

## D FINANCIAL NETWORKS AND FINANCIAL STABILITY

*The recent global financial crisis has illustrated the role of financial linkages as a channel for the propagation of shocks. It also brought to the fore the concept that institutions may be “too interconnected to fail”, in addition to the traditional concept of being “too big to fail”.*

*This special feature introduces recent research on networks in disciplines other than economics, reviews its application to financial networks and discusses how network analysis can be used to gain a better understanding of the financial system and enhance its stability.*

### INTRODUCTION

The recent financial crisis has revealed the intertwined nature of modern financial systems. While the events unfolded, it became clear that the consequences of such interconnected and complex systems are particularly hard to predict. However, the intricate structure of linkages between financial institutions, among sectors of the economy and across entire financial systems can in fact be captured by using a network representation.

Faced with the challenging task of strengthening the current framework for financial stability, economists and policy-makers have developed a stronger awareness of the need for analytical methods that help to better identify, monitor and address systemic linkages, i.e. sources of systemic risk.<sup>1</sup> Recognition of the fact that the impact of systemic risk depends on the collective behaviour of market participants and on their interconnectedness underpins the recent emphasis on the adoption of a macro-prudential framework for financial regulation. Regulations that target individual institutions, but also take account of vulnerabilities that emerge from exposures to particular (potentially systemically relevant) counterparties in the system, may prevent a local crisis from becoming global.

Supranational institutions and fora, such as the International Monetary Fund (IMF) and the Financial Stability Board, are fully aware of the need to take into account network aspects of the global financial system in order to develop new measures of financial fragility.<sup>2</sup> The work of the new European Systemic Risk Board in mapping financial risks and their concentration at the system level, and therefore in issuing warnings as deemed appropriate, would certainly benefit from the availability of methods that make it possible to model interlinkages and mutual exposures among financial institutions, to identify the central nodes in the system and to detect and assess shock transmission channels.

The literature reviewed in this special feature, and the significant progress made by the research community in the last decades with respect to understanding complex networks, suggest that financial network analysis has the potential to represent a useful policy tool to that end.<sup>3</sup>

### THE ANALYSIS OF NETWORKS

The general concept of a network is very intuitive: a network describes a collection of *nodes* or *vertices* (e.g. financial institutions) and the links between them, which can be directed (i.e. arcs) or undirected (i.e. edges). The links denote different relationships between the nodes, depending on the domain of analysis. In the financial context, it is of particular interest to focus on credit relationships, on exposures between banks and on liquidity flows in the interbank payment system.

The main premise of network analysis is that the structure of the links between the nodes matters.

- 1 In ECB, “The concept of systemic risk”, *Financial Stability Review*, December 2009, systemic risk is broken down into three forms: contagion, macroeconomic shocks and unwinding of imbalances. This special feature focuses on contagion.
- 2 See IMF, “Assessing the systemic implications of financial linkages”, *Global Financial Stability Report*, April 2009.
- 3 In October 2009 the ECB organised a workshop on “Recent advances in modelling systemic risk using network analysis”. A detailed summary of the topics discussed was published on the ECB’s website (<http://www.ecb.europa.eu>) in January 2010.

The properties and behaviour of a node cannot be analysed on the basis of its own properties and behaviour alone, as these may be affected by nodes that have links to it, and also by other nodes that have no directed links, but are linked to its neighbours. Thus, in order to understand the behaviour of one node, one must analyse the behaviour of many nodes, including those that are, perhaps, several other nodes apart in the network.<sup>4</sup>

From the perspective of analysing the financial system, perhaps the most relevant adjacent fields where research on networks is advanced are within sociology (social network analysis) and physics (network science or physics of networks).

Social network analysis is the older of the fields and has brought forth a number of important findings related, for instance, to the diffusion of ideas, the contagiousness of habits and behaviours, the efficiency of groups based on their social network properties, the origins of power among groups and the concepts of centrality or importance of nodes in a network. The approach in physics has been to focus more on the statistical properties of networks, the resilience of different structures and the processes that take place in networks; moreover, researchers have tried to explain how networks grow over time and exhibit the complex non-random structure that has been uncovered for many empirical networks.<sup>5</sup> Newman, as well as Albert and Barabási,<sup>6</sup> review advances in modelling complex networks, focusing on the statistical mechanics of network topology and dynamics. The main models and analytical tools are used to explain a wide range of natural and societal systems, ranging from the World Wide Web and the internet to cellular, ecological and citation networks – to name but a few.

