis emphasizes how fault lines in the long chains linking together a variety of globally dispersed actors and objects contribute not only to the *occurrence* of instabilities but also are crucially relevant to subsequent *governance strategies* pursued to address the vulnerabilities.

In examining the relationship between information infrastructures and financial crises, we distinguish between three stages in the construction and decoupling of long chains. In a first instance, new infostructures enhance the management of risks in ways that enable rapid expansions of financial activities by firms. In the second phase, such expansions increasingly overburden the capacity of the new infostructure to adequately manage risks, creating fault lines in long chains facilitating information flows amongst dispersed actors and objects. Yet, most firms and

governments do not adjust their behaviors accordingly. Accumulations of risks then render the financial system vulnerable to a break in information flows. In the third phase, ruptures that might otherwise contribute to minor volatilities can spread instability through the infostructure, contributing to wider manias and panics. Subsequent attempts at regulatory repair then introduce different risks into existing or new infostructures. Though not fundamental to *all* financial infrastructures, fault lines in long chains become more *likely* to emerge as major changes instigate particular types of information flows and interactions between public and private financial actors.

Our analysis has several implications for related efforts to both conceptualize financial crises and elaborate policies seeking to prevent and adequately respond to these events. Sharing some characteristics with existing explanations of financial crises, our stress on socio-technical connections underpinning financial infostructures bridges the tendency to understand manias and panics as more purely psychological, intersubjective or interest-based. Infrastructures do not preclude traditional power politics, nor are fault lines in long chains the sole triggers of crises. Rather, our analysis illustrates how the roles of power and interests in financial crises that IPE studies have contributed to identifying often work through and are shaped by breakdowns in financial infrastructures which actor-network theory and SSF are especially useful in understanding. As such, instead of offering a new ‘grand theory’, the tracing of fault lines in infostructures bridges insights into crises from related but infrequently bridged interdisciplines. A practical implication stemming from this analysis is our proposal for regulators to develop qualitative early warning indicators of crisis. Recognizing associated difficulties, we make the case for a qualitative focus to supplement rather than replace the widespread reliance on quantitative efforts to identify fragilities that can impact the causes, unfolding and responses to crises.

This article proceeds in four sections. First, we elaborate an original approach to illustrate the relationships between financial infrastructures, information and crises. Second, we examine three of the most significant changes in financial infostructures of the past half-century: loan syndication, which preceded the 1980s debt crisis; the securitization which preceded the 2007–2008 global financial crisis; and high-frequency trading (HFT), which preceded the 2010 ‘Flash Crash’. This second section draws out the insights from tracing the development of fault lines and decoupling of three infostructures and the crises associated with them before a penultimate section considers wider implications for governance. Given that more comprehensive examination goes beyond the scope of one article, we discuss the generalizability of fault line development and decoupling of long chains in a final section. We conclude by indicating additional examples that might be further investigated in revealing how likely this pattern is to appear in past and future financial crises. We also provide wider reflections on how insights from actor-network theory and SSF can contribute to ongoing policy and IPE efforts to better understand these events.

Information, infrastructure and crisis

Information is an essential component of the global financial system. IPE as well as SSF scholars have considered finance an ‘information business’ (Wolf, 2016), with money being regarded as a specific kind of information (Strange, 1990, p. 263) that

serves as the ‘cornerstone of financial markets’ (Preda, 2008, p. 915). Extrapolating from credit theories of money (Ingham, 2004; Moini, 2001) suggests a view of global finance as a system for keeping track (and profiting from the manipulation) of information on ownership claims, debts, revenue streams, exposure to or protection from risk. Across these and further fields like media studies, there is no single definition of information that prevails (Babe, 2011; Lee, 2013; Mirowski & Nik-Khah, 2017). The common treatment of information as a commodity tends to be countered in the SSF where it is largely understood as a ‘social phenomenon’, yet one that has a ‘contingent, communitarian, embedded and materially mediated character’ (Pardo-Guerra, 2010, p. 86). The objects forming the substance of global finance – bonds, derivatives, stocks – are considered forms of knowledge derived from and acted upon through social practices of observation, classification and calculation. Information then is neither stable nor circulated by the ‘invisible hand of the market’. Rather, information is accumulated, transmitted and communicated by and through material objects and social practices that have been increasingly identified and considered ‘critical’ by a range of policy analysts (e.g. Angori, Baldoni, Dekel, Dingsor, & Lucchetti, 2012; see more widely Hyslop, 2007).

Since the 2007–2008 global financial crisis there has been increased regulatory and media commentary devoted to the *material* components of financial infrastructures (e.g. Bank for International Settlements and International Organization of Securities Commissions, 2016; Haldane, 2012; Mitchener & Richardson, 2016; Morgensen, 2013; Tarullo, 2015; Tett, 2013). Meanwhile, IPE studies have highlighted shifts in the *ideational* infrastructures of global finance (Hall, 2008; e.g. Baker, 2013; Blyth, 2013; Moschella, 2010; Mügge & Perry, 2014). Financial infostructures consist of both the mental equipment relied upon by brokers, traders and others in processing and acting upon financial flows within and across national borders as well as material equipment like fiber-optic cables and paper documents. Drawing on actor-network theory and Bruno Latour’s notion of ‘long chains’ (2005, p. 173), we emphasize how information can only flow and be acted upon if it is carried by things with a material presence, such as human bodies, phone lines, paper documents or computer disk drives. Moreover, information can only flow over long distances and from one moment to the next if actors and objects are linked in predictable and stable ways. Infostructures involve a high degree of functional interdependence (Porter, 2014), similar to the need to carry electricity at certain voltages for an electrical grid to function (Hughes, 1983). In finance, infostructures may primarily be visible as widespread financial practices, such as the cases of international loan syndication, securitization and HFT that we examine below. However, infostructures are far more than choices or schema that reside in the heads of financial actors. They only function due to their integration with objects that also have a material dimension. This material dimension sustains these practices over time and space. An important feature of financial infostructures that differs from other ‘critical’ infrastructures such as city sewers is that the mix of fluid, relatively intangible and decentralized flows with the hard materiality needed to sustain these are more complex. As our cases below illustrate, financial infostructures may appear in the form of an assemblage of ideas, objects and practices that exist in and across many different market locations, but nevertheless work together to display the characteristics of infrastructure. At the same time, the disaggregated character of these assemblages contributes to the likelihood that fault lines will emerge as connections between human actors and non-human objects crucial

to sustaining information flows decouple. In turn, the decoupling of disparate nodes connecting human-technology interfaces and conduits of global financial systems condition the occurrence, form and resolution of financial crises.

