

## Chapter 21: Networks in Finance\*

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### Abstract

*Modern financial systems exhibit a high degree of interdependence, with connections between financial institutions stemming from both the asset and the liability sides of their balance sheets. For instance, banks are directly connected through mutual exposures acquired on the interbank market. Likewise, banks are indirectly linked through holding similar portfolios or sharing the same mass of depositors. Networks – broadly understood as a collection of nodes and links between nodes – can be a useful representation of financial systems. By modeling economic interactions, network analysis can better explain certain economic phenomena. In this chapter, Allen and Babus argue that the use of network theories can enrich our understanding of financial systems. They explore several critical issues. First, they address the issue of systemic risk, by studying two questions: how resilient financial networks are to contagion, and how financial institutions form connections when exposed to the risk of contagion. While more links between banks might be expected to increase the risk of contagion, their research shows that banking systems with a more complete set of connections may be less susceptible to contagion than those with an incomplete structure. The second issue they consider is how network theory can be used to explain freezes in the interbank market of the type observed in August 2007 and subsequently. Third, they examine how social networks can improve investment decisions and corporate governance, based on recent empirical results. Fourth, they examine the role of networks in distributing primary issues of securities (such as in initial public offerings), or seasoned debt and equity issues. Finally, they consider the role of networks as a form of mutual monitoring, as in microfinance.*

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The turmoil in financial markets in August 2007 and the following months has revealed, once again, the intertwined nature of financial systems. While the events unfolded, it became clear that the consequences of such an interconnected system are hard to predict. What initially was seen as difficulties in the US subprime mortgage market rapidly escalated and spilled over to debt markets all over the world. As markets plunged, investors' risk appetite was reduced. Banks became less willing to lend money as freely. Interbank lending rates started to rise and soon the market for short-term lending dried-up. The credit crunch ultimately triggered a bank run at the British mortgage lender Northern Rock - something not seen in the UK for over 140 years and in Western Europe for the last 15 years.

Connections in the financial world are varied. The dependencies between financial institutions stem from both the asset and the liability sides of their balance sheets. For instance, direct asset linkages result from exposures between banks acquired through the interbank market. Financial institutions are indirectly connected by holding similar portfolio exposures. When they share the same mass of depositors, banks are connected in a network through the liability side of the balance sheet.

The intricate structure of linkages between financial institutions can be naturally captured by using a network representation of financial systems. The general concept of a network is quite intuitive: a network describes a collection of nodes and the links between them. The notion of nodes is fairly general; they may be individuals or firms or countries, or even collections of such entities. A link between two nodes represents a direct relationship between them; for instance, in a social context a link could be a friendship tie, while in the context of countries a link may be a free trade agreement or a mutual defense pact. In the context of financial systems, the nodes of the network represent financial institutions, while the links are created through mutual exposures between banks, acquired on the interbank market by holding similar portfolio exposures or by sharing the same mass of depositors. In this chapter, we argue that network theory may provide a conceptual framework within which the various patterns of connections can be described and analyzed in a meaningful way.

A network approach to financial systems is particularly important for assessing financial stability and can be instrumental in capturing the externalities that the risk associated with a single institution may create for the entire system. A better understanding of network externalities may facilitate the adoption of a macro-prudential framework for financial supervision. Regulations that target individual institutions, as well as take into account vulnerabilities that emerge from network interdependencies in the financial system may prevent a local crisis from becoming global.

More generally, network analysis may help address two types of questions: the effect of the network structure and the process of network formation. While the first type of question captures aspects related to social efficiency, the second type highlights the tension between socially desirable outcomes and the outcomes that arise as a result of the self-interested action of individuals. The first type of question, on network effects, studies processes that take place on fixed networks. For instance, we can study what is the impact of the financial network structure on the way the banking system responds to contagion. We can show not only that network structures respond differently to the propagation of a shock, but the fragility of the system depends on the location in the network of the institution that was initially affected. At the same time, financial institutions may gain significant payoff advantages from bridging otherwise disconnected parts of the financial network. Hence, certain network structures may provide additional benefits for those financial institutions that are able to exploit their position as intermediaries between other institutions. Network structure can also play a role in how effective mutual monitoring is for the enforcement of risk-sharing agreements, as in microfinance.

The second type of question, on network formation, studies how financial institutions form connections. We can gain new insights on the issue of systemic risk if we understand how financial institutions form connections when exposed to the risk of contagion. Risk sharing can be an important driving force that explains how financial institutions form connections. Moreover, theories of network formation may help explain freezes in the interbank market of the type we have observed in August 2007 and subsequent months. When the risk associated with lending funds on the interbank market is too high, links become too costly relative to the benefits they bring. In this case, a network formation game would predict an empty network, where no two banks agree to form a link.

