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Rethinking financial stability: Challenges arising from financial networks' modular scale-free architecture

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ABSTRACT

We examine the connective architecture of the main Colombian payment and settlement systems in order to update what we know about local financial networks, and to elaborate on the main consequences for financial stability. Evidence suggests that local financial networks display a modular (i.e. clustered) scale-free (i.e. inhomogeneous) architecture. Results concur with other real-world networks, and propose new insights and challenges for authorities contributing to financial stability. For instance, (i) traditional reductionist assumptions for modeling financial systems (e.g. homogeneity) may be particularly misleading; (ii) the observed modular scale-free architecture favors robustness and resilience; (iii) the generating process of such architecture overlaps with literature on trading relationships; (iv) carelessly reducing inhomogeneity in financial systems may backfire in the form of a less robust and less resilient financial system; and (v) financial authorities should understand and take advantage of the existing architecture by means of designing and implementing macro-prudential regulation and system-calibrated requirements.

1. Introduction

Identifying and examining the connective architecture of financial systems has been pinpointed as a critical factor for understanding financial markets. As is the case of other complex systems, the architecture of financial systems not only reveals how they have evolved, but it also suggests how they may be affected by shocks, and how authorities should intervene in order to pursue its safe and efficient functioning. In this vein, unlike traditional institution-centric (i.e. micro-prudential) approaches to financial markets, a comprehensive or macro-prudential approach that addresses the architecture of linkages between financial institutions may aid authorities to better understand, regulate, supervise and oversee the financial system.

Network science has been widely used for examining the connective architecture of complex systems. It contrasts, compares and integrates techniques and algorithms developed in several disciplines to increase the understanding of natural and man-made networks (Börner et al., 2007). Under the network analysis approach financial markets are nothing but a weighted and directed network among financial institutions (Barabási, 2003). Thus, financial networks may be studied and analyzed with the aim of identifying, examining and contrasting financial markets' main connective features in order to better understand their structure and evolution.

Accordingly, our work uses network science with two main objectives. First, we identify and examine the connective architecture of transactions from the three main Colombian payment and settlement systems. Second, we contrast their main actual features with those assumed by traditional models of financial systems (e.g. Allen and Gale, 2000) and with those documented for most real-world networks. Such examination and contrast serves the purpose of updating what we know about the connective architecture of local financial networks and to elaborate on how to pursue

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financial stability under a macro-prudential approach. In this sense, our work elaborates on the importance of taking into account financial networks' structure when trying to devise policies that enhance the resilience of the financial system (Battiston et al., 2009).

Our work verifies that local financial networks exhibit a modular (i.e. clustered) scale-free (i.e. inhomogeneous) structure, a ubiquitous architecture well-documented in other social and biological networks. Related literature points out that the inhomogeneity in scale-free networks yields a structure that is robust to random shocks but fragile to targeted attacks, as in the nowadays celebrated "robust-yet-fragile" characterization of financial networks by Haldane (2009). On the other hand, a modular architecture favors resiliency by limiting cascades and isolating feedbacks (Anderson, 1999; Haldane and May, 2011; Kambhu et al., 2007). Therefore, according to literature on networks, the observed modular scale-free architecture tends to make the financial networks under analysis robust and resilient, yet fragile.

The observed connective architecture contradicts the main assumptions of conventional research on financial contagion and financial stability (e.g. Allen and Gale, 2000; Battiston et al., 2012; Cifuentes et al., 2005; Freixas et al., 2000; Gai and Kapadia, 2010; Nier et al., 2008). The modular and scale-free architecture of financial networks invalidates traditional homogeneous and non-hierarchical oversimplifying case models, and cautions about how prior beliefs regarding contagion and financial stability may be unfounded and potentially misleading.

Identifying a hierarchical connective structure in financial networks overlaps with two distinct literature strands. First, it concurs with evidence of hierarchies in the German, Italian, Dutch and UK interbank markets, as reported by Craig and von Peter (2014), Fricke and Lux (2014), in 't Veld and van Lelyveld (2014), and Wetherilt et al. (2010), respectively; however, our findings suggest that the hierarchical form may be modular scale-free, whereas prior works point to a core-periphery structure. Second, the generating process for a modular scale-free hierarchical architecture proposed by Assenza et al. (2011) may be considered a generalization of the trade-off between the benefits and costs of becoming a financial intermediary in trading relationships literature (e.g. Afonso et al., 2013; Babus, 2012; van der Leij et al., 2013), which yields hierarchical structures as well.

