A Network View on Interbank Liquidity *

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Abstract

The euro area overnight interbank market is best described as a network of lending relationships. We study liquidity reallocation in this interbank network using a novel dataset of all interbank loans settled between European banks and document a significant change in the network structure around the bankruptcy of Lehman Brothers. We show that a bank's position in the interbank network, measured by its centrality, has an economically significant effect on its liquidity access and provision. The effect is stronger for the price of liquidity than for the volume, and stronger for liquidity provision than for access to liquidity.

Keywords: interbank networks, liquidity, network formation

JEL Classification: D85, E5, G1, G21

1 Introduction

The smooth and cost-efficient reallocation of liquidity in the interbank market is key for the resilience of the financial system and the implementation of the monetary policy stance, especially during periods of large adverse shocks when there is a risk of an interbank market *freeze*. This is particularly true in the euro area where interbank lending constitutes a much larger share of banks' total assets than in the United States.[1] Banks borrow and lend on the overnight interbank market multiple times during a day and act as intermediaries between banks with a liquidity surplus and banks with a liquidity deficit. Thus, the euro area interbank market can best be described as a network of lending relationships amongst banks. Contracts are bilaterally negotiated. Therefore, information about trading partners, volumes, and prices is not typically available to the public or even to the supervisor.[2]

As a consequence, many important questions about the reallocation of liquidity in the interbank market remain unanswered. Does a bank's position within the interbank network affect how much liquidity this bank obtains and at what price? Does it affect the amount and price of liquidity a bank provides? A simple example can provide intuition why the answer to those questions should be: *yes*. Some banks within the interbank network have a more pivotal position than others. Consider the highly stylized example with 8 banks shown in Figure 1 and compare banks A and B, which are identical in size and the number of banks they borrow from. Locally, both are identical. They differ only in their position within the interbank network. Intuitively, bank A has better access to liquidity than bank B since its only counterparty, bank C, borrows from a much larger set of banks than bank B's

[1] On average, interbank lending accounts for over 25% and interbank borrowing for roughly 21% of total asset size in the euro area in 2008 (see European Central Bank (2009)).

[2] A notable exception is the Italian e-MID trading platform. Banks voluntarily choose whether or not to trade in a transparent way using e-MID. However, since only the most viable banks will choose to trade transparently, e-MID likely suffers from a self-selection bias. In addition, e-MID only covered about 14% of the turnover in the euro area interbank market before the crisis, most of which involved Italian banks only.

only counterparty. Following a similar argument, bank C should have it easier to provide liquidity to the interbank market than bank B, especially during times of distress. We formalize this intuition in two hypotheses:

(H1) Banks that have a more pivotal position in the interbank network obtain more liquidity during times of distress.

(H2) Banks that have a more pivotal position in the interbank network provide more liquidity during times of distress.

We quantify the informal notion of how *pivotal* a bank is within a network using various measures of centrality in networks which are inspired by graph theory.

Our hypotheses relate local liquidity provision, the formation of new lending relationships between banks, with the existing global structure of the interbank network, which is important for at least six reasons. First, understanding how interbank networks form and evolve over time is of particular importance during times of distress when a shortage of interbank liquidity can trigger costly fire-sales and thus impair financial stability. Second, access to interbank liquidity directly affects provision of credit to the real economy (see Khwaja and Mian (2008) and Iyer et al. (2014)). Third, interbank linkages create a counterparty risk externality (see Acharya and Bisin (2014)). This externality is at the heart of models of contagion in interbank networks (see, amongst others, Zawadowski (2013), Elliott et al. (2014), Acemoglu et al. (2015)). Fourth, interbank lending implements, as Rochet and Tirole (1996) point out, a form of peer monitoring. Whether or not a link is formed affects market discipline and efficiency. Fifth, our hypotheses provide empirical guidance for models of interbank network formation (recent examples in this literature include Farboodi (2014) and Gofman (2011)). And since, sixth, trading in OTC markets reveals information available to dealers in the market, we study two additional hypotheses relating the bilaterally negotiated price of liquidity in interbank markets to the global network structure:

(H3) Banks that have a more pivotal position in the interbank network pay a lower price on their interbank borrowing.

(H4) Banks that have a more pivotal position in the interbank network charge a higher price for their interbank lending and make larger intermediation spreads.

To test these hypotheses we use novel and unique data on all unsecured interbank loans settled between any two European banks between July and December 2008 obtained from TARGET2, the euro area's large value payment system.[3] Interbank loans are identified using the algorithm originally developed by Furfine (1999) in the implementation of Arciero et al. (2013).[4] Because we have information on the ultimate originator and final beneficiary of each transaction, the typical identification problem of false positives is much less prevalent in our data. This allows us to extract interbank loans from the raw set of payments with unprecedented accuracy. We split our sample in five periods, with a two week window at the beginning of the sample, before and after the Lehman insolvency, following the Eurosystem's first special refinancing operation that was conducted as a full-allotment tender, and following the change to a full-allotment regime of monetary policy.

Our identification relies on two sets of regressions. First, we test all four hypothe-

[3]In 2012 TARGET2 settled 92% of the total large-value payment system traffic in euro. The remaining fraction of the total turnover is settled mostly via the EURO1 payment and settlement system (see European Central Bank (2013)). The settlement of secured interbank loans involves central counterparties which we drop from our data to ensure that we only consider unsecured interbank loans.

