Networks in Finance*

Franklin Allen
University of Pennsylvania

Ana Babus
Erasmus University

February 17, 2008

Abstract

Modern financial systems exhibit a high degree of interdependence. There are different possible sources of connections between financial institutions, stemming from both the asset and the liability side of their balance sheet. For instance, banks are directly connected through mutual exposures acquired on the interbank market. Likewise, holding similar portfolios or sharing the same mass of depositors creates indirect linkages between financial institutions. Broadly understood as a collection of nodes and links between nodes, networks can be a useful representation of financial systems. By providing means to model the specifics of economic interactions, network analysis can better explain certain economic phenomena. In this paper we argue that the use of network theories can enrich our understanding of financial systems. We review the recent developments in financial networks, highlighting the synergies created from applying network theory to answer financial questions. Further, we propose several directions of research. First, we consider the issue of systemic risk. In this context, two questions arise: how resilient financial networks are to contagion, and how financial institutions form connections when exposed to the risk of contagion. The second issue we consider is how network theory can be used to explain freezes in the interbank market of the type we have observed in August 2007 and subsequently. The third issue is how social networks can improve investment decisions and corporate governance. Recent empirical work has provided some interesting results in this regard. The fourth issue concerns the role of networks in distributing primary issues of securities as, for example, in initial public offerings, or seasoned debt and equity issues. Finally, we consider the role of networks as a form of mutual monitoring as in microfinance.

*Prepared for the forthcoming book entitled *Network-based Strategies and Competencies* edited by Paul Kleindorfer and Jerry Wind to be published by Wharton School Publishing. We are grateful to the editors and to participants at the conference on November 8-9, 2007 where the book's papers were presented for their helpful comments.

1 Introduction

The turmoil in financial markets in August of 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 side of their 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 relation 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 defence 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 paper, we argue that the theory of networks 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 what externalities 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 becoming global.

More generally, network analysis may help address two types of questions. On the one hand there are questions concerning network effects, and, on the other hand, there are questions related to 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 studies processes that take place on fixed networks. For instance, the resilience of a banking system to contagion can be evaluated depending on the network structure that connects financial institutions. It can be shown 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 facilitate 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 studies how financial institutions form connections. New insights in the issue of systemic risk can be gained 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 of 2007 and subsequent months. When the risk associated with the lending of 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. In this paper, we elaborate on these themes aiming to emphasize the role of network theories.

This paper 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.

2 Applications in Economics

Economists aim to identify the relevant questions where network analysis provides meaningful insights. There are several themes that have been approached and we briefly survey them in this section.

Networks of relations are prevalent in a range of situations. For instance, connections facilitate access to information on job opportunities; networks underlie the trade and exchange of goods in non-anymous markets; risk sharing agreements in developing countries can be traced back to social relationships. Further applications include diffusion of new technologies and products, research and development and collusive alliances among firms, international alliances and trade agreements.

The interest in how networks are involved in labor markets stems from 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, e.g. Rees (1966), Granovetter (1995), Montgomery (1991). Moreover on average 40-50 percent of the employers use social networks of their current employees (i.e. they hire recommended applicants) to fill their job openings, e.g. 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, there has been a constant interest over time in 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.[1] 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

[1] For a general introduction on how decentralized markets shape economic activity , see Kirman (1997).

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 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 fast.

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 at 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 serve for 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, Bramoulle and Kranton (2005) 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, Bramoulle and Kranton (2007) 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 product adoption decisions. The work by Katz and Shapiro (see Katz and Shapiro, 1994 and Economides, 1996 for surveys) captured 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).[2] However, the applications to industrial organization on research and development networks (Goyal and Moraga-Gonzales, 2001; Goyal et al., 2004) and trade agreements (Furusawa and Konishi, 2005) bring important insights.

3 Applications to Finance

Modern financial systems exhibit a high degree of interdependence. There are different possible sources of connections between financial institutions, stemming from both the asset and the liability side of their balance sheet. Direct asset linkages result, for instance, from exposures between banks acquired through the interbank market. Financial institutions are indirectly connected by having 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.

