How to Measure Interconnectedness?

Jean-Cyprien Héam[24]

Abstract

Interconnectedness is considered as a key component to systemic risk supervision. However, there is little guidance on its measurement. Using a unique dataset of bilateral exposures between 21 French financial institutions, we analyse and compare several strategies to measure interconnectedness. We show that these measures tackle interconnectedness from different vantage points: substitutability, integration, core-periphery, systemic importance and systemic fragility. Without promoting one strategy as a panacea to measure interconnectedness, we provide insights on the pros and cons of each measure.

1. Introduction

The latest financial crisis with the defaults of AIG, Lehman Brothers or Bear Stearns has highlighted the risk of contagion through financial institutions' interconnections. Consequently, interconnectedness is a significant concern for supervisory and regulatory authorities. In particular, the Financial Stability Board [see FSB (2009)] uses three criteria –size, substitutability and interconnected-ness to identify Systematically Important Financial Institutions (SIFIs). Qualifying a financial institution as SIFI may lead to requirements in terms of additional loss absorption requirements. Interconnectedness is defined as 'linkages with other components of the system' and in case of banking groups and insurance groups as well, it is mainly measured by 'intra-financial system assets and liabilities' [see IAIS (2013), BCBS (2011)]. Although very convenient, this measurement of interconnectedness can be upgraded to account for contagion risks. Several academics or researchers in supervisory authorities have proposed alternative strategies. From a policy perspective, the outcome is a large set of measures potentially inconsistent between themselves.

The objective of our paper is to propose guidelines to understand and assess the features of three main strategies to measure interconnectedness. Actually, we show that these measures assess different aspects of interconnectedness. Therefore, we do not advocate using one ultimate measure but rather propose to

---

pick up measures according to policy concerns. To illustrate the different measures, we use a unique dataset of bilateral exposures between 21 French financial institutions.

The remainder of the paper is organized as follows. Section 2 presents briefly the data set. In Section 3 we analyse risk indicators. Section 4 proposes a way to compare interconnectedness of two financial institutions. In Section 5 we discuss the results of identifying a core-periphery structure, as well as topological indicators. In Section 6 we derive interconnectedness measure from outcome of contagion stress-test. Section 7 concludes by providing general guidelines on interconnectedness measure from a supervisory perspective.

2. Dataset

The perimeter is shaped by 21 large French financial institutions combining 4 pure banks, 11 pure insurers and 6 financial conglomerates[25], representing at least 85% of the French financial sector. In terms of size, the 6 conglomerates represent about half of the sector while pure banks and pure insurers account for about a quarter each. Combining large exposure reports for banks and security-by-security reports for insurers, we gather all exposures between the 21 financial institutions distinguishing bonds from shares, as at 31/12/2011. In large exposures reports, banking groups provide all their exposures above EUR 300mn or 10% of their equity. All French insurers fill security-by-security reports. The bond category gathers all types of debt securities (secured/unsecured, subordinated…) and loans. The share category encompasses all equity securities (traded shares, capital investment…). Our final dataset is composed of three exposure matrices: one for shares, one for loans and one for total exposures. Table A1.1 represents the network of total exposures between the 21 institutions.

The institutions report a total of EUR 227bn of which about 90% is composed of debt securities. There are 261 nonzero bilateral exposures (over 420 possible links) leading to a density of 62%. The distribution of exposures is very specific. First, 38% of potential exposures are zero. Second, among the 62% exposures that are non-zero, there is a large mass of very small exposures, even if there are few large exposures. With round numbers, half of exposures are lower than EUR 250mn, and only a quarter of them are higher than EUR 800mn.

To describe more accurately the allocation of exposures between the institutions, we report two indicators distinguishing the nature (conglomerate or pure bank or pure insurer) of the counterpart. First, we present the local density which is the

---

[25] We have a continental European point of view that contrasts with an Anglo-Saxon vocabulary. In this paper, a financial conglomerate has banking activities (collecting deposit, granting loans, investment…) and insurance activities. Our perspective is in line with the European Directive 2002/87/EC.

fraction of non-zero bilateral exposure between specific types of institutions. At one extreme, conglomerates form an almost complete network with 97% of potential links. On the contrary, pure banks report almost no exposures to pure insurers. Pure insurers seem to have a funding role in the network since they are exposed to almost all conglomerates and pure banks whereas few pure banks or conglomerates are exposed to them. This feature can be explained by the nature of insurance activity with respect to the banking activity as well as a diversification motive.