[4]This implementation is extensively tested and verified using data on actual interbank transactions obtained from the e-MID trading platform in Italy and the Spanish MID trading platform. This verification reveals that the implementation of the Furfine algorithm used in this paper correctly identifies about 99% of all e-MID trades, and over 90% of all trades reported in MID. Concerns regarding the identification quality of the Furfine algorithm are voiced Armantier and Copeland (2012). However, Kovner and Skeie (2013) show that the identified interbank loans show a statistically significant correlation with interbank loans reported on the FRY-9C, which indicates that the Furfine algorithm can indeed be used to identify interbank loans.

ses in a simple OLS model in which we compute a bank's interbank network position in a reference period and then study whether, in subsequent periods, banks with a high centrality have significantly better access to liquidity than banks with low centrality. We control for time period dummies and a set of relevant bank controls reported for the end of 2007. Because a bank's position in the interbank network is computed in a reference period, we avoid issues of reverse causality. Second, to address the issue that an exogenous shock might affect not only supply, but also demand of liquidity, we use a loan-level regression and restrict our sample to loans to banks that borrow from at least two lenders. We then introduce borrowing-bank fixed effects to account for all unobserved heterogeneity in the demand for interbank loans. Changes in the supply of liquidity are solely driven by changes in lender characteristics in this setting. We test hypotheses (H2) and (H4) in a difference-in-differences approach that compares lending before and after the Lehman insolvency across banks with different positions in the interbank network.

We find ample support for all four hypotheses. As a necessary first step in our identification, we show that the structure of the euro area overnight interbank market is substantially different before and after the Lehman insolvency. Empirical studies show that domestic interbank networks tend to have a *core-periphery* structure, i.e. are comprised of a small group of highly connected banks (the core) and a large group of banks (the periphery) which is only connected through the core.[5] The euro area overnight interbank market is a network in which banks from the national cores are connected in a larger European core. There is substantial variation between the pre-Lehman and the post-Lehman interbank networks. Roughly 60% of all links change between those periods.

We find, somewhat surprisingly, a significant increase in interbank lending following the Lehman insolvency. This can best be understood in the context of asym-

[5]See, for example, Craig and von Peter (2014) for a study of the German interbank market.

metric information. Glode and Opp (2014) study intermediation chains as a means to overcome large asymmetric information. The key result of their model is that an increase in asymmetric information leads to an increase in trading activity before asymmetric information ultimately becomes too large and the market breaks down. Our main explanatory variables are the number of banks a borrower borrows from, the amount it borrows, its betweenness centrality, and its Katz centrality, all measured in the initial reference period. Our explanatory variables are all significant for hypotheses (H1) and (H3) when we measure access to liquidity as the amount of liquidity obtained, the volume-weighted spread of interbank borrowing, and the number of banks lending to a given borrower. The effects are economically significant, too. We find that a 10% increase in a bank's betweenness (Katz) centrality in the inital period corresponds to a 3.5% (1.9%) increase in the amount borrowed subsequently. The effect of centrality in the interbank network during a reference period on the price paid for liquidity is also sizeable. A 10% increase in a bank's betweenness (Katz) centrality in the initial period leads to a 3.5% (5.6%) lower spread subsequently.

Turning to the provision of liquidity, and our hypotheses (H2) and (H4), we find that the impact of centrality on the amount of liquidity provided is comparable to the access of liquidity, while the impact on the price of liquidity is even larger (a 10% increase in betweenness centrality in the initial period corresponds to a 9% increased provision of liquidity in subsequent periods). Using the difference-in-differences approach with the Lehman insolvency as exogenous shock, we show that a one standard deviation decrease in betweenness centrality (Katz centrality) implies a 2.8% (1.4%) increase in the likelihood that an existing interbank lending relationship is terminated, and a 1.8% (1.3%) decrease in the likelihood that a new interbank lending relationship is created. In line with the model of Heider et al. (2015), our results indicate that banks start hoarding liquidity when they are rationed on the interbank market: A EUR 1m decrease in interbank liquidity provided to the lending-bank implies a EUR 2m decrease in the amount lent. A one standard deviation decrease in a bank's betweenness centrality implies 2.1% decrease in the amount of liquidity provided, which is about the same size for a one standard deviation decrease in Katz centrality.

Our paper contributes to the literature in various aspects. First, most papers that study the interbank network structure study only global network properties. To the best of our knowledge, no paper studies whether the global network structure has an impact on the local access and provision of liquidity. Second, we provide empirical guidance for the rapidly growing theoretical literature that studies the formation and efficiency of interbank networks (see, amongst many others, Leitner (2005), Gofman (2011), Farboodi (2014), Babus and Kondor (2014), in't Veld et al. (2014), Blasques et al. (2014), and Colliard and Demange (2015)). Third, the literature on the bank-lending channel (see, for example, Khwaja and Mian (2008), Iyer et al. (2014)) studies the impact of interbank liquidity shocks on credit provision. We study heterogeneity in the access to interbank liquidity based on a bank's position within the interbank network, a dimension that has not been studied in the literature. And fifth, studying the dynamics of liquidity provision during times of distress contributes to the literature on money market freezes. Our results are in line with Afonso et al. (2011), who show that the overnight segment of the fed funds market in the United States was *"stressed, but not frozen"*. Acharya and Merrouche (2013) document that large settlement banks in the UK hoarded liquidity precautionary, following the first period of heavy turmoil in euro area interbank markets in August 2007. Heider et al. (2015) show that during times of large asymmetric information banks anticipate a dry-up of interbank lending and start hoarding liquidity as a result. Acharya and Skeie (2011) and Acharya et al. (2011) develop a model of interbank markets with precautionary demand for liquidity. Our contribution is that we add a cross-sectional, structural, perspective to the aggregate perspective taken in the literature.

2 The Institutional Framework

Turmoil in international financial markets reached a new high when the US investment bank Lehman Brothers filed for bankruptcy on 15 September 2008. Interbank markets in the euro area experienced an unprecedented surge of risk premia, measured as the spread between the London Interbank Offered Rate (LIBOR), and the most common proxy of a risk-free rate, the interest rate on a maturity matched index rate (OIS).[6] The dynamics and size of this surge in risk premia indicates that market participants–particularly in Europe–did not anticipate the insolvency of Lehman Brothers, which makes it a prime example for an exogenous shock to the euro area interbank market. In response to this shock, the Eurosystem took various exceptional and unprecedented measures to ensure the liquidity provision for European banks. On 30 September, the Eurosystem conducted a Special Refinancing Operation (SRO) to ease banks' mounting liquidity needs. Starting from 15 October 2008 the operational framework of monetary policy implementation was changed from the regular variable-rate tender procedure to a fixed-rate full allotment policy which would guarantee banks the allocation of the full amount of liquidity they demand, provided they can pledge sufficient collateral.