Recently, a number of academics and policy-makers have pointed out the strong potential of network analysis as a tool to better understand financial markets and to model and assess systemic risk.<sup>7</sup>

## FINANCIAL NETWORK ANALYSIS

Starting with the seminal papers by Allen and Gale, and Freixas et al.,<sup>8</sup> the economic literature has focused on the implications that a higher/lower degree of *completeness* of interbank structures (i.e. of interconnectedness generated by cross-holdings of deposits) might have for financial stability. These papers evaluate the potential for contagion that follows an aggregate and/or an idiosyncratic liquidity shock or a bank's failure and analyse the role of the central bank in preventing systemic repercussions. While the results depend strongly on the assumptions of the process taking place in the network, the common lesson learnt from these models is the importance of understanding the *structure* of financial flows in order to understand the functioning of the system, and thus to be able to assess systemic stability.<sup>9</sup>

In fact, a recent paper by Allen and Babus argues that 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.<sup>10</sup>

4 The study of network externalities in economics, by contrast, has traditionally assumed a fully connected network structure.

5 For a comprehensive synthesis of several strands of network science in sociology, physics, mathematics, computer science and economics, see M.O. Jackson, *Social and Economic Networks*, Princeton University Press, 2008.

6 M.E.J. Newman, "The structure and function of complex networks", *SIAM Review*, 2003; R. Albert and A.L. Barabási, "Statistical mechanics of complex networks", *Review of Modern Physics*, 2002.

7 See G. Tumpel-Gugerell's introductory remarks at the ECB workshop on "Recent advances in modelling systemic risk using network analysis", Frankfurt am Main, October 2009; A.G. Haldane, "Rethinking the financial network", speech delivered at the Financial Student Association, Amsterdam, April 2009; and D. Strauss-Kahn, "An IMF for the 21st century", speech held at the Bretton Woods Committee Annual Meeting, Washington D.C., February 2010.

8 F. Allen and D. Gale, "Financial contagion", *Journal of Political Economy*, 2000; X. Freixas, B. Parigi and J.C. Rochet, "Systemic risk, interbank relations, and liquidity provision by the central bank", *Journal of Money, Credit, and Banking*, 2000.

9 See also E. Nier, J. Yang, T. Yorulmazer and A. Alentorn, "Network models and financial stability", *Journal of Economic Dynamics and Control*, 2007.

10 F. Allen and A. Babus, "Networks in finance", *Wharton Financial Institutions Center Working Paper*, No 08-07, 2008.

May et al. stress the importance of identifying structural attributes shared by diverse systems – such as ecosystems and financial systems – that have survived rare systemic events, or have been shaped by them, to get indications about which characteristics of complex systems correlate with a high degree of robustness.<sup>11</sup>

In this respect, market microstructure studies carried out from a network perspective can significantly enrich the traditional view taken in economics. First, network analysis contributes to existing theoretical results on systemic risk in the interbank market by considering the overall structure of the network (thus going beyond the earlier focus on its degree of completeness). Second, it provides a stronger basis for the assessment of contagion risk by means of counterfactual simulations.<sup>12</sup>

Early analyses applying network concepts to financial data include Boss et al. for interbank exposures in Austria,<sup>13</sup> and Soramäki et al. on payment flows between banks in the US real-time gross settlement system, the Fedwire Funds Service.<sup>14</sup>

The empirical findings of both papers were in marked contrast to the interbank networks that had usually been considered in the economic literature. The networks were found to be complex with a small number of highly connected large nodes that had connections with a large number of small nodes. The cores of the networks, composed of the most connected banks, processed a very high proportion of the total value. More recently, a number of studies have looked at national interbank networks, reconstructed using payment flows.<sup>15</sup>

The unsecured overnight money market (broadly called *interbank* market) is one of the segments of financial markets where network analysis has been applied intensively as well. This is due to the key role money markets play in modern financial systems. Money markets constitute the locus where banks exchange deposits, which allows the efficient redistribution of liquidity in the system and the effective implementation

of the monetary policy stance, and represent a possible channel of contagion.

