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Dynamical macroprudential stress testing using network theory

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ABSTRACT

The increasing frequency and scope of financial crises have made global financial stability one of the major concerns of economic policy and decision makers. This has led to the understanding that financial and banking supervision has to be thought of as a systemic task, focusing on the interdependent relations among the institutions. Using network theory, we develop a dynamic model that uses a bipartite network of banks and their assets to analyze the system's sensitivity to external shocks in individual asset classes and to evaluate the presence of features underlying the system that could lead to contagion. As a case study, we apply the model to stress test the Venezuelan banking system from 1998 to 2013. The introduced model was able to capture monthly changes in the structure of the system and the sensitivity of bank portfolios to different external shock scenarios and to identify systemic vulnerabilities and their time evolution. The model provides new tools for policy makers and supervision agencies to use for macroprudential dynamical stress testing.

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1. Introduction

As the banking system of the world has become ever more complex and technological, there has been the need for more advanced supervision of the banking system as well. The financial crisis of 2007–09 made it more clear than ever before that the financial system is a complicated network and needs to be modeled as such by regulators. Most regulation standards still focus on microprudential factors, and although many advances have been made in modeling and stress testing bank networks. we are still far from a unified framework to confidently monitor systemic risk.

So far, most network-based models have focused on bank-to-bank networks, generally linking either via correlated exposures or direct interbank obligations. Such models can be useful when stress testing using individual bank failures as a starting point. However, financial crises often begin with toxic assets, as we saw with real estate-based assets in the 2007–09 financial crisis. A valuable tool to model such crises is a bipartite bank-asset network with banks and assets as elements of the system. We present such a tool and show how it may be used to monitor the whole system's sensitivity to shocks in various asset prices, as well as which banks are most likely to fail.

1.1. Basel regulation

The Bank of International Settlements (BIS) is a multilateral agency that has paid attention to financial crises since the 1980s. Guidelines on regulation and financial supervision have emerged out of BIS research (http://www.bis.org/forum/research.htm). Although BIS guidelines are not mandatory, the technical prestige and respectability of the institution attracts voluntary compliance.

In 1988 the Basel Committee on Banking Supervision, BCBS, posted the Basel Capital Accord (International Convergence of Capital Measurement and Capital Standards), better known as Basel I, which proposed banks should keep a minimum amount

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of equity, equivalent to 8 percent of their risk-weighted assets (Basel Committee on Banking Supervision (BCBS), 1998) in order to maintain global financial stability and a solid and adequately capitalized system.

In 2004, the BCBS published the New Capital Adequacy Framework, known as Basel II. While Basel I considered market and credit risks, Basel II substantially changed the treatment of credit risk and also required that banks should have enough capital to cover operational risks. Basel II also demanded greater transparency of information about credit risk and increased the documentation required to debtors, as well as diversification of balance through insurance activities (Basel Committee on Banking Supervision (BCBS), 2006).

In 2008, the BCBS introduced Basel III. Basel III introduces more stringent regulations to address liquidity risk and systemic risk, raises loan underwriting standards, and emphasizes the need for appropriate handling or removal of spaces with conflict of interest (Ito, 2011). Basel III also instituted some macroprudential measures to ensure banking operation even in times of systemic problems. During the 2010 G-20 Summit in Seoul, South Korea, Basel III standards were established to create greater banking stability through better microprudential supervision. Those standards will be implemented over the next decade.

However, Basel III is complex and opaque, a problem that should be addressed. Haldane and Madouros (2012) raised the general question of well-intentioned reforms, the tension between them, and transparency in simplicity, stating "Because complexity generates uncertainty, not risk, it requires a regulatory response grounded in simplicity, not complexity."

A key element of Basel III is addressing the financial system as a whole and not just focusing on the strength of individual institutions. The aim of macroprudential policy is systemic financial stability, which can be defined as exogenous (robustness to external shocks) or endogenous (resilience to endogenous shocks). In other words, the goal of Basel III macroprudential measures is to better deal with financial systemic risk. Addressing this issue has resulted in a growing interest in the application of network theory in finance and economics, because it has the ability to reduce the financial system to a set of nodes and relationships, deriving from them the systemic underlying structure and the complexities that arise from it.