We are interested in the network structure of the euro area overnight interbank market. Thus, an in-depth analysis of actual individual banks' transactions is required. The interbank market, however, is an over-the-counter (OTC) market where trade details are only known to the involved parties. Transaction level information is thus notoriously hard to obtain. One alternative to track liquidity flows in the interbank market is through the way trades are actually settled. Interbank payments (denominated in euros) are almost exclusively settled via TARGET2, the real-time

[6] The LIBOR panel is updated periodically to only include the most trustworthy banks. This implies that there is a risk that the current LIBOR panel contains a bank which could experience distress in the future. This risk is priced and, thus, the LIBOR-OIS spread is positive.

gross settlement (RTGS) system owned and operated by the Eurosystem.[7] With a daily average of 354,185 payments and EUR 2,477 billion settled in 2012, TARGET2 is one of the largest payment systems in the world, alongside Fedwire in the United States and the CLS multi-currency cash settlement system.

The database we use in this paper relies on a methodology recently developed by the Eurosystem allowing to identify unsecured overnight interbank loans from payments settled through TARGET2 (see Arciero et al. (2013)). This methodology relies on a refined version of the algorithm originally developed by Furfine (1999) to find loan-refund combinations from payment data. In its simplest form the algorithm assumes a round value transferred from bank A to bank B at time t and the same value plus a plausible interest rate amount from bank B to bank A at time $t+1$. Among other enhancements, the refined version developed for the Eurosystem investigates several areas of plausibility for implied interest rates (i.e. several interest rate corridors) and develops a method to choose the most plausible duration in case of multiple loan-refund matches. Moreover, the implementation has been comprehensively validated against actual interbank loans. In contrast with the validation exercise carried out by Armantier and Copeland (2012) on a "plain-vanilla" implementation of the Furfine algorithm done at the Federal Reserve Bank of New York, the performance of the Eurosystem's algorithm is very encouraging. More specifically, Arciero et al. (2013) report a very low Type 2 error of less than one percent for the best algorithm setup, of which only 0.26% represent wrong matches (see Arciero et al. (2013) for more details on the sources used for and the results of the validation). In contrast to the Furfine implementation used for the Fedwire analyses, our data contains not only the settlement banks involved, but also the initial originator and final beneficiary of each transaction. In this paper we undertake

[7] In 2012 TARGET2 settled 92% of the total large-value payment system traffic in Euro. The remaining fraction of the total turnover is settled mostly via the privately operated EURO1 settlement system. However, it should be noted that as far as non-commercial payments are concerned, banks can use other settlement channels, such as automated clearing houses and correspondent banking. See European Central Bank (2013).

a detailed analysis of the dynamics of the euro area interbank market around the Lehman insolvency.

We are interested in the role a bank's position in the interbank network plays in the reallocation of liquidity. Settlment banks do not act on their own behalf and their network position is a result of the ultimate borrower's (and lender's) position in the interbank network. For a clean identification it is thus crucial to resort to originator and beneficiary data. A more practical advantage is that the set of lenders and borrowers increases substantially. For the pre-Lehman period, for example, the number of originator increased from a mean of about 135 settlement banks per day to over 227 lenders per day, while the number of recipients increased from about 106 settlement banks per day to over 147 daily borrower. As a consequence, the possibility that the Furfine algorithm identifies a false re-match is further reduced.

We study the period between 04 July and 30 October 2008 and split our sample into five different periods: The period from 28 August to 12 September is denoted the *pre-Lehman* period. The period from 15 September to 29 September is denoted the *post-Lehman period.* On 29 September the ECB announced a *Special Refinancing Operation (SRO)* which was conducted on 30 September 2008 and lasts until 14 October 2008.[8] On 15 October 2008, the ECB adopted a *full-allotment* regime of monetary policy, which was announced on 8 October 2008. We include dates from 15 until 30 October 2008 to have the same number of days in the pre-Lehman and the full-allotment period. In addition, we use the period from 04 July to 21 July as an *initial* reference period.

Figure 2 shows turnover in the euro area overnight interbank market from July 2008 and during the different subperiods of our analysis. A slow decline is evident in July-August 2008, but we can observe a rebound during the pre-Lehman period

[8] Technically, the SRO was conducted as a variable rate tender with no pre-set amount and the ECB alloted a total of EUR120 billion out of EUR141 billion total bids.

when banks borrowed an average of 590.1 million Euro from 6.3 counterparties. This number even increased to 671.3 million Euro borrowed from 7.1 counterparties in the post-Lehman period before substantially declining once the Eurosystem starts providing liquidity through full-allotment procedures.

3 Characterizing a Bank's Position in the Interbank Network

It is useful to introduce the notation used to characterize a bank's position in the interbank network separately from the models used to estimate whether their position affects bank's access to liquidity. A network G is a set of nodes together with a set of links between the nodes. We are interested in interbank networks, each node is thus a bank and each link is a loan from one bank (the originator) to another bank (the beneficiary). The network is represented by an adjacency matrix g with $g_{ij} = 1$ whenever two banks have a loan with each other and $g_{ij} = 0$ otherwise.[9] A loan from bank i to bank j at time t is denoted as $\text{Loan}_{ij,t}$ and interbank market turnover for the sample period is thus given as:

$$\text{Loan}_t = \sum_i \sum_j g_{ij,t} \times \text{Loan}_{ij,t}. \tag{1}$$

We study access to liquidity along four dimensions: access, amount, price, and number of counterparties. The extensive margin of liquidity access is given by $\text{Access}_{i,t}$, which equals one if we take a borrower perspective and bank i borrowed

[9] Technically, the adjacency matrix can contain the value of the loan from i to j as weight. We use the unweighted network, unless noted otherwise.

on the interbank market at time t, i.e.:

$$\text{Access}^{l}_{i,t} = \max_{j}\{g_{ij,t}\}, \tag{2}$$

where the superscript l indicates access on the liability side. If we take a lender perspective and bank i lends on the interbank market at time t we denote access as $\text{Access}^{a}_{i,t}$.

