BANK OF ENGLAND

Working Paper No. 516
Mapping the UK interbank system

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November 2014

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Abstract

We present new evidence on the structure of interbank connections in key markets: derivatives, marketable securities, repo, unsecured lending and secured lending. Taken together, these markets comprise two networks: a network of interbank exposures and a network of interbank funding. Network structure varies across and within these two networks, for reasons related to markets' different economic functions. Credit risk and liquidity risk therefore propagate in the interbank system through different network structures, with implications for financial stability.

Key words: Interbank markets, core-periphery, intermediation, financial networks, market microstructure.

JEL classification: D85, G21, L14.

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The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England, UK Prudential Regulation Authority, European Central Bank, or European Systemic Risk Board. We are grateful to Omer Bugarinovic for excellent research assistance. The following people provided valuable contributions and comments: Piergiorgio Alessandri, Ivan Alves, Andrew Bailey, Giovanni Bassani, Mario Eboli, Sanjeev Goyal, Andrew Haldane, Eliza Hammel, Andrew Hauser, Anna Jernova, Sujit Kapadia, Dror Kenett, Christoffer Kok, Iman van Lelyveld, Jakob Lund, Marco Marinopiccoli, Matteo Marsili, Jamie McAndrews, Jack McKeown, Paolo Mistrulli, Claus Puhr, Ben Richardson, David Rule, Gerhard Rünstler, Vicky Saporta, Andrei Sarychev, Martin Scheicher and Daan in 't Veld; seminar participants at the Bank of England; members of the Analysis Working Group of the European Systemic Risk Board; participants at the Latsis Symposium 2012 at Zurich ETH; participants at the European Banking Authority's inaugural research workshop on banks' business models in 2012; participants at the workshop on network approaches to interbank markets in Castellon; participants at a joint conference of the Financial Stability Committee and Payment and Settlement Systems Committee of the European Central Bank; the editor of Bank of England Working Paper series; and several anonymous referees. We would also like to thank Ben Craig and Goetz von Peter for sharing code; and Samantha Cook, Kristian Dupont and Kimmo Soramäki of Financial Network Analysis for developing superb networks graphing software. Any errors are the authors'.

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ISSN 1749-9135 (on-line)

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Summary

This paper maps the structure of the network of interbank connectedness in the UK banking system. Using a new regulatory dataset on the UK interbank exposures, we construct two networks: the exposures network is comprised of banks' counterparty credit exposures to other banks across different financial instruments; and the funding network aggregates banks' cash funding from other banks.

The exposures network and the funding network have different structures. The exposures network exhibits a 'core-periphery structure', in which core banks are densely connected to each other and peripheral banks are weakly connected to each other. The derivatives market in particular is characterised by a densely connected core, which we interpret as evidence of there being strong economies of scale associated with trading derivatives. In contrast, the funding network has less of a core-periphery structure, owing to a lower degree of connectedness among core banks in the unsecured lending and repo markets.

These structural differences between the two networks suggest that credit risk and liquidity risk propagate in the interbank system in different ways. To dig deeper, we divide banks into clusters according to the markets in which their interbank activity is concentrated. Large derivative houses dominate the system, absorbing funding from all other clusters, particularly non-UK investment banks (using repo) and smaller UK banks (using unsecured loans). A reduction in funding provided by these banks could trigger widespread liquidity shortages.

We also identify contagious links, where a bank's single counterparty exposure is greater than its capital. We identified the contagious links from core banks to many peripheral banks, implying that the isolated default of certain core banks causes multiple peripheral banks to default. However, higher-round effects from these defaults appear to be relatively limited, given that core banks tend to be relatively well diversified with respect to their bank-counterparty credit risk. We infer that core-periphery structures tend to be robust, because core banks can act as fire-stops against contagion. But such structures are also potentially fragile, because a core bank's distress could propagate throughout the network. In principle, this finding supports the application of capital surcharges on systemically important banks to build the resilience of these fire-stops in the core of the network.

'Focus on the wood, not the trees.'[1]

1 Introduction

The interbank system is made up of many interbank markets. In each market, banks transact with each other using a particular financial instrument. To understand the structure of the interbank system, we must analyse not only individual markets – but also how those markets relate to each other. In doing so, this paper answers the call of Haldane (2009): to treat the financial system as a system, with connections among its components, and not just a collection of individual markets.

An example makes the point. Lehman Brothers' bankruptcy was not caused by its positions in a single market. Rather, bankruptcy occurred owing to a combination of related events across different markets: Lehman's counterparties supplying short-term funding, through repo and unsecured lending, withdrew; as did non-dealer counterparties to derivatives trades, stripping Lehman of vital cash from initial margins (Duffie, 2010). Combined with Lehman's already thin stock of liquid assets, these simultaneous runs across different markets proved fatal. Moreover, these runs were endogenous to each other – it would be unlikely for a run to take place in one market and not another with similar characteristics.

By focusing on, say, the repo market at the beginning of 2008, analysts could have identified Lehman's importance within that market. But only by combining that insight with information on other markets and Lehman's balance sheet could analysts have inferred that Lehman faced risks great enough to cause it fail. Only by analysing banks' activities across interbank markets can we understand the mechanisms of contagion in the system of all interbank markets.

This paper represents an initial attempt to map the structure of interconnectedness across the many different interbank markets that together comprise the interbank system. To do so, we define two types of connectivity: asset interconnectedness (defined as the credit risk of institutions' assets) and liability interconnectedness (the liquidity risk of institutions' liabilities), following the terminology of Scott (2012). We construct two networks: one based on multiple layers of exposures, by aggregating banks' counterparty credit exposures; and another based on multiple layers of funding, by aggregating banks' cash funding from other banks. We find that these two networks – the 'exposures network' and the 'funding network' – have different structures. Structural differences suggest that credit risk and liquidity risk propagate in the

[1] Mervyn King (2012), BBC Today Programme Lecture.

interbank system by different contagion processes, as demonstrated in the emerging literature on multi-layered financial networks (Bargigli et al, 2013; Montagna and Kok, 2013).[2]

Our analysis is made possible by a new regulatory dataset, which is the most granular representation of a large interbank system available worldwide. The dataset includes bilateral interbank lending, issuer risk, securities financing transactions, derivatives and other off balance sheet exposures, with further breakdowns by instruments and maturities. It is important to observe these distinct markets, because each market is unique in its economic rationale and design. As a result, different instruments transfer different types and quantities of risk, including credit and liquidity risk.

Many prior studies tend to focus on individual interbank markets in isolation. For example, Furfine (2003) studies overnight unsecured interbank lending; Brunnermeier et al (2013) focus on contagion risks in the CDS market; and Gorton and Metrick (2012) describe behaviour in the repo market. Such studies reveal important insights about these individual interbank markets. Nevertheless, by focusing only on individual markets, researchers obtain only a partial view on the interbank system.

Other existing research has focused on aggregate interbank exposures, without distinguishing between exposures generated in different interbank markets. For example, Wells (2004) and Alessandri et al (2009) model contagion processes within the UK interbank system using regulatory large exposures data. These data help to provide an approximation of aggregate bilateral interbank exposures, summed across markets. But the lack of a breakdown by instrument implies that differences and interactions between interbank markets could not be explored in these studies.

The paper is structured as follows. In Section 2, we describe the new regulatory dataset. In Section 3, we construct the multi-layered interbank system and infer stylized facts regarding the formation of exposures and the flows of funds within the exposure and funding networks. Section 4 elaborates on the structural properties of the interbank system, and the ways in which those properties vary across different markets. Section 5 provides economic interpretation of these results.

[2] The term "multi-layered" does not imply any hierarchy of layers. Rather, each layer simply represents an individual interbank market. This terminology is commonly used in the recent literature (see, for example, Montagna and Kok, 2013).

2 Data

This paper is based on a new regulatory dataset on interbank exposures in the UK. By providing a thorough breakdown of interbank exposures by financial instruments, the new dataset represents an important improvement on existing data. This section summarises these improvements, and explains how they are necessary for the subsequent analysis.

2.1 The new dataset on interbank markets

UK banks report their exposures to other banks and broker dealers by financial instrument, including:

- lending (unsecured, secured[3] and undrawn);
- holdings of equity and fixed-income securities (marketable securities) issued by banks;
- credit default swaps (CDS) bought and sold[4];
- securities lending and borrowing (gross and net of collateral);
- repo and reverse repo (gross and net of collateral); and
- derivatives exposures (with breakdown by type of derivative).[5]

Moreover, banks report exposures with breakdown by the maturity of the instrument.[6] Banks' internal risk management limits with respect to counterparties and instruments are also supplied.

Each bank reports exposures by instrument to their top 20 bank and broker-dealer counterparties.[7] Reporting occurs half-yearly; banks will submit data monthly in the near future.[8] 176 UK consolidated banking groups report as such to the Bank of England, of which 48 are UK banks, 47 are UK building societies, 14 are the UK regulated entities of investment banks, and 67 are the UK regulated entities of other banks resident outside of the UK (overseas banks). Additionally, there are 314 non-UK banks in the dataset, because the 176 UK incorporated banks report their exposures to other banks' global consolidated group. These 314

[3] Secured loans do not include reverse repos which have a different contractual nature. Secured loans are collateralised by various assets such as buildings, lands and other physical assets.
[4] This captures the market risk in the net amount of credit default protection sold on securities issued by banks. Note this is different from derivatives exposures mentioned below, which capture the counterparty credit risk arising from over-the-counter derivative contracts.
[5] The breakdown covers interest rate derivatives; credit derivatives; equity derivatives; foreign-currency derivatives; commodities derivatives; and other derivatives. In the case of derivatives, requested types of exposure include net mark-to-market (before and after collateral); exposure at default; potential future exposure; and the number of trades outstanding.
[6] Categories of maturities are: open; less than three months; between three months and one year; between one year and five years; and more than five years. Derivatives are not reported with a maturity breakdown.
[7] If the top 20 does not have at least six UK-based counterparties, firms are asked to report exposures to up to six UK-based counterparties in addition to the top 20. Branches of foreign banking groups in the UK are not included in the data collection.
[8] Data presented in this paper are based on the first data submission, which occurred at the end of 2011. Results regarding the structure of the interbank market are qualitatively robust to changing exposures over time.

non-UK banks do not submit their own exposures to the Bank of England, but are counterparties to at least one of the 176 reporting banks.

The resulting dataset consists of matrices with dimensions 176 x 490 for each financial instrument and for each maturity bucket. These data are supplemented by balance sheet information obtained from the Bank of England and Bureau van Dijk's BankScope database. Some reporting banks with larger balance sheets (of which there are 91) submit interbank exposures for 163 items (comprising different instruments and maturities); the remaining 85 reporting banks submit a reduced template with 58 items.[9] The full dataset therefore comprises [(163 x 91) + (58 x 85)] x 490 = 9.7 million observation.

2.2 Improvements over existing datasets

The new dataset on interbank exposures has clear advantages over the types of datasets analysed in the existing literature, in terms of both coverage and granularity. Sources used in existing literature can be classified into three broad categories: data from large exposures reports, payment systems and credit registers. Table 1 summarises these sources, in comparison with the new dataset.

A large strand of prior research has used data reported under large exposures regulation (Wells, 2004; Alessandri et al, 2009). Under this regulation in the UK, banks are required to report exposures to counterparties when the value of each of these exposures exceeds 10% of the reporting bank's regulatory capital. In the new regulatory dataset, 81.5% of observations, amounting to £200bn (or 75.8%) of interbank exposures, fall below 10% of own regulatory capital, and therefore are not reported under the large exposures regulation. As a result, very few exposures among large banks are captured in the large exposures dataset. Previously, analysts often filled gaps in observed networks using techniques such as maximum entropy, which attempts to estimate bilateral exposures from banks' balance-sheet characteristics (Upper and Worms, 2004; Wells, 2004; Degryse and Nguyen, 2007; Alessandri et al, 2009). Using real data, Mistrulli (2011) shows that maximum entropy techniques tend to underestimate the extent of contagion in the case of interbank markets. Observing all interbank exposures directly, as in the new regulatory dataset, is therefore a substantial improvement in accuracy, in addition to granularity.