In order to gain insights into unsecured interbank loan networks, variations of a methodology proposed by Furfine have been applied to payment data to construct time series of this market.<sup>16</sup> In its simplest form, the algorithm looks for two payments: first, a payment with the value  $v$  from bank A to bank B on day  $t$  and, second, a payment with the value  $v + \text{interest}$  on day  $t+1$  from bank B to bank A. Loan data of this granularity are generally not available from other sources. The data sets generated with this algorithm can be used to analyse the topology and contagion in interbank markets. A representative paper following this approach is that of Atalay and Bech,<sup>17</sup> who use data from Fedwire to recover federal funds loans.<sup>18</sup> Iori et al. perform a network analysis of the

11 R.M. May, S.A. Levin and G. Sugihara, “Complex systems: ecology for bankers”, *Nature*, No 451, 2008.

12 Note that this strand of empirical analysis of contagion is often criticised on the grounds that simulations ignore endogenously emerging risks and feedback effects. The argument here is that more realistic structural assumptions – determined by an improved understanding of the structure underlying financial flows – might strengthen the robustness and the reliability of results.

13 M. Boss, H. Elsinger, M. Summer and S. Thurner, “The network topology of the interbank market”, *Computer Networks and ISDN Systems*, 2004.

14 K. Soramäki, M.L. Bech, J. Arnold, R.J. Glass and W.E. Beyeler, “The topology of interbank payment flows”, *Physica A*, 2007.

15 See, among others, C. Becher, S. Millard and K. Soramäki, “The network topology of CHAPS Sterling”, *Working Paper Series*, No 355, Bank of England, 2008; M. Boss, G. Krenn, V. Metz, C. Pühr and S.W. Schmitz, “Systemically important accounts, network topology and contagion in ARTIS”, *OeNB Financial Stability Report*, No 15, Oesterreichische Nationalbank, 2008; M. Pröpper, I. van Lelyveld and R. Heijmans, “Towards a network description of interbank payment flows”, *DNB Working Papers*, No 177, De Nederlandsche Bank, 2009; and L. Embree and T. Roberts, “Network analysis and Canada’s Large Value Transfer System”, *Discussion Paper Series*, No 13, Bank of Canada, 2009.

16 C. Furfine, “The microstructure of the federal funds market”, *Financial Markets, Institutions & Instruments*, 1999.

17 M.L. Bech and E. Atalay, “The topology of the federal funds market”, *Staff Report No 354*, November 2008, Federal Reserve Bank of New York.

18 Other applications are K. Bonde and M.L. Bech, “The topology of Danish interbank money flows”, *Finance Research Unit Working Paper Series*, No 2009/01, 2009; A. Wetherilt, K. Soramäki and P. Zimmerman, “The sterling unsecured loan market during 2006–2008: insights from network topology”, in H. Leinonen (ed.), *Simulation analyses and stress testing of payment networks*, Bank of Finland Scientific Monographs E:42, 2009.

Italian overnight money market using a different data source.<sup>19</sup> Iazzetta and Manna identify banks that are important in terms of a liquidity crisis, based on the distribution of liquidity among Italian banks since 1990.<sup>20</sup>

Empirical research on other parts of the financial system is less common, probably on account of the restricted nature of sufficiently detailed data. Bonanno et al. look at networks of financial stocks,<sup>21</sup> while Degryse and Nguyen investigate the extent of systemic risk and network structure in the Belgian banking system over a ten-year period.<sup>22</sup> Hasan and Schmiedel find evidence that the adoption of network strategies by stock exchanges creates additional value in the provision of trading services.<sup>23</sup> On a more aggregate level, Castren and Kavonius use a network approach to flow-of-funds data to look at shock transmission within sectors of the economy in the euro area.<sup>24</sup>

### TOO INTERCONNECTED TO FAIL

As a consequence of the recent financial crisis, the concept of “too interconnected to fail” has emerged alongside the traditional “too big to fail” paradigm.