3.1 Measuring the Intensive Margin of Access to Liquidity

To study the intensive margin of access to liquidity, we define the amount borrowed by bank i at time t as:

$$\text{Amount}_{i,t} = \sum_{j:i} \text{Loan}_{ji,t}. \tag{3}$$

We also use the price a bank pays for liquidity, measured as the spread to the main refinancing rate. Denote the price of a loan from i to j at time t as $p_{ij,t}$ and the volume-weighted price as $\widehat{\text{p}}_{ij,t}$:

$$\widehat{\text{p}}_{ij,t} = p_{ij,t} \times \frac{\text{Loan}_{ij,t}}{\sum_{i:j} \text{Loan}_{ij,t}}. \tag{4}$$

The spread to the mean interbank interest rate that borrower i pays on the interbank market at time t is defined as:

$$\text{Spread}^{l}_{i,t} = \sum_{i:j} \widehat{\text{p}}_{ij,t} - \widehat{\text{p}}_{t}. \tag{5}$$

where $\widehat{\text{p}}_{t}$ is the average interbank interest rate at time t, $\widehat{\text{p}}_{t} = \sum_{i}\sum_{i:j} \widehat{\text{p}}_{ij,t}$. Finally, we use the number of counterparties of bank i for which it is useful to draw on the networks literature. The set of banks $\{j\}$ to which bank i has a loan at time t is denoted as the asset-side neighborhood of i, defined as:

$$N_i^a = \{j|\text{Loan}_{ij,t} > 0\} \tag{6}$$

while the set of banks j that have a loan to bank i is denoted as the liability-side neighborhood of i: $N_i^l = \{j|\text{Loan}_{ji,t} > 0\}$. Bank i's asset-side diversification $\text{div}_{i,t}^a$ is therefore defined as the size of the asset-side neighborhood, i.e. as the number of counterparties j to which i has a loan at time t:

$$\text{div}_{i,t}^a = |N_i^a| \tag{7}$$

Equivalently, a bank's liability side diversification $\text{div}_{i,t}^l$ is the size of the liability-side neighborhood, i.e. the number of counterparties j that have an interbank loan to i at time t. Asset side diversification of a bank i is also denoted as bank i's out-degree, while liability side diversification of bank i is also denoted as i's in-degree. Following this nomenclature, we sometimes denote the amount bank i borrows from others as i's in-volume and the amount bank i lends to others as i's out-volume.

3.2 Measuring a Bank's Position in the Interbank Network

Before we can address the question if a bank's position in the interbank network affects access to liquidity, we have to specify in more detail *which* network we are using. There are two ways to specify the interbank network. The first is to use the daily networks of newly established interbank loans G_t directly (i.e. the daily turnover networks), compute the relevant network measures, and then average them over a sample period. The alternative is to compute the interbank network as an aggregate over a sample period and then compute the network measures.[10] In this

[10]Because network measures are not additive, e.g. the betweenness on a sum of networks is different from sum of the betweenness of the individual networks.

paper, we follow the latter approach because banks, by their very nature, engage in maturity transformation. Their lending decision and subsequently the endogenously chosen network structure at date t depends not only on their borrowing at t, but also on the borrowing (network structure) in $t - \Delta t$. Aggregating over a sample period is also the more natural choice if one is interested in access to liquidity because an interbank link that exists at some point during the aggregation period indicates that the two banks in question are able to engage in interbank lending. A link in the sample period is therefore indicative of the potential to raise liquidity, i.e. determines the access to liquidity. Thus, all network measures in this paper are computed for a reference period:

$$G_\tau = \bigcup_{t \in \tau} G_t = \sum_{t \in \tau} g_{ij,t} \tag{8}$$

where τ is one of the sample periods defined in Section 2.

Network theory provides a wide variety of measures to quantify a node's position in a network and for our analysis we select measures that have a natural economic interpretation in the context of interbank lending. Many network measures incorporate not only information about node i's (direct) neighbors, but also about neighbors of neighbors and so on. We are interested in network measures that proxy a bank's access to liquidity in a given period τ. To this end, we first define a shortest path between two banks i and j in network G_τ. A path from bank i to bank j in a network G_τ is a sequence of banks $i, \ldots, j$ in which all banks are distinct and each bank has a link to its successor. The length of the path is the number of banks it contains minus one. If more than one path exists from bank i to bank j, the shortest such paths is called geodesic and denoted $\sigma_{ij,\tau}$. The distance $d_{ij,\tau}$ from bank i to bank j is defined as the length of the geodesic between them, $d_{ij,\tau} = |\sigma_{ij,\tau}|$. The average shortest path for bank i is the mean geodesic distance separating the bank from all other banks in the network:

$$\overline{d_{i,\tau}} = \frac{\sum_{j:i} d_{ji,\tau}}{|N| - 1} \tag{9}$$

The average shortest path length of the network is the sum over all nodes' individual shortest paths divided by the number of nodes and gives the average number of links that connect any two nodes in the network. Similarly, the diameter of the network is the length of the longest shortest path between any two nodes in the network. A network is connected if there exists a path between any two nodes in the network. The largest connected component is the largest connected set of nodes.

A very broad, but useful global measure is the network density, which is defined as the ratio of actual links in a reference period $\#\text{Loans}_\tau$ to possible links. For an undirected network, the density is defined as:

$$\rho_\tau^{\text{m}} = \frac{\#\text{Loans}_\tau}{\text{N}_\tau \times (\text{N}_\tau - 1)}. \tag{10}$$

The most direct measure of bank i's access to liquidity is the Betweenness centrality of bank i, defined as the fraction of all shortest paths between any two banks j and k that pass through i:

$$\text{Betweenness}_{i,\tau} = \frac{\sum_{j:i} a_{jk,\tau|i}/a_{jk,\tau}}{(|N| - 1) \times (|N| - 2)} \tag{11}$$

where $a_{jk,\tau|i}$ denotes the number of geodesics between j and k that contains i, $a_{jk,\tau}$ is the total number of geodesics between j and k.[11] The betweenness of bank i is a proxy for how easy it is for this bank to access liquidity in the interbank market, i.e. accessing a random Euro of liquidity flowing between any two banks in the market.