As set out in the introduction to this special issue, infrastructures involve continually evolving relations between human actors and technical objects that are identifiable through five key characteristics: facilitation (making other activities possible), openness (to many actors), durability (related in part to their materiality), centrality (sustaining core functions) and obscurity (working in the background). Financial infrastructures, as conceived by Bernards and Campbell-Verduyn (this issue), are the socio-technical systems enabling basic yet crucial financial functions to be carried out, but that tend to be taken for granted and assumed. They stress how materiality, spatiality and power are central to analyzing financial infrastructures. As emphasized by actor-network theory specifically and STS more generally, infrastructures operate through local settings and micro-level interactions that involve hybrid mixes of human and non-human objects. However, in analyzing relationships between infrastructure, information and crises, it is also important to also consider the types of larger patterns of power and interests that IPE has specialized in making visible and which STS scholars of infrastructure have also called for an enhanced focus upon (Edwards, Bowker, Jackson, & Williams, 2009, p. 372).

Canonical studies of financial panics, their causes and possible policy solutions have sought to clarify the key market signals and social behaviors associated with bubbles (Kindleberger, 2011 [1978]; Galbraith, 1994). In the wake of the 2007–2008 global financial crisis, extensive efforts have been undertaken by firms, scholars and public authorities alike to model bubbles and identify statistical warning signals that can be used to anticipate and forestall crises (Aldasoro, Borio, & Drehmann, 2018; Best, 2016; Drehmann & Juselius, 2013). These tend to involve quantitative indicators, such as the growth rate of real credit or property prices relative to long-range trends. What have remained largely unexplored, however, are the qualitative dimensions of changing connections between ideas, objects and practices that underlie infostructures. While scholars drawing on network theory have usefully highlighted the significance of the topology of financial networks in shaping the occurrence, scope and intensity of financial crisis (Oatley, Winecoff, Pennock, & Danzman, 2013), their analysis focuses on the *quantities* of connections between nodes and does not engage with the *qualities* of the long chains in which information flows between globally dispersed actors and objects.

There have been valuable recent contributions to understanding the roles of information and knowledge in finance, but these too do not fully consider the distinctive properties of infrastructures noted above. For instance, MacKenzie (2011) identifies striking differences in the evaluation practices associated with asset-backed securities (ABS) and collateralized debt obligations (CDOs) despite their close structural similarities due to the historical path dependency of their organizational routines and how these contributed to governance through credit ratings. Tett (2015) identifies pathologies associated with information silos within banks and mental silos, which contributed to failures to recognize the emergence of larger systemic problems associated with the financial crisis. Bookstaber (2017) identifies four broad information-related properties of contemporary financial crises that standard economic approaches fail to address: emergent phenomena, non-ergodicity (things that cannot be treated as mechanical routines yet contribute to path dependency), radical uncertainty, and computational irreducibility (problems are

too complex to be reduced to formula). He shows the importance of heuristics in coping with these and models crises by creating a stylized set of interactions between financial actors (such as banks, hedge funds, funding providers) to explain the 2008 crisis. The emphasis on the emergent and therefore historical and path dependent character of 2007–2008 crisis is very useful in understanding the roles of knowledge limitations and information in crises. Yet, like other recent contributions, the focus is on human cognition, knowledge practices and information problems, which are implicitly conceived as independent of infrastructures.

What then is the distinctive contribution of financial infrastructures to crises? Fluid global markets with multiple financial actors, relatively intangible risks and values, and the need to ensure payments over large expanses of time and space are only sustainable with infrastructures that possess the first four properties set out above: facilitation, openness, durability and centrality. One-off arm's length communications over a phone may be sufficient to arrange and confirm a trade, yet finance only functions in the context of far larger socio-technical systems enabling the flow and exchange of trusted information about such matters as prices, ownership, values, reputations, standards and procedures. However, the fifth property of infrastructure, obscurity, contributes to a persistent tendency to underestimate its importance and vulnerabilities.

Power and profit-seeking then interact with the properties of infrastructures to create long chains whose development and decoupling can be identified in three phases. In the first, a new financial infrastructure is developed that opens commercial opportunities which a few knowledgeable firms eagerly exploit, followed by large numbers of less knowledgeable financial actors that rush in. A similar pattern was identified by Kindleberger (2011 [1978]) a half-century ago, yet from an actor-centered perspective that did not adequately consider the role of infrastructure. Actor-network theory and the SSF highlight the inseparability of these types of financial activities from the materiality of the technical artifacts and local settings that enable them. The rush into new financial activities is sustained by the close integration of ideas with material objects such as paper documents or electronic networks, which then begin to have distinctive organizational implications such as the development of shared standards (Hanseth, Monteiro, & Hatling, 1996).

In a second phase, fault lines develop as new and less knowledgeable financial actors further crowd into activities enabled by an infrastructure whose increasingly strained ability to carry out such activities is neither apparent to nor acknowledged by most financial actors or public authorities. The actions of firms in this phase are similar to the well-recognized tendency of dominant technology firms to try to exploit emerging technologies before their competitors master them and profits decline (Cantwell, 1989). Psychological, political and economic incentives to deny risks of disasters (Paine, 2002) contribute to the widespread overconfidence that Kindleberger (2011 [1978]) warned often precede panics and manias. While the limitations of human cognition play a part in this pattern, they interact with the properties of infrastructure. New types of financial communications technologies or documents act like prostheses (Haraway, 1991) that extend cognition, without necessarily revealing their limitations to the human actors using them, exacerbating the 'distancing' processes in which financial actors are disconnected from the impacts of their decisions (Coeckelbergh, 2016). These technical artifacts have a mixed public/private character that profit-seeking actors work to dominate in

strategic locations to maximize private returns while excluding others who become dependent on the open public character of an infostructure that is degenerating as fault lines develop (Howe et al., 2016).

In a third phase, what would otherwise constitute a minor impact from a break in the information flows enabled by fragile connections between disparate human and non-human actors contributes to a wider systemic crisis. Here the materialities of infrastructures have distinct effects that interact with the ideational intersubjective dimension of crises increasingly recognized in IPE (Broome, Clegg, & Rethel, 2012, p. 11; Widmaier, 2003, p. 64; 2004, p. 450; 2007, p. 55). Complex technical systems based on fast occurring and unanticipated relationships are inherently unmanageable and prone to what Perrow (1984) designated as 'normal accidents'. In conceptualizing this third and final phase of long chains decoupling, we draw inspiration from Didier Sornette's (2009) notion of 'critical rupture' to identify tensions in 'fault lines' that can transform otherwise random minor tectonic events into major earthquakes. Expanding his research into the analysis of financial crisis, Sornette argues that while any contingent event might remain fundamentally unpredictable, it is possible to identify points where the underlying tensions of a system lead events that might otherwise have had only minor impacts to set off chain-reactions leading to major tectonic or financial volatilities. We use the notion of 'fault lines' to refer to indicators of stresses or breaks in the overall integrative capacity of the financial infostructure. These may be multiple small examples of failures or gaps in information flows that signal accumulating stress. In contrast to the widely discussed 'black swan' theories that regard financial crises as fundamentally unpredictable events (Taleb, 2010), Sornette identifies moments when largely quantitative indicators call for pre-emptive action to avoid or at least mitigate the worst effects of financial crises (2009, see also Weatherall, 2013).