Table A1.1: Local density (proportion of non-zero exposures) according to institution type

			on	
Exposures		Conglomerates	Pure Banks	Pure Insurance
from	Conglomerates	97%	92%	51%
	Pure Banks	70%	33%	7%
	Pure Insurance	91%	80%	52%

Example: the ratio of non-zero bilateral exposures between conglomerates over all potential exposures between conglomerates is 97%. The ratio of non-zero bilateral exposure of conglomerate to pure bank is 92%.

Second, we adopt a quantitative perspective and report the proportion of exposures between groups of institutions (over the total of EUR 227bn) in Table A1.2. First, about half of the exposures are between conglomerates. Second, exposures of pure insurers to conglomerates account for about 20%. Then, exposures of conglomerates to pure banks and to pure insurers represent about 10% each of the total volume.

Table A1.2: Breakdown of volume exposures according to institution type

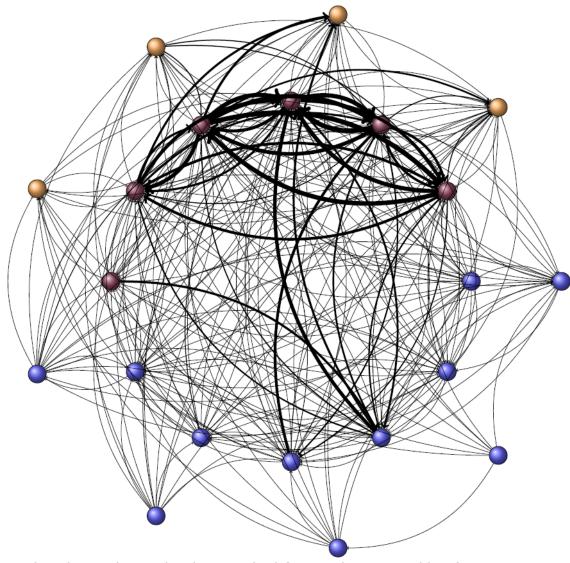|			on	
Exposures		Conglomerates	Pure Banks	Pure Insurances
from	Conglomerates	47.7%	9.8%	8.2%
	Pure Banks	4.7%	0.4%	0.1%
	Pure Insurance	20.8%	6.0%	2.3%

Example: 47.7% of the total volume of exposures concern exposures between conglomerates. 20.8% of the total volume of exposures are reported by insurers on conglomerates.

These first summary statistics draw four stylized facts. First, the exposures are modest: about one third of potential exposure are zeros and on the two last third most exposures are small. However, large exposures are not absent. Second, the conglomerates appear to be the most important players in terms of number of links and in terms of volume. Third, pure insurers are mostly net fund providers to other institutions, in particular of conglomerates. This behaviour is

in line with basic economic arguments. Fourth, debt instruments are the most common instruments of exposures.

3. Summary risk statistics

Representing exposure in volume, *i.e.* in bn Euros, may be misleading since size effect may blur the picture. Actually, an exposure represents a credit risk for the owner and a funding risk for the issuer. Since the sizes of the owner and of the issuer can differ, we need to derive two risk metrics that take control for their respective sizes. For simplicity, we build a credit risk matrix by dividing exposures by the equity of the owner and we build a funding risk matrix by dividing exposures by the equity of the issuer. Considering basic descriptive statistics of the lines of these matrices provide us with interconnectedness measures. We call them *summary risk statistics*.

Figure A1.1: Network of French financial institution (all instruments)

Note: Node colour indicates legal status (red for conglomerates, blue for pure insurers and yellow for pure banks). Edge width is proportional to exposure.

Table A1.3 provides the summary statistics of these indicators over the whole population. With round numbers, half exposures represent less than one percent of the equity of the owner and less than one percent of the equity of the borrower. The tail of credit risk is fatter than the tail of funding risk. A quarter of exposures represent more than 7.5% of the equity of the owner while a quarter of exposures represent more than 2.46% of the equity of the borrower. In other words, funding sources seem to be more diversified than investment targets.

Summary risk statistics are easy to compute. They disentangle credit risk from funding risk controlling size effects. However, they lack robustness. For instance, two institutions may have the same summary risk statistics but may be exposed to counterparties that differ widely with respect to their fragilities. Therefore, such risk statistics should be seen as additional summary statistics with clear interpretation and limits.

Table A1.3: Summary risk statistics

	Credit Risk	Funding Risk
1st quartile	0.48%	0.22%
Median	1.34%	0.80%
4th quartile	7.50%	2.46%

Example: Half of the exposures represent less than 1.34% of the equity of the lender.