This chapter is organized as follows: Section 2 briefly describes how economists have modeled various phenomena using a network approach. Section 3 considers the limited literature in finance that uses network theory and suggests a number of areas for future research where such an approach is likely to be fruitful. Section 4 reviews some of the main techniques developed in network theory, discussing possible ways they can be applied. Finally, Section 5 contains concluding remarks.

## **APPLICATIONS IN ECONOMICS**

As demonstrated in the diverse chapters of this book, network theory has been applied to a wide range of situations. We consider a few examples from economics to illustrate the scope of theories of networks: labor markets, buyer-and-seller networks, risk-sharing networks, and product adoption. For example, studies of how networks are involved in labor markets examine the imperfections in the matching process between workers and their employers. Two types of information are relevant in labor markets, the information on job vacancies and the information on the ability of workers. Networks can play a role in transmitting information across individual workers and between employers and workers. In fact, evidence shows that on average about 50 percent of the workers obtain jobs through their personal contacts (Rees, 1966; Granovetter, 1995; Montgomery, 1991). Moreover, on average 40 to 50 percent of employers use social networks of their current employees (i.e., they hire recommended applicants) to fill their job openings (Holzer, 1987). This motivated a thorough study of the effect of social networks on employment and wage inequality (Calvó-Armengol and Jackson, 2004, 2006; Arrow and Borzekowski, 2003; Ioannides and Soetevent, 2006), labor market transitions (Bramoullé and Saint-Paul, 2006), and social welfare (Fontaine, 2004).

Besides labor markets, researchers have studied the role of networks in markets in general. The standard formal Arrow-Debreu model of the economy assumes that agents interact anonymously in centralized markets, and prices are formed following their independent decisions. An alternative view holds that markets are not centralized, but rather consist of a complex structure of bilateral trades and relationships.<sup>1</sup> A spatial flavor has been introduced to motivate why agents do not interact with all the other agents in the economy simultaneously, but only with their neighbors in a network (see Durlauf, 1996; Ellison, 1993; Benabou, 1993, 1996). Corominas-Bosch (2004) formulates a model of bargaining between buyers and sellers who are connected by an exogenously given network. Transactions occur only between buyers and sellers that are connected by a link, but if a player has multiple links, then several possibilities to transact become possible. Thus, the network structure essentially determines the bargaining power of various buyers and sellers. Similarly, Kranton and Minehart (2001) look at the formation of buyer-seller networks. The valuations of the buyers for a good are random and the determination of prices is made through an auction rather than alternating offers bargaining. Recently, Gale and Kariv (2007) investigate experimentally the effect of intermediation between buyers and sellers

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<sup>1</sup> For a general introduction on how decentralized markets shape economic activity, see Kirman (1997).

on networks. In their design, traders are organized in an incomplete network. Although this represents a potential source of friction, they find that trade is nevertheless efficient and prices converge to the equilibrium price very quickly.

The work on risk-sharing networks has been driven by some empirical irregularities. In theory, risk-sharing arrangements with complete markets should ensure that individual consumption varies positively with aggregate consumption and does not respond to income shocks. However, due to asymmetry of information and moral hazard, risk-sharing arrangements are primarily established depending on the enforceability of contracts, proxied by short distances, rather than the diversification of income risk. Moreover, a number of empirical studies point out that the existing network of interpersonal relationships shapes the formation of the network of risk-sharing agreements (Fafchamps and Lund, 2003; de Weerdt, 2004; Fafchamps and Gubert, 2006). Despite the evidence, there are only a few papers that approach these issues theoretically. Bloch et al. (2006) investigate under what network structures bilateral insurance schemes are self-enforceable. The basic idea is that network links play two distinct roles: first, they provide insurance, as conduits for transfers, and second, they facilitate monitoring, as conduits for information. The latter allows for individuals that defect from the insurance scheme to be punished by exclusion. Networks where insurance schemes are self-enforceable are either "thickly connected" or "thinly connected", whereas under intermediate degrees of connectedness, individuals are more likely to defect.

In contrast, Bramouille and Kranton (2007c) study the formation of risk-sharing networks. When income shocks are randomly distributed over a population, efficient networks (indirectly) connect all individuals and involve full insurance. However, equilibrium networks connect fewer individuals, yielding asymmetric risk sharing outcomes. In a later piece, Bramouille and Kranton (2007b) study risk sharing across communities. When agents face idiosyncratic and community-level shocks, networks that span communities can yield higher welfare than networks that connect all agents within a village.

The use of network theory is especially relevant in analyzing diffusion and product adoption. The work by Katz and Shapiro (see Katz and Shapiro, 1994; and Economides, 1996 for surveys) capture situations where social pressure was critical, and individuals cared only about population averages. Recently there has been significant progress in studying diffusion processes including explicit social network structures (Galeotti and Goyal, 2007; Golub and Jackson, 2007; Lopez-Pintado, 2007; Lopez-Pintado and Watts, 2007).<sup>2</sup> Network analysis has also offered important insights into research and development (R&D) networks (Goyal and Moraga-Gonzales, 2001; Goyal et al., 2004) and trade agreements (Furusawa and Konishi, 2005). All of this research begins to suggest how network analysis might be applied to understanding finance.