[9] The fact that a minority of (smaller) banks submit a less granular template does not affect most of our analysis, given that all banks report the key elements that comprise the exposures and funding network (defined subsequently). However, certain breakdowns, such as maturity breakdown for marketable securities and derivatives exposures by asset class, are not available for smaller banks.

Table 1: Comparing datasets on interbank exposures

	Frequency	Time period	Number of counterparties reported	Instrument breakdown	Maturity breakdown	Reference
The new BoE dataset	Semi-annual	Since end-2011	20 (including at least six UK counterparties)	Yes	Yes	This paper
Large exposure regime	Semi-annual	Since late 2008	Exposures above 10% of total capital (i.e. less than 20% of the number of counterparties reported in the new BoE dataset)	No (exposures aggregated across instruments)	No	Wells, 2004; Alessandri et al, 2009; Upper and Worms, 2004; Degryse and Nguyen, 2007
Payments data	Daily or intra-day	Varies	All	No (only one instrument: overnight lending)	Partly (weighted average maturity only)	Furfine (1999); Becher et al (2008)
Credit registers	Monthly	Most registers start c.1990	Minimum transaction value varies by country (e.g. Portugal and Spain have very low thresholds; Germany has a much higher threshold of €1.5m).	No (only one instrument: medium-term lending)	No	ECB (2003); Iazzetta and Manna (2009); Craig and von Peter (2014)

Another set of papers only study interbank short-term loans extracted from payments data, deploying the method proposed by Furfine (1999). National payments systems have been studied in the UK (Wetherilt, Zimmerman and Soramaki, 2010). Similar papers have been published using data from the US (Furfine, 2003; Bech and Atalay, 2008); Denmark (Bech and Rørdam, 2009); Germany (Bräuning and Fecht, 2012); Italy (Iori et al, 2008) and Norway (Akram and Christophersen, 2010). In addition, the 'Furfine methodology' provides high-frequency interbank exposures data with price information, but inference is subject to error. Using TARGET2 data, Arciero et.al. (2013) find that the Furfine algorithm is relatively reliable, whereas Armantier and Copeland (2012) find significant errors using Fedwire data.

The third typical source of interbank exposures data is centralised credit registers of banks' loan- or borrower-level exposures, which are maintained in many European countries (ECB, 2003). Some of these national credit registers have been used to observe interbank networks. Iazzetta and Manna (2009) exploit data from the *Centrale dei Rischi* of the Banca d'Italia to describe the network topology of the Italian interbank market. Craig and von Peter (2014) use the Deutsche Bundesbank's *Gross- und Millionenkreditstatistik* to show that the German interbank is tiered, with a small number of core banks intermediating between peripheral banks.

For the purposes of financial network analysis, credit registers benefit from a long time-series, but are much poorer in terms of cross-sectional granularity. The European credit registers typically record only unsecured and secured lending: this limitation may be acceptable for financial systems with little interbank activity beyond traditional lending, but not for sophisticated financial systems. In the UK, for example, only around a quarter of interbank exposures arise from unsecured and secured lending.

There are two limitations of the new regulatory dataset on UK interbank exposures. The first limitation is based on jurisdiction. Banks in the UK which are subsidiaries of a foreign parent – comprising 43% of all UK banks – only report their UK subsidiaries' interbank exposures, not those of the foreign group. Nevertheless, these UK subsidiaries account for a sizeable share (41%) of their groups' global assets. In addition, we do not observe interbank positions held by banks with no regulated subsidiary in the UK. These jurisdictional data constraints are binding for almost all existing studies; one rare exception is Alves et al (2013). Another new source is the Financial Stability Board, which has recently started to collect data on all global systemically important banks' group-level interbank exposures.[10]

The second limitation is that UK banks report exposures to their top 20 bank and broker-dealer counterparties. Exposures to counterparties beyond the top 20 are not observed. In the data submitted at the end of 2011, 62 of the 176 UK banks reported exposures to fully 20 counterparties. The total value of the 20th exposure across these 62 banks was £2.3bn – 0.9% of total exposures reported by these banks, and less than 1% of these banks' capital. However, this £2.3bn is not evenly distributed across the 62 banks; it is likely that a few very large banks have significant counterparty exposures not captured in the top 20. Nevertheless, only a few of the 176 UK banks reported exposures to all six additional UK counterparties (recall that banks need to report exposures to six UK counterparties in addition to the top 20, as mentioned in footnote 7). So our dataset captures the majority of the UK-to-UK interbank market (excluding foreign branches) and UK banks' exposures to non-reporting foreign banks. We therefore consider that we do not have to populate the network matrices further by maximum entropy or any other algorithms.

We have checked the interbank exposures dataset against comparable datasets, including the large exposures data, to ensure that the quality of the dataset is adequate. We have also compared our dataset with public data: particularly UK monetary and financial institutions (MFIs) data collected by the Bank of England. The MFI data aggregate all inter-MFI lending, but with no counterparty breakdown. About 85% of the interbank activity recorded in these data

[10] See http://www.financialstabilityboard.org/publications/r_120328l.pdf.

refers to transfers within banking groups, which often occur as part of banks' day-to-day asset-liability management. In particular, some banks located in the UK typically 'upstream' funding to parent entities resident outside of the UK. Looking only at inter-group transactions, unsecured lending by UK MFIs to UK-resident banks amounted to £95.3bn, or 1.1% of total assets, in Q4 2011. By comparison, the new regulatory interbank exposures data show that unsecured lending by UK banks to other banks globally totalled £58.9bn at the end of Q4 2011. Of this, £40.1bn (68%) is lent by UK banks to other UK-resident banks. The discrepancy between the Bank of England's MFI data and the new regulatory interbank data is mainly due to technical differences in definition and scope, rather than issues with the quality of our dataset.[11]

3 Constructing the Multi-Layered Interbank System

This section constructs the multi-layered UK interbank system by aggregating over individual financial instruments. We define two principal networks – the exposures network and the funding network – which are relevant for systemic credit risk and systemic liquidity risk respectively.

3.1 The exposures network and the funding network

Each financial instrument is associated with its own market. We can talk, for example, of the 'repo market' or the 'derivatives market'. By the same logic, each instrument is associated with its own network. The 'repo network' is a set of banks connected to each other through repo contracts. In the new regulatory dataset, we observe banks' exposures to each other broken down by key instruments, each broken down by maturity.

Our interest lies in the type of risk which is transferred, rather than the name of the financial instrument per se. For example, if one is interested in interbank funding, one should look at the notional amount of repo in addition to other forms of funding, such as prime lending. The 'repo network' on its own is not fully informative, because it ignores funding (and associated risks) transferred using other instruments, and it misses the role of collateral within the repo market.

Following Scott (2012), we focus on the two dimensions of balance sheet interconnectedness: on the asset side of lending banks (credit risk) and on the liability side of borrowing banks (funding risk). We therefore generate two networks, denoted as the exposures network and funding network:

[11] For example, deposit-taking branches of foreign banking groups are included in the Bank of England MFI dataset but not in the new regulatory dataset.

$$\textbf{\textit{Exposures network}}$$
$$= \text{Lending} + \text{Marketable Securities} + \text{CDS Sold} - \text{CDS Bought}$$
$$+ \text{Securities Lending and Repo Exposure} + \text{Derivatives Exposure}$$

$$\textbf{\textit{Funding network}}^{12} = \text{Lending} + \text{Reverse Repo Exposures}$$

The *exposures* network is relevant for assessing the risk that a bank becomes insolvent following the default of counterparties. This network includes unsecured interbank lending (notional amount), marketable securities (mark-to-market value), CDS sold minus CDS bought (notional amount), securities lending and repos (potential exposure after collateral), and derivatives exposures (potential exposure after collateral). The funding network is relevant for liquidity: it includes unsecured interbank lending and repos (notional amount before collateral).[13] Exposures are measured net of collateral, whereas funding is measured gross.

Figures 1 and 2 show the exposures network and the funding network, respectively. Each node represents a bank in the network. The width of lines represents the pound-sterling value of exposures or funding. The size of nodes represents the total value of exposures or funding received and provided by the bank. The overriding impression conveyed by these figures is that the interbank system is complex. In order to disentangle this complexity, we next describe the composition of the exposures network and the funding network. Decomposing the two networks in this way conveys important information about the multiple layers (markets) which comprise the networks.

[12] We did not include debt instruments in the funding network, because the exposures reported by banks are net of short positions in those securities and hence may not be equal to the actual amount of funding provided.
[13] Debt instruments are not included in the funding network, because exposures reported by banks are net of longs and shorts and so might not be equal to the actual amount of funding provided.

Figure 1: Interbank Exposures Network

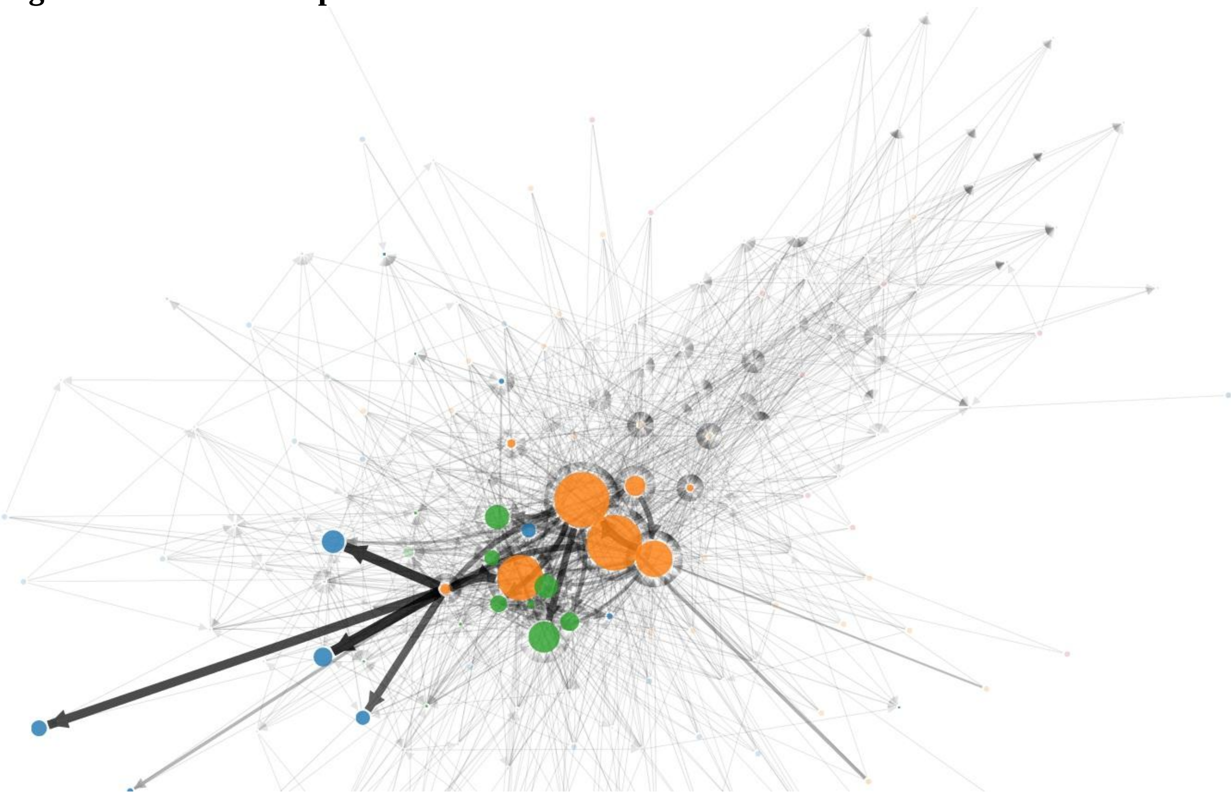
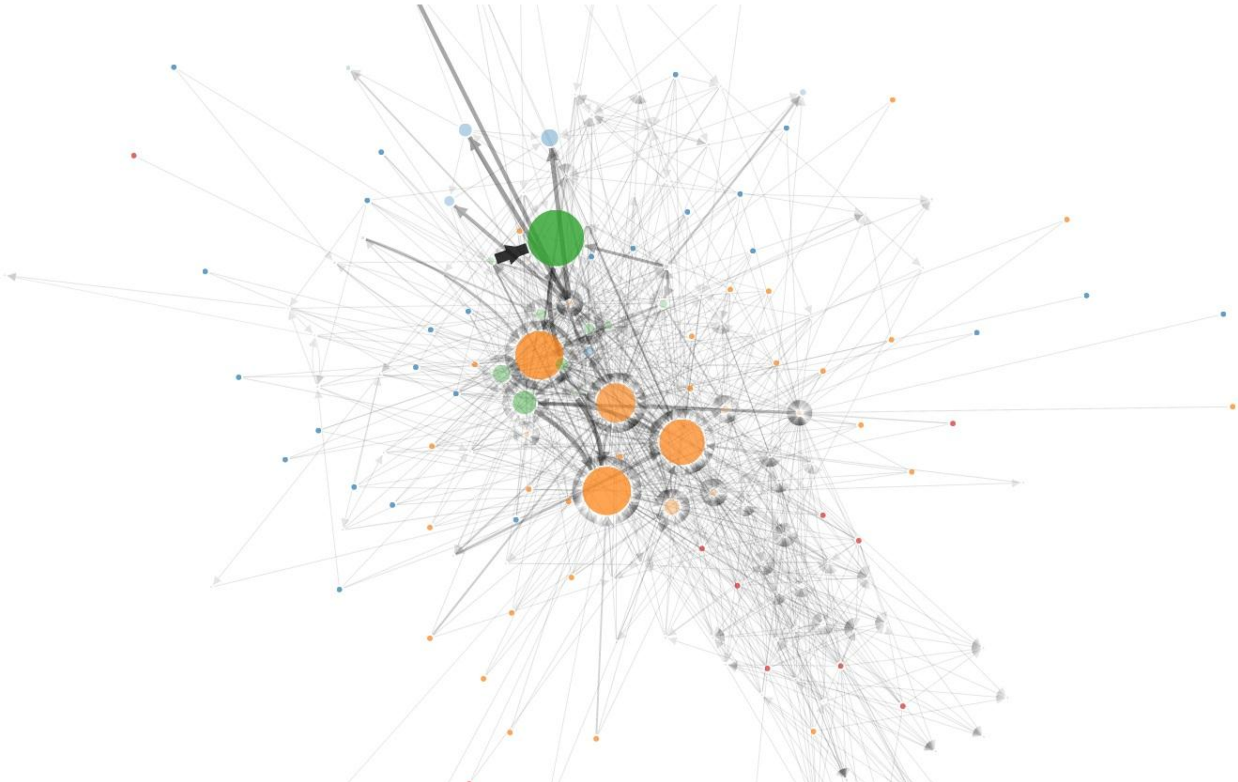


