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# The Contagion Risk of a Banking System

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## Abstract

*The global credit crisis that started in 2007 has shown how contagion risk can propagate in the financial system. It has triggered a huge interest in the use of network concepts to understand how contagion risk can propagate through the banking system. In the recent years, the field of financial networks models and its applications to contagion risk have attracted growing interest both among scholars and practitioners. The literature on network models of contagion risk is today quite vast, covering both theoretical and empirical aspects. This review concentrates on different classes of contagion risk discussed by various scholars such as default contagion, common assets contagion, distress contagion, funding liquidity contagion and network-based stress testing. Our observation show that default contagion is the most important line of research for researchers and scholars, however this domain of contagion risk remains a fertile area for academic research into the next decades.*

**Keywords. Contagion risk, Default contagion, Banking system, Financial stability.**

## 1. Introduction

Contagion risk refers to the process whereby a problem experienced in one sector of the world economy leads to the problems in other unrelated sectors. When Russia defaulted on its debt in 1998, there was a flight to quality and credit spreads on the bonds increased. During the global financial turmoil that commenced in 2007, there was a similar flight to quality and again credit spreads increased. The accompanying downturn led to a record number of financial institutions defaulting, for instance the collapse of Lehman Brothers in 2008 have alerted financial regulators the necessity of managing contagion risk so as to downsize the probability of defaults of other financial institution in the future.

Financial contagion is considered to be one of the main parts in the study of systemic risk. Interconnections among the financial institutions that allow interbank market can trigger essential channels for contagion risk and escalation of financial shocks to the banking system. Though non-monotonic, the increase in degree of interconnectedness tends to be associated with increasing levels of contagion risk and banks' contribution to it (Glasserman and Young, 2015). The interconnectedness of the banking system has played a major role in the world financial crisis. It has triggered the propagation of financial distress from one institution to the other parts of the system through bilateral exposures. The crisis has shown that financial contagion is highly dynamic and may assume many forms, slowly accumulating in normal market conditions, but rapidly emerging during periods of unfavourable market conditions (Georg, 2013).

It is believed that the interbank market structure is regarded as an essential driver affecting the propagation of financial contagion in banking network systems. To be more clearly, the default of one bank can trigger the failure of its creditor banks due to their direct exposures. This situation occurs if the write-downs on the exposures to the defaulted bank cannot be absorbed by the creditor banks' capital buffers. If one of these creditor banks also defaults,

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it would cause another scenario of bank default. This situation could lead to several rounds of bank failures basically known as domino effects. Thus, one obvious stress testing exercise is to investigate how many subsequent bank failures occur as a consequence of direct exposures in the scenario that one bank fails for some exogenous reason. There are other transmission channels of contagion that have been proposed in the literatures such as liquidity mechanism that comes from asset fire sales or refinancing problems because of dried up interbank markets and others which occur due to information contagion or exposure to common risks (Memmel and Sachs. 2013)

Previously, regulators and scholars found problems in anticipating the effect of contagion risk partly due to a lack of both visibility and relevant indicators on the structure of the banking system. As a result, they have been concerned in the recent years to study the structure and empirical features of interbank networks in order better understand how institutions are interconnected. They use a set of bilateral exposure to examine the network structure of the banking system. Several studies have assessed the empirical features of interbank networks in different countries: For instance, Furfine (2003) in the US, Upper and Worms (2004) in Germany, Agnes Lubloy (2006) in Hungary, van Lelyveld and Liedorp (2006) in the Netherlands, Wells (2004) and Elsinger et al. (2006a) in Austria, Wells (2004) in the UK and Mistrulli (2007) in Italy.

We find motivated in writing this review paper as there are few reviews on this topic. This review will attract other scholars, financial regulators and even who are not familiar in this research area to be conversant with the subject matter and propose diverse quantitative analytics for modeling contagion risk of the banking system.