## APPLICATIONS TO FINANCE

Economic research on networks offers insights into how network analysis might be applied to financial systems. While there would appear to be many applications of network analysis to financial systems, the literature on financial networks is still at an early stage. Most of the existing research using network theory concentrates on issues such as *financial stability and contagion*. Moreover, most of the research done in financial networks studies *network effects* rather than *network formation*. The literature primarily investigates how different financial network structures respond to the breakdown of a single bank to identify which structures are more fragile. In the first subsection below, we discuss this literature on contagion. In the next subsection, we consider whether network theory can be used to understand how interbank markets can freeze, as they did in the months after August 2007. The third considers the role of

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<sup>2</sup> The literature on diffusion overlaps with the literature on learning on networks. For a survey, see Goyal (2004).

social networks in investment decisions and corporate governance, among other areas. The fourth subsection considers how network theory can be used to analyze investment banking. Finally, we look at how networks can help understand microfinance and other types of network-based relationships.

### **Contagion**

*More connections between banks may reduce the risk of contagion.* While the risk of contagion might be expected to be larger in highly interconnected banking system, research indicates that shocks may have complex effects. To the extent that the more complete the set of links between banks is, the lower the risk of contagion in the system.

The literature on contagion takes two approaches: examining direct linkages and indirect balance-sheet linkages. In looking for contagious effects via direct linkages, early research by Allen and Gale (2000) studied how the banking system responds to contagion when banks are connected under different network structures. In a setting where consumers have the liquidity preferences introduced by Diamond and Dybvig (1983) where consumers have random liquidity needs, banks perfectly insure against liquidity shocks by exchanging interbank deposits. The connections created by swapping deposits, however, expose the system to contagion. The authors showed that incomplete networks are more prone to contagion than complete structures. Better connected networks are more resilient since the proportion of the losses in one bank's portfolio is transferred to more banks through interbank agreements. To show this, they take the case of an incomplete network where the failure of a bank may trigger the failure of the entire banking system. They prove that, for the same set of parameters, if banks are connected in a complete structure, then the system is more resilient to contagious effects.

The research that followed, although using stylized models, captured well the network externalities created from individual bank risk. Freixas et al. (2000) considered the case of banks that face liquidity shocks due to uncertainty about where consumers will withdraw funds. In their model, the connections between banks are realized through interbank credit lines that enable these institutions to hedge regional liquidity shocks. As in Allen and Gale's study, more interbank connections enhance the resilience of the system to the insolvency of a particular bank. One drawback is that this weakens the incentives to close inefficient banks. Moreover, the authors find that the stability of the banking system depends crucially on whether many depositors choose to consume at the location of a bank that functions as a money center or not.

Concerned with optimal financial network, Leitner (2005) constructs a model where the success of an agent's investment in a project depends on the investments of other agents she is linked to. Since endowments are randomly distributed across agents, an agent may not have enough cash to make the necessary investment. In this case, agents may be willing to bail out other agents to prevent the collapse of the whole network. Leitner examines the design of optimal financial networks that minimize the trade-off between risk sharing and the potential for collapse. Vivier-Lirimont (2004) addresses the issue of optimal networks from a different perspective: he is interested in those network architectures where transfers between banks improve depositors' utility. He finds that only very dense networks, where banks are only a few links away from one another, are compatible with a Pareto optimal allocation. Dasgupta (2004) also explores how linkages between banks, represented by crossholding of deposits, can be a source of contagious breakdowns. The study examined how depositors who receive a private signal about banks' fundamentals may wish to withdraw their deposits if they believe that enough other depositors will do the same. To eliminate the multiplicity of equilibria the author uses the concept of global games. Dasgupta isolated a unique equilibrium, depending on the value of the fundamentals. Although this study analyzed only two banks, it would be interesting to study a setting where multiple banks are connected through a network.

Other researchers studied contagion in other industries beyond banking. Cummins et al. (2002) show how the structure of catastrophe insurance markets can lead to contagion. State

guarantee funds, such as the one in Florida, are based explicitly on allocating defaulted policy claims to other solvent insurers, typically in proportion to the net premiums written by these insurers. Cummins et al. show how this network structure limits the capacity of the insurance industry to absorb the effects of a major catastrophic event to well below the total amount of equity capital in the industry.