Figure 2: Interbank Funding Network

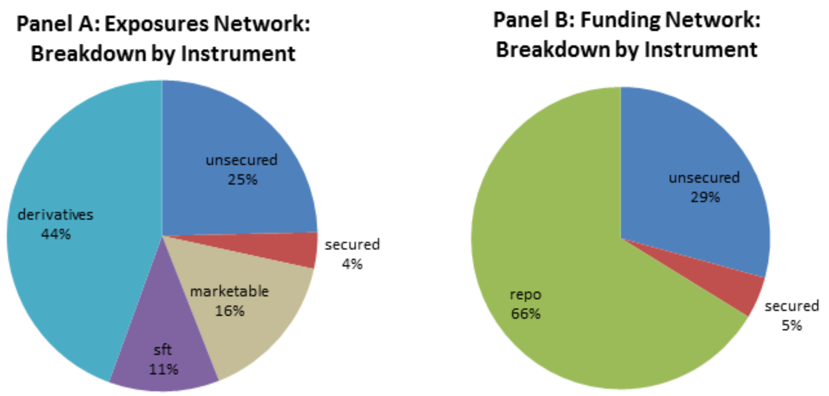


Note for figures 1 and 2: Each node represents a bank. Arrows point away from the exposed bank in the Exposure Network and away from the lending bank in the Funding Network. Circles' diameters are proportional to the logarithm of banks' total interbank exposures in the exposures network and the logarithm of banks' received interbank funding in the funding network. Orange circles represent selected large UK banks, green circles represent investment banks, blue circles represent overseas banks and red circles represent building societies. The widths of arrows are proportional to the value of the exposures and funding amounts.

3.2 *Composition of the two networks*

In this section, we describe the composition of the two networks. Figure 3 shows the composition by instrument of the exposures and funding networks. In terms of exposures (Panel A), derivatives are the most substantial, comprising nearly half of all interbank exposures. Unsecured loans (25%), marketable securities (16%) and securities financing transactions (11%) make up most of the remainder. The funding network (Panel B) is dominated by repo (66%) and unsecured loans (29%).

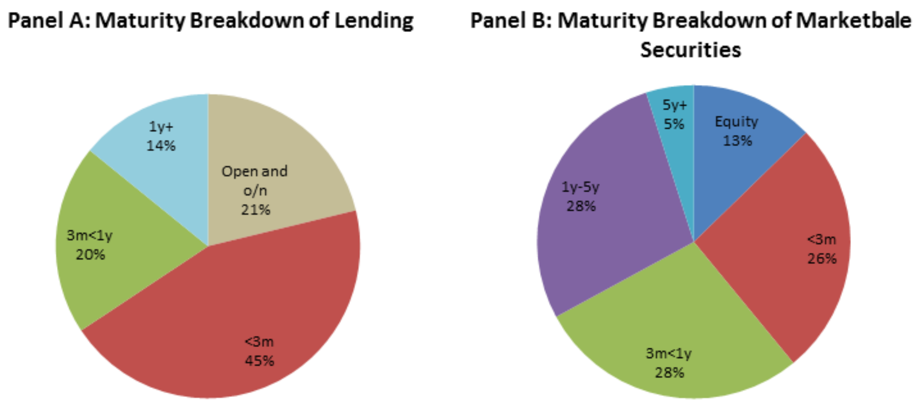
Figure 3: Instrument Breakdown of the Exposures and Funding Networks



Note: The percentages are based on the aggregate amount of exposures and funding reported, broken down by instrument.

We can examine the characteristics of the two networks in more detail. Figure 4 shows the maturity breakdown of lending instruments (including repo and interbank lending) and marketable securities (equity and debt securities), two layers of the funding network. The majority of lending instruments (66%) have an outstanding maturity of less than 3 months; only 14% mature in over one year. The share of marketable securities with maturity above one year is somewhat higher, at 33%.

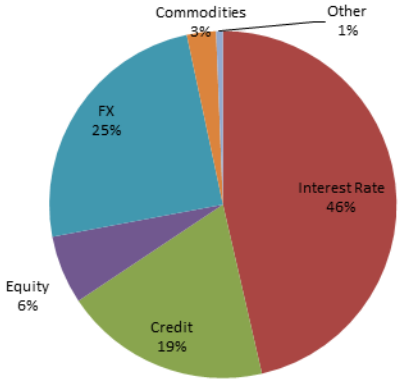
Figure 4: Maturity Breakdown of the Interbank Market



Note: The percentages are based on the aggregate amount of unsecured lending and marketable securities) broken down by maturity.

Figure 5 shows the breakdown of derivatives exposures by asset class, including equity, FX, credit, interest rate, commodity and other derivatives. The largest category is interest rate derivatives, followed by FX and credit derivatives, reflecting demand for hedges against latent interest rate, currency and credit risks. Exposures in other derivatives are relatively small.

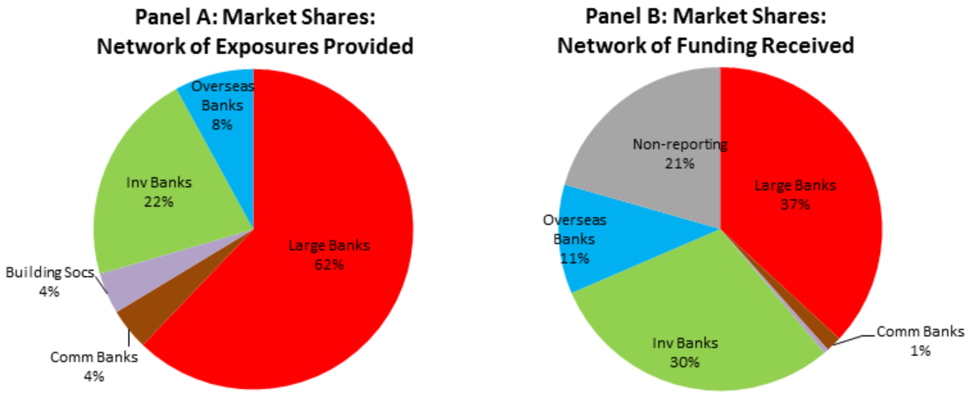
Figure 5: Derivatives Breakdown by Derivative Type



Note: Percentages based on aggregate value of derivative exposures (net of collateral) broken down by trade types.

Figure 6 cuts the exposures and funding networks by bank type. We classify banks as the eight largest UK banks; other UK banks; building societies; foreign investment banks with UK subsidiaries; other overseas banks with UK subsidiaries; and non-reporting foreign banks with no UK subsidiary. As shown in Figure 6, 62% of exposures are reported by large UK banks, followed by investment banks (22%). In the funding network, 37% of funding is provided to large UK banks, followed by investment banks (30%) and non-reporting banks (21%).

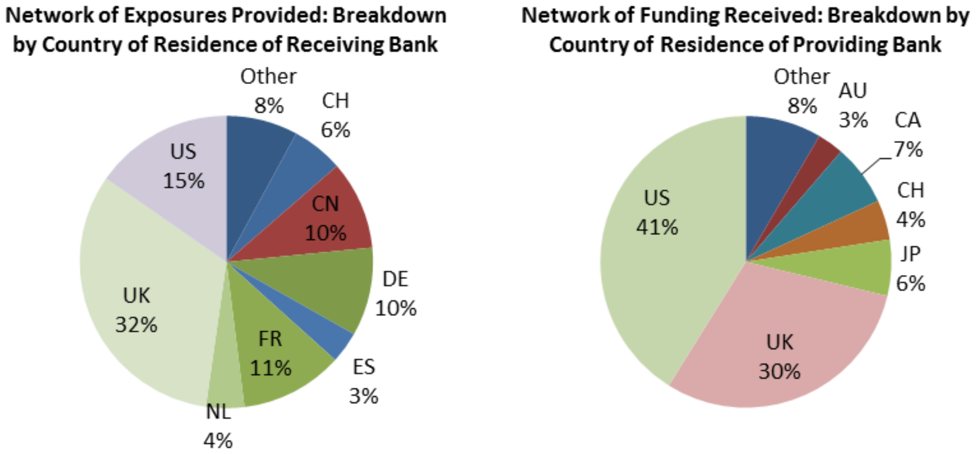
Figure 6: Market Share Breakdown by Bank Type



Note: Percentages based on the values of exposures and funding, broken down by bank type.

Figure 7 illustrates the decomposition by country in which a bank is headquartered. 68% of interbank exposures are to banks headquartered outside of the UK, topped by the US, France, Germany and China. In the funding network, US banks are more predominant, providing 41% of total interbank funding. Overall, Figure 7 reinforces the stylized fact that UK banks are heavily integrated in global markets.

Figure 7: Market Share Breakdown by Country



Note: Percentages based on aggregate values of exposures and funding, broken down by the location of headquarter offices.

The above analysis provides an overview of the composition of the exposures and funding network. However, more detailed analysis on the structure of the networks, as presented below, is needed to understand the interconnectedness and potential contagion channels of the interbank market.

3.3 Exposures relative to capital

Building societies reported the highest interbank exposures relative to their total core Tier 1 capital (214%); the figure is 72% for UK commercial banks, 70% for large UK banks, 88% for investment banks and 138% for overseas banks. Globally, large banks are most reliant on interbank markets, with 0.9% of their global liabilities comprising obligations to other UK banks. The corresponding figures are 0.8% for building societies; 0.7% for investment banks; 0.4% for commercial banks; 0.2% for overseas banks; and 0.2% for non-reporting banks.