The pattern of long-chain development and decoupling we identify in financial infrastructures, and their material properties, point to the need to look beyond quantitative indicators and to develop complementary qualitative indicators that provide early warnings of the development of fault lines and possible decoupling of long chains. Any such indicator could include the four elements we highlight: (a) excessive openness and a surge of new participants into a socio-technical systems that (b) has become central to the functioning of the financial system despite (c) stress on connections between human actors and non-human objects, which are facilitating information flows in manners that are (d) fragile and vulnerable to shock yet nevertheless trusted and assumed to function. There are obvious measurement challenges with regard to each of these elements, as well as the overall scale necessary to provide a useful indication of impending systemic crisis. Detecting these elements in any single firm or widely used 'platform' may not signal a wider systemic crisis. As digitization continues into the future, text-mining may generate useful measures of both infostructure size and the fragility of connections between its globally dispersed human and non-human elements. At present, however, interpretive analysis of financial commentary and the character of emerging financial technologies can complement the statistical macro-economic indicators that, as noted above, tend to be used as early warning indicators of crisis by firms, scholars and public authorities alike (see also Borokova, 2016; Srnicek, 2018, pp. 7–8).

In addition to pointing to the need for developing qualitative fault line indicators, our analysis provides a further warning regarding governance efforts to address and resolve systemic financial crises. Not unlike the ‘path dependence’ well recognized in public policy scholarship (Pierson, 2000), the durable characteristics of infrastructures entail that regulatory efforts are typically embedded within the very infostructures that have contributed to volatilities. The very regulatory ‘retrofit’ undertaken to mitigate risks can paradoxically introduce new risks (Howe et al., 2016). The introduction of new ideas, objects and practices to repair the causes of the crisis can create the kind of commercial opportunities and risks that may spark the pattern we have identified anew.

In sum, finding fault lines in long chains involves examining both the interactions between dominant profit-seeking firms and the ideas, technical objects and practices that constitute infostructures. This focus is thus complementary to the larger extensive work on the IPE of finance, including the interaction of dominant firms with public authorities. To empirically illustrate the relationships between financial infrastructures, information and crisis that this section has developed theoretically, we turn to a trio of cases in which the development of fault lines in new large-scale infostructure shaped and conditioned different periods of crisis.

Fault lines in long chains and three financial earthquakes

This section examines three of the most significant changes in global financial infostructures over the past half-century: the loan syndication that preceded the 1980s debt crisis, the mortgage securitization that preceded the 2007–2008 global financial crisis, and the computerized securities trading that preceded the 2010 ‘Flash Crash’. While these developments and subsequent crises have been studied extensively elsewhere, the distinctive roles played by financial infrastructures in such periods of change and volatility have not received sufficient attention. Our cases are selected to assess the relevance of the pattern we have identified and not to claim that fault lines in long chains are either evident in *all* types of financial infrastructures, or that their decoupling is sufficient to explain and understand all financial crises. We also cannot provide a comprehensive account of the cases in the scope of this article. Rather our goal is to show how incorporating an analysis of long chains specifically and financial infrastructures more generally provide distinctive and useful insights complementing those produced in existing scholarly literature.

Syndicates and the 1980s developing country debt crisis

The debt crisis signaled by the 1982 Mexican government announcement that it could no longer service its bond payments threatened the stability of the global financial system and created enormous hardship for developing countries. This case study emphasizes how the introduction and subsequent expansion of a novel yet fragile infostructure produced stresses and fault lines in the long chains of information that conditioned the occurrence and scope of this financial earthquake.

Following problems with international bond markets in the Great Depression private lending to developing countries was minimal (Folkerts-Landau, 1985), but the 1960s witnessed a key change in the financial infostructure: syndicates consisting of

hundreds of banks sharing the risks of larger loans (Edwards, 1986, p. 568). Cross-default clauses in loan contracts helped ensure that a failure by a borrower to pay one bank would damage its subsequent ability to borrow from any bank, and government guarantees in the home markets of large international banks enhanced confidence in them (Edwards, 1986). This strengthened the hands of creditors relative to borrowers, forcing them to reschedule payments rather than default (Folkerts-Landau, 1985; Lipson, 1981). Change in long chains began in the largely unregulated London-based Euromarkets, facilitated by 'cheap reliable air travel, transcontinental telephone and telex communications, and the spread of computerization' (Healey, 1994, p. 79). International syndicated loans increased from \$7 billion in 1972 to \$133 billion in 1981 (Altunbas, Gadanez, & Kara, 2006, p. 694).

Throughout the 1970s, this new infrastructure contributed to a vast expansion of financial activity. An enormous inter-bank market funded longer-term loans to developing country borrowers from short-term borrowing in international wholesale inter-bank markets, facilitated by telephone and telex (Bank for International Settlements, 1983, p. 7). Long chains of financial information developed to allow banks from developing countries with knowledge of local conditions to link up with international banks headquartered in financial centers (Alvarez, 2015; Altunbas et al., 2006, p. 693).

However, fault lines in the long chains of financial information developed as relations among participants in the interbank market became more atomistic, reducing accountability. As the Bank for International Settlements (1983, pp. 33–34) described it,

...banks frequently deal with a large number of counterparties in the market, and many may not be fully aware of the management structures, balance sheets or the nature of the business of banks with which they deal in the interbank market.

Brokers began displacing the direct dealing between banks, reducing information flows (Bank for International Settlements, 1983, p. 8). The share of private debt not guaranteed by governments increased, encouraged by the belief that private actors had a self-interest in and were skilled at anticipating risks (Devlin & French-Davis, 1995, p. 124).