There would appear to be many applications of network analysis to financial systems. Despite this, 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 mostly investigates how different network structures respond to the breakdown of a single bank in order to identify which ones 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

[2] The literature on diffusion overlaps with the literature on learning on networks. For a survey, see Goyal (2005).

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

3.1 Contagion

The theoretical literature on contagion takes two approaches. On the one hand, there is a number of papers that look for contagious effects via direct linkages. An early paper in the field that generated a stream of subsequent articles is Allen and Gale (2000). The paper studies how the banking system responds to contagion when banks are connected under different network structures. In a setting where consumers have the Diamond and Dybvig (1983) type of liquidity preferences, banks perfectly insure against liquidity shocks by exchanging interbank deposits. The connections created by swapping deposits expose the system to contagion. The authors show that incomplete networks are more prone to contagion than complete structures. Better connected networks are more resilient to contagion 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 resilient to contagious effects.

The models that followed, although stylized, capture well the network externalities created from an individual bank risk. Freixas et al. (2000) considers the case of banks that face liquidity needs as consumers are uncertain about where they are to consume. In their model the connections between banks are realized through interbank credit lines that enable these institutions to hedge regional liquidity shocks. In the same way as in Allen and Gale (2000), interbank connections enhance the resilience of the system to the insolvency of a particular bank. The 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. 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, in order to prevent the collapse of the whole network. Leitner is interested in 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 discusses how linkages between banks represented by crossholding of deposits can be a source of contagious breakdowns. Fragility arises when depositors, that 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. A unique equilibrium is isolated and this depends on the value of the fundamentals. Although the analysis is done only for two banks, it would be interesting to study a setting where multiple banks are connected through a network.

It is not only in the banking industry that contagion can occur. Cummins et al. (2002) show how the structure of catastrophe insurance markets can also 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, there is a number of papers that make use of network techniques developed in mathematics and theoretical physics to study contagion. For instance, Eisenberg and Noe (2001) take this kind of technical approach when investigating 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. 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 second approach focuses on indirect balance-sheet linkages. 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 who 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. These papers all share the same finding: financial systems are inherently fragile. Fragility, not only arises exogenously, from financial institutions' exposure to macro risk factors, as is the case in de Vries (2005). It also evolves endogenously, through forced sales of assets by some banks that depress the market price inducing further distress to other institutions, as in Cifuentes et al. (2004).

Complementary to the literature on network effects, Babus (2007) considers a model where banks form links with each other in order to reduce the risk of contagion. The network is formed endogenously and serves as an insurance mechanism. 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 to being involved in a link prevents banks from forming connections more than required by the connectivity threshold. Banks manage to form networks where contagion rarely occurs. Castiglionesi and Navarro (2007) are also interested in whether banks manage to decentralize the network structure a social planner finds optimal. 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, there has been a substantial interest in looking 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 on the Portuguese interbank market. Furfine (2003) studies the interlinkages between the 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 a 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 in terms of assets. These results heavily depend on how the linkages between banks, represented by credit exposures in the interbank market, are estimated. 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 lendings as evenly as possible. 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. Upper (2006) contains a survey of this literature.

Departing from the simulation approach, 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.

3.2 Freezes in interbank markets

Although academics and researchers at central banks have devoted a great deal of time to analyzing possible forms of contagion in interbank markets, the actual type of contagion that occurred came as something of a surprise. What happened during the months following August 2007 was that 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) is one paper that allows the possibility of gridlocks. This paper is mainly concerned with 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 experience gridlocks, even when all banks are solvent. However, payment systems functioned well and could have ensured smoothly the flow of money, during the crisis of the summer of 2007. An alternative explanation is required 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. This requires 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.

Mobius and Szeidl (2007) propose a model of lending and borrowing in a social network, where relationships between individuals can be 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 aims to measure 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 the lending and borrowing activities on the market.