4 Analysing the Multi-Layered Interbank System

In the previous section we highlight the characteristics of the exposure network and the funding network from various different angles. Aggregation is in many cases a very useful measure to summarise the nature of a system, if exposures and funding are uniformly distributed across banks. However, as Figure 1 and 2 show, the distribution of exposures and funding is highly skewed; aggregate numbers therefore do not describe the full structure of the interbank market. In the rest of this section, we disentangle that complexity. In particular, we analyse network structure along three different dimensions. Analysis of network structure provides insights on the economics which define the structure of the networks illustrated in Figures 1 and 2, as well as the insights on contagion risks in the system (the latter is discussed in Section 5.2).

4.1 Network structure by banks' sectors

Bank sectors are defined by banks' general business models and by the historical formation of the banking market: in the UK, sectors are defined as large UK banks; other UK commercial banks; building societies; investment banks; overseas banks; and, due to the nature of our dataset, 'non-reporting' banks, which are not regulated by the Bank of England, but nevertheless entities to which UK-regulated banks are exposed. This categorisation is used by the UK's bank regulator, the Prudential Regulation Authority. Furthermore, we can expect that banks in the same category would have a similar business model and therefore the banks are more likely to fail at the same time, which justifies bundling banks in the same category (Figure 8 and 9).

In the exposures network (Figure 8), large UK banks are the centre of the network, with significant exposures to investment banks, non-reporting banks and large UK banks[14]. A large part of the exposures of large UK banks arise from derivatives transactions with UK branches of foreign banking groups.

In the funding network (Figure 9), large UK banks seem to rely heavily on funding from investment banks, mostly via repos. Other UK commercial banks and building societies are pure lenders in the interbank market. I.e. the funding network has a unilateral from smaller UK banks to large UK banks.

Overall, the UK interbank system is dominated by large UK banks that are very active in the derivatives market. In addition, these large UK banks receive unsecured funding from small banks and building societies, and secured funding from investment banks. Investment banks are net lenders in the funding network, and probably rely on intragroup funding from overseas parents.

[14] This illustrates an advantage of this dataset over the dataset based on banks' reported large exposures. Most of the exposures between large banks would not be observed in the large exposures dataset because the values of those exposures are less than 10% of the reporting bank's capital.

Figure 8: Exposures Network by Bank Sector Type

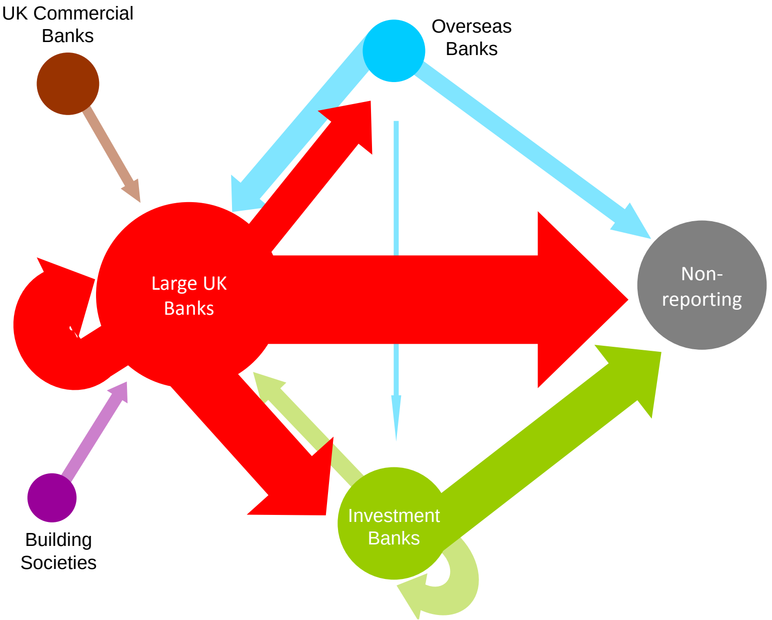
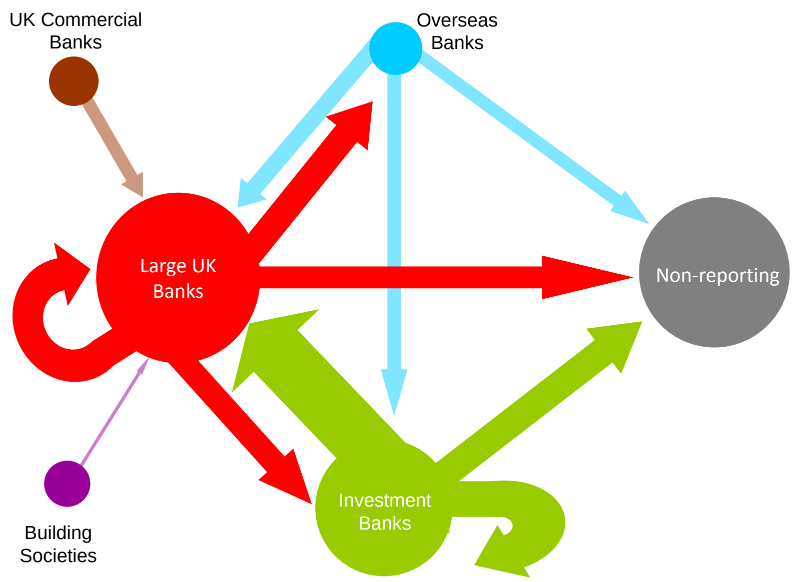


Figure 9: Funding Network by Bank Sector Type



Notes for Figures 8 and 9: Links below £10bn are not shown in the graph. Arrows point away from the exposed set of banks in the Exposures Network and away from the lending set of banks in the Funding Network. The sizes of the circles in Figure 8 and 9 are proportional to the total core Tier 1 capital of banks in each sector type, and the total assets of banks in each sector type, respectively.

Figure 10 illustrates the dominance of large UK banks in the interbank system. The scatterplot shows out-degree in the *exposures* network (the number of banks a given bank is exposed to) against in-degree in the *funding* network (the number of banks providing funding to a given bank). The area of the markers is proportional to the log of banks' total group-level liabilities. Most large banks are exposed to 20 or more counterparties (except non-reporting banks and a few overseas banks). However, only a few large UK banks receive funding from more than 50 banks in our sample. In this representation, four large UK banks (top right of Figure 10) clearly emerge as significant players in the interbank market, with in-degree near 100 and out-degree at the upper bound of 26 [15].

Figure 10: Degree distribution: Exposures Network versus Funding Network

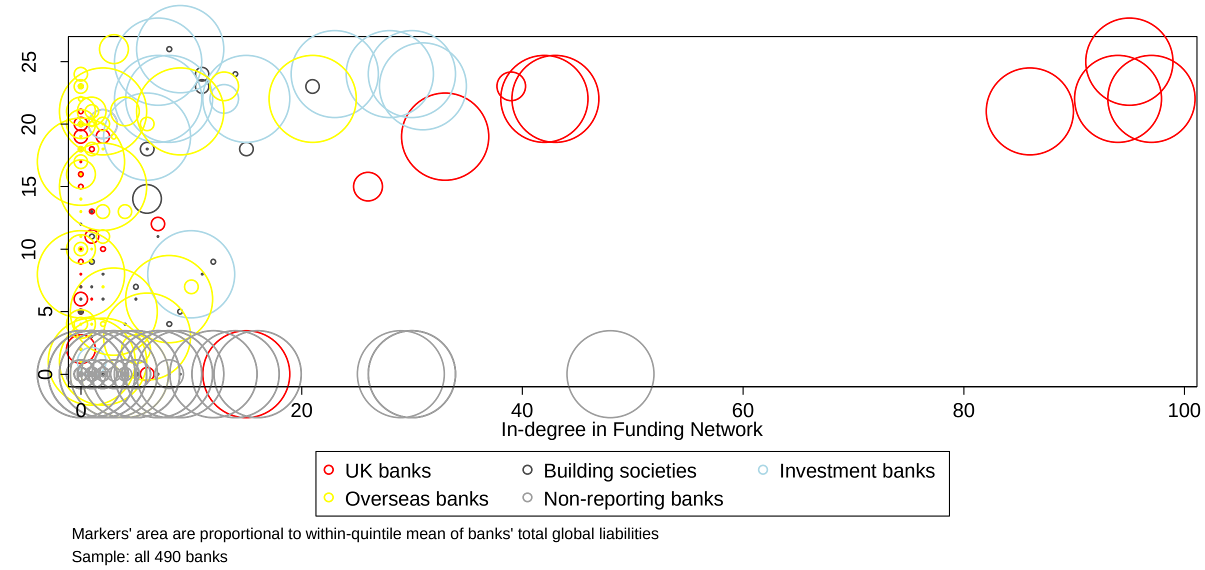
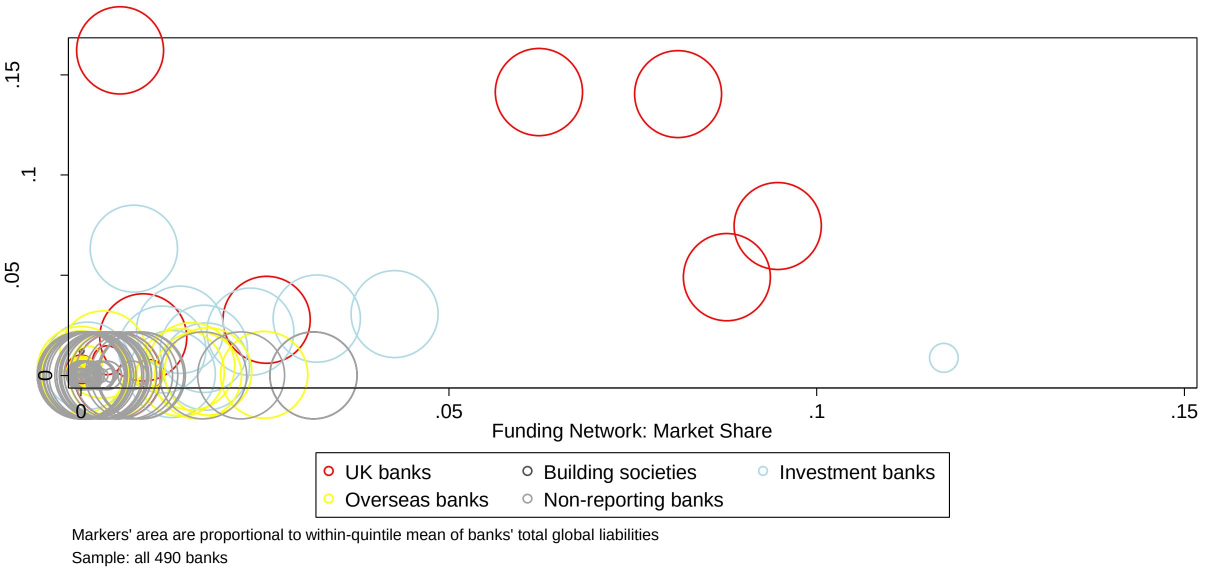


Figure 11: Market share: Exposures Network versus Funding Network



However, the picture changes substantially when we account for the values (or weights) of links among banks. We define out (in) strength as the sum of the pound-sterling value of links from

[15] As mentioned in footnote 7, banks may report up to six UK counterparties in addition to the top 20.

(to) a given node to (from) all other nodes. To obtain the market share of each bank, we normalise bank-level strength by total strength in the interbank market. The distribution of out-market share in the *exposures* network and in-market share in the funding network is right-tailed in both cases, with positive skewness of 5.8 and 8.1 respectively. Of 176 banks, 10 account for 74% of the market in the *exposures* network. The funding network is somewhat less concentrated, with the most active 10 banks accounting for 60% of the total market.

Again, four UK banks stand out as the largest players in the interbank market, together taking 41% of market share in the *exposures* network and 33% of market share in the *funding* network (Figure 11). But some additional insights emerge from this weighted approach which were obscured by simple un-weighted degree (Figure 10). Beyond the large UK banks, approximately six investment banks play a significant role in both the exposures and funding markets.