Parallel to this literature, other researchers applied network techniques developed in mathematics and theoretical physics to study contagion. For instance, Eisenberg and Noe (2001) investigate default by firms that are part of a single clearing mechanism. First, the authors show the existence of a clearing payment vector that defines the level of connections between firms. Next, they develop an algorithm that allows them to evaluate the effects small shocks have on the system. This algorithm produces a natural measure of systemic risk based on how many waves of defaults are required to induce a given firm in the system to fail. Similarly, Minguez-Afonso and Shin (2007) use lattice-theoretic methods to study liquidity and systemic risk in high-value payment systems, such as for the settlement of accounts receivable and payable among industrial firms, and interbank payment systems. Gai and Kapadia (2007) develop a model of contagion in financial networks and use similar techniques as the epidemiological literature on spread of disease in networks to assess the fragility of the financial system, depending on the banks' capital buffers, the degree of connectivity, and the liquidity of the market for failed banking assets. As with Allen and Gale, they find that greater connectivity reduces the likelihood of widespread default. However, shocks may have a significantly larger impact on the financial system when they occur. Moreover, the resilience of the network to large shocks depends on shocks hitting particular fragile points associated with structural vulnerabilities.

*The impact of indirect linkages on contagion* is considered as well in another set of studies. These studies share the same finding with the previous stream of research that financial systems are inherently fragile. Fragility, not only arises exogenously, from financial institutions' exposure to common macro risk factors such as economic downturns; it also evolves endogenously, through forced sales of assets by some banks that depress the market price, inducing further distress to other institutions.

Lagunoff and Schreft (2001) construct a model where agents are linked in the sense that the return on an agent's portfolio depends on the portfolio allocations of other agents. In their model, agents that are subject to shocks reallocate their portfolios, thus breaking some linkages. Two related types of financial crisis can occur in response. One occurs gradually as losses spread, breaking more links. The other type occurs instantaneously when forward-looking agents preemptively shift to safer portfolios to avoid future losses from contagion. Similarly, de Vries (2005) shows that there is dependency between banks' portfolios, given the fat tail property of the underlying assets, and this carries the potential for systemic breakdown. Cifuentes et al. (2005) present a model where financial institutions are connected via portfolio holdings. The network is complete as everyone holds the same asset. Although the authors incorporate in their model direct linkages through mutual credit exposures as well, contagion is mainly driven by changes in asset prices.

*The issue of network formation is considered in two studies.* Babus (2007) proposes a model where banks form links with each other as an insurance mechanism to reduce the risk of contagion. At the base of the link formation process lies the same intuition developed in Allen and Gale (2000): better connected networks are more resilient to contagion. The model predicts a connectivity threshold above which contagion does not occur, and banks form links to reach this threshold. However, an implicit cost associated with being involved in a link prevents banks from forming more connections than required by the connectivity threshold. Banks manage to form networks where contagion rarely occurs. Castiglionesi and Navarro (2007) are also interested in decentralizing the network of banks that is optimal from a social planner perspective. In a setting where banks invest on behalf of depositors and there are positive network externalities on the investment returns, fragility arises when banks that are not sufficiently capitalized gamble with

depositors' money. When the probability of bankruptcy is low, the decentralized solution approximates the first best.

Besides the theoretical investigations, *empirical studies* of national banking systems have looked for evidence of contagious failures of financial institutions resulting from the mutual claims they have on one another. Most of these papers use balance sheet information to estimate bilateral credit relationships for different banking systems. Subsequently, the stability of the interbank market is tested by simulating the breakdown of a single bank. Upper and Worms (2004) analyze the German banking system. Sheldon and Maurer (1998) consider the Swiss system. Cocco et al. (2005) present empirical evidence for lending relationships existing in the Portuguese interbank market. Furfine (2003) studies the interlinkages between US banks, while Wells (2004) looks at the UK interbank market. Boss et al. (2004) provide an empirical analysis of the network structure of the Austrian interbank market and discuss its stability when a node is eliminated. In the same manner, Degryse and Nguyen (2007) evaluate the risk that a chain reaction of bank failures would occur in the Belgian interbank market. These papers find that the banking systems demonstrate high resilience, even to large shocks. Simulations of the worst case scenarios show that banks representing less than 5% of total balance sheet assets would be affected by contagion on the Belgian interbank market, while for the German system the failure of a single bank could lead to the breakdown of up to 15% of the banking sector based on assets.

These results depend heavily on how the linkages between banks, represented by credit exposures in the interbank market, are estimated (Upper 2006). For most countries, data is extracted from banks' balance sheets, which can provide information on the aggregate exposure of the reporting institution vis-a-vis all other banks. To estimate bank-to-bank exposures, it is generally assumed that banks spread their lending as evenly as possible (i.e. the maximum entropy method). In effect, this assumption requires that banks are connected in a complete network. Hence the assumption might bias the results, in the light of the theoretical findings that better connected networks are more resilient to the propagation of shocks. This is confirmed by Mistrulli (2007), who analyses how contagion propagates within the Italian interbank market using actual bilateral exposures. He also applies the maximum entropy method to the same dataset, and he finds that it tends to generally underrate the extent of contagion.

Other researchers have examined the impact of specific bank failures. Iyer and Peydro-Alcalde (2007) test for financial contagion using data about interbank exposures at the time of the failure of a large Indian bank. They use detailed information on the interbank exposures of banks in the system with the failed bank, as well as information on the interbank linkages of banks among themselves apart from the exposures with the failed bank. They find that banks with higher interbank exposure to the failed bank experience higher deposit withdrawals, and that the impact of exposure on deposit withdrawals is higher for banks with weaker fundamentals.