1.2. Network science and its applications in finance and economics

Despite all the reforms and progress made, systemic monitoring standards continue to be rooted in microprudential supervision, focused on the strength of units of the system. This weakness remains a crucial issue that must be seriously addressed (Greenwood et al., 2012). Greater understanding of the externalities of economic and financial networks could help to design and adopt a framework of prudential financial supervision that considers the actors of the system (financial institutions) and the vulnerabilities that emerge from their interdependence in network. Such a framework would improve investment and corporate governance decisions and help prevent crises or minimize their negative impacts. Network modeling framework provides a systemic perspective with less complexity.

Network science has evolved significantly in the 21st century, and is currently a leading scientific field in the description of complex systems, which affects every aspect of our daily life (Newman, 2009; Jackson, 2010; Boccaletti et al., 2006; Cohen and Havlin, 2010; Havlin et al., 2012; May, 2013). Network theory provides the means to model the functional structure of different spheres of interest and understand more accurately the functioning of the network of relationships between the actors of the system, its dynamics, and the scope or degree of influence. In addition, network theory measures systemic qualities, e.g., the robustness of the system to specific scenarios or the impact of policy on system actions. The advantage offered by the network science approach is that, instead of assuming the behavior of the agents of the system, it rises empirically from the relationships they really hold. The resulting structures are not biased by theoretical perspectives or normative approaches imposed "by the eye of the researcher".

Modeling by network theory could validate behavioral assumptions of other economic theories, such as the relevance of diversity compared to traditional theory of diversification (Haldane and May, 2011a). Network theory can be of interest to various segments of the financial world: the description of systemic structure, analysis and evaluation of contagion effects, resilience of the financial system, flow of information, and the study of different policy and regulation scenarios, to name a few (Lillo, 2010; Summer, 2013; Tumminello et al., 2010; Kenett et al., 2010, 2012; Cont, 2013; Glasserman and Young, 2015; Li et al., 2014; Garas et al., 2010; Haldane and May, 2011b; Haldane, 2009; Cont et al., 2010; Amini et al., 2012; Chan-Lau et al., 2009; Majdandzic et al., 2014).

The interbank payment system can be seen as an example of a complex network, and thus, considered as a network, from which one can derive information on the system's stability, efficiency and resilience features (see for example Hüser, 2015). Analytical frameworks for the study of these structures are varied, and range from the identification of the type and properties of the network to the analysis of impact of simulated shocks, in order to quantify inherent risks and design policy proposals to mitigate them. For example, once the payment system can be mapped as a network, such as the recently introduced funding map (Aguiar et al., 2014), then the structure of the network can be used as input for models that simulate the dynamics of the system (Bookstaber et al., 2014b).

Recent studies by Inaoka et al. (2004), Soramäki et al. (2007), Cepeda (2008), Galbiati and Soramäki (2012), investigated the interbank payment system using network science. Considering the system as a network allows the design of scenarios and the visualization of specific effects, and these authors were able to uncover the structure of the system. Iori et al. (2008) analyzed the overnight money market. The authors developed networks with daily debt transactions and loans with the purpose of evaluating the topological transformation of the Italian system and its implications on systemic stability and efficiency of the interbank market.

The structure of interbank exposure networks also has been investigated (Boss et al., 2004, 2006; Elsinger, 2009). In an interbank exposure network, the nodes are banks. If banks have a debt exposure to another bank, there is a link between them. If information on the size of the exposure is included, these links can also be weighted by the value of the liabilities.

Considering the problem of contagion, Allen and Gale (1998) study how shocks can spread in the banking system when it is structured in the form of a network. Drehmann and Tarashev (2013) develop a measure that captures the importance of an institution in term of its systemic relevance in the propagation of a shock in the banking system.

Bearing in mind the size of the banks, the diversification and the concentration in the financial system, Arinaminpathy et al. (2012) develop a model combining three channels of transmission of contagion (liquidity hoarding, asset price and counterparty credit risk), adding a mechanism to capture changes in confidence contributing to instabilities. More recently, Acemoglu et al. (2013c,b,a) develop a model of a financial network through its liability structure (interbank loans) and conclude that complete networks guarantee efficiency and stability, but when negative shocks are larger than a certain threshold, contagion prevails, as does the systemic