The new infrastructure enabled an over-reliance on short-term financing of longer-term loans, obscuring the possibility that disruptions in the long chains connecting dispersed actors and objects could lead to the shrinking of this financing (Guttentag & Herring, 1985, p. 3). The follower banks in syndicates relied on the risk assessments of a relatively small number of lead banks which may have had an incentive to downplay that risk in order to get the follower banks to continue to lend while collecting lucrative fees for organizing the syndicate (Gai, 1997, p. 62). Rather than risk assessments, information memoranda about borrowers from leading banks often simply resembled sales documents (Bogdanowicz-Bindert & Sacks, 1984, p. 71). Well-paid and mobile but inexperienced lower-level loan officers had an incentive to offer loans that did not accurately reflect the risks of the foreign borrowers since they could move on from the bank before risks became apparent, and their managers back home were not familiar with the international infrastructure (Darity, 1986).

The 1982 Mexican moratorium on debt payments triggered panic in financial markets. This relatively localized event sparked wider panic amongst banks due to

fault lines in the informational infrastructure developed over the previous decades. Banks were unsure of their exposure to the sovereign debt of developing nations in similarly precarious situations. Even for leading banks, expanding volume and reduced loan spreads, combined with overconfidence in sovereign borrowers, had led to a neglect of risk assessment (Kettel & Magnus, 1986, p. 62). The major American banks, the leaders of the system, were in fact very heavily exposed to the subset of countries least able to sustain their interest payments. In 1986, the top nine American banks had a \$41 billion exposure to the four most indebted countries: Argentina, Brazil, Mexico and Venezuela. At the end of 1982, the exposure of these banks to the least developed countries was 288% of bank capital, with all American banks having a 187% exposure (Sachs, Huizinga, & Shoven, 1987). As awareness of the crisis spread, small and medium banks, which had relied relatively more on trust in the new infostructure, began to pull away from the syndicated loan market. The interbank component of the international markets declined for the first time in 1983, after six years of 26% annual growth rates (Kettell & Magnus, 1986, pp. 48–49).

Overall then, this case displays the three phases of the long development and decoupling that we identified theoretically. First, the development of a syndication infostructure played a key role in the initial boom that connected various dispersed actors and objects together into long chains. As with other financial infrastructures, syndication integrated human cognition with widely recognized practices and the materiality of the documents, telexes and other communication systems that enabled it. Second, dominant profit-seeking firms exploited the opportunities the infostructure provided, drawing in less knowledgeable ones. The obscurity of the infostructure contributed to unwarranted confidence in it, and lack of awareness of the fault lines developed. Third, a relatively localized event sparked wider panic amongst actors that had been linked together in a fragile infostructure. All four of the elements of our qualitative early warning indicator were evident: the surge of new participants; the presence of a new and large-scale infostructure; the decreasing quality of the connections enabling information to flow amongst actors and objects; the excessive trust that the infostructure would remain stable. Each of these elements also become apparent two and a half decades later in the run up to the most severe period of volatility since the Great Depression.

Securitization and the 2007–2008 global financial crisis

The outbreak and development of the 2007–2008 crisis is by now a well-known story, provoked amongst other factors by cognitive and ethical failures, by regulatory failures, by poorly designed financial products, by accumulations of risk in particular firms such as AIG, by financial relationships between the US and the rest of the world, including cheap credit from China, and by many other large and small problems. However, the role of the securitization infostructure throughout this has not been fully recognized, despite displaying fault lines in long chains of financial information that were remarkably similar to those afflicting the syndication infostructure in the early 1980s. Extensive analysis of the 2007–2008 global financial crisis tends to underemphasize the important role played by the decoupling of the securitization infostructure that led rising defaults in a relatively

obscure sector of the American mortgage markets to spark the most severe period of financial market instability since the Great Depression.

A new infostructure enabling bank loans to be securitized began to develop in the 1970s as actors and objects dispersed around the world were connected together through long chains in which risk was believed to be spread rather than concentrated. Multiple bank loans were packaged into securities that were sold first to off-balance sheet special purchase vehicles (SPV) and subsequently to investors as ABS. Much like syndication, the infrastructural character of securitization is obscured if considered only to be the practices resulting from choices or schema in the heads of financial actors. Certainly, securitization began with an innovative idea. Yet, it only grew into a vast globally connected infostructure through the close integration of dispersed humans and objects. Digital modeling 'cashflow analytics' systems like Intex, for instance, were harnessed in making the profit-potential of ABS 'mentally tractable' (MacKenzie, 2010) to their producers, sellers, buyers and other actors like the credit-rating agencies (CRAs) who granted the crucial ratings for institutional investors to purchase securitized products. Furthermore, credit default swaps (CDS), a type of tradable derivative contract, were used as a form of insurance that was expected to pay out if the issuers of the complex securitized products defaulted on their payments. Fieldwork by Riles (2008) has highlighted the importance of paper forms standardized by the International Swaps and Derivatives Association for the sustainability of these and other derivatives.

In the 1990s and early 2000s, fault lines in the long chains emerged as new sets of non-bank financial firms, such as Countrywide Financial, rapidly expanded their roles in the markets enabled by the securitization infostructure. Fast growth in securities that bundled together an increasing array of car, credit card, home equity, student and other types of loans led to a momentous expansion of risks that were not initially visible to most market participants (Bryan & Rafferty, 2006; Buffet, 2002; Tsingou, 2006). Although meant 'to diffuse and reduce risk' securitized products were marked by a growing 'deterioration in the quality of the underlying financial assets' (Boyer, 2013, p. 10). In particular, mortgage-backed securities (MBS) began containing large quantities of 'sub-prime' loans of increasingly dubious quality. Despite exceptions, many large investment banks and CRAs relied on simulations as well as cash flow and risk models rather than expending resources to do more fine-grained research into the quality of assets underlying their securitized products (Crotty, 2008, p. 27). These models, however, tended to obscure risks by, for instance, not integrating sufficient information on earlier periods of systemic instability, or in the case of Intex providing limited information on complex CDOs made up of contained pools of MBS and other ABS, including 'tranches' of other CDOs (MacKenzie, 2010). As a result, opacity particularly characterized markets for securities often comprised of bundles of re-packaged MBS. The very materiality of standardized infrastructural objects contributed to the obscurity of the securitization infostructure, such as when piles of paper loan documentation went unread by CRAs or loan officers in banks.

These fault lines in information flow continued to be disregarded as key market actors profited handsomely and politicians complacently enjoyed the economic boom (Cameron, Nesvetailova, & Palan, 2011, p. 124). CRAs and other market firms, for instance, relied on models that 'often led to serious underestimation' of the risks in products like CDOs, which were analyzed as if they were regular bonds

or securities rather than extremely complex financial instruments (MacKenzie, 2010). Lacking financial incentives to recognize and act on such fault lines, these and other profit-driven actors, such as the investors who bought such securities, all largely ‘underestimated the riskiness of the assets’ (Sinclair, 2009, p. 452). Those investment banks that did recognize such risks sought to profit on the wider lack of knowledge by misleading clients into purchasing toxic CDOs, most infamously in Goldman Sachs’ ABACUS-2007-AC1 (de Goede, 2017, pp. 201–203).