One of the striking features of the events of August 2007 and subsequently is the low credit quality of many banks' assets that they originally thought were actually high quality. One popular explanation of this is to blame the ratings agencies. However, taking the kind of network perspective adopted above underlines how difficult credit analysis is in a complex, interconnected system. When there is a chain of claims with many links, it becomes very difficult to judge the ultimate credit quality.

### **Freezes in Interbank Markets**

Although researchers have devoted a great deal of time to analyzing possible forms of contagion in interbank markets, the actual type of contagion that occurred in the months following August 2007 came as something of a surprise. The interbank markets simply dried up. Even though interest rates were high and in many cases outside the ranges specified by central banks, it was not possible for many institutions to borrow at a range of short-term maturities. An important issue is whether existing contagion theories can be adapted to understand this phenomenon or whether new ones need to be developed.

Freixas et al. (2000) do consider the possibility of gridlocks, primarily due to payment systems' breakdowns. The authors analyze different market structures and find that a system of credit lines, while it reduces the cost of holding liquidity, makes the banking sector prone to gridlocks, even when all banks are solvent. However, payment systems functioned well during the 2007 crisis and could have ensured smoothly the flow of money. We need an alternative explanation for the freeze in the interbank market.

One way to understand market freezes is through a network formation game, where the empty network emerges as an equilibrium, using the kind of analysis in Babus (2007). In her model, the endogenous formation of networks worked well and led to efficiency. However, by including frictions it may be possible to have exogenous changes in risk that are small have large effects by causing agents to withdraw from the network. This may help explain what happened in August 2007.

In a study of social networks, Mobius and Szeidl (2007) propose a model of lending and borrowing where relationships between individuals are used as social collateral. They find that the maximum amount that can be borrowed in a connected network at most equals the lowest value of a link between any two agents. Although the model focuses on trust in social networks, it can be relevant to describe interactions in the interbank market. In interbank markets, links, representing loans between banks, evolve over time. The current network between banks may serve as collateral to form a network in a future period. In this setting, a decrease in the value of the collateral may trigger an adverse effect on how links will be formed in the next period. A small perturbation can, thus, result in a significant drop in lending and borrowing activities across the network.

### **Social Networks and Investment Decisions**

A recent trend of empirical research advances a new important set of questions: the effects of social networks on investment decisions. Cohen et al. (2007) use social networks to identify information transfers in security markets. They use connections between mutual fund managers and corporate board members via shared educational institutions as a proxy for the social network. They find that portfolio managers place larger bets on firms they are connected to through their network, and perform significantly better on these holdings relative to their non-connected holdings. These results suggest that social networks may be an important mechanism for information flow into asset prices. However, it is less clear whether there are network externalities. In other words, it is less clear how far information travels through the network and whether it affects asset prices across more than two links. Hochberg et al. (2007) look at venture capital (VC) firms that are connected through a network of syndicated portfolio company investments. They also find that better-networked VC firms experience significantly better fund performance, as measured by the proportion of investments that are successfully exited through an IPO or a sale to another company. This implies that one's network position should be an important strategic consideration for an incumbent VC, while presenting a potential barrier to entry for new VCs.

Another set of studies investigates problems related to corporate governance. Nguyen-Dang (2007) is concerned with the impact of social ties between CEOs and directors within a board of directors on the effectiveness of board monitoring. The paper investigates whether CEOs are less accountable for poor performance depending on their position in the social network. To map the social network, the author uses data on educational background of CEOs from the largest French quoted corporations. Social ties are also formed through interlocking directorships. He finds that when some of the board members and the CEO belong to the same social circles, the CEO is provided with a double protection. She is less likely to be punished for poor performance and more likely to find a new and good job after a forced departure. In later work, Kramarz and Thesmar (2007) run a similar analysis and find evidence to support that social networks may strongly affect board composition and may be detrimental to corporate governance. Braggion

(2008) considers another proxy for social networks between firms' managers: the affiliation with Freemasonry. He finds that social networks help to resolve agency problems between lenders and borrowers in firms that have difficulties in obtaining debt finance. However, in large publicly quoted corporations that were managed by Freemasons, social connections give rise to agency conflicts between managers and shareholders and worsen economic performance.

In related work, Gaspar and Massa (2007) find that personal connections between divisional managers and the CEO within a firm increase the bargaining power of the connected managers and decrease the efficiency of decisions within the organization. Further studies confirm that firms whose directors are better connected and whose connections are with better connected directors exhibit weaker firm governance. In particular, in firms where members of the board are highly connected, CEO pay is higher, CEO pay is less sensitive to firm performance, and poorly performing CEOs are less likely to be fired (Barnea and Guedj, 2007). Similarly, in the mutual fund industry, directors tend to hire advisory firms that they have worked with in the past, and, when creating new funds, advisory firms tend to offer board seats to directors they have had business relationships with in the past (Kuhnen, 2007).