[11] Dividing by $(|N|-1)\times(|N|-2)$ obtains a normalized version of betweenness, because this factor represents the maximum number of pairs of banks not including i, hence the maximum value that this indicator can take. Our measure for betweenness is thus normalized: $\text{Betweenness}_{i,\tau} \in [0, 1]$.

It is also a direct measure for a bank i's intermediation function. Banks with high betweenness are in a larger number of intermediation chains. Thus, they are more relevant for financial intermediation, as a shock at such pivotal banks will affect the smooth flow of funds more strongly.

As a robustness check, we will also use the Katz centrality, which computes the relative influence of bank i within a network by measuring the number of its immediate neighbors (lenders) and also of all other banks in the network that lend to bank i through these immediate neighbors. The Katz centrality for bank i is defined as:

$$\text{Katz}_{i,\tau} = \alpha \sum_{j:i} g_{ji,\tau} + \beta \tag{12}$$

where $g_{ji,\tau}$ is the adjacency matrix representing the network with eigenvalues λ, and $\beta = 1$. The parameter $\alpha \leq 1/\lambda_{max}$ is an attenuation factor that allows to penalize loans made amongst distant neighbors, i.e. with neighbors of neighbors (of neighbors of ...) of bank i. [12] Moreover, extra weight can be provided to immediate neighbours (lenders) of bank i through the parameter β, which controls for the initial centrality.[13]

3.3 The Changing Interbank Network Structure

The measures defined above can be used to quantify the change in the network structure of the euro area overnight interbank market. In our empirical design we use both measures of daily liquidity access and provision, as well as the period aggregated networks. Before analyzing the network structure of the aggregate networks G_τ, it is instructive to look at aggregate measures of the daily networks G_t first. Fig-

[12]The algorithm uses the power iteration method to compute the eigenvector corresponding to the largest eigenvalue of g. The condition that α be less than (or equal to) the inverse largest eigenvalue of g is necessary for the algorithm to converge.

[13]For $\alpha = 1/\lambda_{\max}$, and $\beta = 1$, which are the parameter choices we make throughout, Katz centrality equals eigenvector centrality.

ure 2 shows the total daily turnover (i.e. $\sum_i \text{Amount}_{i,t}$ where the sum runs over all banks i borrowing on a given day t) during our sample period. A downward sloping trend lasts until the end of August and daily turnover drops from around EUR180bn to EUR140bn. In the two weeks prior to the Lehman insolvency, turnover picks up again and is at about EUR150bn on 12 September. Somewhat surprisingly, though, the Lehman insolvency did not lead to a breakdown of lending in the euro area overnight interbank market.[14] Rather, the increase in overnight turnover is accompanied by a substantial decrese in term interbank lending. The turnover decreases by over 25% once the Eurosystem conducts the special refinancing operation on 29 September, and until it matures on 08 November 2008.

Table 1 provides further information on the the daily interbank networks G_t. The aggregate picture for turnover is reflected in the amount borrowed during the different sample periods. The mean number of lenders increases by about 12% from the pre-Lehman to the post-Lehman period, and then drops by almost 30% in the full-allotment period. The price of interbank liquidity is shown in Figure 3 and further discussed in Table 1. During the pre-Lehman period, the spread is smallest, with an even positive median, which indicates that a relatively small number of banks have access to cheap liquidty, while a relatively large number of banks have to pay a high price for their interbank liquidity. Spreads decrease substantially once the ECB conducts the special refinancing operation and during the full-allotment period, in line with what one would expect during times of excess supply of liquidity from the central bank.

As can be seen in Table 2, the volume of loans increases from the pre- to the post-Lehman period by almost 10%, reaching the level of the Init period. This increase is accompanied by a similar increase in the number of loans. Following the ECB's special refinancing operation, and during the full-allotment period, the amount of

[14] This is well in line with the results by Afonso et al. (2011) who show that the Fed funds market in the US is *"stressed, but not frozen"* in the aftermath of the Lehman insolvency.

interbank lending shrinks by over 35% while the number of interbank loans shrinks by over 33%. From the pre- to the post-Lehman period, the number of borrowers decreases by about 7%, while the number of lenders remains roughly constant: fewer banks obtain more liquidity through more linkages from a roughly constant number of lenders. This behavior is consistent with lender concerns about borrower quality. As a result of this process, the network density slightly increases, the average shortest path length slightly decreases, and the diameter decreases from 9 to 7. The size of the largest connected component increases slightly, while the share of nodes in the largest connected component remains very high with over 98% of banks being part of the largest connected component. Betweenness and Katz centrality decrease slightly, although this global decrease does not yet reveal the heterogeneity across banks. The number of borrowers and lenders continuously decrease, from the pre-Lehman to the full-allotment period by around 13%. The density decreases by around 10%, while the shortest average path length increases by around 5% and the diameter remains constant at 7. Betweenness and Katz centrality substantially decline by 33% and 21% from the pre-Lehman to the full-allotment period, respectively.

Our characterizing of the change in the interbank network structure around the Lehman insolvency and ECB intervention is important to understand the welfare implications of different network structures. Gofman (2011) shows the existence of a bargaining friction in over-the-counter markets which implies that not all network structures are equally efficient. Specifically, Gofman (2011) shows that networks which are *under*-connected, i.e. which have a too low network density, are inefficient. From this perspective, the euro area overnight interbank market is likely to become more efficient after the Lehman insolvency as the network density increases. This effect is reversed once the ECB steps in: the density of the interbank network decreases, indicating a likely lower efficiency. Another consequence of the bargaining friction described in Gofman (2011) is that financial institutions with many counterparties can improve trading efficiency. Across all events (Lehman insolvency and

ECB intervention), we find a substantial reduction in the number of active trading partners which further decreases the efficiency of the network. Overall, our results show that the interbank market did not just drop in volume, the change in the network structure left it less efficient, an aspect that can only be seen when a market freeze is studied through a network lense.