Our results entail several challenges related to financial stability. First, results urge a revision of how financial contagion is modeled: assuming that financial networks are homogeneous and non-hierarchical is false, thus modeling and analyzing contagion based on these assumptions may be questionable. Second, due to the benefits of a modular scale-free architecture, namely the ability to limit cascades and isolate feedbacks, popular efforts to reduce financial markets' inhomogeneity by simply downsizing or dismantling systemically important financial institutions may backfire in the form of a less robust and less resilient financial system. Third, systemic-calibrated prudential requirements (e.g. capital, liquidity) should be designed and imposed to enhance the ability of the observed architecture to limit cascades and isolate feedbacks. These three challenges are consistent with a macro-prudential approach to systemic risk.

2. Literature: from homogeneous to modular scale-free financial networks

Real-world networks, both biological and social, tend to display inhomogeneous connective structures, in which connections are approximately distributed as a *power-law*, commonly known as scale-free networks after the seminal work of Barabási and Albert (1999). Moreover, not only are most real-networks inhomogeneous, but they also tend to display a particular hierarchical structure characterized by the existence of clusters or communities of dense interaction, also known as hierarchical modularity. Such modularity is at odds with the standard scale-free connective structure of Barabási and Albert (1999). Thus, both features constitute a particular type of networks introduced by Barabási (2003): modular scale-free networks.

To the best of our knowledge, the evidence attained in this paper contributes to the financial literature by documenting for the first time the presence of a modular scale-free architecture in financial networks. Furthermore, we contribute by linking the observed architecture to literature on financial stability.

2.1. From homogeneous to inhomogeneous financial networks

Most literature that models the interactions between financial institutions is based on the assumption of homogeneity, in which financial institutions tend to connect to each other in a dense and uniform manner. Under such assumption influential papers (Allen and Gale, 2000; Battiston et al., 2012; Cifuentes et al., 2005; Freixas et al., 2000; Gai and Kapadia, 2010; Nier et al., 2008) converge – *ceteris paribus* – to diversification or absorption effects due to the dispersion of shocks within larger or denser financial networks.[1] Accordingly, as reported by Allen and Babus (2008), examining direct linkages generally results in more connections reducing the risk of contagion.

Some of these influential papers eventually arrive to a non-monotonic relation between financial connectedness and stability. Nevertheless, they do it after examining *indirect balance-sheet linkages* (Allen and Babus, 2008), which consists of modeling the impact of other feedback effects, such as the mark-to-market of portfolio holdings, bank runs, next-period tighter funding conditions and institutions' dissimilar initial endowments. Yet, at the core of conventional models there is a homogeneous network structure of direct linkages, as in early research by Allen and Gale (2000).

Traditionally, networks of complex topology have been described with the random graph theory of Erdös and Rényi (Barabási and Albert, 1999). Erdös and Rényi (1960) study a particular type of network in which connections are homogeneously distributed between participants due to the assumption of exponentially decaying tail processes for the distribution of links – such as the Poisson distribution. This type of network, also labeled as "random" or "Poisson", is – explicitly or implicitly – the main assumption of most literature on financial contagion.

However, as first documented by Barabási and Albert (1999), a particular type of inhomogeneity is ubiquitous in real-world networks, with the distribution of connections approximating a power-law distribution. In this type of network there are a few heavily connected participants and many poorly connected participants, in which there is no typical or representative participant; thus, it has no scale, it is scale-free or scale-invariant.

Besides documenting the inhomogeneity of real-world networks and their approximate scale-free nature, Barabási and Albert (1999) suggested *growth* and *preferential attachment* as the corresponding generating process. Against customary network models

[1] For instance, Allen and Gale (2000) use a homogeneous four-bank structure to demonstrate that if the network is complete (i.e. all having exposures to each other) the impact of a shock is mitigated. Gai and Kapadia (2010) assume that interbank linkages form randomly and exogenously, with the probability of all links being independent and distributed as a Poisson process, akin to the core model by Nier et al. (2008). Freixas et al. (2000) analyze the "diversified lending" case, in which every bank gives credit lines uniformly to all other banks. Cifuentes et al. (2005) simulate banking linkages by fixing the number of possible counterparts for all banks. Battiston et al. (2012) assume "uniform risk sharing", where all participants share the same number of counterparties.