Pistor (2007) provides a more integrated approach, looking at the financial system from a global perspective. She argues that network-finance is a critical institutional arrangement, allowing the combination of features of different governance systems and leading to innovation when there is great uncertainty about financing choices.

### **Investment Banking and Networks**

While there is a very large literature that explains the emergence of *commercial* banks, there has been very little work done on why *investment* banks exist. In an important contribution, Morrison and Wilhelm (2007) argue that investment banks exist because they create networks. The researchers suggest that the central role of investment banks is to issue and underwrite securities. This requires that they develop two networks. The first is an information network, which allows them to acquire information about the demand for an issue. This network consists of large-scale investors such as pension funds and insurance companies. When an investment bank is trying to sell an issue, this network provides information on how much investors are willing to pay, helping to set a fair price. In addition to this information network, the bank needs a liquidity network to provide the funds to purchase the securities. This network may overlap to some extent with the information network. These networks are compensated by the average underpricing that has been well documented in the literature. Morrison and Wilhelm argue that the role of trust and reputation is crucial for these networks to function. Contracting technology is insufficient to provide the correct incentives.

Schnabel and Shin (2004) document how in the eighteenth century networks of merchant banks allowed capital accumulated in one part of Europe to be invested in far distant parts. For example, Amsterdam banks were networked with Hamburg banks that were in turn networked with Berlin banks. This allowed savings to flow from Amsterdam to be invested in Berlin and other parts of Prussia. In this case, these networks compensated for asymmetric information due to distance.

Formal network theory of the type described above has not been used extensively in these studies of investment banks. This is an important and interesting area with many phenomena that are only partially understood such as long run underperformance of new issues. Network theory potentially provides a new approach to explain such phenomena and also to provide a basis for normative models to analyze regulation.

### **Microfinance**

Microfinance has emerged as a powerful way for people in the developing world to mitigate risk. Households in developing countries often are faced with unpredictable income streams and expenditures. The uncertainty related to health, weather, crop pests and job

opportunities create large income variation over time. Medical bills and funeral costs are large expenditures, not always foreseeable (Coudouel et al., 2002). Microfinance may help smoothing fluctuations in consumption that are triggered by shocks in income.

Social interactions play a crucial role in the success of microfinance. For example, in India, Self Help Groups (SHGs) form the basic constituent unit of microfinance.<sup>3</sup> An SHG consists of five to twenty people, usually poor women from different families. Members pool their savings into a fund that they deposit with the bank. After the bank has observed the accumulation in the fund for a while, it starts to lend to the group, without asking for collateral. Instead, the bank relies on peer pressure and self-monitoring within the group to ensure that loans are repaid.<sup>4</sup>

The success of micro-finance in the developing world can be traced to two main factors: i) a significant decrease in the default rate of loans issued under micro-finance terms, and ii) group sanctions that are exercised within the micro-finance group to reinforce cooperation. In other words, the social network helps make this financial model work.

Although institutions such as the Grameen bank became widely known, formal microcredit markets are a fairly recent innovation in developing countries. When access to credit is limited, substantial evidence points out that risk-sharing occurs through informal bilateral agreements.

While microfinance often depends upon local personal networks such networks have their weaknesses. Group-based models such as microfinance SHGs are often fraught with free-riding and moral hazard problems. These issues and the lack of enforceability of agreements have been identified as the main deterrents for efficient risk-sharing (Udry, 1994). Inefficiencies arise from the tradeoff between the benefits these arrangements provide and the risks involved. Specifically, the gains from risk-sharing are maximized when individuals have uncorrelated or negatively correlated income. Localization is also an issue. Households that live far apart or rely on different occupations are more likely to have different income streams or to be exposed to different sources of risk. Thus, the gains from risk-sharing are maximized at large social and geographical distances. However, larger distances make the enforceability of risk-sharing agreements increasingly difficult. For this reason, as has been documented empirically, individuals tend to insure sub-optimally, foregoing benefits from risk-sharing for better enforceable contracts. For instance, Fafchamps and Gubert (2006) show that the major determinants for the formation of risk-sharing agreements are geographic proximity, as well as age and wealth differences, and not occupation or income correlation. In other words, risk-sharing arrangements are primarily established depending on the enforceability of contracts, proxied by short distances, rather than the diversification of income risk. Understanding the role of networks in this group incentive problem is one potential way of understanding the success of microfinance. We reviewed a few models above that explore the mechanisms behind cooperation in risk-sharing networks.

Further evidence points out the importance social networks in emerging economies. Bunkanwanicha, Fan and Wiwattanakantang (2008) show that marriage might be used to strengthen business alliances. It appears that in Thailand, between 1991 and 2006, more than two thirds of marriages of big-business owners' offspring were beneficial to the family's firms. This is reflected in the positive reaction the stock market has to the wedding news when the partner is from an economically or politically powerful family.