Securitization thus became much more than an idea, technique or a set of products. It was a widely recognized practice enabled by the integration of globally dispersed actors and technical artifacts such as the hardware and software widely used to produce and circulate ‘value at risk’ calculations (Lockwood, 2015), or the standardized derivatives forms mentioned above. The assemblage of these infrastructural elements possessed the four infrastructural properties that enabled the rapid expansion of markets (facilitation, openness, durability and centrality) but also the fifth property, obscurity, that contributed to the concealment or unawareness of the fragility and limitations of the securitization infostructure. Profit-seeking firms were eager to privately appropriate the opportunities that the infostructure facilitated without adequately recognizing and addressing the growing risks that by 2007 included the rising rates of default in American subprime mortgage markets. This relatively localized mortgage default problem then turned into a global liquidity crisis in part due to the specific informational fault lines present in the fragile composition of the long chains assembling disparate actors, objects and practices into a global market for CDOs and other complex securities (Brunnermeier, 2008, p. 27).

The very infrastructural properties that had contributed to the expansion of markets for securitized products as well as fault lines in the long chains enabling flows of financial information also contributed to the rapid spread of the crisis in 2007–2008. The initial liquidity crisis wherein attempts to simultaneously offload holdings of ABS instigated a freeze in the markets for such securities as well as the money markets through which most banks finance their daily operations was in part a result of individual banks not having sufficient holdings and sources of liquid funding. However, the liquidity crisis was also created by the inability of the securitization infostructure to carry the needed information flows as the crisis developed. Certainly, the increasing reliance on intangible calculations of value such as ‘mark to model’ accounting in the absence of market prices contributed to the information failures. Yet, destabilizing effects were amplified and transmitted by infrastructural deficiencies, such as the physical impediments to the flow of information needed to produce prices, and the interdependencies that the infrastructural linkages had created. Banks, investors and other market actors were simply unable to judge the extent of losses on securities containing pools of subprime mortgages. In an International Monetary Fund Working Paper discussing the role of securitization in the crisis, Segoviano, Jones, Lindner, and Blankenheim (2011) note how the ‘operational infrastructure’ overwhelmed servicers and trustees that arranged payments and administered SPVs, the CRAs and the monoline insurers.

The decoupling of the long chains enabling the securitization infostructure in 2007–2008 has close parallels with the 1980s debt crisis. All four of the elements of our qualitative indicator were once again evident: the surge of new participants, the presence of a new and large-scale infrastructure, the deterioration in quality of the information flows, and the excessive trust in the stability of the infostructure. The

development of the securitization infrastructure integrated human cognition with widely recognized practices and the materiality of the documents, computing technologies and other communication systems that enabled it. Dominant firms exploited the profit-making opportunities the infrastructure provided, drawing in less knowledgeable ones. The obscurity of the infrastructure contributed to unwarranted confidence in it, and lack of awareness of the growing risks associated with it. These fault lines led a relatively minor break in the long chains of financial information to set off a wider systemic crisis, the most severe financial crisis since the Great Depression. Our third example of how fault lines in long chains advance understanding financial volatility turns to the computerized trading infrastructure whose introduction and expansion over several decades conditioned the occurrence and scope of the 2010 Flash Crash.

Computerized trading and the 2010 Flash Crash

Like the 2007–2008 global financial crisis, numerous factors have been associated with an event entailing the disappearance of one trillion dollars in market value in a time span of just 20 minutes on the afternoon of 6 May 2010 (Commodity Futures Trading Commission and Securities and Exchange Commission, 2010; Kirilenko, Kyle, Samadi, & Tuzun, 2014; Moosa, 2015). Although alluded to in post-crisis reports and investigations, fault lines in the long chains that underpinned a computerized trading infrastructure developed over several decades have been largely overlooked (Borch, 2016).

The new financial infrastructure began to develop as globally dispersed actors and objects became integrated into long chains in which algorithms, fiber-optic cables and data centers connected through electronic communication networks (ECNs) enabled flows of information to traders around the world. Electronic buy and sell order books enabled information on the prices and quantities of bids to be nearly instantaneously displayed to traders. By the mid-1990s, digital processing of information by algorithms led to the automated placing as well as canceling of orders. Although designed and continually refined by human ‘quants’, these technical objects enabled HFT at speeds of up to a millisecond, as well as ‘ultra-HFT’ to be automatically executed in nanoseconds. Meanwhile, new digital exchanges developed at the beginning of the new millennium posed challenges to the existing commodity and stock exchanges, who in turn allowed computerized trading to gradually overtake verbal trading over telephones and in ‘pits’ (Golumbia, 2013; MacKenzie & Pardo-Guerra, 2014).

This infrastructure developed fault lines as the varieties and volumes of financial products traded electronically grew rapidly. In the 1990s, major actors in every region and segment of global finance began to employ and rely upon some form of computerized trading (Lin, 2014). By the early 2010s, HFT, for instance, came to account for more than half of equities and futures trading in the United States (Cardella, Hao, Kalcheva, & Ma, 2014, p. 232). The potential to make better informed and faster trades drove a ‘war for profit’ and major expansion of computerized trading (Hardin & Rottinghaus, 2015, p. 558). An ‘arms race’ (Harris, 2012) developed as firms sought to overcome so-called latency, or relative slowness, by harnessing increasingly powerful computers and by paying ‘the (very high) salaries of the experts required to constantly tweak the algorithms’ (Snider, 2014, p. 753).

Financial firms with sufficient resources to afford renting space in the data centers of exchanges ‘co-located’ their computer servers in order to decrease or eliminate such latency. Yet, such ‘symbiosis’ (MacKenzie, Beunza, Millo, & Pardo-Guerra, 2012) enhanced the vulnerabilities of the computerized trading infrastructure to technical malfunction at exchanges that were shut down due to outages on numerous occasions (e.g. *New York Times*, n.d.).