## 2. Financial networks and Contagion risk.

Financial networks are very appealing in the evaluation of contagion risk compared to the traditional measures because the traditional based measures do not consider the interbank market and thus do not reveal the interconnection in the banking system. The traditional based measures like Marginal expected shortfall and distress insurance premium evaluate a financial institution's loss conditional on the banking system being in distress while CoVaR evaluates systemic losses conditional on each financial institution being in distress. These measures usually take into account size, the probability of bank default, and even the correlation of each bank, either implicitly or as direct inputs. However, the correlation fails to gauge the degree of interconnectedness correctly because it does not take into account the different interactions like contagious defaults and the correlation between interconnectedness and the systemic importance in a banking system.Based on that, researchers and scholars consider network model in assessing contagion risk. The network models usually consider the interbank network as propagation channel for financial contagion.

Financial networks usually represent complex financial systems with a set of nodes connected to each other through the edges. The nodes usually represent financial institutions while the edges represent connections between the nodes for instance financial transactions. An evaluation of financial networks would provide alarm to financial regulators and banking institutions about contagion risk from the channels through which shocks propagate (Kanno, 2015). An analysis of financial networks allows to test the resilience of a network and to identify systemically significant nodes. The understanding of these networks model allows researchers and regulators to model complex financial risk affecting the banking system. This situation will help to understand complex adaptive systems, make good investment and risk management decisions, and in the future will allow regulators to protect banking systems from defaulting. Furthermore, financial network models help to assess systematically important financial institutions and test the effectiveness of macro-prudential policies. Network model used to study financial contagion in banking system are becoming imperative and some of them are considered as a part of stability reports by central banks, For example Nier et al. (2006) for UK, Boss et al. (2004a, b, 2006) for Austria and Muller (2006) for Switzerland. Currently, there has been an ongoing effort to comprehend network models as a requirement to perform stress testing exercises because such models capture macroeconomic shocks that affects the financial system.

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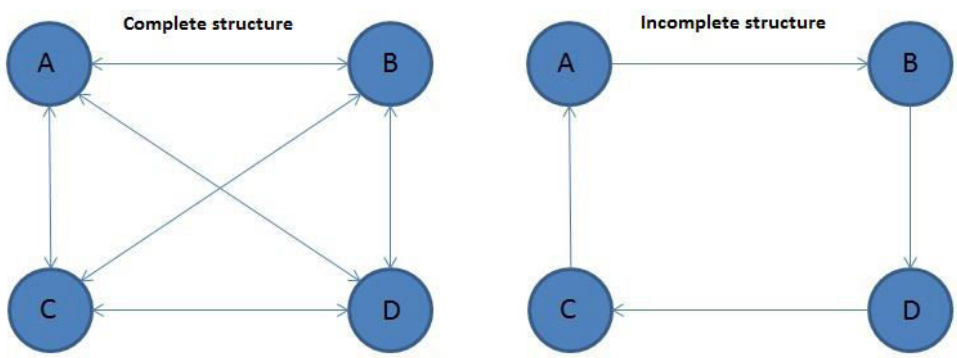
Financial networks are considered as robust-yet-fragile Acemoglu et al., (2015), Glasserman and Young (2015), which means that they can detect smaller shocks to the system but might show contagion and cascade defaults when exposed to a huge amount of financial shocks. The stream of literatures on financial contagion in financial network starts with the work of Allen and Gale (2000) who give a model of risk propagation through interbank exposure network. They show that the possibility for contagion hinges on the precise structure and design of the interbank market and show that a complete structure of claims in which every bank has symmetric exposures to all other banks is resilient to shocks than an incomplete structure; thus, for same amount of shocks some structures would result in contagion while others would not. Freixas et al.(2000) show that for contagion to happen in a banking system with money-centre banks where the institutions on the periphery are connected to banks at the centre but not to each other depends on the precise values of the model's parameters computed. Contrary to the findings, Elsinger et al., (2006) show that assuming a complete interbank market structure will cause an increase in contagious defaults and thus summarize that a simple classification of interbank market into complete and incomplete structures does not usually reflect the full picture of the interaction between the market topology and financial volatility of the banking system.Nier et al. (2006) show the relationship between contagion and connectivity to be non-monotonic within the incomplete network structure, that is to say, while the increase in connectivity negatively impacts the endurance of the banking system for a low level of interbank linkages as shock transmitters, the opposite is true for banking systems which are highly connected. The interbank market with tiering is the common example of incomplete interbank network structure explained more by scholars in the financial network field (Upper and Worms, 2004; Craig and von Peter, 2010; Langfield et al., 2014; van Lelyveld and In't Veld, 2014). In the case of heavily tiered interbank markets, a few numbers of core banks are important for the smooth functioning of the entire banking system. Scholars such as Gai and Kapadia and Nier et al. (2006) consider direct interbank linkages.