4. Substitutability and integration

Facing the interconnectedness concern, one strategy may be to not measure – give a figure—for each institution but only to compare them. In that respect, we propose to analyse two dimensions of interconnectedness: *substitutability* and *integration*. We state that two financial institutions are close with respect to integration (to the network) if their exposures are similar regardless of the counterparts. We state that they are close with respect to substitutability (in the network) if they have similar exposure and exposure to the same counterparts. Note that the substitutability criterion is stronger than the integration criterion: if two institutions are close in terms of substitutability, they are necessary close in terms of integration. These definitions correspond to usual statistical tests to compare two random distributions. Substitutability analysis and integration analysis can be computed on volume matrix, and also on credit risk matrix and funding risk matrix to control for size. Based on the closeness between every couple of institutions, we can build a group of institutions with similar integration and similar substitutability.

Applied to our dataset, we conclude that conglomerates form a clear group with respect to integration on volume while we cannot distinguish pure banks from pure insurers. However for integration on funding risk, conglomerates do not shape a specific group and there is no group mixing pure banks and pure insurers. In other words, even if the type of institutions explains partially volumes allocation, they lose their power when a risk perspective is adopted.

Integration and substitutability are pair-wise measures of interconnectedness: they cannot be used to provide an interconnectedness score to each institution of the network. Nevertheless, they can unveil unexpected (di)-similarity of the investment profile and of the funding profile between financial institutions.

5. Core – peripheral institutions and topological indicators

Although interconnectedness matter is relatively new in supervision, economists, sociologist or IT scientists have already investigated the topic. Some researchers propose a technological transfer. In particular, economists in game theory show that some stylized structure of networks characterized the setup of cost-benefit balance to link formation (see Figure A1.2 for few examples). Empirical papers on banking network usually conclude that the banking system adopts a *core-periphery structure* [see Anand *et al.* (2014)]. In this framework, banks fall into two groups. The few banks of the core are completely interconnected between themselves. The banks of the periphery are connected to only one bank of the core. In Figure A1.2, the star network can be interpreted as an extreme core-periphery structure with a core composed of a single institution.
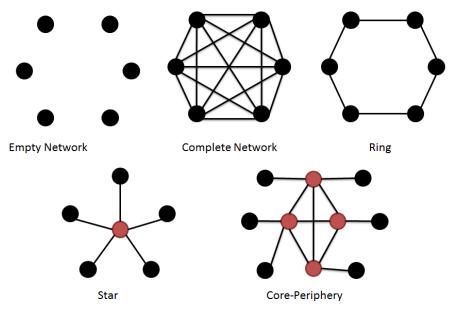
Figure A1.2: Example of stylized network structures

Empty Network   Complete Network   Ring

Star   Core-Periphery

The methodology relies on two elements. First, the exposure matrix, which contains continuous information, has to be converted into an adjacency matrix which is composed of 0 (absence of link) and 1 (presence of link). In order to eliminate noise, we recommend introducing a free threshold. Second, a distance between the observed adjacency matrix and a theoretical one is to be defined. In Craig and von Peter (2014), the distance is linked to the number of discrepancies between the observed adjacency matrix and the theoretical adjacency matrix. Building on these two steps, an algorithm selects the

allocation of the institution of the system between the core and the periphery that minimizes the distance between the observed adjacency matrix and the theoretical adjacency matrix.[26] This optimal partition provides the set of core institutions and peripheral institutions.

We applied this methodology on the volume, credit risk and funding risk matrices. Results are reported in Table A1.4. The core-periphery structure appears relevant when considering the volume (with only 5% of errors): the score is composed of 5 conglomerates. However, when size is taken into account, the picture becomes blurry. For credit risk, fitting is much less accurate (15.7% of errors). Moreover, the core is almost as large as the periphery, whereas usually the core institutions are much less numerous than the peripheral ones. For funding risk, there is no core-periphery structure since there are about 71.4% errors. In other word, the core-periphery structure is not relevant when we get rid of the size effect. It may come from the fact that the considered network is limited in reality to a French entity.

Finally, the core-periphery structure is a good candidate for flow analysis, or volume of exposures. When adopting a risk perspective, this structure is no longer relevant. In particular, using the membership of an institution to the core as a flag for a high degree of interconnectedness is severely corrupted by size. Furthermore the core-periphery structure does not hold for funding.