The obscurity of infrastructural elements that made automated trading profitable also created incentives that thwarted recognition of the growing fault lines in the computerized infrastructure. The global expansion of computerized trading relied on largely unseen networks of fiber-optic cables across oceans as well as micro-waves placed on top of tall buildings that remained vulnerable to seabed trawling and heavy rain, respectively (Borch, Hansen, & Lange, 2015; MacKenzie, 2018, pp. 513–514). As in the case of securitization, the computerized trading infrastructure relied on models and algorithms that in some cases drew on limited information histories and in others had difficulties incorporating qualitative data or navigating the complexities of markets plagued by predatory trading intended to fool competitors into revealing their strategies. Research on foreign exchange markets revealed how HFT strategies often mirrored one another and were ‘not as diverse as those used by human traders’ (Bias & Woodley, 2012, p. 35). Even those actors best able to distinguish and benefiting from ‘evolved capacities to process market noise’ (Dragos & Wilkins, 2014), lacked financial incentives to recognize and act on growing fault lines (though exceptions included Arnuk & Saluzzi, 2008, 2009). Instead of attending to these fault lines, computerized trading in general and HFT, in particular, thrived on the rapid fluctuations in market prices, with some firms reportedly earning 10 times their typical profits during the crises of 2007–2008 (Spicer & Lash, 2009). Such volatilities were of course not unrelated to the development of this new infrastructure, with computerized trading recognized as a contributing factor to the 19 October 1987 Black Monday crash in which the Dow Jones Industrial Average dropped by nearly a quarter within a few hours (Carlson, 2006, p. 4; Norris, 2012). Nevertheless, overconfidence in the sophistication of computerized trading infrastructure entailed that risks of disruption to the long chains enabling information flows were not addressed.

Fault lines in the computerized trading infrastructure enabled a minor break in a long chain assembling globally dispersed actors and objects together to produce a short but intense period of volatility over 20 minutes on the afternoon of 6 May 2010. According to one controversial report critical of the official joint investigation conducted by the US Commodity Futures Trading Commission and Securities and Exchange Commission (Buchanan, 2011; *Nanex*, 2010), at approximately 14:42:44:075 pm, a ‘tidal wave’ of electronic orders overloaded the capacity of market actors to calculate prices. The resulting delays quickly led to drops in prices that sparked a herd-like sell off a wide range of unrelated stocks in a wider panic that negatively affected nearly all traders, some of whom were nevertheless able to reap handsome profits from the short but extreme market volatility. The decoupling of the long chains of financial information was triggered by a mismatch between the volume of trades made possible by electronic trading and HFT programs, the speed at which HFT programs reacted to delays in price changes, and the computational capacities HFT programs used to accurately measure prices in a timely manner.

The long chains underlying the computerized trading infostructure shaped not only what triggered a crisis but also how it unfolded. Computerized trading integrates human cognition with widely recognized practices and the materiality of the documents, computing technologies and other communication systems. Dominant profit-seeking firms exploited the opportunities the infostructure provided, drawing in less knowledgeable ones. The obscurity of the infostructure contributed to unwarranted confidence in the financial practices it enabled, as well as a lack of awareness of the risks associated with it. Once again all four of the elements of our qualitative indicators were evident in this case: the surge of new participants; the presence of a new and large-scale infrastructure; degrading quality of the connections between human actors and non-human objects enabling information flows; excessive trust in the stability of the infostructure.

What do these three cases tell us?

Large-scale infrastructural change of the type that we theorized as prone to fault lines in long chains contributed to the three financial crises that we identified. The specific characteristics of the infostructure differed, with telexes being important in the syndication case, computerized calculations in the securitization case and high-speed networks in the HFT case. However, in all three cases, the five defining properties of infrastructure were present: facilitation, openness, durability, centrality and obscurity. These properties contributed to the rapid expansion of the markets, the concealment of and inattentiveness to the risks that were accumulating, the crowding in of new and less knowledgeable firms, the inability of the infrastructure to keep up with the required volume of information flows as it came under stress, and the rapid transmittal of the crisis once it began.

Recognizing the well-known factors that contributed to each of these crises, our emphasis on infrastructure provides two new types of insights that have not been adequately considered in the literature and policy discussions analyzing these events. The first is to highlight the larger roles played by infrastructure, which is valuable in conceptualizing how different actors and objects are brought together in launching new markets, and how their interactions can lead to a pattern of rapid expansion and collapse. Our emphasis on the physical properties of technical objects that sustain and connect actions in local contexts is very different from prevailing analyses that stress larger and more intangible factors, such as abstract measures of the growth of credit, leverage, global imbalances, financialization or the accumulations of risk. It also differs from the approaches discussed above (Bookstaber, 2017; Tett, 2015) that focus on the limitations of human cognition and abstract knowledge. While valuable, these types of more abstract explanations miss the significance of the distinctive properties of infrastructures, including their materiality.

This conceptual insight then enables a second more empirical and practical set of qualitative warning signs in order to *anticipate* systemic financial crises that have been occurring at increasingly shorter time intervals (Haldane, 2010). In each case, all four of the elements of our qualitative fault line indicator were evident: the surge of new participants; the growing centrality of a new and large-scale infrastructure; the degrading quality of the information flows; and the trust in the system accompanied by the tendency to background its growing fragility. Market

participants and governmental actors were very aware that a new assemblage of ideas, objects and technology-enabled practices had appeared and become significant to their activities. Despite widespread commentary on the novelty and significance of syndication, securitization and HFT, little explicit attention was given to the fragility of connections between elements of the new infostructure. A surge of new participants was visible and easily measured quantitatively and qualitatively. The information problems were also visible. For instance, as noted in the syndication case, information memoranda about borrowers from leading banks began to resemble sales documents rather than discussions of risk. In that historical moment, financial actors excused such information deficiencies because of their trust in the new infostructure, and many enthusiastic commentaries about the capacities of the new technologies appeared in business, official and popular publications, which is a measure of the element of trust.

As noted earlier, we are not claiming that elements of qualitative fault line indicator are present in all crises, or that these alone are sufficient to always predict the crisis. However, if all four elements appear it is highly likely, in the absence of governmental intervention, that crisis will follow. The implication is then that much more regulatory attention must be devoted to the qualitative character of existing and emerging infostructures in global finance if crises are to be anticipated and prevented. It is not sufficient to try to ensure that individual actors can weather crises, whether these are sovereign borrowers and banks involved in syndicated loans, SPVs in the 2008 crisis, or firms engaged in computerized trading at greater and greater speeds. Nor is it sufficient to optimistically assert that flaws in financial infrastructures can 'be fixed by technocrats with new tools' (Engelen et al., 2012, p. 363, 373). Speaking metaphorically, it would be far better for regulators to focus on the varying *quality* of pipes and wires than to ask users of utilities to store extra *quantities* of water or electricity. Global financial infostructures are far more complex, yet a similar degree of attention to the materiality of the long chains sustaining information flows in finance is equally needed. Future research will allow further refinement of all these measures, but our cases provide an initial confirmation that such a qualitative fault lines indicator can be a useful complement to other existing quantitative ones and others that are being developed.