Using measures from network theory is only one possibility to quantify the change in the interbank network structure, though. Another possibility is to check to what extent the network structure is of core-periphery type. Empirical studies of interbank networks find that they tend to have a core-periphery stucture in which a subset of banks (the core) is highly interconnected, and a different subset of banks (the periphery) is connected only to the core. We identify core- and periphery nodes following the methodology of Craig and von Peter (2014). The euro area overnight interbank market has 732 banks with 3936 loans. The size of the identified core in the pre-Lehman period is 25 (and the size of the identified periphery thus 707). In the pre-Lehman period, there are 253 links within the identified core, 1650 links within the identified periphery, and 2033 links between the identified core and the identified periphery. The interbank network in the pre-Lehman period is thus *not* following a clean core-periphery structure and the error score defined by Craig and von Peter (2014) is 0.507. In the post-Lehman period there are only 617 of the banks in the identified periphery active and there are 232 links within the identified core, 2070s links between the identified core and periphery, and 1755 links within the identified periphery. The error score slightly increases to 0.52 in the post-Lehman period. Both, the identified core and the identified periphery shrink between the pre-Lehman and the post-Lehman period, but the identified periphery shrinks more.

Another useful possibility to study the change of a network is to define a measure of the structural persistence based on individual transactions, which can be quantified using the Jaccard index $\mathrm{J}(L_\tau, L_{\tau'})$ where L_τ and $L_{\tau'}$ are subsets of the set of unweighted links in networks G_τ and $G_{\tau'}$, respectively. Recall that an link $l_{i,j} \in L$ iff $g_{ij} > 0$. In its most general form the Jaccard index measures how similar two sets of links are, and is defined as:

$$\mathrm{J}(L_\tau, L_{\tau'}) = \left| \frac{L_\tau \cap L_{\tau'}}{L_\tau \cup L_{\tau'}} \right|. \tag{13}$$

We measure the Jaccard index on subsets of links in the pre-Lehman and post-Lehman period, since this is the main exogenous shock we study.[15] The Jaccard-Index yields 0.4 for the comparison between all links, 0.54 for the comparison of links within the identified core, 0.38 for links within the identified periphery, and 0.43 for links between the identified core and the identified periphery. This means that more than half of all links in the network change from the pre- to the post-Lehman period. As expected, the identified core maintains the highest structural stability, while lending between banks in the identified periphery is the least structurally stable.

Our analysis shows that in the euro area overnight interbank network, both the identified core and the identified periphery shrink, but the identified periphery shrinks more. It is noteworthy that the network cannot be characterized as a pure core-periphery network, since the error scores are high (with about 0.5 and 0.7) compared to the error score for the German interbank market of 0.12. There might be an institutional reason for this finding: the euro area interbank market is highly integrated and has a core of large European banks. The national interbank markets are more likely to be core-periphery, which implies that the joint European interbank network can best be characterized as a network of connected core-periphery networks.

[15]The Jaccard index for the post-Lehman and SRO , and the post-Lehman and full-allotment period is even smaller, indicating even more variation in the network structure.

4 Access to Liquidity and Network Position

One of the hypotheses of our paper is that banks with higher centrality in the euro area overnight interbank network have better access to liquidity. A first indication for this hypothesis can be seen in Figures 4 and 5 where we show the amount banks borrow in interbank market and the volume-weighted spread they pay for their interbank borrowing for two groups of banks: those in the upper and lower tercile of centrality (betweenness and Katz centrality) in the initial period. In Figure 4 we normalize the borrowing $\text{Amount}_{i,\tau}$ by borrowing in the initial period. The aggregate amount both groups borrow diverges over time, both for Betweenness and Katz centrality. The volume-weighted spread for banks with high centrality is below the volume-weighted spread that banks with low centrality pay, except in the full-allotment period when banks with higher centrality pay a slightly higher price for their interbank borrowing.

To further understand the impact of network centrality on liquidity access, we estimate a simple OLS model:

$$\begin{aligned} A_{i,t} \quad = \quad & \beta(\text{Date}) + \beta_0 \left(\text{Date} \times \text{Assets}_{i,2007}\right) + \beta_1 \left(\text{Date} \times \text{Loan Loss Reserves}_{i,2007}\right) \\ & + \beta_2 \left(\text{Date} \times \frac{\text{Amount}_{i,t}}{\text{Assets}_{i,2007}}\right) + \beta_3 (\text{Date} \times \text{Network Position}_{i,\text{initial}}) \end{aligned} \tag{4}$$

where liquidity access, $A_{i,t}$, is measured along three dimensions, amount $\text{Amount}_{i,t}$, spread $\text{Spread}_{i,t}$, and the number of loans obtained, $\#\text{Loans}_{i,t}$. We estimate (4) separately for borrowers and, later, for lenders to also study the provision of liquidity. We introduce a time-period dummy Date for every period and use a set of bank-specific control variables which we obtain from bankscope. Values for the control variables were reported for the end of 2007 and we use total asset size $\text{Assets}_{i,2007}$, the loan-loss reserves $\text{Loan Loss Reserves}_{i,2007}$ as a risk proxy, and the relative size of interbank lending $\text{Amount}_{i,t}/\text{Assets}_{i,2007}$.[16] Our main explanatory variable is Network $\text{Position}_{i,init}$ and we use four different measures of a bank's position in the network G_{init}, i.e. the euro area overnight interbank network in the initial period. For borrowers, we use a bank i's liability side diversification (i.e. its in-degree) $\text{div}^{l}_{i,\tau}$, the amount it borrowed $\text{Amount}_{i,init}$, its betweenness centrality $\text{Betweenness}_{i,init}$, and its Katz centrality $\text{Katz}_{i,init}$.