The work of Upper (2011) gives a summary of contagion studies in the financial network literature and reveals that a complete interbank structure in which every bank has symmetric exposures to all other banks is resilient to shocks than an incomplete interbank structure whereby banks are linked only to one neighbour. Disconnected structures seem to be vulnerable to financial contagion than complete structures, however they reduce financial contagion from spreading to all banks. Finally, the possibility for propagation of contagion in a system with money Centre banks whereby institutions on the periphery are linked to banks at the centre but not to each other, essentially depends on the precise values of the model's parameters computed. The other different forms of interbank network structure discussed are Erdos-Renyi structure, Nier et al., (2006) and Scale free structure, Cont. et al., (2010) as portrayed in figure 1.



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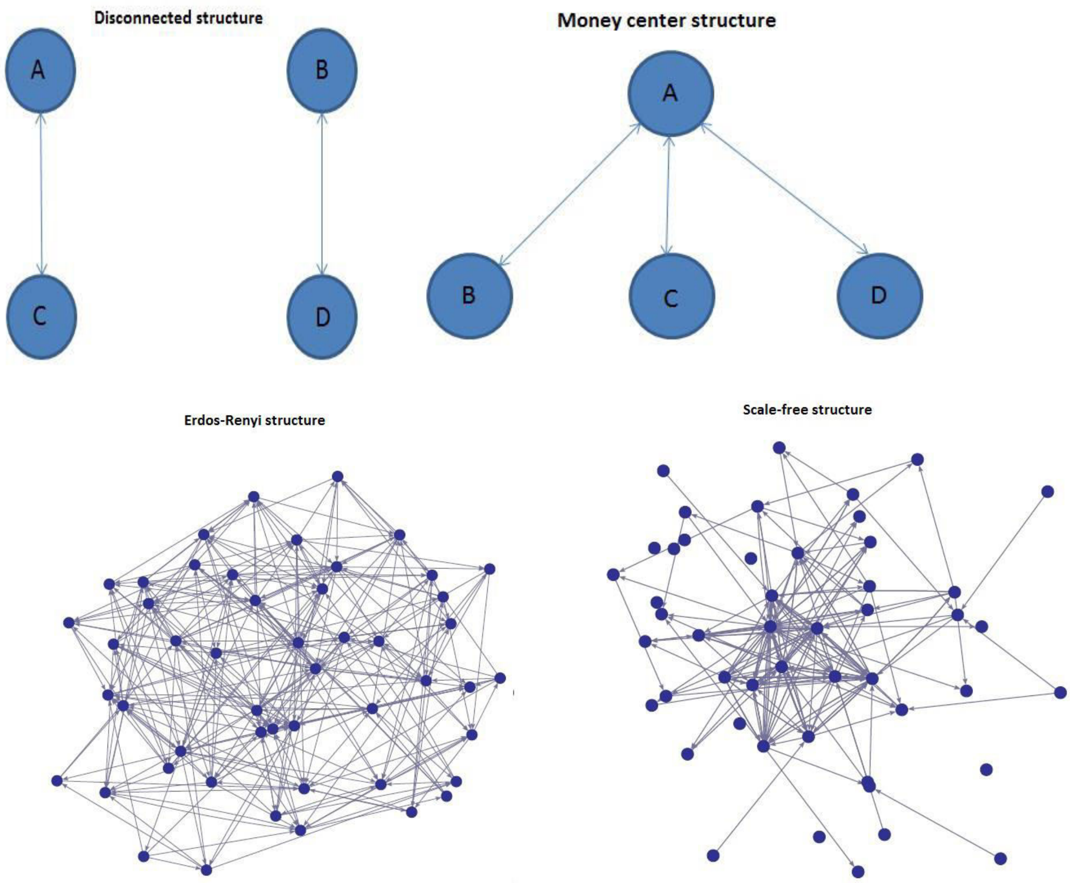