4.2 Network structure by banks' roles in the interbank system

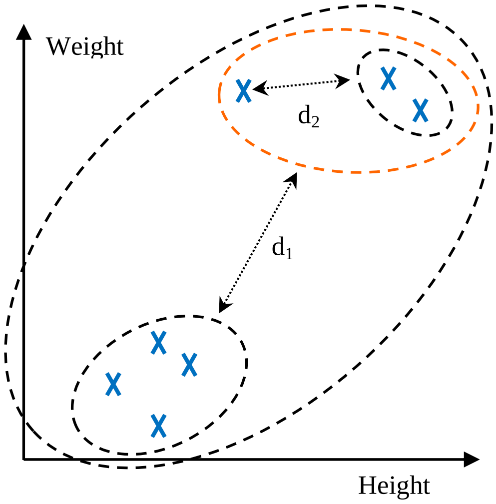
We looked at the network of exposures between sectors in the previous section. Those inter-sector networks assume that the fortunes of banks within a sector are correlated, by virtue of similar business models. But banks with similar business models do not necessarily play the same roles within the interbank system. Some banks might specialise in providing unsecured loans; others would act as market makers in derivative markets. The sectoral categorisation we have seen above does not necessarily reflect how banks behave in the interbank system: in other words, how banks specialise.

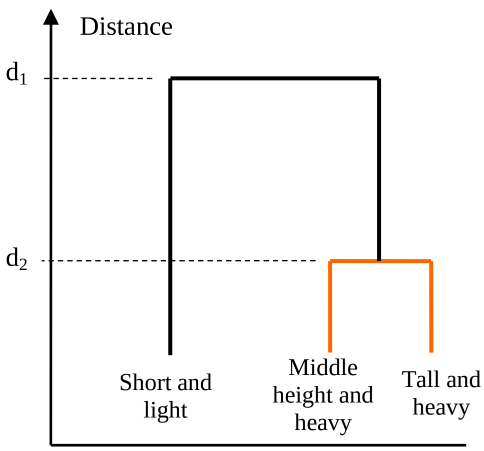
In this section, we categorise banks by their exposures in each market in order to identify groups with common concentrations to distinct market instruments. These market instruments include unsecured loans, secured loans, market products, derivative and others. We categorise banks by their activity in the interbank market using cluster analysis, which helps us to infer groupings (clusters) from multivariate data: a cluster of banks identified is exposed only to unsecured lending, which can be characterised as a cluster specialising in the supply of unsecured loans. Cluster analysis has been used in other fields of finance. Ang and Longstaff (2011), for example, use the method to identify asset price co-movement.

Cluster analysis works as follows. Suppose that we categorise people jointly by height and weight. To do this, we calculate distance between people across the two dimensions of height and weight. The definition of distance is illustrated by d_1 and d_2 in the left-hand panel of Figure 12. Based on this distance, we bundle nearest people to create a cluster. In the next step, we calculate distance between these small clusters; the closest clusters are again bundled into a larger cluster. This process continues until all people are merged into one big cluster.

The sequential process of bundling creates a hierarchical structure of clusters of different sizes. The dendrogram on the right of Figure 12 clarifies the hierarchy. The vertical axis is the ‘threshold of distance’ between clusters. For example, a cluster of two people who are ‘tall and heavy’ is separated from another cluster of ‘middle height and heavy’ people by d_2. Further up the hierarchy, these ‘tall and heavy’ and ‘middle height and heavy’ people form a single cluster, which is separated from the ‘short and light’ cluster by d_1. Thus, the distance d quantifies the difference between clusters. The dendrogram therefore provides different categorisations for different sizes of clusters.

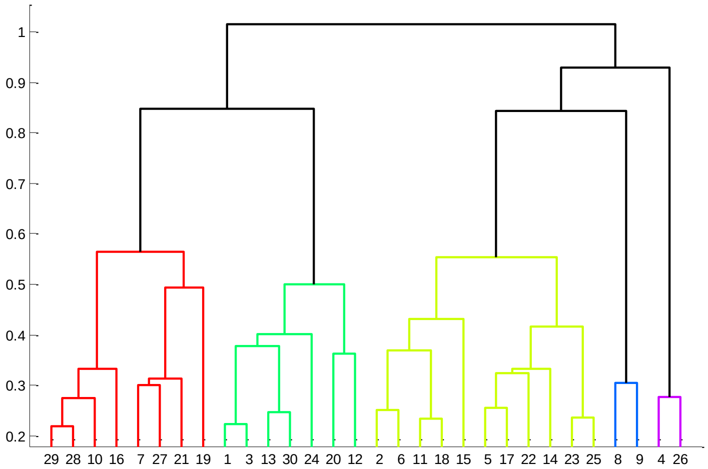
Figure 12: Overview of Cluster Analysis and Dendrogram





We identify clusters of reporting banks based on the instrument breakdown of their interbank exposures. For each of the 176 reporting banks, we calculate their proportions (relative to each bank’s total interbank exposure) of holdings of unsecured loans, secured loans, marketable securities, net CDS sold, securities financing transactions (SFTs) and derivatives. These six instruments create six dimensions of banks’ characteristics. In this set-up, two banks with concentrations of exposures in unsecured interbank lending have low relative distance and therefore tend to be assigned to the same cluster early in the sequential process. In contrast, if one bank primarily holds unsecured loans and another mostly bonds and derivatives, those two banks have different business models. This difference is elicited by cluster analysis. The resulting dendrogram for the interbank exposures network is shown in Figure 13.

Figure 13: Dendrogram for the UK Interbank System



Note: the numbers on the horizontal axis represent small clusters (groups), which consist of one or more banks.

Categorising banks by their concentration of exposures leads to significantly different groupings than those obtained from a sectoral breakdown. Table 2 shows the six major clusters identified and the composition of clusters' exposures.[16] Overall, we find that banks can be usefully divided into six clusters: unsecured lenders; secured lenders; marketable securities holders; derivative houses; SFT specialists; and banks with no interbank exposures. In addition, the cluster of marketable securities holders can be divided into two sub-clusters depending on the degree of their concentrations in unsecured lending.[17] The cluster of derivative houses can be also divided into two sub-groups depending on their diversification of exposures across instruments other than derivatives.

Table 2: Exposures in different instruments as % of total (within-cluster average)

Cluster	Sub-cluster	Unsecured lending	Secured lending	Marketable securities	Net CDS sold	SFT exposures	Derivatives exposures
Marketable securities holders	more unsecured lending	51%	0%	41%	0%	1%	6%
	less unsecured lending	18%	1%	71%	0%	6%	5%
Unsecured lenders		92%	1%	5%	0%	1%	1%
Secured lenders		26%	66%	1%	0%	0%	7%
Derivative houses	Pure derivative houses	6%	0%	7%	0%	8%	80%
	Diversified banks	25%	5%	12%	2%	16%	40%
SFT Specialists		8%	0%	10%	1%	70%	11%

Note: The numbers in each row show the percentage breakdown of the total exposures of entities in the specific cluster / sub-cluster in terms of different types of instruments. Banks without any interbank exposures are omitted.

[16] The major clusters are identified by setting a threshold of distance between sub-clusters. Since this analysis first identifies small clusters close to each other, the distance between them becomes longer as the algorithm identifies larger clusters. Once the distance between clusters exceeds a threshold, those clusters are defined as major clusters. The threshold is set to be 50% of the longest distance.
[17] Note that the division is done again by cluster analysis. Figure 13 shows the red cluster which represents the marketable securities holders has two sub–clusters within it.

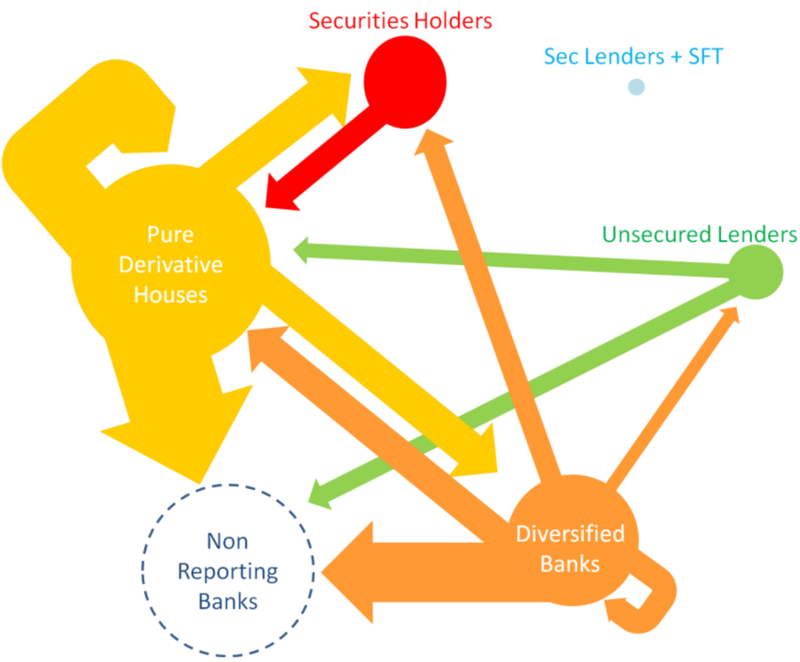
These clusters have the following characteristics:

- *Marketable securities holders cluster.* This cluster includes banks with exposures primarily in marketable securities (issued by banks) but also in unsecured interbank lending. Banks in this cluster are mainly small UK banks, building societies and overseas banks, but a small number of large UK banks also fall under this category. Within the cluster, we can identify two sub-clusters: some banks have concentrated exposures in marketable securities (sub-clusters 7, 19, 21, 27 in Figure 13) and the others have balanced exposure between unsecured loans and marketable securities (10, 16, 28, 29).
- *Unsecured lenders cluster*. This includes banks with exposures concentrated in unsecured interbank lending. More than half of reporting banks fall into this cluster: the majority of small UK banks, building societies and overseas banks. A few investment banks are included in this cluster although their market activities are known to be broad, since some investment banks conduct their main business via their UK branches (which did not report exposures to the Bank of England) rather than subsidiaries.
- *Secured lenders cluster*. This is a small group of a handful of overseas banks and others, which have the majority of their interbank exposures in secured lending.
- *Derivative houses cluster*. This cluster captures mainly banks with large derivatives exposures. Most large UK banks and half of the investment banks in the sample are included in this cluster. A few small UK banks and building societies also have significant exposures in derivatives. This cluster can be divided into two sub-clusters: one which has most interbank exposures in derivatives (minimal clusters 2, 6, 11, 15, 18), denoted as ‘pure derivative houses’, and the other which has relatively diversified exposures in unsecured lending, marketable securities and SFTs, in addition to derivatives (5, 14, 17, 22, 23, 25), denoted as ‘diversified banks’. Around half of large UK banks are in the former category, with heavily concentrated exposure in derivatives. The latter more balanced category consists of most investment banks and a small number of large UK banks.
- *Securities financing transactions (SFT) specialists cluster*. This is a small group of SFT specialists concentrating to repo and securities lending transactions.
- There are around 20 reporting banks with no interbank exposures, which are not categorised in any of the clusters above.

Overall, each smaller bank tends to concentrate their interbank activity in a particular instrument. This could be because each one of the diversified activities needs a large fixed cost and thus exhibits scale economies (i.e. operating many small activities would be too costly compared with the benefit of the diversification). Large banks are in a relatively better position to diversify activities, but some large banks concentrate their interbank exposures in derivative contracts, and therefore can be categorised as 'pure derivative houses', reflecting their sizable investment banking operations as derivative dealers, alongside some investment banks. On the other hand, some large investment banks operating in the UK have a more evenly distributed spectrum of activity in the interbank market. This implies that the taxonomy 'large UK banks' and 'investment banks' (Figures 8 and 9) does not necessarily reflect the nature of banks' roles in the UK interbank system.