During the recent crisis, considerations about the linkages of troubled institutions in the markets, in addition to their absolute size, sometimes became an important factor in the decisions to provide them with emergency funding.<sup>25</sup> A key question now is how systemically important institutions could be identified ex ante so that regulators can prepare for these adverse events.

A key concept in social network analysis, also suitable for applying to the financial system, is *centrality*. In a broad sense, centrality refers to the importance of a node in the network. Traditional centrality measures have included the number of links that terminate on a node (*in-degree*) or that depart from a given node (*out-degree*), or the distance from other vertices (*closeness*) via the shortest paths. Centrality can depend iteratively on the centralities of a node’s neighbours (so-called *eigenvector centrality*<sup>26</sup>),

or by the fraction of shortest paths between other vertices that a certain node falls upon (*betweenness centrality*).

Each of these established measures was originally developed for its own area of application. The challenge for financial network analysis is to devise centrality measures that accurately correlate with the impact of adverse events. These measures may differ, depending on the particular episode, as well as on the market or part of the financial infrastructure where the episode takes place. Borgatti provides a classification of network processes and proposes relevant centrality indicators for them.<sup>27</sup> For instance, financial losses can spread via a process of “parallel duplication” (to many nodes at once and with all originating nodes retaining their losses), while payment flows are a “serial transfer”-type of process (whereby money moves serially from one bank to another, and sent funds are no longer available to the originating node). Important nodes in the former type of system could be captured by eigenvector centrality, while important nodes in the latter case could be better identified by a special stochastic process called a Markov chain. In their

19 G. Iori, G. de Masi, O.V. Precup, G. Gabbi and G. Caldarelli, “The microstructure of the Italian overnight money market”, *Journal of Economic Dynamics and Control*, 2008.

20 C. Iazzetta and M. Manna, “The topology of the interbank market: developments in Italy since 1990”, *Working Paper Series*, No 711, Banca d’Italia, 2009.

21 G. Bonanno, G. Caldarelli, F. Lillo, S. Micciché, N. Vandewalle and R.N. Mantegna, “Networks of equities in financial markets”, *The European Physical Journal B*, 2004.

22 H. Degryse and G. Nguyen, “Interbank exposures: an empirical examination of systemic risk in the Belgian banking system”, *International Journal of Central Banking*, 2007.

23 I. Hasan and H. Schmiedel, “Networks and equity market integration: European evidence”, *International Review of Financial Analysis*, 2004.

24 O. Castren and I. Kavonius, “Balance sheet interlinkages and macro-financial risk analysis in the euro area”, *Working Paper Series*, No 1124, ECB, December 2009.

25 See, for instance, the Federal Reserve’s decision to extend funding to Bear Sterns on account of its “prominent position in the markets” (Minutes of the Board of Governors of the Federal Reserve System, 14 March 2008).

26 A version of eigenvector centrality is behind Google’s PageRank score to assess the relevance of search results. Pages that are linked to pages with a high PageRank get a higher PageRank score themselves.

27 S. Borgatti, “Centrality and network flow”, *Social Networks*, 2005.

recent paper, Bech et al.<sup>28</sup> use Markov theory to model the money exchange process flowing through Canada's Large Value Transfer System and provide a ranking of system participants according to liquidity holdings, as predicted by their network analysis.

The study of centrality measures might have important policy implications, especially in the current policy debate on how to best reform financial regulation. The strengthened focus on a macro-prudential orientation calls for a pragmatic approach that considers and cross-checks a number of indicators to calibrate prudential tools with respect to the systemic importance of financial institutions.<sup>29</sup> Centrality measures could prove a good tool to "operationalise" the new framework.