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<sup>3</sup> See, e.g., Chakrabarti (2005).

<sup>4</sup> Social lending is pervasive in well developed countries as well. Peer-to-peer lending marketplaces, such as Prosper in the United States, and Zopa in Great Britain, offer borrowers cheaper credit than conventional markets. Seemingly, they also do better assessing risk, relying on endorsements by friends that help lenders to judge the risk of a specific borrower.

Most of the work on risk-sharing networks has focused on monitoring and enforceability problems. Other aspects are worth considering as well. For instance, it would be interesting to study the effect that the structure of a pre-existent social network has on the formation of a risk-sharing network. Concepts of "strong" and "weak" ties, first introduced by Granovetter (1973), can be useful to describe the structure of the social network. A strong tie refers to a relationship at a close social or geographic distance, while a weak tie reflects a more distant connection. There may be spillovers across different links. For instance, parties are more likely to establish a risk-sharing agreement over a weak tie if they are involved in other risk-sharing agreements conducted over strong ties. Varying the distribution of strong ties and weak ties in the population yields information on what social network structures are more likely to favor efficient risk-sharing.

A further question is how introducing a formal institution (i.e. a bank) that reduces the need for informal risk-sharing agreements in one region of the network affects the efficiency of risk-sharing in the overall network. A closely related issue is to understand the effects of changes in the underlying social network, for example due to migration, on the overall efficiency of the network of risk-sharing agreements.

## METHODOLOGY

Network theories draw primarily from two methodological approaches. One approach that has its roots in the literature in network economics, taking a micro perspective that considers how agents' behavior is driven by incentives. The other approach is rather mechanical, employing various stochastic procedures, and draws from the statistical physics literature, overlapping with literature in sociology and biology. We discuss these two approaches below to understand their strengths and weaknesses.

The economic modeling of networks, as with economic modeling in general, takes the approach that social and economic phenomena should ultimately be explained in terms of choices made by rational agents. The choice perspective assumed by the research on the theory of networks translates mostly into models of network formation. Agents choose with whom they interact by weighing the costs and benefits from being connected. The key assumption is that there exists a natural metric that determines how an agent benefits from another agent, depending on their relative position in the network. Hence, externalities across players are network dependent. That individuals are supposed to form or sever relationships, depending on the benefits they bring, can be modeled through a game of network formation.

Various equilibrium concepts have been advanced in the past few years to analyze the formation of bilateral connections in settings where agents are fully aware of the shape of the network they belong to and of the benefits they derive from it.<sup>5</sup> The difficulty arises from the fact that bilateral connections require consent to be formed from both sides (the vast majority of interactions falls within this category). Hence, a non-cooperative concept, such as Nash equilibrium, is not very useful to solve a network formation game.<sup>6</sup> A simpler notion, proposed by Jackson and Wolinski (1996), looks directly at stable networks. According to them, a network is pairwise stable i) if a link between two individuals is absent from the network then it cannot be that both individuals would benefit from forming the link, and ii) if a link between two individuals is present in a network then it cannot be that either individual would strictly benefit

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<sup>5</sup> Jackson (2004) provides an extensive survey of the literature on network formation, while Bloch and Jackson (2007) provide a comprehensive summary of stability and equilibrium definitions.

<sup>6</sup> Myerson (1991) attempted to model a noncooperative linking game in which agents independently announce which links they would like to see formed and then standard game-theoretic equilibrium concepts can be used to make predictions about which networks will form. There are at least two drawbacks with this approach. The first is that there is a multiplicity of equilibria with different types of network. There is also always an "empty network" equilibrium. It is always a Nash equilibrium for each agent to say that he or she does not want to form any links, anticipating that the others will do the same.

from deleting that link. There are many alternatives to this notion that have been proposed in the literature, mainly varying how many relationships agents can manage at the same time. For example, Gilles and Sarangi (2006) consider that individuals can change multiple relationships at the same time rather than just one at a time, while Goyal and Vega-Redondo (2007) go one step further by allowing pairs of individuals to coordinate on how they change relationships.<sup>7</sup>

Bloch and Jackson (2007) propose another linking game where players can offer or demand transfers along with the links they suggest, which allows players to subsidize the formation of particular links. For the cases when consent is not needed, so that agents can unilaterally form new relationships, Bala and Goyal (2000) return to the Nash equilibrium concept.

The literature goes beyond a static equilibrium approach to study dynamic processes where the network gradually evolves over time (Jackson and Watts, 2002; Dutta et al. 2005; Page et al., 2005; Mauleon and Vannetelbosch, 2004). In this type of model, players add or delete links each period through myopic considerations of whether this would increase their payoffs.