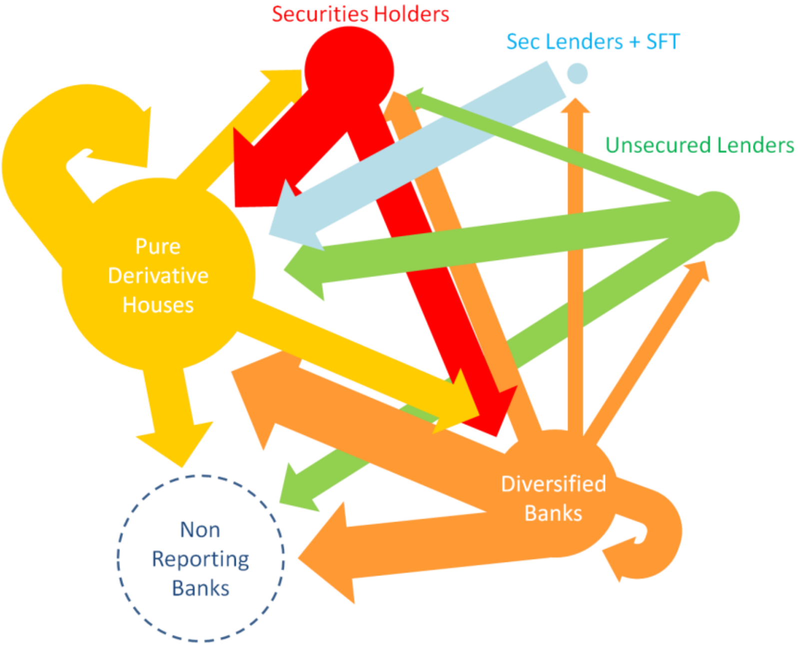
Figures 14 and 15 illustrate the exposures and funding networks, where nodes represent the clusters of banks. The size of circles represents each cluster's total core tier one capital, while the width of arrows represents the size of exposures. Due to the secured nature of SFTs, exposures arising from SFTs are typically much smaller than those from other instruments, despite the large scale of the activity.

Figure 14: Network of Inter-Cluster Exposures



Note: small links (less than 2% of total exposures) are not shown. The sizes of the circles are proportional to the total size of banks' core Tier 1 capital in each cluster. Arrows point away from the exposed set of banks. The clusters of secured lenders and SFT specialists are merged in Figure 14 and 15 since the natures of their business are similar.

Figure 15: Network of Inter-Cluster Funding



Note: small links (less than 2% of total funding) are not shown. The sizes of the circles are proportional to the total size of bank assets in each cluster. Arrows point away from the lending set of banks.

Pure derivatives houses are at the core of the exposure network. This cluster comprises a group of dealers with significant exposures to securities holders, diversified banks, and other banks in their own cluster, mostly in the form of derivatives. They are exposed to securities holders most likely because they provide these banks derivatives to hedge risks on holding the securities, while they have exposures in both directions with more diversified banks partly because many banks in the two clusters are involved in market making activities.

The two sub-clusters containing derivative counterparties have different funding structures. The pure derivative houses are net borrowers in the system and borrowing from all the other clusters. Diversified banks, on the other hand, are net lenders: banks in this cluster are mostly foreign investment banks which rely on wholesale funding from other countries and intra-group funding from their parents. The diversified banks also provide a significant quantity of secured funding to pure derivative houses. If the UK were to experience a liquidity shortage triggered in foreign countries, it would be this cluster that would transmit the shock, which would then propagate to all clusters since the diversified banks provide liquidity to all clusters. Given this international connection, the diversified banks comprise a key cluster in the UK funding network. Including the cluster of marketable securities holders that engages in intensive mutual financing with the diversified banks and the pure derivative houses; these three clusters are central in the UK funding market.

The inter-cluster networks provide several insights that could not be observed in inter-sector networks. Since each cluster is highly specialised in one instrument (except for the diversified banks), we can capture the diversification of roles in the interbank system. This permits us to consider the nature of potential risks arising from a stress in a specific cluster: for instance, it is immediate from Figure 15 that a stress on small (commercial) banks could result in a significant decline of unsecured lending, which hits the pure derivative houses most.

The inter-cluster networks helps to identify the roles banks play in the system, and thereby visualise the multi-layered structure of connections among banks in the UK. Figure 3 shows that derivative exposures represent the largest proportion of exposures. But this observation must be combined with the insight that derivatives are typically traded by larger banks. Figure 14 uncovers this centrality of derivatives houses within the interbank system, compared with the simple inter-sector network shown in Figure 8.

Furthermore, cluster analysis highlights the risk arising from unsecured lending in the UK. The interbank exposure of unsecured lenders is small relative to the total exposures in the system, but unsecured lenders' ratio of interbank exposures to their own capital is higher compared with other clusters. Unsecured lenders' relative vulnerability to the failure of a bank to which they have an exposure could cause contagion within the funding network, through the squeeze of unsecured lending, with important ramifications for other banks especially the pure derivative houses. In particular, the cluster of unsecured lenders is a disproportionately important source of funding in the UK: the unsecured lenders are the second largest net lender in the UK interbank system (as the largest cluster, diversified banks, are dominated by foreign banks, this unsecured lender cluster is the largest domestic funding source). Data behind Figure 15 show that one sixth of derivative houses' external funding comes from unsecured lenders.

The inter-cluster funding network (Figure 15) provides information the inter-sector network (Figure 9) does not. Figure 9 highlights the major UK banks' reliance on investment banks only, but Figure 15 shows that derivative houses rely on funding from all clusters (whereas most investment banks are classified as derivative houses, diversified banks or SFT specialists).

4.3 Core-periphery structure by financial instrument

Sections 4.1 and 4.2 established that the UK interbank market is highly concentrated. Most banks have small exposures to other banks: the average bilateral exposure in the *exposures* network is £119 million. But some banks have large exposures to other banks. The distribution of strength in the *exposures* network is therefore right-tailed, with positive skewness of 5.8. We will test if the UK interbank system follows a specific concentrated structure, as described below.

Intuitively, then, the concentrated UK interbank system appears to mimic a so-called 'hub and spoke' or 'core-periphery' structure. Figures 1 and 2 convey this impression graphically. Informally, the core consists of a set of banks that are strongly connected to other banks in the core and possibly also to banks on the periphery; in contrast, the periphery consists of banks that are only connected to the core banks but not to other peripheral banks. This topology has pedigree in the existing networks literature. In Borgatti and Everett (1999), the core-periphery structure is exemplified by a core perfectly connected to itself: in matrix terminology, a block of ones. In contrast, the periphery is perfectly disconnected from itself: periphery-to-periphery elements form a block of zeroes. These stylised features are summarised in Table 3. In this formulation of the stylised core-periphery matrix, we are agnostic with respect to linkages between the core and periphery. Elements in the core-periphery and periphery-core blocks can take any value in this stylised core-periphery structure. In financial networks, it is not clear *a priori* how the core should connect with the periphery in the stylised core-periphery structure; hence our agnosticism. But Craig and von Peter (2014) argue that a core bank should lend to at least one and borrow from at least one peripheral bank. Their intuition is that core banks should play an intermediation role not limited to their activity within the core block. In practice, this additional constraint never binds in our data. On the contrary, core banks play a strong intermediation role between peripheral banks.

Table 3: Stylised Core-Periphery Matrix Structure

	Core block	Periphery block
Core block	Block of ones	Agnostic (blank)
Periphery block	Agnostic (blank)	Block of zeroes

Defining the stylised core-periphery structure allows us to test how closely the UK interbank network approximates such a structure. Formal testing facilitates greater precision than may be achieved from general inferences regarding strength distributions and market concentration. Borgatti and Everett (1999) quantify the degree of fitness of the core-periphery model to the observed interbank network, using a Pearson correlation between the stylised matrix $\boldsymbol{X}$ (Table 3 adapted to the dimensions of our data) and the observed matrix of interbank exposures $\boldsymbol{E}$. This approach has the virtue of simplicity and transparency. Moreover, Pearson correlation accounts for the values of links by construction. This is because although the stylised core-periphery matrix of Table 2 remains un-weighted – elements are either zero, one or blank – the Pearson correlation tests the extent to which the mean of elements in the core block is significantly greater than the mean of elements in the periphery block, relative to within-block variance. The Pearson correlation coefficient, *r*, is given by:

$$r = \frac{\sum_{i=1}^{176}\sum_{j=1}^{176}[(E_{ij} - \overline{E})(X_{ij} - \overline{X})]}{\sqrt{\sum_{i=1}^{176}\sum_{j=1}^{176}(E_{ij} - \overline{E})^2}\sqrt{\sum_{i=1}^{176}\sum_{j=1}^{176}(X_{ij} - \overline{X})^2}},$$

where X_{ij} denotes the elements in the stylised core-periphery matrix $\boldsymbol{X}$ and E_{ij} denotes the elements in the observed matrix of exposures $\boldsymbol{E}$ (i.e. adjacency matrix). Variables with an upper bar denote sample means. $r=1$ if $\boldsymbol{E}$ and $\boldsymbol{X}$ are perfectly correlated, and $r=0$ if uncorrelated.

The first step is to define the composition of the core and periphery blocks. We exploit a genetic algorithm developed by Borgatti, Everett and Freeman (2002). The algorithm searches for a composition of core and peripheral banks to maximise r. The resulting categorisation of the core and periphery is optimal, in the sense that it is the categorisation which for that observed matrix approximates most closely the stylised core-periphery structure.

We apply the algorithm to the *exposures network* for a square 176x176 matrix comprised of the reporting banks only. That is, we drop exposures from reporting banks to non-reporting banks. For this network, the algorithm finds the optimal core comprised of seven banks; the remaining 169 banks therefore comprise the periphery. Fitness between the *exposures network* and the stylised core-periphery structure is 0.672, suggesting significant fitness. In contrast, the *funding network* comprises an optimal core of nine banks and exhibits fitness of 0.385 with respect to the stylised core-periphery structure. See Section 5.1 for an interpretation of the heterogeneous fitness levels.

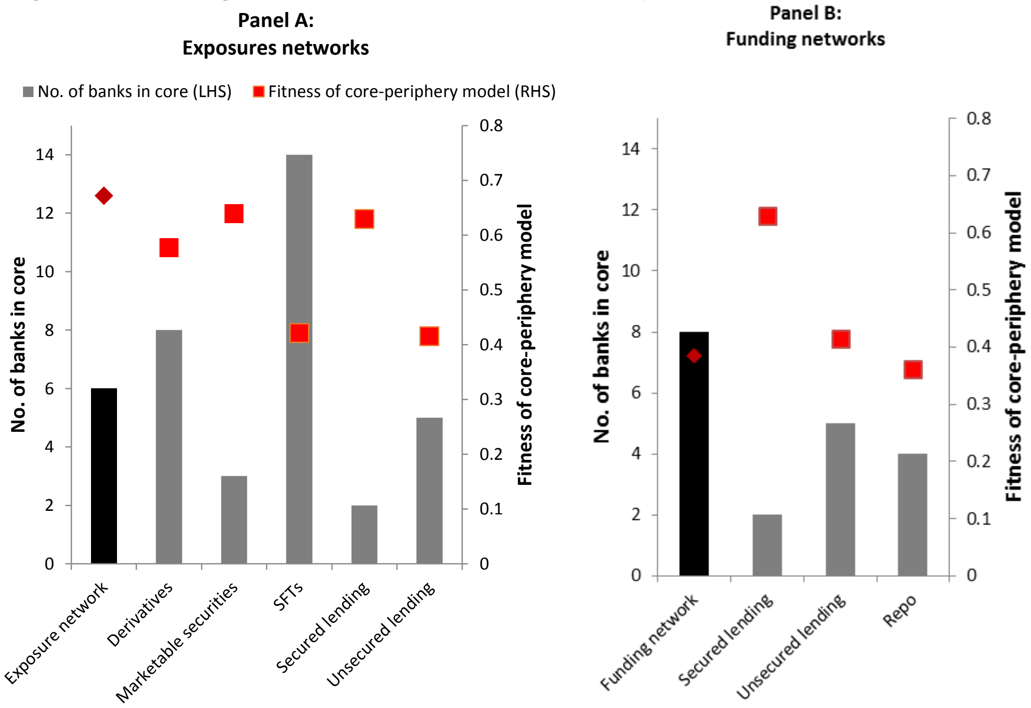
We can investigate core-periphery fitness in more detail by implementing the algorithm on networks by the major financial instrument categories: derivatives, marketable securities, SFTs (including repos), unsecured lending and secured lending.[18] The results indicate that the

[18] Note that unsecured and secured lending appear in both panels A and B, since they are components of both the exposure and funding networks. The two instruments' fitness and the number of core banks are the same in panel A and B since they are measured on gross of

closeness of the observed unsecured lending and repo networks to the stylised core-periphery structure is relatively low, with fitness of 0.415 and 0.362 respectively. Given that repo is 66% of the total *funding network* (Figure 3), fitness of 0.362 drives relatively low fitness of 0.385 in the overall *funding network*. In contrast, fitness in the derivatives and marketable securities networks (blue dots), which comprise part of the overall *exposures network*, is relatively high, at 0.577 and 0.639 respectively.[19]

Another interesting facet of these instrument-specific results is how the composition of the core changes by instrument. Figure 16 shows core-periphery results based on eight different networks: total exposures, which is the sum of derivatives, marketable securities, securities financing transactions, secured lending (gross) and unsecured lending (gross); and total funding, which is the sum of secured lending, unsecured lending and repo (gross).