*Figure 1Stylized network structures of the interbank market (Cont. el al.2010)*

### 3. Literatures on the classes of contagion risk.

The literature on networks models of contagion risk have been discussed in different ways by various scholars. This review paper describes the literatures on contagion risk based on default contagion, distress contagion, common assets contagion, funding liquidity contagion, and network-based stress-testing. This classification shows wide range of possible contagion mechanisms in the banking system.

***Default contagion.***

The underlying assumption regarding this type of contagion risk is that only bankrupt banks triggers contagion. This is the main type of contagion risk which has been discussed mostly by researchers. The early work was done by Allen and Gale (2001) who find that the possibility for contagion depends on the precise structure of the interbank market and therefore for same shocks some banking structures might cause contagion while others would not, Eisenberg and Noe (2001) defined a clearing payment mechanism for interbank market networks that includes all possible contagion effects in a static network structure. Elsinger et al. (2006) included bankruptcy costs in their simulation approach to assess systemic risk in the Austrian banking system and find that the system is able to absorb financial shocks for small bankruptcy costs while large dead weight losses can destabilize the banking system while Rogers and Veraart (2013) modelled clearing in the interbank networks with bankruptcy costs and show an analysis of those incidents in which banks have incentives to bail out distressed bank.

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Mistrulli (2011) revealed that the heterogeneity of interbank network can be a channel allowing a bank default to spread to other banks. Upper and Worms (2004) found that in the absence of a safety net, there is considerable scope for contagion that could affect a large proportion of the banking system. Furfine (2003)assessed the likelihood that failure of one bank would lead to subsequent collapse of a large number of other banks using unique data on interbank payment flows. Nier et al. (2006) show the relationship between contagion and connectivity to be non-monotonic within the incomplete interbank network structure, while Amini et al. (2016) assessed the magnitude of contagion in a large counterparty networkand show that institutions which contribute most to network instability have both large connectivity and a large fraction of contagious links. Zhang et al. (2018) show that the default risk contagion is much severer under RS mechanism than that of ES, because the multi-money center structure generated by ES mechanism enables borrowers to borrow from more liquid banks with lower interest rates.

In another study Martínez-Jaramillo et al. (2010) used the systemic risk network model (SyRNet) to estimate the distribution of losses for the banking system that is the losses incurred by the initial shock and the losses which result from the propagation of contagion risk, conduct stress tests and investigate the impact of different levels of correlation have on the distribution of losses. Leonidov and Rumyantsev (2016) explored systemic risk of contagious default in the Russian banking system based on the probabilistic model of interbank contagion that take into account the empirical bow tie structure reflecting functionality of the interbank market loans. The basic features of systemic risk computed by this model are shown to be in agreement with those of explicit stress tests. Most of the literatures falling under this contagion type are described in the work of Upper (2011).

