Financial networks and systemic risk

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1 Introduction

To build a stable and efficient financial system, it is necessary to determine the causes of systemic risk and act to prevent such risk from arising in the financial sector. Using the definition in De Bandt and Hartmann (2002), systemic risk is any risk that influences the entire financial sector [1)]. With the analysis of financial crisis in recent decades, the theory and frameworks relating to systemic risk have evolved. In particular, the global financial crisis of the late 2000s revealed that the composition of financial networks can affect the speed of spreading of systemic risk and the magnitude and depth of financial crisis.

The financial network comprises two layers of networks: direct connections and indirect connections. Direct connections are =those in which banks hold a lender–borrower relationship when they borrow liquidity in the interbank market. In contrast, indirect connections are those in which bank asset portfolios are overlapped when they hold common risky assets. Given indirect connections, bank asset returns are positively correlated even if they do not have a direct relationship.

During recent financial crises such as the global financial crisis of the late 2000s, indirect connections between banks were considered as the main channels for systemic risk to spread in the financial network. To review the discussion about financial network and systemic risk literature, I first review how financial theory regards the emergence of financial crises, especially as the structures of financial institutions are, in themselves, fragile given the coordination problem between creditors. Next, I review the situation before the 2008 global financial crisis, with the epicenter of systemic risk considered as the interbank market and the emergence of systemic crisis expressed as a domino effect. Finally, I review the theoretical and empirical findings concerning the global financial crisis in the late 2000s and identify that indirect connections caused by overlapping portfolios or asset commonality between financial institutions were the main channel for the emergence of systemic risk.

2 Individual bank run models

In this section, and referring to Diamond and Dybvig (1983), I first review individual bank run occurs when creditors face a coordination problem. Then, to overcome the problem of multiple equilibrium, the method of global games is developed by referring to Goldstein and Pauzner (2005).

2.1 Diamond and Dybvig (1983)

Diamond and Dybvig (1983) were the first to present a theoretical mechanism for an individual bank run. In their model, a bank, having an opportunity to invest in a long-term illiquid technology, faces the withdrawal of deposits in some interim period. In this environment, there arise multiple equilibria. The first equilibrium is where a bank invests in a long-term investment and patient depositors do not withdraw their deposits in the interim period. The second equilibrium is that a long-term investment is liquidated in the interim period and depositors withdraw their deposits. Diamond and Dybvig (1983) then show that due to this maturity mismatch, an individual bank is prone to a run by depositors.

In the Diamond and Dybvig framework, where information is complete for both banks and depositors, a bank run occurs when an inefficient equilibrium is chosen. In other words, a bank run arises due to coordination failure among depositors because they do not have sufficient confidence about their banks. However, this problem of multiple equilibria makes the analysis of systemic risk in a financial sector more difficult for two reasons. First, which equilibrium will be selected *ex post* depends on "sunspots," such that *ex ante* banking behaviors cannot be analyzed. Second, the bank run is derived as a panic-based not a fundamentals-based run. In other words, a bank run can arise even if the bank is fundamentally very healthy. However, looking back at the most recent financial crisis, most banks, in fact, were subject to runs when their fundamental values had deteriorated.

2.2 Goldstein and Pauzner (2005)

The emergence of tractable analysis in the form of global games overcomes these difficulties associated with multiple equilibria, as presented in Carlsson and van Damme (1993) and Morris and Shin (2002). These show that in a strategic environment in which information about other players becomes incomplete, a unique equilibrium can be obtained in a multiple equilibria coordination game. Goldstein and Pauzner (2005) modify the framework in Diamond and Dybvig (1983) by introducing stochastic fundamentals about bank investment and noisy signals for depositors.

In this environment, there arises a threshold of signals regarding bank's fundamentals, below (above) which depositors withdraw (rollover) their deposits, and by using the global game methodology, this threshold is uniquely determined. A unique equilibrium then arises when there is a strategic complementarity among depositors. That is, when more depositors rollover (withdraw) their deposits, any one depositor is more likely to roll over (withdraw) its deposit. The primary novelty of Goldstein and Pauzner (2005) is that by introducing some information incompleteness about bank investment returns or signals for depositors, they can derive a unique equilibrium. This enables us to derive the *ex ante* probability of a bank run or the *ex ante* behaviors of bank asset choices.

3 Direct connection and contagion

Given that an individual bank faces a bank run, there is a need to investigate how it spreads to the financial system as a whole. Traditionally, the interbank market is considered as the epidemic center of systemic risk, such that an individual bank run generates the failure of other banks as a contagion through the direct connections among banks. Direct connections here are those in which banks hold a lender–borrower relationship via interbank transactions[2)]. That is, when a bank faces a liquidity shortage, it borrows liquidity from other banks in the interbank market. Indeed, Clerc, et al. (2016) argue that the dot-com crash of the early 2000s revealed that it was the failure of contractual obligations by counterparties that provided the main source of systemic risk.