Table A1.4: Results of Core-Periphery Identification

	Volume	Credit Risk	Funding Risk
Core	5 conglomerates	5 conglomerates 3 pure banks 2 pure insurers	2 conglomerates
Periphery	1 conglomerate 4 pure banks 11 pure insurers	1 conglomerate 1 pure bank 9 pure insurers	4 conglomerates 4 pure banks 11 pure insurers
Distance	5%	15.7%	71.4%
Threshold	Euro 1.5bn	1%	0.1%

Note: in the process, the threshold is optimized in order to minimize the distance.

Beside the identification of a stylized structure, a related strand promotes using topological indicators such as closeness, betweenness, and centrality. Although these indicators are very pertinent in sociology or computer sciences, we are cautious using them in a financial network. As in the core-periphery identification, most of these indicators are derived from adjacency matrix with

---

[26] See the background paper for more methodological details.

no consideration of size or noise-filtration. This does not hamper results when relationships concepts are qualitative (friendship, neighbour, alumni…). Moreover, the interpretations are often assuming some kind of independence on the exposures: this assumption is very strong in a financial framework. For instance, having a new friend on an on-line social network is almost costless whereas providing a new loan means to fail providing it to another potential partner and implies to engage a counterparty risk analysis. We take the view that these indicators can be transposed only with reliably adapted guidelines to finance.

6. Systemic importance and systemic fragility

As mentioned in the introduction, interconnectedness is considered as a characteristic of systemic institutions for contagion risk concerns. Over the last decade, contagion models have been developed to analyse how an external shock is propagated through a financial system. These contagion models are widely used to run network stress-tests. We use the model developed in Gourieroux *et al.* (2012). The authors propose a model for solvency contagion distinguishing shares and debt securities. This model is relevant to analyse long-term positions but includes no liquidity features (such as fire-sale or debt rolling-over).

Following Alves *et al.* (2013), we derive two metrics of interconnectedness. *Systemic importance* is the impact of one institution on the other institutions (the direction is 'firm-to-system'), whereas *systemic fragility* is the sensitivity of one institution to the defaults of the other institutions (the direction is 'system-to-firm'). We run 21 stress-test scenarios where one institution is assumed to be initially in default. For each scenario, we analyse the loss of all other institutions. We measure systemic importance of one institution as the number of institutions who lose more than 10% of their equity. Symmetrically, we measure systemic fragility of one specific institution as the number of institutions which default generates a loss higher than 10% of the specific institution's equity. The threshold of 10% is arbitrary. Note that using another threshold (5% for instance) would change the systemic importance score and the systemic fragility score of all institutions. Therefore, we do not interpret the exact figures but the overall relative scores of institutions.

Figure A1.3 provides the systemic fragility and importance for the French financial institutions. Three groups are visually identified: financial institutions that are only systemically fragile, financial institutions that are only systemically important, and financial institutions that are neither systematically fragile nor systemically important. Generally speaking, important institutions are conglomerates, which are also the largest institution in the system. Most insurers fall in the group 'neither'. Since there is no institution jointly systematically fragile and systemically important, we deduce that a long chain of contagion – the so-called 'domino effect' – is unlikely. Policy implication could be to provide incentives to fragile institutions to diversify further their exposures to rely less on systemically important institutions.

Measuring contagion risk through stress-test exercises is often more costly in terms of operational resources than using measurement of interconnectedness based on statistical tools (such as descriptive statistics or the closeness analysis previously presented). Therefore, it is tempting to assess the correlation between the results of the various methods in order to predict the results of contagion risk. Such a strategy needs a clear assessment of the 'predictive power' of the statistical measures.

To do so, we compare our results based on descriptive and statistical methods for the three groups identified according to systemic importance and systemic fragility. Statistical theory helps us to formalize the match between groups. We find that systemic importance can be linked to statistical measures of interconnectedness. However, we fail to uncover any clear association between these statistical measures and systemic fragility. Consequently, running contagion models on a regular basis is a paramount tool to assess contagion risk and measure interconnectedness from a supervisory perspective. Results should be read with respect to the limits of the underlying contagion model.