3.3 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 transfer in security markets. Connections between mutual fund managers and corporate board members via shared education institutions proxy 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 (2005) is concerned with the impact of CEO interlocking directorships on the effectiveness of board monitoring. Using data on educational background of CEOs from the largest French quoted corporations, the paper investigates whether CEOs are less accountable for poor performance depending on their position in the social network. 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. Kramarz and Thesmar (2006) run a similar analysis with the same data base and find evidence to support that social networks may strongly affect board composition and may be detrimental to corporate governance. In related work, Gaspar and Massa (2007) study what impact the personal connections between divisional managers and CEO within a firm have on firm performance. They find evidence that the existence of a social network between the CEO and the divisional managers increases the bargaining power of the connected managers and decreases the efficiency of the decisions within the organization.

A more integrated approach to connections in the financial system is provided in Pistor (2007). The author looks at the financial system from a global perspective and advances the idea of network-finance as a critical institutional arrangement. She argues that network finance allows features of different governance systems to be combined and leads to innovation when there is great uncertainty about the financing choices being made.

3.4 Investment banking and networks

There is a very large literature on the reason for the existence of commercial banks. In contrast there has been very little work done on the reason that investment banks exist. In an important contribution, Morrison and Wilhelm (2007) argue that investment banks exist because they create networks. They 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 would consist 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 they are willing to pay so that a fair price can be arrived at. 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 to the operation of these networks. 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 other possibly 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 overcome an asymmetric information problem that arises as a result of distance.

Formal network theory of the type described above has not been used extensively in this literature on 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.

3.5 Microfinance

Microfinance is one of the most important ways that individuals and households in the developing world can deal with risk. It is often the case that households in developing countries are faced with unpredictable income streams and expenditures needs. 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). Thus, mitigating risk becomes a central concern so as to smooth 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.[3] An SHG consists of five to twenty people usually poor women from different families. People pool

[3] See, e.g., Chakrabarti (2005).

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 collateral. Instead the bank relies on peer pressure and self-monitoring within the group to ensure that loans are repaid.[4]

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.

Although institutions such as 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. However, insurance in village communities is only limited (Grimard, 1997). Group-based situations such as microfinance SHGs are often fraught with free-riding and moral hazard problems. These and the lack of enforceability of agreements have been identified as the main deterrents for efficient risk-sharing (Udry, 1994). Inefficiencies arise from the trade off 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. 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 nor 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. In Section 2 we reviewed a few models that

[4] 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 a better assessing risk, relying on endorsements by friends, that help lenders to judge the risk of a specific borrower.

explore the mechanisms behind cooperation in risk-sharing networks.

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. These concepts may be used to incorporate spillovers across different links. For instance, a risk-sharing agreement over a weak tie is more likely to be established if both parties 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.

4 Methodology

In this section we briefly review some network techniques that have been used as tools to investigate the issues discussed above and can also be used to consider new directions for research. Network theories draw primarily from two sources. One approach that has its roots in the literature in network economics, is microfounded and considers that 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, like much of economic modelling 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.[5] The difficulty arises from the fact that bilateral connections require consent to be formed from both sides involved (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.[6] A simpler notion looks directly at stable networks and has been proposed by Jackson and Wolinski (1996). 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 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.[7] 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

[5] 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.

[6] 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 mulitiplicity 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.

[7] 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).

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 models, players add or delete links each period through myopic considerations of whether this would increase their payoffs.

In addition to network formation games, there is a vast number of models that look at behavior on 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 modelling of networks assumed in the 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.[8] 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 k other nodes decays as a power law. This suggests that very few nodes have a large number of links, while there exists a large number of nodes with very few links. Clustering

[8]For a detailed description of these properties and a comprehensive survey on complex networks, see Newman (2003).

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. Networks formed through this procedure have the appealing feature that the proportion of nodes that have k links follows a power-law in k.

There is also a number of models on networks effects that 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 focussed 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 on 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 rather 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. As for the techniques developed by other non-economic literatures, they 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 type of 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.

5 Concluding Remarks

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. It is important to stress that these are just some of the topics in finance that this kind of analysis is likely to be important for going forward.

Moreover, recent events have made clear that there is a strong need for sound empirical work. 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 that exist within the financial sector or between financial sector and other sectors, but would also consider the quality of these links. This kind of work is necessary to guide the development of new theories as well as the design of new regulations.

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