Tables 6 - 17 show the results of our estimation. Model (1) is a baseline regression with only period dummies and control variables. The main explanatory variable is added in model (2) and the difference between models (1) and (3) is that we add interactions between the period dummies and the control variables in model (3). Finally, in our main specification, model (4), we add a further interaction between the period dummies and our main explanatory variable to study whether it acts differently in different periods.

We turn to amount borrowed first. Tables (6) to (9) show that banks borrow significantly more in the post-Lehman period, and significantly less in the full-allotment period than in the initial period. The latter is only true for small banks when interacting period dummies with bank controls. Second, larger banks almost always obtain more liquidity than smaller banks, in particular during the full-allotment period. Third, riskier banks obtain less liquidity. And fourth, banks that have a higher share of interbank lending relative to total assets obtain more liquidity. In line with our hypothesis, all explanatory variables that describe a bank's position in the network are significant and positively correlated with the amount of liquidity a bank obtains in the euro area overnight interbank market. Banks that have 10% more lenders in the initial period borrow on average 3.9% more subsequently and, similarly, banks that borrow a 10% larger amount in the initial period borrow

[16] We have performed a robustness check where we use non-performing loans as alternative risk proxy and all results still hold. The coverage of loan-loss reserves on bankscope is better, however, than of non-performing loans. We have also performed the same analysis using data from SNL instead of bankscope. All results hold, but the coverage is not as good.

on average 2.8% more subsequently. The relation is less pronounced for network centralities, which is to be expected as these capture also non-local effects which can work opposite to the positive local effects. We find a 10% increase in a bank's betweenness (Katz) centrality in the Inital period corresponds to a 3.5% (1.9%) increase in the amount borrowed subsequently. The interaction of betweenness centrality with period dummies reveals that the effect is significantly stronger in the post-Lehman period than in the SRO and full-allotment period. For Katz centrality, the interaction shows a more than twice as large effect in the post-Lehman period than on average.

Banks with a better network position do not only obtain more liquidity, they also obtain it at a cheaper price. Relative to the initial period, spreads are significantly higher in the pre-Lehman period, but significantly lower in the full-allotment period across almost all specifications. Banks-specific controls have very little impact on price, highlighting that the overnight interbank market mainly uses reserves to balance short-term liquidity fluctuations. Despite this, network variables do have an impact on the price of liquidity: A 10% increase in the number of lenders a bank borrows from in the initial period translates into a 7.1% lower spread, while a 10% increase in the amount borrowed leads to a 3.3% lower spread. And a 10% increase in a bank's betweenness (Katz) centrality in the initial period leads to a 3.5% (5.6%) lower spread subsequently. The impact of all network variables is stronger in the post-Lehman period.

Finally, a better network position in the initial period also translates into access to more lenders in the subsequent periods. On aggregate the number of lenders does not change significantly, except in the full-allotment period when it is slightly smaller than in the initial period. Not surprising, the relative size of a bank, i.e. how much it borrows on the interbank market in the initial period is positively correlated with the number of lenders subsequently. Our main explanatory variables are significant again and we can observe the same pattern as with the other measures of access to liquidity. A 10% increase in the number of lenders in the initial period leads to a 2.6% increase in the number of lenders subsequently. A 10% increase in the amount borrowed leads to a 1% increase in the number of subsequent borrowers. A 10% increase in betweenness (Katz) centrality in the initial period leads to a 2.6% (1.2%) increase in the number of borrowers subsequently.

Overall, we find overwhelming support for our hypothesis that banks with a more central position in the interbank network have better access to liquidity in the euro area overnight interbank market.

5 Liquidity Provision and Network Position

The interbank market can only have a non-trivial network structure, if banks intermediate liquidity, i.e. there are some banks that are borrowers and lenders at the same time. We have argued in Section 3.3 that the euro area overnight interbank market consists of a European core which connects a set of national cores. The core banks are the ones that intermediate liquidity, while periphery banks are usually borrowers or lenders, but not both. So far we have studied access to liquidity and found a significant impact of a bank's network position. In this section we study the other side of intermediation, i.e. whether a bank's position in the interbank network affects the provision of liquidity as well.

We first estimate the model (4) for lenders. If bank i is a lender, we use the betweenness and Katz centrality as measures of bank i's network position, as well as i's asset side diversification $\text{div}^a_{i,init}$ and amount lent $\text{Amount}_{i,init}$. The results of our regression can be found in the right panel (models (5) - (8)) of Tables 6 - 17. The first thing to notice is that the effect of the different time periods on the amount of liquidity provided is less pronounced for lenders than for borrowers. At the same time, our main explanatory variables act stronger on the amount of liquidity provided, except for betweenness centrality, which is slightly weaker, but still strongly significant and positive. And interacting betweenness centrality with time period dummies shows that during the SRO period even betweenness centrality has a larger impact on liquidity provision than on access to liquidity.

The effect of centrality on spreads is stronger for lenders than for borrowers, in particular in the SRO and full-allotment period. Table 10 shows that banks who have more lending relationships obtain higher spreads, which is well in line with predictions by models of bargaining in interbank markets (see, for example, Farboodi (2014)). The effect is stronger in the post-Lehman and full-allotment period. The strong effect of network position on lending spreads is confirmed by the results for betweenness and Katz centrality. An increase of 10% betweenness centrality in the initial period, for example, corresponds to a 9% increase in the spread in the post-Lehman period. Tables 14 - 17 for the number of loans provided confirm our results for the significance of a bank's network position on the provision of credit. However, the results are significant but weaker for betweenness and Katz centrality.