In addition to network formation games, many models look at behavior in networks. These studies consider that the pattern of connections between individuals has a significant impact on their choices. They employ game theoretical tools to measure how the payoff an individual gains from an action depends on the choices made by others she is linked to. In this setting, one may study how learning takes place in networks (Bala and Goyal, 1998, 2001), how network structure impacts beliefs (Gale and Kariv, 2003; Choi, Gale and Kariv, 2005) or how investments in public goods depend on the network (Bramoulle and Kranton, 2007). A general theoretical framework to analyze such strategic interactions when neighborhood structure is taken into account is proposed in Galeotti et al. (2007).

The modeling of networks in other non-economic literatures starts from different premises. Empirical research has revealed a set of common properties that describe many real-world networks. For example, the world-wide-web, the film actors network, metabolic networks that determine the physiological and biochemical properties of a cell, all seem to exhibit similar features: a small-world property, unequal degree distribution, and high clustering.<sup>8</sup> The small world property implies that the average shortest distance between pairs of nodes in a social network tends to be very low. The distance between two nodes is measured as the number of links between the two nodes in the network. The maximum distance between any pair of nodes in a network is also small. Networks tend to exhibit high inequality in the number of links nodes have. For instance, it has often been shown that the distribution of number of links per node in a network follows a power-law distribution. That is, the probability that a node in a network interacts with other nodes decays as a power law. This suggests that very few nodes have a large number of links, a large number of nodes have very few links. Clustering coefficients measure the tendency of linked nodes to have common neighbors. The level of clustering in a social network is very high when compared to networks where links are formed at random.

Since these properties appear to be universal for complex biological, social, and engineered systems, most of the research has focused on explaining how they emerged. For instance, Watts and Strogatz (1998) develop a model by starting with a symmetric network and randomly rewiring some links. This way, they generate networks that are small worlds and exhibit high clustering. In Price (1976) and Barabasi and Albert (1999), nodes form links through preferential attachment: new nodes link to existing nodes with probabilities proportional to the existing nodes' numbers of links.

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<sup>7</sup> This is a special case of the general setting that allows groups to coordinate their changes in relationships - see Dutta and Mutuswami (1997) and Jackson and van den Nouweland (2005).

<sup>8</sup> For a detailed description of these properties and a comprehensive survey on complex networks, see Newman (2003).

Other models on networks effects study the physical spread or transmission of infections and behavior that are transmitted directly or by chance, and not through some updating or optimization procedures. Standard models of such spreading come from the epidemiology literature, which has focused on the spread of contagious disease.

These techniques can be used as tools to describe and analyze financial systems. For instance, the modeling of interactions on the interbank market ought to take into account that links between financial institutions are created mainly through lending of funds for a very short term. That financial institutions have the opportunity to reconsider their links on a daily basis can be modeled as a dynamic game of network formation. On the other hand, connections in security markets are based on informal agreements between investment banks and investors. Although not binding, these informal agreements imply that investors will provide the necessary liquidity and that the investment bank will reward them in return. This situation is better modeled through a static game of network formation. Financial institutions form links at once, taking into account the repeated nature of interactions over links and the discounted value of future gains obtained through these links. The models of games on networks may be useful in understanding how banks decide on the level of mutual exposures towards each other, for a given pattern of interconnections. Techniques developed by other non-economic literatures are more appropriate to study complex processes in financial systems.

Which of the two approaches is more appropriate to model financial networks depends on whether financial institutions are assumed to behave strategically or not. A game theoretical analysis requires that players know the game they play. In other words, agents need to be aware of the shape of the network they belong to and the impact of the network on their gains. A mechanical approach that draws from the physics and mathematics literatures can only provide cause-and-effect insights. For instance, using models from the epidemiological literature on the spread of disease in networks to study contagion in the banking system requires the limiting assumption that contagion takes place instantaneously and banks have no time to react.

## **CONCLUDING REMARKS**

Our financial systems are networks, and today these networks have grown increasingly complex and interlinked. In this paper, we have argued that network analysis can potentially play a crucial role in understanding many important phenomena in finance. At the moment, this type of approach has mostly been restricted to analyzing contagion in interbank markets. More recent work has focused on the effects of social networks in various contexts, including investment and corporate governance. It seems clear that networks are also crucial in understanding investment banks and microfinance. Another issue to be explored is how some financial institutions exploit their position as intermediaries between other institutions. Financial institutions that bridge otherwise disconnected parts of the network might gain significant payoff advantages. Financial networks will, thus, be shaped by incentives that drive institutions to acquire the intermediation gains. These are just some of the topics in finance that a network analysis could be useful for going forward.

Moreover, recent events have made clear that there is a strong need for sound empirical work in this area. Mapping the networks between financial institutions is a first step towards gaining a better understanding of modern financial systems. A network perspective would not only account for the various connections within the financial sector or between the financial sector and other sectors, but would also consider the quality of these links. We need this work to guide the development of new theories that can help us understand events such as the August 2007 crisis, as well as design new regulations that better meet the challenge of an increasingly networked world.

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