In what follows, I first review the theoretical mechanism through which an individual bank run triggers the failure of other banks. Next, I review the literature about the coordination failure among banks in the interbank market analyzed by the method of global games.

3.1 Allen and Gale (2000, 2007)

Allen and Gale (2000, 2007) establish that the domino effect arises through the transmission of liquidity shocks in the interbank network system. They also assess how the structure of the interbank network affects the transmission of liquidity shock, by considering two types of network structure. The first of these is a complete network in which all banks have a lender–borrower relationship with all other banks. In this case, each bank holds deposits in every other bank. The second is an incomplete network in which each bank holds only one deposit in a neighboring bank and lends only to this other neighboring bank. In this case, banks are connected as a member of a credit chain.

Now let's compare the two networks through which a liquidity shock is transmitted. In a complete network, as the lending of each bank is diversified across many banks, any liquidity shock to one bank is transmitted at a small magnitude to other banks. However, in an incomplete network, as the loans for each bank are not diversified, a liquidity shock to one bank also directly and significantly damages the balance sheet of the neighboring connected bank. Using this model, Allen and Gale (2000, 2007) show that a liquidity shock is transmitted to other banks when the financial network is incomplete, such that diversifying bank asset portfolios is a useful device for decelerating the transmission of liquidity shocks.

3.2 Coordination failure in the interbank market

As shown by Allen and Gale (2000, 2007), the interbank market can allow systemic risk to spread to the entire financial system. Freixas, Parigi and Rochet (2000) demonstrate that the interbank payment system enables banks to reduce the costs of holding liquidity and preserve their long-term investment opportunities. However, they also show that if depositors become anxious about the credibility of the bank checks of the counterparty bank, they rely more on cash. As a result, there may arise a gridlock equilibrium in which depositors withdraw cash, and depositors in other banks also coordinate themselves to withdraw cash, such that interbank lending collapses.

Rochet and Vives (2004) assess bank runs triggered by liquidity crises and reevaluate lender of last resort facilities by central banks. Using the global game framework, they then consider the coordination failure among investors in the interbank market and reveal that a bank may be forced to be closed inefficiently if it is still solvent but illiquid. To overcome this coordination failure in the interbank market, they insist that the proper role of lender of last resort facilities by central banks is to provide liquidity in the interim period.

Liu (2016) considers the interaction between creditor runs and liquidity evaporating in the interbank market. Using the method of global games, Liu (2016) endogenizes the illiquidity shock, which is derived from a bank-specific shock and coordination failure among the depositors of the bank. Liu (2016) shows that there arises a feedback loop between an interbank interest rate and creditor runs. That is, a higher interest rate brings about more creditor runs, which in turn tightens liquidity in the interbank market such that the interbank rate also moves higher.

These studies show that when banks borrow liquidity from other banks, they hold a lender–borrower relationship. The direct connection can then be the main channel for the systemic risk to spread to the entire

financial system. Accordingly, to prevent a financial crisis, diversifying their asset portfolios will be useful for mitigating the magnitude of systemic risk.

4 Indirect connections in the financial network

However, several studies suggest that the domino effect among banks is less likely to occur through the interbank market[3)]. Especially, after the global financial crisis in the late 2000s, many researchers put more importance on the indirect interconnection among banks. As Yellen (2013) notes, as securitization and syndicate loan markets grow, financial institutions become interconnected indirectly through an overlapping of their portfolios holding similar assets. In other words, through these asset holdings, banks are indirectly connected because their asset returns are positively correlated even if they do not hold a lender–borrower relationship through the interbank transactions.

The characteristics of a global financial crisis of the late 2000s highlight the importance of indirect connections between banks because the financial system suddenly malfunctions and the small initial shock is amplified such that systemic risk prevails in the financial sector. As Clerc, et al. (2016) notes, having such indirect connections was a key channel whereby institutions in the financial network were simultaneously damaged during the sub-prime financial crisis. Also, Brunetti, et al. (2019) show that while direct connections were decreased drastically, indirect connections were increased during the global financial crisis. Moreover, Billio, et al. (2011) find that, prior to the financial crisis, the returns of hedge funds, banks, broker/dealers and insurance companies were positively correlated, which indicates the possibility of financial crisis becomes more intense due to the indirect connections between banks. According to the findings in this section, I firstly review how banks come to hold indirect connections and note that overlapping portfolios or asset commonality is the key ingredient for indirect connections among banks. Then, I review how having indirect connections among banks raises the systemic risk in the financial system.

4.1 Overlapping portfolios

Securitization enables banks to hold claims on the payoffs of other banks so that they can share credit risks between them. As Kopytov (2023) asserts, the value of mortgage- and asset-backed securities originated by banks increased before the global financial crisis. Most of these securities were held by financial institutions, suggesting that their asset portfolios necessarily overlapped through securitization.