Figure 16 – Weighted Fitness of Core-Periphery Model by Instrument



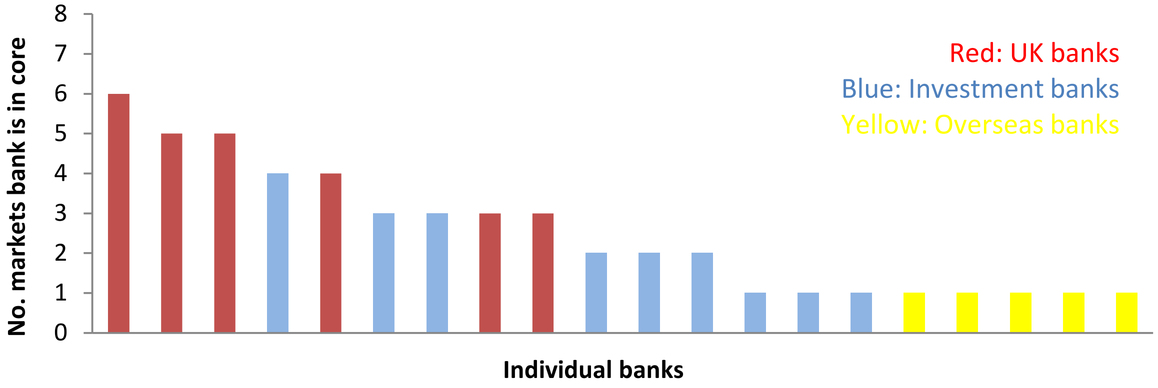
In total, 20 banks comprise part of the core in at least one network. But many of these banks are core banks in more than one network, such that the number of core-banks sums to 50 across the eight networks. Figure 17 shows that one bank comprises part of the core in six of the eight networks considered here. Eleven other banks comprise part of the core in at least two sub-

collateral basis in both the exposure and funding network. Repo is a subset of SFT and implicitly appears both panels, but panel A calculate repos on net of collateral basis, while panel B measures on a gross basis.

[19] Secured lending also shows high fitness. However, this has a small weight in the total funding network since secured lending is very small compared with unsecured lending and repo.

networks. All of these core banks are either large UK banks or investment banks. Finally, eight banks appear in the core only once: these banks may be thought of as product-specialists, which are significant from a systemic perspective only in one particular market.

Figure 17 – Composition of the Core by Bank Type (Weighted Fitness)



Some subtleties of these results are sensitive to the definition of fitness. For robustness, we implement an alternative approach suggested by Craig and von Peter (2014). Their measure of fitness is a simple count of the number of elements in the observed matrix which are not equal to the respective element in the stylised core-periphery matrix. This approach therefore ignores the values of links, which is captured by the Pearson approach suggested by Borgatti and Everett (1999).

We run the algorithm again, using Craig and von Peter's 'error count' approach. Several differences are worth highlighting. First, the 'error count' approach suggests that the secured lending network approximates a core-periphery structure much more strongly than any other network (Figure 18). In contrast, the Pearson correlation approach found that fitness in the secured lending network was similar to fitness in the derivatives and marketable securities networks (Figure 16). Second, the 'error count' approach defines the optimal core to be larger than that found using the Pearson correlation approach in every network except that of securities financing transactions. Third, in terms of 'product specialists', the 'error count' approach defines four building societies and one overseas bank as part of the core in one or two networks, whereas the Pearson correlation approach identified no building society and five overseas banks as part of the core in one network. In the latter case, building societies might have many links with other core banks, but these links are relatively small in value: hence they are excluded from the core in the Pearson approach, but included in the 'error count' approach.

Figure 18 – Un-weighted Fitness of Core-Periphery Model by Instrument

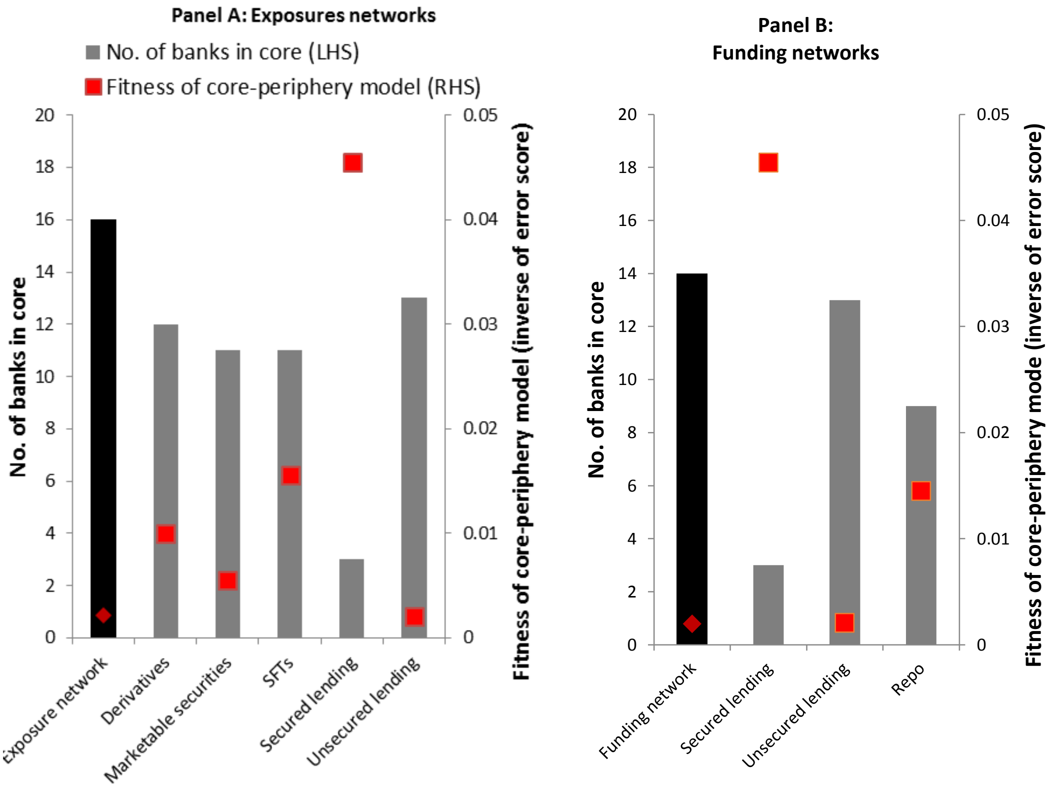
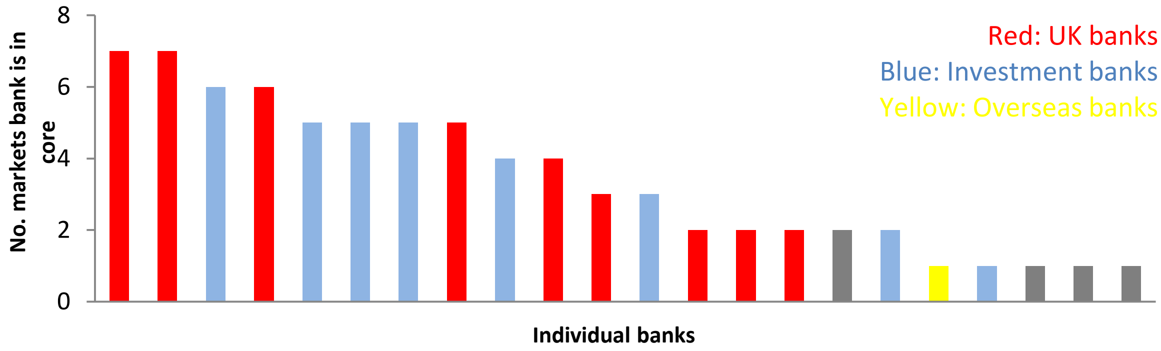


Figure 19 – Composition of the Core by Bank Type (Un-weighted Fitness)



Notably, both the Borgatti and Everett (1999) and the ‘error count’ approach identify similar banks which comprise the core in at least three networks. The Pearson approach finds that six UK banks and three investment banks comprise the core in at least three networks, while the ‘error count’ approach identifies six UK banks and six investment banks. Despite some important differences between the Pearson and ‘error count’ approaches, the central finding with respect to the ‘most core’ banks is robust to the definition of fitness.

5 Interpretation

We have observed that the UK interbank system clearly exhibits a core-periphery structure. In this section, we draw on the existing banking and networks literature to explain why such a network structure might emerge from interbank transactions, and to infer implications for the stability of the financial system as a whole.

5.1 *The mechanisms behind the core-periphery structure*

Several papers have identified the core-periphery structure in other European interbank systems: Craig and von Peter (2014), Fricke and Lux (2012) and van Lelyveld and Veld (2012). But there is little theory to help understand why interbank systems tend to adopt a core-periphery structure.

Degryse and Nguyen (2007) show that the integration of European banking systems after the introduction of the euro established the core-periphery structure of Belgian interbank system in the late 1990s. They argue that Belgian banks had more cross-border transactions after the introduction of the euro, and only large banks with a good international reputation could act as correspondents for smaller banks that could not overcome the problem of asymmetric information (Freixas and Holthausen, 2005).

Degryse and Nguyen's observation that larger banks act as intermediaries in cross-border transactions is consistent with our finding. We identify 20 core banks in various markets, mostly comprising large UK banks and investment banks (see Figure 17). As Figure 8 shows, these banks' largest exposures are to foreign non-reporting banks. At the same time, smaller domestic banks (commercial banks and building societies) are predominantly exposed to large UK banks. This implies that large UK banks act as intermediaries in cross-border transactions. Figure 17 also shows that five overseas banks comprise part of the core in one market: analogously to the large UK banks, these overseas banks act as portals for their domestic banks to tap international markets. This insight implies that the core banks identified in the UK interbank market are also likely to be core banks in global markets.

Another network formation theory supported by our finding is provided by Duffie, Gârleanu and Pederson, (2005). Their argument – that market-makers reduce search costs, balancing demand and supply between (unsophisticated) market participants – could help to explain why we identify core-periphery structure in each financial market we test. In many financial markets, a few traders quote both bids and offers; other less active traders deal with them at the quoted prices, and do not trade with banks which are not market-makers. This naturally creates a concentrated exposure network, depicted by Figure 10.

However, these theories do not explain our other key finding: that core-periphery fitness varies substantially by instrument, especially between exposure and funding networks (Section 4.3). This is partly because the theories consider star-shaped networks with a single core bank, while our core-periphery networks allow for multiple core banks.

One descriptive explanation for the relatively low core-periphery fitness observed in the funding network is that this network exhibits a lower degree of connectedness between core banks. In the unsecured lending and repo markets, the big players are not strongly connected to each other. Instead, core banks tend to absorb funding from peripheral banks (Figure 15). In other words, core banks are net borrowers in the funding network – in part because *all* market-makers have a latent demand for liquidity, which must therefore be provided by non-market-makers. This asymmetric distribution of funding scarcity across banks endogenously generates a network structure which approximates several sub-networks, with an individual bank at the core of each sub-network. The links across these sub-networks are sparse; hence the funding network exhibits low core-to-core fitness. This feature of the funding network can be observed in Figure 2, compared with Figure 1.