***Common assets contagion***

In the literature common assets contagion and fire sales are considered as a main source for propagation of contagion risk. The indirect interactions among banks arise due to the fact that they invest in common assets. For example, if as a result of a shock on the asset price, one bank sells the same asset in a quantity sufficient to move further down the price, the other banks holding the same asset will experience both the initial shock as well as a secondary shock induced by the initial bank reaction. They may eventually start to sell the asset themselves leading to a devaluation spiral. In other words, in common assets contagion the underlying network structure is not derived from bilateral counterparty relationships, but instead occur in the form of a bipartite financial holding network, linking agents to assets by their underlying portfolio holdings. When one agent experiences a financial shock, this forces portfolio rebalancing. This, in turn, affects asset prices. Subsequently, other agents holding common assets are affected by the price shifts, which cause further rebalancing and downstream effects (Battiston and Martinez Jaramillo, 2018). A strand of literatures falling in this research includes the work of Georg, (2013) who proposed a dynamic model of a banking system that can be used to evaluate the impact of the interbank network structure on financial stability in a way that once depositors decide on deposit invest via a random walk process, banks pay their maturing loans depending on their liquidity capacity. Caccioli et al., (2014) assessed common shocks resulting from overlapping securities portfolios. This study reveals that, upon bank default, when the threat of contagion looms, other banks might be in weak position as well making them more vulnerable to contagion. Tasca and Battiston, (2016) developed a model that considers the temporal dynamics of single-firm credit risk and the contagion across banks via a network of obligations and common assetswhile Allen et al. (2012) proposed a model in which asset commonality and short-term debt of banks interact to propagate excessive systemic risk affecting the banking system. On the other hand of the spectrum Kiyotaki and Moore (2002) assessed different mechanisms by which contagion may occur in the banking system through balance sheet effects. They considered the indirect effects that downfalls in asset prices have on collateral values and also through the direct effects that default on or postponement of debt repayments have when there are chains of credit. In addition, Diamond and Rajan (2011) described the ways which could be used to limit contagion risk during the financial crisis. They argued that an overhang of distressed banks that

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may be forced to sell assets in the future can increase the private returns to holding illiquid assets sufficiently that weak banks have no interest in selling them.

***Distress contagion.***

The idea behind this contagion type is that contagion can start prior to default event, and therefore financial distress can propagate even though the obligor does not default. This research field is still in infancy, however it's really evolving. According to the Basel Committee on Banking Supervision (2011) it shows that during the financial turmoil roughly two-thirds of losses attributed to counterparty credit risk were due to CVA losses and only about one-third were due to actual defaults. A stream of literatures which focus on distress contagion risk includes the work of Glasserman and Young (2015) who assessed how one can obtain useful bounds on the losses attributable to the network with almost no knowledge of the specific network topology and under very general assumptions about the shock distributions. Their results implied that it is relatively difficult to generate contagion solely through spill over losses in a network of payment obligations. Network structure matters more for the escalation effect, in which losses among defaulting nodes multiply because of their obligations to one another. Tasca and Battiston (2016) proposed a model that considers the temporal dynamics of single-firm credit risk and the contagion across banks through a network of obligations and common assets and the model showed that contagion can spread well before any default occurs, through the value of the obligations held by other parties.

Fink et al. (2016) proposed an algorithm to model contagion in the interbank market through credit quality channel. The proposed model allows shocks to be transmitted via asset devaluations and deteriorations in the credit quality. According to the model, probability of default of those banks directly affected by some shock seemed to increase.This situation increased the expected loss of the credit portfolios of the initially affected banks' counterparties, thereby reducing the counterparties' regulatory capital adequacy ratio. Thurner and Poledna (2013) assessed the risks associated with lending to other banks in the network by using network metrics such as Debt Rank of the interbank liability network. The model proposed showed a large reduction of systemic risk due to the massive reduction of cascading failures in the transparent system. Poledna et al. (2015) examined the systemic risk profile of the Mexican banking system on all market layers.The results showed that focusing on a single layer underestimates the total systemic risk by up to 90% and therefore concluded that market-based systemic risk indicators systematically underestimate expected systemic losses. In another study Poledna and Thurner (2016) show that financial markets are exposed to systemic risk and through an agent-based model systemic risk tax leads to a self-organized restructuring of financial networks that are practically reducing systemic risk while Battiston et al., 2012a revealed that a financial network can be most resilient for intermediate levels of risk diversification.