Caccioli, et al. (2014) develop a network approach and consider the relation between overlapping portfolios and leverage. They find that when banks diversify their portfolios such that their portfolios overlap, a shock is easily spread to other banks and the effect is increased as leverage becomes higher. Cabrales, et al. (2017) also show that through overlapping portfolios, financial institutions may face a trade-off between the benefit of sharing credit and other risks among themselves and the cost of risk exposure emerging in other financial institutions. Lastly, Poledna, et al. (2021), using data on the security holdings of Mexican financial intermediaries, show that overlapping portfolios can be the major component of the systemic risk and suggest that systemic risk is underestimated by up to half if we focus only on direct bank connections.

4.2 Asset commonality

Another type of indirect connection is formed when banks hold risky assets in common. Siedlarek and Fritsch (2019) observe that large US banks concentrate their asset portfolios in the US Treasury and other US securities agencies and agency mortgage-backed securities. Kopytov (2023) also shows that banks increased their loan ratios to syndicate loans prior to the global financial crisis. As a result, when banks hold common assets, they are all subject to a shock to the common asset such that systemic risk spreads to the financial system. Blei and Ergashev (2014) consider the patterns of asset commonality among large US bank holding companies during the 2001–2013 period and find that the degree of asset commonality can indicate the risk of contagion.

Dissem (2019) considers the patterns of asset commonality among 43 banks over 15 European countries from 2011 to 2016 and finds that asset commonality among banks not only decreases bank returns, but also increases their volatility. Cai, et al. (2018) find that banks are indirectly connected through the syndicate loan market, which, in turn, increases measures of systemic risk. Finally, Barucca, et al. (2021) consider UK banks, UK insurance companies, and European open-ended investment funds and show that portfolio overlap exists between these different types of financial institutions, such that contagion arising from a price shock is transmitted across these financial institutions through their indirect connections.

4.3 Diversification

When banks connect indirectly, individual asset diversification plays an important role. As Beale, et al. (2011) argue, if a bank diversifies its asset portfolio, its likelihood of failure declines, and this behavior will then be optimal for the risk management of its portfolio. However, if other banks also diversify their portfolios in a similar way, their portfolios either overlap, or they come to hold common assets such that they are indirectly connected. Beale, et al. (2011) demonstrate that systemic risk derived from an individual optimum is much higher than that of the system optimum.

Ibragimov, et al. (2012) also show that individual risk diversification generates a negative externality in the form of systemic risk, whose degree depends on the distributional properties of the risk. Elliott, et al. (2014) also consider the trade-off between diversification and integration in financial networks and show that these have different and nonmonotonic effects on the realization of systemic risk[4]. Lastly, Tasca, et al. (2017) derive the probability of systemic defaults in an environment in which the asset portfolios of banks overlap and find that banks overdiversify their asset portfolios relative to the social optimum.

4.4 Indirect connections and systemic risk

Indirect connections were thus the main channel for spreading systemic risk in recent financial crises[5]. Several studies then consider the relationship between the externality offered by fire sales and systemic risk. For example, Greenwood, et al. (2015) argue that a fire sale by one bank spills over to other banks when they face common risk exposures. Duarte and Eisenbach (2019) also consider fire sale factors and find that delivery speed and the concentration of illiquid assets are the main indicators of the aggregate vulnerability of the financial system.

Other papers also place some importance on the interconnections in financial networks. Gai, et al. (2011) show that when a financial network becomes complex and the risk exposure of large banks becomes great, the fragility of the financial system is amplified. Battiston, et al. (2012) also consider financial network resilience and show that it is important for financial networks not to connect too much.

5 Conclusion

This paper reviewed the financial network and systemic risk literature. I first reviewed the mechanism for an individual bank run. I then discussed the role of contagion in the interbank market. Finally, I examined the mechanisms underlying overlapping portfolios and asset commonality among banks and observe that it was the indirect connections between banks formed by overlapping portfolios or asset commonality that generated systemic risk in recent financial crises. There are many ways in which future research could contribute to better establishing the relationship between financial network and systemic risk. For example, how overlapping portfolios or asset commonality affect the likelihood of a financial crisis using the global games method would be a fruitful research direction. This research should contribute to the design of a stable and efficient financial system.

Notes

1) Several recent papers attempt to measure systemic risk in the financial sector. For details, see Acharya, et al (2016) and Adrian and Brunnermeier (2017). Brunnermeier (2009), Brunnermeier and Oehmke (2013) and Freixas and Rochet (2008) also survey systemic risk in the financial sector.
2) See Caccioli, et al. (2015), Clerc, et al. (2016), Brunetti, et al. (2019), and Roncoroni, et al. (2021).
3) See, for example, Furfine (2003), Upper and Worms (2004) and Degryse and Nguyen (2007).
4) In Elliott, et al. (2014), while integration refers to the level of exposure of financial organizations to each other, diversification refers to the spread of the crossholdings of financial organizations.
5) For useful surveys of systemic risk, see Benoit, et al. (2017) and De Bandt and Hartmann (2002).

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