5.2 *Network structure and financial stability*

Although the core-periphery structure has been observed in several interbank systems, the existing literature is not conclusive on whether the network structure is robust or vulnerable to systemic risk. Allen and Gale (2000) show the risk of contagion increases in incomplete networks; in contrast, Battiston et al (2012) argue that a highly connected network could amplify the effect of an initial negative shock. In this vein, Gai and Kapadia (2010) find that while the probability of contagion is decreasing in connectivity, the impact of contagion should it occur is increasing in connectivity.

Freixas, Parigi and Rochet (2000) show how core banks can act as ‘fire stops’ in the case of peripheral banks’ defaults. The robustness of core banks arises from their opportunity to diversify counterparty credit risk, since the core bank is connected to many other banks. Core banks indeed have many connections with peripheral banks in our dataset. The average in-degree of cores from peripherals in the exposures network is 89, and the average out-degree of cores to peripherals is 22.

However, Nier et al (2007) argue that the connectivity between core and peripheral banks is not monotonic. If a core bank is connected to few peripherals then the default of that core bank is likely to trigger peripheral banks' default. But if a core bank is connected with many peripheral banks, the insolvency shock is diluted and therefore less likely to create a systemic problem. The theoretic result follows from simulations which assume homogeneous banks. But our paper has shown that banks are highly heterogeneous in terms of both balance-sheet characteristics and levels and types of activities in the interbank markets.

It is therefore important to interact balance-sheet characteristics with interbank market activity in a way that captures banks' heterogeneity. To do this, we extend a metric suggested by Amini, Cont and Minca (2014), Contagious Link, to incorporate peripherals banks' heterogeneity. The metric defines vulnerable links as those where the exposed counterparties becomes insolvent when a bank becomes insolvent. In the first instance, we assume that the exposed counterparties become insolvent when their exposure is larger than their core Tier 1 capital – implicitly assuming a loss given default of 100%.

To identify contagious links, we examine the impact on counterparties' capital given the default of each single bank. In our dataset, there are 98 such contagious links. We find that 50% of these links are exposures of peripheral banks to core banks (i.e. a core bank's default triggers multiple defaults by peripheral banks); 30% are exposures of peripherals to non-reporting banks; and the remaining 20% are exposures between peripheral banks. If we define contagious links as exposures larger than 50% of the exposed bank's capital, the number of contagious links increases to 270 – although the aforementioned breakdown (50%-30%-20%) remains the same. All of the banks which are exposed to these contagious links are peripheral banks, suggesting that these banks are less diversified with respect to their counterparty credit risk.

Since the isolated default of certain core banks causes multiple peripheral banks to default, it is natural to consider that further (second- and subsequent-round) effects could be systemic. To assess the risk of domino effects, we calculate possible higher-round effects arising through contagious links, by checking if any bank loses (50% of) its capital as a result of the multiple defaults. If any bank becomes insolvent, we repeat the process to investigate whether the additional defaults trigger further defaults. In our dataset, the potential for these higher-round effects appears relatively contained. Including higher-round effects increases the number of contagious links to just 99 (from 98) when defined as exposures greater than 100% of exposed banks' capital; and to 295 (from 270) using a 50% threshold.

This relatively small increase in the number of contagious links including higher-round effects arises because the exposed banks are mainly peripheral banks, which are connected to core banks. These core banks tend to be better diversified with respect to their bank-counterparty credit risk. Thus the central expectation is that higher-round effects are safely absorbed by better-diversified core banks.

This insight illustrates the resilience of a core-periphery network in which core banks act as fire-stops against default contagion (Freixas et al, 2000). However, the strength of the fire-stop depends on the quality of core banks' diversification of bank-counterparty risk and the relative quantity of core banks' loss-absorbing capital. Moreover, since core banks are connected to many peripheral (and other core) banks, their default – if it occurred – could cause widespread losses. Core-periphery network structures therefore possess a 'robust-yet-fragile' property, which is common to many financial networks (Gai and Kapadia, 2010). In principle, this finding supports the application of capital surcharges on systemically important banks to build the resilience of these fire-stops in the core of the network.

6 Conclusion

This paper describes the features of the UK interbank system, using a new regulatory dataset on interbank exposures. To our knowledge, this dataset is the most granular representation of a large interbank market available worldwide. The dataset allows us to analyse the structure of the interbank system by asset class. We find that the network of interbank exposures has a different structure of connections from the network of interbank funding. This distinction between 'exposure' and 'funding' networks is important to fully understand contagion processes.

In addition, we divide banks into different clusters according to the financial instruments in which their interbank activity is concentrated. Our analysis shows that banks play different roles: large derivative houses, dominant in the system, absorb funding from all other clusters, particularly from non-UK investment banks (using repo contracts) and UK smaller banks (using unsecured loans). This highlights a potential systemic risk, whereby a reduction in funding provided by foreign investment banks, or by UK commercial banks with less capital and less risk diversification (see Section 5.2), could trigger widespread liquidity shortages.

Finally, we calculate the closeness of interbank networks to a hypothetical core-periphery structure. The networks clearly exhibit such a structure, but the strength of this approximation varies by asset class. For example, the network of interbank exposures is much closer to a core-periphery structure than the network of interbank funding. Also, many banks are in the core of certain markets but not others. A core-periphery structure has ambiguous implications for financial stability: such a structure is robust to ‘random shocks’ (such as defaults by peripheral banks) but vulnerable to ‘targeted attacks’ (such as a default by a core bank).

References

Akram, Q F and Christophersen, C (2010), 'Interbank overnight interest rates – gains from systemic importance', Norges Bank Working Paper no.11.

Alessandri, P, Gai, P, Kapadia, S, Mora, N and Puhr, C (2009), 'Towards a Framework for Quantifying Systemic Stability', *International Journal of Central Banking*, September.

Allen, F and Gale, D (2000), 'Financial Contagion', *Journal of Political Economy*, vol 108, no 1, pp 1-33.

Alves, I, Ferrari, S, Franchini, P, Heam, J C, Jurca, P, Langfield, S, Laviola, S, Liedorp, F, Sanchez, A, Tavolaro, S and Vuillemey, G (2013), 'The structure and resilience of the European interbank market', ESRB Occasional Paper no.3.

Amini, H, Cont, R and Minca, A (2014), 'Resilience to contagion in financial networks', *Mathematical Finance*, vol.24.

Ang, A and Longstaff, F A (2011), 'Systemic Sovereign Credit Risk: Lessons from the U.S. and Europe', NBER Working Paper no.16982.

Arciero, L, Heijmans, R, Heuver, R, Massarenti, M, Picillo, C and Vacirca, F (2013), 'How to measure the unsecured money market? The Eurosystem's implementation and validation using TARGET2 data', DNB Working Paper no.369.

Armantier, O and Copeland, AM (2012), 'Assessing the quality of Furfine-Based algorithms', Federal Reserve Bank of New York Staff Report no.575.

Bargigli, L, Iasio, G, Infante, L, Lillo, F and Pierobon, F (2013), 'The multiplex structure of interbank networks', *arXiv preprint*: 1311.4798.

Battiston, S, Gatti, D, Gallegati, M, Greenwald, B and Stiglitz, J E (2012), 'Default cascades: When does risk diversification increase stability?' *Journal of Financial Stability*, vol. 8, pp.128-149.

Bech, M L and Atalay, E (2008), 'The topology of the federal funds market', Federal Reserve Bank of New York Staff Report no.354.

Bech, M L and Rørdam, K B (2009), 'The topology of Danish interbank money flows', Banks and Bank Systems vol.4, pp.48-65.

Becher, C, Millard, S and Soromaki, K (2008), 'The network topology of CHAPS Sterling', Bank of England Working Paper no.355.

Borgatti, S P and Everett, M G (1999), 'Models of core/periphery structures', *Social Networks* 21 375-395.

Borgatti, S P, Everett, M G and Freeman, L C (2002), Ucinet for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.

Boss, M, Elsinger, H, Summer, M and Thurner, S (2004), 'Network topology of the interbank market', *Quantitative Finance*, 4:6, 677-684.

Bräuning, F and Fecht, F (2012), ‘Relationship lending in the interbank market and the price of liquidity’, Deutsche Bundesbank Discussion Paper no.22/2012.

Brunnermeier, M K, Clerc, L and Scheicher, M (2013), ‘Assessing contagion risks in the CDS market’, Banque de France Financial Stability Review, April.

Brunnermeier, M K and Pedersen, L H (2009), ‘Market liquidity and funding liquidity’, *Review of Financial Studies*, vol. 22(6), pp.2201-2238.

Craig, B and von Peter, G (2014), ‘Interbank tiering and money center banks’, *Journal of Financial Intermediation*, forthcoming. Previously published as BIS Working Paper no.322.

Degryse, H and Nguyen, G (2007), ‘Interbank Exposures: An Empirical Examination of Contagion Risk in the Belgian Banking System’, *International Journal of Central Banking*, June.

Duffie, D (2010), ‘The Failure Mechanics of Dealer Banks’, *Journal of Economic Perspectives*, vol.24 no.1, pp.51-72.

Duffie, D, Gârleanu, N and Pederson, L H (2005), ‘Over-the-counter Markets’, *Econometrica*, vol.73, no.6, 1815-1847.

European Central Bank (2003), ‘Memorandum of understanding on the exchange of information among national central credit registers for the purpose of passing it on to reporting institutions’.

Freixas, X and Holthausen, C (2005), ‘Interbank market integration under asymmetric information’, *Review of Financial Studies*, Vol. 18(2), pp.459-490.

Freixas, X, Parigi, B and Rochet, J-C (2000), ‘Systemic risk, interbank relations, and liquidity provision by the central bank’, *Journal of Money, Credit and Banking*, vol.32, no.3, part 2.

Fricke, D and Lux, T (2012), ‘Core-Periphery Structure in the Overnight Money Market: Evidence from the e-MID Trading Platform’, Kiel Working Paper no.1759.

Furfine, C (1999), ‘The microstructure of the federal funds market’, *Financial Markets, Institutions and Instruments*, Vol. 8, No. 5, pages 24-44.

Furfine, C (2003), ‘Interbank exposures: quantifying the risk of contagion’, *Journal of Money, Credit and Banking*, Vol. 35, No. 1, pages 111-128.

Gai, P and Kapadia, S (2010), ‘Contagion in financial networks’, *Proc. R. Soc.*, 466, pp.2401-2423.

Gorton, G and Metrick, A (2012), ‘Securitized banking and the run on repo’, *Journal of Financial Economics*, vol.104, issue 3, pp.425-451.

Haldane, A (2009), ‘Rethinking the financial network’, speech delivered at the Financial Student Association, Amsterdam.

Iazzetta, C and Manna, M (2009), ‘The topology of the interbank market: developments in Italy since 1990’, *Banca d’Italia Temi di discussione* no.711.

Iori, G, De Masi, G, Precup, O V, Gabbi, G and Calderelli, G (2008), ‘A network analysis of the Italian overnight money market’, *Journal of Economic Dynamics and Control*, vol.32, no.1, pp.259-278.

King, M (2012), *The Today Lecture 2012: Sir Mervyn King*, BBC Radio 4 transcript.

van Lelyveld, I and Veld, D (2012), ‘Finding the core: Network structure in interbank markets’, DNB Working Paper no.348.

Mistrulli, P E (2011), ‘Assessing financial contagion in the interbank market: Maximum entropy versus observed interbank lending patterns’, *Journal of Banking & Finance*, vol.35, issue 5, May, pp.1114-1127.

Montagna, M and Kok, Christoffer (2013), ‘Multi-layered interbank model for assessing systemic risk’, Kiel Working Paper no.1873.

Nier, E, Yang, J, Yorulmazer, T and Alentorn, A (2007), ‘Network models and financial stability’, *Journal of Economic Dynamics & Control*, 31, pp.2033-2060.

Scott, H S (2012), ‘Interconnectedness and contagion’, Committee on Capital Market Regulation.

Upper, C and Worms, A (2004), ‘Estimating bilateral exposures in the German interbank market: Is there a danger of contagion?’, *European Economic Review* 48 827-849.

Wells, S (2004), ‘Financial interlinkages in the United Kingdom’s interbank market and the risk of contagion’, Bank of England Working Paper no.230.

Wetherilt, A, Zimmerman, P and Soramaki, K (2010), ‘The sterling unsecured loan market during 2006-08: insights from network theory’, Bank of England Working Paper no.398.