***Funding liquidity contagion***

This domain focuses the issue of contagion on the liability side of the balance sheet. If the bank creditors decide to restrict liquidity rather than providing it to other market participants, this may have negative effects to the other institutions which may trigger bank defaults. Acharya and Merrouche (2013) examined the liquidity demand of large settlement banks in the UKand show that the liquidity demand by settlement banks caused overnight inter-bank rates to rise and volumes to decline, an effect virtually absent in the pre-crisis period. Gai et al. (2011) assessed a network model of interbank lending in which unsecured claims, repo activity and shocks to the haircuts applied to collateral assume centre stage. The analysis reveals how a range strict liquidity regulation, could make the financial system more resilient. Fourel et al. (2013)examined the effects of banks' liquidity hoarding behaviour for the stability of the French banking system by proposing a new model of banking contagion channels which are bilateral exposures and funding shortage. They included banks' hoarding behaviour in a standard iterative default cascade algorithm to assess the propagation of a common market shock in a banking system. The results showed the French banking sector to be stable to the combination of an initial market shock and of the resulting solvency and liquidity contagion. In addition,Lee (2013) proposed a method for calculating systemic liquidity shortages by including direct liquidity

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shortages as well as indirect liquidity shortages due to the knock-on effects through interbank linkages and find that a deficit bank can mitigate a liquidity shortage by holding more claims on a surplus bank while Galbiati et al., (2013) examined how liquidity needs through financial network could enhance financial stability.These few studies generally characterize the sources of contagion and financial fragility of the banking system based on the liability structure of the banks. An observation we reveal from this category of contagion risk is that more empirical research is needed on how to combine it with contagion on the asset side of the balance sheet and with common assets contagion.

***Network-based stress-testing***

Stress testing approach is used to determine how a portfolio will get along during a period of financial distress. Following the 2007 global financial crisis, regulatory reporting for the financial industry and specifically banks was significantly expanded with a broader focus on stress testing. It is believed that lack of stress testing programs that raised before the turmoil has in one way triggered the outburst of the global financial turmoil. In these incidents, network models are now important components of the stress testing frameworks which are used by several financial authorities and regulatory institutions. Most of the literatures on network-based stress testing approaches are based on the framework proposed by Eisenberg and Noe, (2001). Elsinger et al., (2006) and Nier et al. (2006) proposed several network-based stress testing methodologies to monitor systemic risk and financial contagion in the financial system. Kanno (2015) proposed a stress test to verify the resilience of the global banking system at an evaluation point in the future. The proposed stress testing appears to differ from typical macro stress tests, which consider the impacts of the shocks of macroeconomic variables on risk parameters for each bank. According to the framework proposed banks which are designated as G-SIBs were proven to have the potential to trigger the contagious defaults of other banks. Hałaj and Kok (2013) proposed a model to simulate and assess interbank contagion effects on banking system soundness and resilience to financial shocks. The framework proposed revealed a strongly nonlinear pattern across the distribution of simulated networks, whereby only for a small percentage of networks the impact of interbank contagion will substantially downsize average solvency of the system. Martinezjaramillo et al. (2014) presented some topological metrics for the interbank exposures and the payments system networks. They found that the proposed measure of interconnectedness can be used to determine the systemic importance of a bank in terms of connectivity. Furthermore, it was found that interconnectedness of a bank is not necessarily related with its assets size but it is linked to the contagion it might cause. Amini et al. (2012) proposed a simulation free framework for stress testing the stability of a financial network to external shocks affecting banking systems. Their findings reveal that the size of the default cascade created by a macroeconomic shock across balance sheets may display a sharp transition when the magnitude of the shock reaches a certain threshold, and above that threshold, contagion risk propagates to a large fraction of the financial system. Generally, network-based stress testing approaches are considered to be one of the primary supervisory tools which can be used to assess systemic importance of a financial institution. For instance, the EU-wide stress test is an example of such a test conducted to test the resilience of banking system to different types of shocks.

In a nutshell, it can be said that the above-mentioned classification shows the different mechanisms for contagion risk. Researchers and scholars model the contagion risk mechanism of the banking system through financial network models. Financial network models enable to grasp how externalities can move along chains of financial contracts and lead to systemic risk in the presence of imperfect information and incomplete risk markets. Thus, network models allow to grab aspects that cannot be explained neither by traditional measures that focus on the aggregate macro-economic spectrum, nor by those metrics looking at the micro-economic level of firms in isolation (Battiston and Martinezjaramillo, 2018).