In particular, centrality measures might offer relevant insights concerning the identification of which nodes should be considered of "systemic importance". These measures could then be used to direct regulatory efforts and, for example, to assess the opportunity to limit institutions' exposures, set up some form of regulatory fees or capital surcharges, or to introduce an insurance fund financed through institution-specific insurance premia. Such an approach has recently also been taken in the IMF's Interim Report for the G20, which outlines that an ideal levy on financial institutions should be based on a network model that would take into account all possible channels of contagion.<sup>30</sup>

## THE WAY FORWARD

The application of network analysis to transaction-level data from national large-value payment systems is a relatively well-established tool used in many leading central banks for the macro-prudential analysis of systemic stability. However, in order to enable financial network analysis to fulfil its promising role in better understanding financial stability, work is needed on three aspects: (1) a better theory on contagion channels in the financial system, on the information content of financial links and on the behaviour of financial institutions under both

normal and stress situations; (2) better tools to manage and analyse the financial information available; and (3) a broader set of data on financial linkages – at bank-to-bank level, cross-market and cross-currency, both nationally and on a cross-border basis. Developments on all these three aspects are likely to depend on each other.

Better theory should be able to identify the various contagion channels in different parts of the financial system and explain the formation of various types and the information content of links between financial institutions and their behaviour under normal and stress situations. Focusing on how institutions form connections, especially when exposed to the risk of contagion, models of systemic risk could make sense of real economic interactions among market participants. Such a focus might help policy-makers in promoting safer financial structures.

Tools for network analysis have developed substantially over the last few years.<sup>31</sup> The application of network analysis to monitor and assess systemic risk and contagion in financial systems should benefit from important progress made in other sciences. It should, however, be kept in mind that the results depend on the process and behaviour of the particular network, and may not be directly applicable to the financial context.

Finally, the availability of relevant data is a key prerequisite for the use of financial network analysis as a surveillance tool. Data on relevant exposures are already collected by many authorities, but these are often neither granular nor frequent enough, or the time series do not

28 See M.L. Bech, J.T.E. Chapman and R. Garratt, "Which bank is the 'central' bank? An application of Markov theory to the Canadian Large Value Transfer System", *Journal of Monetary Economics*, forthcoming.

29 See, for example, J. Caruana, "The international policy response to financial crises: making the macroprudential approach operational", panel remarks in Jackson Hole, August 2009.

30 IMF, "A fair and substantial contribution by the financial sector – interim report for the G20", 24 April 2010.

31 A recent addition designed particularly for the analysis of financial networks is the "Financial Network Analyzer", an open-source project sponsored by Norges Bank (see: [www.financialnetworkanalysis.com](http://www.financialnetworkanalysis.com)).



cover long enough periods for a statistical analysis of different market conditions. Going forward, regulators and overseers should continue to develop ways to systematically collect, share and analyse the data from both market sources and financial infrastructures. Uncovering the intricate structure of linkages between financial institutions and infrastructures, among sectors of the economy or across entire national financial systems, is crucial for understanding channels of systemic risk; but this is also important because network metrics, reflecting the architecture of interactions that arise among economic agents when they form connections, can provide an insight into agents' behaviour.

As regards the Eurosystem, it is planned to make data on TARGET2 available for oversight purposes to the ECB and the relevant national central banks of the European System of Central Banks. TARGET2 is the pan-European interbank payment system in which a total of €551 trillion was settled in 2009. These data will allow the formation of a picture of interbank payment flows in euro, and of their evolution and stability both during the crisis and in simulated stress scenarios, so as to uncover parts of the euro money market and to develop proxies for the linkages established between institutions and infrastructures that settle their payments in TARGET2.

#### CONCLUDING REMARKS

Recently, a substantial amount of research has been carried out with respect to the network properties of various systems in biology, telecommunications and sociology. The main premise of network analysis is that the structure of the links between the nodes matters. The properties and behaviour of a node cannot be analysed in isolation of its position in the network.

The intricate structure of linkages between financial institutions and infrastructures, among sectors of the economy or across entire financial systems, can be captured using a network representation.

By understanding the financial system as a complex and dynamic network, empirical analysis on the properties of this network and the development of contagion and behavioural models using this information would allow regulators to acquire a deeper understanding of systemic risk and the ability to better identify systemically important financial institutions.