7. Policy perspective

We presented several strategies to measure interconnectedness. We do not think that there is only one way to measure interconnectedness. Interconnectedness is in all likelihood a multi-faceted concept that requires therefore several measures to be accounted for. Ultimately, the choice of measure is to be driven by the accurate objectives of the policy makers: the right tool for the job.
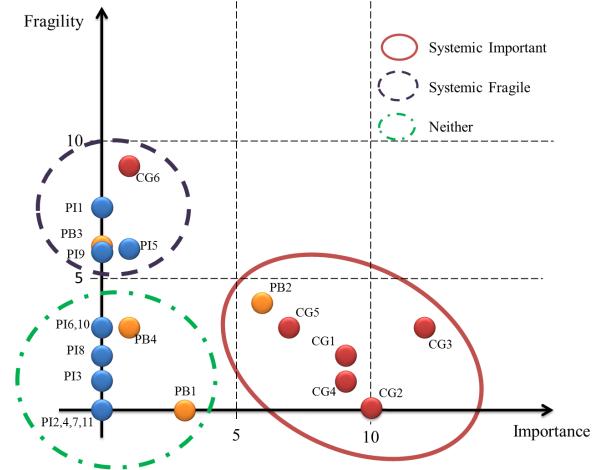
Figure A1.3: systemic importance and systemic fragility of French financial institutions

Note: Systemic fragility and systemic importance are defined using a threshold equal to 10% of equity.

First at all, we recommend picking interconnectedness measures with parsimony to avoid unnecessary complexity. Provided a volume exposure matrix, we recommend deriving a credit risk matrix and a funding risk matrix. The *descriptive risk statistics* are very informative to have the broad picture of the interconnection in a risk analysis perspective.

Comparing pair-wise institutions along *substitutability* and *integration* is useful to assess similarities between institutions or to detect outliers. However, this strategy does not provide individual scores of interconnectedness.

Identifying *core-periphery structure* is to be handled with care. Our results suggest that this method is mainly driven by a size effect. A formal identification of the core of a network helps see where volumes dwell but does not necessarily pinpoint riskiness. Moreover, note that the results are binary ratings of interconnectedness – either in the core or in the periphery – and give no score of interconnectedness.

Contagion models provide two clear measures of interconnectedness: *systemic importance* representing the contagion risk generated by the institution and *systemic fragility* catching the exposure to contagion risk. These last measures provide scores and robustness can easily be carried out. Nevertheless, these measures depends on the model used, in particular the contagion channels that are included. Therefore, score should be read keeping in mind the limits of the underlying model.

The general characteristics of each strategy are summarized in Table A1.5.

Table A1.5: Summary of the potential strategy

Strategy	Interconnectedness design	Interconnectedness measure	Implementation	Identified potential bias	Policy Concern
Descriptive risk statistics	continuous individual	quantitative	easy		usual monitoring
Integration & substitutability	continuous pair-wise	none	easy		cross-market comparison
Core-Periphery identification	binary system-wide	qualitative	complex	size effect	SIFIs identification
Systemic importance and fragility	continuous system-wide	quantitative	complex	model dependence	SIFIs identification

8. Concluding remarks

Taking into account interconnectedness of financial institutions is mandatory to supervisory authorities to prevent contagion risks. If the general objective is clear, there is no consensus on the best way to measure interconnectedness. Using a unique dataset of bilateral exposures between 21 French financial institutions −6 financial conglomerates, 4 pure banks and 11 pure insurers– we describe and analyse several strategies to measure interconnectedness. Without promoting one strategy as a panacea to measure interconnectedness, we provide insights on the pros and cons of each measure.

References

Anand, K., Craig, B., and von Peter, G. (2014): Fill in the blanks: Network structure and interbank contagion, Bank of Canada Working Paper, No 2014-26.

Alves, I., Ferrari, S., Franchini, P., Héam, J.C., Jurca, P., Langfield, S., Liedorp, F., Sanchez, A., Tavolaro, S., and Vuillemey, G. (2013): The Structure and Resilience of the European Interbank Market, European Systemic Risk Board (ESRB) Occasional Paper, No. 3.

Basel Committee on Banking Supervision (BCBS) (2011): Global systemically important banks: assessment methodology and the additional loss absorbency requirement Rules text November 2011.

Craig, B., and von Peter, G. (2014): Interbank Tiering and Money Center Banks, Journal of Financial Intermediation, 23, 3, 322-347.

Financial Stability Board (FSB) (2009): Guidance to Assess the Systemic Importance of Financial Institutions, Markets and Instruments: Initial Considerations, October 2009.

Gouriéroux, C., Héam, J.C., and Monfort, A. (2012): Bilateral Exposures and Systemic Solvency Risk, Canadian Journal of Economics, 45, 1273-1309.

Hauton, G., and Héam, J.C. (2014): How to Measure Interconnectedness between Banks, Insurers and Financial Conglomerates?, forthcoming in ACPR Working Paper.

International Association of Insurance Supervisors (IAIS) (2013): Global Systematically Important Insurers: Initial Assessment Methodology, July 2013.