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Table 1. Summary of relevant literatures on classes of contagion risk.

| **Contagion mechanisms** | **Relevant literatures** |
|---|---|
| Default Contagion | Allen and Gale (2001), Eisenberg and Noe (2001), Upper and Worms (2004), Elsinger et al. (2006), Nier et al. (2006), Martínez-Jaramillo et al. (2010), Gai and Kapadia (2010), Gai et al.(2011), Mistrulli (2011), Anand et al. (2012), Acemoglu et al. (2015), Elliot et al. (2014), Battiston et al. (2012b), Glasserman et al. (2015), Upper (2011), Kano (2015), Leonidov and Rumyantsev (2016), Zhang et al. (2018), Rogers and Veraart (2013), Furfine,(2003), Amini et al. (2016).. |
| Common assets contagion. | Kayotaki and Moore (2002), Diamond and Rajan, (2011), Georg (2013), Allen et al. (2012), Caccioli et al. (2014), Tasca and Battiston (2016). |
| Distress contagion. | Tasca and Battiston (2016) , Thurner and Poledna (2013), Poledna and Thurner (2016), Poledna et al.(2015), Fink et al.(2016), Puliga et al.(2014), Bardoscia et al.(2015, 2016, 2017),Glasserman and Young (2015), Battiston et al.(2012a,b) |
| Funding liquidity contagion | Gai et al. (2011), Acharya and Merrouche (2013), Galbiati and Soramaki (2010), Galbiati et al. (2013), Lee (2013), Fourel et al. (2013). |
| Network-based stress-testing. | Eisenberg and Noe (2001), Elsinger et al. (2006), Nier (2007), Martinez Jaramillo (2014), Kanno (2015), Montagna and Lux (2017), Amini et al. (2012). |

**Conclusion and areas for future research.**

The 1998 Russia debt crisis, global credit crisis that started in 2007 and the 2011 Greece crisis has shown how contagion risk can propagate in the financial system. The defaults of Drexel in 1990, Barings and Lehman Brothers in 2008 have alerted financial regulators the necessity of managing contagion risk so as to downsize the probability of defaults of other financial institutions in future.

The interbank market of the banking system has been regarded as the major channel for propagation of contagion risk. Therefore, this paper has reviewed the concept of contagion risk of the banking system in order to provide an understanding to researchers and financial regulators who are interested in this field.

This review paper discussed on the application of financial network models as the major tool in modeling and management of contagion risk. Nowadays, the field of financial networks models and its applications to systemic risk and contagion methods have attracted growing interest both among scholars and practitioners. This research field has

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built both on the literature on complex networks (Gai and Kapadia, 2010; Elsinger et al, 2006) and on the literature in economic networks (Goyal and Vega-Redondo, 2005). This review paper views this concept using different classes of contagion risk such as default contagion, distress contagion, common assets contagion, funding liquidity contagion and network-based stress testing. Our observation has revealed that default contagion is the most important line of research which has received probably most of the attention by researchers and scholars,

As of today, the field is mature to provide policy insights and policy applications to financial stability and macro-prudential regulation. The financial network provides different insights on network effects such as the indirect exposure of an institution to shocks on its counter parties can have comparable or even larger impact thanits direct exposure along different types of contagion transmission channels. This field contrast with traditional views on financial stability that neglect the effect of interactions among financial institutions and the various mechanisms of shock propagation. Therefore, increasing the financial stability of modern financial systems embarks from the analysis of the conditions under which financial instability may emerge.

Some of these challenges require attention by researchers and scholars; since the financial system is always described as a multiplex network, thus the financial stability properties of the system depend on the interplay of the contagion processes across different layers. By considering one layer at a time, one can fail to reveal instability and fail to show the possible contagion channels. While it is certainly important to study how incentives endogenously lead to different network designs, the study of the stability of exogenously given architectures is a compulsory precondition to understand financial stability. Moreover, the current stress testing approaches should be supplemented to take into account the real economy. Thus, this field of research should show how macroeconomic shocks can be described by taking into account the networks effects in the real economy. On the other hand of the spectrum, explaining the financial system as a multiplex network comes with some new challenges in terms of big data analysis and in terms of complex data consolidation. Remarkable efforts in these directions are ongoing but much work is still needed on this research field in the future.

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