Finally, our cases prompt further reflection on how generalizable the pattern in which long chains develop fault lines and decouple may be. While it reached the threshold of a new large-scale infrastructure, the scale of the computerized trading infostructure in 2010 was more constrained than were syndication or securitization infostructures in 1982 or 2007–2008, respectively. Although it reached a high share of trades in certain markets, computerized trading was not as thoroughly linked to the larger global financial system as the other infostructures we examined were. The 'Flash Crash' was commensurably smaller and shorter as well, suggesting that the pattern that we identify is likely also to be present at smaller scales, but perhaps less easily observed. Confirming this, however, would require further research along the lines we suggest after a penultimate section illustrating the wider implications of our analysis for governance.

Implications for governance

The pattern we have identified in the development and decoupling of long chains has both theoretical and practical implications for global financial governance.

Governments have traditionally played key roles in the development of infrastructures for reasons that are closely related to the five properties of infrastructures. The properties of *centrality* and *facilitation* mean that infrastructures are crucial to other widespread activities that citizens and governments care about, even if the *obscurity* of infrastructures entail that their users do not directly care about them. The essential *openness* of infrastructures further adds to the tensions with developing shared standards and difficulties even raising funding for their continued function by charging or taxing users. The *durability* of infrastructure also typically requires the capacity to make longer-range commitments that is one of the advantages that governments have over markets.

Conventional rationales for governmental responsibility for infrastructures also express these points in conceiving infrastructures as natural monopolies, non-excludable public goods or essential services. As a World Bank report (Kessides, 2004, p. xi) has put it,

Infrastructure's enormous economic importance, a desire to protect the public interest in industries supplying essential services, and concerns about private monopoly power led governments to conclude that control over these services could not be entrusted to the motivations and penalties of free markets. Governments also believed that, given the large investments involved, public resources were required to increase infrastructure coverage. Accordingly, a single public entity usually controlled every aspect of a utility.

This report goes on to applaud the widespread push to privatize an infrastructure that allegedly had become too big, complex and costly for governments to manage. Yet the report also soberly analyzed the widespread problems that the privatization of water utilities and other infrastructure had created. It notes that 'effective regulation – including the setting of adequate tariff levels – is the most critical enabling condition for infrastructure reform' (Kessides, 2004, p. xii). In the push to privatize, the organizational capacities of markets tend to be overestimated and the pathologies of self-interest associated with them were underestimated. Infrastructure regulation, with its more complicated mix of public and private elements than traditional public utilities, can resemble the type of governmental regulation that is feasible and required for global financial infrastructures to function.

The global financial infrastructures that our cases have explored are prone to the same types of infrastructure governance problems as identified by the World Bank, exacerbated by their even greater complexity and scale, and the widespread failure to even recognize their infrastructural properties. These problems were exacerbated since all three large-scale infrastructures underpinning syndication, securitization and computerized trading were novel when they emerged. Moreover, in contrast to traditional utilities, these infrastructures took the less recognizable form of an assemblage of ideas, practices, technical artifacts and other objects distributed globally across very diverse locations and types of actors. The infrastructure needed to sustain long chains of information in global finance is more complex than pipes carrying water or wires carrying electricity and involves more potentially fragile connections between disparate human actors and objects to be maintained in stable manners.

One of the key policy insights that arose out of the 2008 global financial crisis was the need to go beyond the prevailing emphasis on micro-prudential regulation and consider macro-prudential regulation (Baker, 2013; Best, 2016; Goodhart, 2015; Jácome & Nier, n.d.). The micro-prudential emphasis on the solvency of individual

banks had failed to consider sufficiently the systemic properties of risk, with the latter reflecting the heightened interconnection of financial actors as the global financial system had evolved. This has tended to be conceptualized as rather abstract ‘interconnectedness externalities’ (see Kenç, 2016) – effects of financial activities that are not captured in prices. Key official responses have included the identification of systemically important financial institutions (SIFIs) and the imposition on them of higher capital requirements, as well as counter-cyclical capital buffers, liquidity requirements and other global regulatory standards that focus on systemic risk but primarily through the individual firm’s capacity to weather it. The creation and adequate capitalization of central counterparties (CCPs) and trade repositories (TRs) in derivatives markets are similar (see Genito in this special issue). As noted previously, there has also been an emphasis on developing macro-economic statistical early warning indicators of crises. While all these initiatives are valuable, they tend to neglect the role of infrastructural properties in crisis, including the materiality of connections enabling basic but crucial flows of information.

Private sector and official responses that sought to address fault lines in long chains without adequately considering how their infrastructural properties created new systemic risks in each of our three cases. In attempts to repair the syndication infostructure, debt was securitized with governmental assistance, for instance with Brady bonds that converted bank loans to developing countries into tradable securities. However, inadequate attention to the infrastructural properties of this type of growing global securitization of official debt contributed to the Mexican and East Asian crises of the 1990s. In post-2008 regulatory repair of the securitization infostructure, concerns remained regarding whether the proliferation of information reported to TRs is too complex and unstructured to be usable (Brammertz & Mendelowitz, 2014), as well as whether CCPs centralized risks in manners undetected by regulatory monitoring mechanisms (Genito, this issue). In post-2010 repair of the computerized trading infostructure, circuit breakers were added to several exchanges to curb market crashes in volatile periods. These ‘kill switches’ have however been widely critiqued. As two market practitioners put it, circuit breakers merely form a ‘short-term band-aid’ that does not fundamentally address trading volatility, which can resume in even more severe form following forced ‘time-outs’ (Arnuk & Saluzzi, 2012, p. 90). In a parallel set of efforts to improve understanding of how market volatilities rapidly develop and spread, the SEC mandated national securities exchanges and their private sector regulator in 2012 to develop centralized information archives on billions of financial trades. The full launch of the Consolidated Audit Trail (CAT) has however been delayed and the scope of information originally intended for collection curtailed due to concerns of vulnerabilities to hacking that were enhanced following prominent cybersecurity breaches of centralized databases maintained by the leading bank JP Morgan Chase in 2014, the credit rating firm Equifax in 2017, as well as the SEC itself a year earlier (Bain, 2017; Fazzini & Moyer, 2019).

Attempts at regulatory repair and their limits highlight how governance responses to crises are significantly shaped by existing fault lines in infostructures, as well as potentially introduce new fault lines in developing additional long chains to circulate financial information. Table 1 provides a summary of each stage of the pattern identified across the three periods we investigated, as well as the subsequent risks introduced in governance responses. The latter point to the potentially

Table 1. Summary of phases in long chain development and decoupling, governance responses, and introduction of new risks across three periods.

Period	<i>Phase 1:</i> Introduction of New Infrastructure	<i>Phase 2:</i> Expansion of Financial Activity & Accumulation of New Risks	<i>Phase 3:</i> 'Break in Chain' and Wider Instability	Regulatory Repair & New Risks
1960s–1980s	Banking syndicates	Overextension of loans to developing countries	Disrupted information flows on exposure to 1982 moratorium on debt payments	Converting debt into tradable securities extends risks in new infrastructure
1970s–2000s	Securitization	Overextension of subprime loans while obscuring default risks	Disrupted information flows on exposure to subprime loans & 2007–2008 global financial crisis	Central counter-parties and trade repositories increase complexity and concentrate risk
1980s–2010s	Computerized trading	Race for speed with (ultra) high- frequency trading	Disrupted information flows on leading to flash crashes	Centralization of information enhances risks of hacking

recursive trajectory of fault lines, a characteristic identified in other recent studies that have harnessed Latourian chains in highlighting how further application of this concept and other insights from STS can advance our understanding of financial crises as well as other key processes and events in the global political economy (de Goede, 2017, 2018; Welfens, 2019).

Conclusions

Understanding financial crises remains incomplete without considering how the factors identified in various IPE analyses of these events are drawn together, as well as drawn apart, in infostructures underlying the global financial system. This article argued that the occurrence, scope and management of financial crisis are significantly conditioned and shaped by the form and varying composition of both material and ideational mechanisms involved in producing, transmitting and analyzing financial information. How specifically such information is stored, circulated and incorporated into financial activities impacts the types of events contributing to financial crises, how they unfold once they begin, as well as the kinds of governance strategies that can be deployed to resolve them. Economic, political and technical factors are all intertwined in long chains as powerful wealthy actors benefit from the initial expansions of new infostructures, as well as the subsequent fault lines that develop in the connections between the disparate human actors and non-human objects.

In helping us to conceptualize these relationships, we harnessed the metaphor of fault lines along with the Latourian concept of long chains to outline a pattern in which infostructures develop and decouple over three distinct phases. First, the development of new informational infrastructures enhances the management of risks and enables expansions of financial activities, benefiting the firms that establish or dominate these infrastructures. Second, further expansions of financial activities overburden the capacity of the system to adequately manage risks, rendering the system increasingly vulnerable to breaks in information flows. Third, because of the fragile

character of the long chains assembling together disparate actors, objects and practices in global financial markets, ruptures that might otherwise contribute to minor volatilities end up causing in major 'earthquakes', rather than minor tremors.

This pattern was then detailed across three periods in which the linkages between actors, objects and practices in long chains channeled information in fragile manners that built up stresses and ultimately contributed to the destabilization of financial markets. New market opportunities and superior risk management were offered by evolving infostructures underpinning the syndications of international inter-bank markets in the 1960s and 1970s, as well as the securitization of financial products and development of computerized trading since the 1980s. Confidence in these new infostructures enhanced financial activities yet contributed to the accumulation of new risks as financial activities became more frenetic, complex and voluminous. Fault lines in the long chains of financial information developed further as these risks became obscured. Powerful actors who benefitted from the expansion of financial activity were incentivized to ignore such problems while the very importance of the infostructure itself, or often even its presence, was not recognized. Finally, breaks in long chains of financial information that might otherwise have resulted in minor volatilities contributed to systemic rather than more localized market panics. The 1982 Mexican moratorium on debt payments, rising American subprime mortgage defaults in 2007, and faulty trading platforms in the 2010s were all set off by relatively small and localized events that became much wider panics as flows of information underpinning global financial markets were disrupted.

This analysis contributes to scholarly and policy literature on financial crisis. First, identifying patterns of fault line development in long chains bridges literature that has tended to stress the material and cognitive dimensions of financial crises separately. The patterns we identify are *not* suggestive of a generalizable theory of financial crisis that *replaces* other existing explanations of these events. To the contrary, financial infostructures and the patterns associated with them interact with powerful self-interested states and firms, national and transnational regulatory arrangements, intersubjective understandings, as well as many other important dimensions of global finance and financial crises that have been extensively and very fruitfully explored by IPE scholars. We have noted some of these interactions, such as the way dominant firms seek to enhance their power and profits by creating and controlling infrastructures, the manners established infrastructures can fade from view, influencing intersubjective understandings of their existence and their significance for risks.

Second, there are important governance implications arising from tracing breaks in long chains of financial information. Here the take-away is not simply that infrastructures matter. More specifically, it is that identifying and interrogating the quality of connections between dispersed actors and objects enabling infostructures is a crucial and necessary task for understanding and stemming the outburst and breadth of systemic crises. Recognizing the often fragile manners in which connections between human practices and non-human objects significantly shape flows of financial information is essential for identifying the kinds of events that can or are likely to set off a crisis, the way that this crisis plays out when it unfolds, and the solutions that can plausibly be deployed by regulators once crises begin. Attempts to repair 'fault lines' in the long chains of information may introduce novel sets of

risks and fault lines into existing or new infostructures. Whether new information reporting to private institutions like the TR or quasi-public initiatives like the CAT, the governance strategies undertaken to combat one set of risks can introduce new sets of risks. This does not fatalistically entail that the global financial system is forever doomed to instability, however. Extending the efforts of Didier Sornette and others to develop quantitative early warning indicators, we have argued for the development of complementary qualitative indicators of fault lines for anticipating financial crises based on each stage in the pattern through which long chains decouple.

In the context of generally increased uncertainty of the financial system, policy-makers have increased their effort to measure and manage systemic risks. This has led to a search for the proper metrics through which inherently more difficult to measure systemic risks can be effectively measured and managed. While recognizing the measurement challenges involved, qualitative indicators along the lines we have suggested could help to prevent crises by improving understanding of how the operations, roles and fault lines of financial infostructures are evolving. Attention to both the material and qualitative character of long chains provided by actor-network theory specifically and SSF more generally can helpfully trace changes in how information is produced, stored, transmitted and analyzed in financial markets. Echoing the introduction to this special issue, persistent stress on concepts central to IPE is important in more widely situating the scale and governance implications of such changes in infostructures, as well as in more effectively assessing both their innovative and disruptive potential. Further insights can likely be gained from examining the development and coming apart of other infostructures, both in the past, as sociologists have investigated with developing country debt crises (e.g. Suter, 1992), as well as in the ongoing emergence of Big Data and blockchain-based financial infostructures (Campbell-Verduyn, Goguen, & Porter, 2017; see also Clarke, Roderick, Rodima-Taylor & Grimes, this special issue). There is much further for IPE scholars and policy-makers to gain by evaluating how specific governance institutions, such as the Committee on Payments and Market Infrastructures at the Bank of International Settlements, enhance recognition of the quality of long chains linking together ideas, objects and practices dispersed globally across locations and types of actors.

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