One concern with estimating regression (4) for the provision of liquidity is that demand for interbank liquidity was affected by the Lehman insolvency. In this case, we would obtain a biased estimation only. To address this concern and obtain an unbiased estimation, we construct a panel of interbank loans that exist before and after the Lehman insolvency and use borrowing-bank fixed effects after first-differencing the data to absorb all borrowing-bank specific demand shocks (see Khwaja and Mian (2008)). Starting from an extremely simplified bank balance sheet:

$$D_{i;t} + B_{i;t} = L_{ij;t} \tag{15}$$

where $D_{i;t}$ is the sum of demand deposits (from households, non-financial firms, etc.) and interbank deposits (from other banks) and $B_{i;t}$ is the amount of alternative financing, e.g. from bonds and equity, bank i faces at time t. $L_{ij;t}$ is the amount of interbank lending from bank i to bank j in period t. We assume that the demand and supply of interbank deposits is linear in each period. Taking the first difference obtains the equilibrium values of L_{ij} and B_i because of the linear model setup. As Khwaja and Mian (2008) show, this model can be estimated without bias by introducing borrowing-bank fixed effects after first-differencing. This yields our baseline regression:

$$\Delta L_{ij} = \beta_j + \beta_1 \Delta D_i + \epsilon_{ij}. \tag{16}$$

The assumption we make is that a bank's access to interbank liquidity, D_i, depends linearly on its position in the interbank network, while the access to demand deposits is independent of the position in the interbank network. Thus, $D_i \equiv \alpha \times \text{Network Position}_i$, where $\text{Network Position}_i \in \{\#\text{Lender}_i, \text{Betweenness}_i, \text{Katz}_i\}$. We use three different measures L_{ij} to measure the intensive margin of liquidity provision. First, we use the difference in the log of interbank liquidity provided by bank i to banks j:

$$\text{Amount}^a_{i,t} = \log\left(1 + \sum_{i:j} \text{Loan}_{ij,t}\right) \tag{17}$$

Second, we use the difference in the average volume weighted spread bank i charges on its interbank lending, $\text{Spread}^a_{ij,t}$. And third, we use the intermediation spread bank i makes on $\text{Loan}_{ij,t}$, which can be measured as:

$$\text{Intermediation Spread}_{ij,t} = \text{p}_{ij,t} \times \text{Loan}_{ij,t} - \sum_{k:i} \widehat{\text{p}}_{ki,t} \tag{18}$$

i.e. as the difference between the price of the loan and the volume-weighted average refinancing cost of the lending bank i. In addition to the intensive margin of *how much* liquidity banks provide, we can also look at the extensive margin, i.e. if they provide liquidity at all. The extensive margin of liquidity provision can be measured by constructing a variable Exit_{ij} for each loan in the pre-Lehman period, which is one if the loan is no longer present in the post-Lehman period, and zero otherwise. Similarly, we construct a variable Entry_{ij} for each loan in the post-Lehman period, which is one if the loan was not present in the pre-Lehman period and zero otherwise. Our borrower-bank fixed effect regression for the extensive margin is:

$$\text{Exit}_{ij} = \beta_j + \beta_1 \Delta D_i + \epsilon_{ij}, \tag{19}$$

and similarly for Entry_{ij}. Summary statistics for the dependent variables can be found in Table 3, summary statistics for the independent variables in Tables 4 and 5.

The coefficient of interest is always β_1, which determines the strength of the interbank lending channel along the intensive and extensive margin. We start with the extensive margin of liquidity provision, i.e. regression (5). Results for terminating an existing interbank relationship, Exit_{ij} (see Panel A), and establishing a new interbank relationship, Entry_{ij} (see Panel B), are shown in Table 18. We use the insolvency of the US investment bank Lehman Brothers as exogenous shock. Results for our regression around this shock are shown in models (1) and (2), with the difference between the two models being that we include the same set of lender controls (i.e. total asset size $\text{Assets}_{i,2007}$, counterparty risk proxy Loan Loss $\text{Reserves}_{i,2007}$, and relative size $\text{Amount}_{i,\text{pre-Lehman}}/\text{Assets}_{i,2007}$) as above. Since lender controls obtained from bankscope (or SNL) are not available for all banks in our sample, we end up with a significantly smaller sample size. The inclusion or omission of lender controls does not change our results qualitatively. One can also argue that the full-allotment special refinancing operation on 30 September was a larger shock because it had a substantial impact on market turnover. Or the shift towards a full-allotment regime of monetary policy on 15 October. To test both possibilities, we include the respective regressions in models (3) and (4). All three events had massive impact on the liquidity reallocation in the euro area overnight interbank market, as Figure 2 shows. But the insolvency of Lehman Brothers, or more specifically the willingness of the US government to let Lehman Brothers fail makes the Lehman insolvency the cleanest exogenous shock of the three. Further evidence of this is the record height of the LIBOR-OIS spread on the day after the Lehman insolvency, which indicates that this event was not anticipated by market praticipants in Europe.

Our main results are shown in model (2) and obtained when using 15 September 2008 as shock and when including lender control variables. We find a statistically significant reduction (increase) in the likelihood of terminating an existing (and creating a new) interbank relationship for all four measures of access to liquidity. Banks are very sensitive to a reduction in interbank lending. If interbank borrowing of bank i between the pre-Lehman and the post-Lehman period is reduced by only EUR 1m, the likelihood that an existing interbank lending relationship is terminated is increased by 0.52%. This is stronger than the effect from losing one existing borrowing relationship (i.e. one of bank i's lenders is no longer willing to provide liquidity). The likelihood that an existing interbank lending relationship is terminated when the number of lenders that lend to a bank is reduced by one standard deviation increases by about 2.7%. Similarly, the likelihood that a new interbank lending relationship is created is reduced by 4% when a bank's number of lenders is reduced by one standard deviation. Betweenness and Katz centrality have a positive, albeit smaller impact on the likelihood that an existing interbank lending relationship is terminated or created. A one standard deviation decrease in betweenness centrality (Katz centrality) implies a 2.8% (1.4%) increase in the likelihood that an existing interbank lending relationship is terminated, and a 1.8% (1.3%) decrease in the likelihood that a new interbank lending relationship is created.

Table 19 shows the results of regression (16) for $\text{Amount}_{ij,t}$. Standard errors are clustered at the lending-bank level. There are 3,070 interbank loans to banks that borrow from two or more counterparties in the pre-Lehman and post-Lehman period. Our results indicate a strong interbank lending channel, a EUR 1m reduction in interbank liquidity provided to the lending-bank implies a EUR 2m reduction in the amount lent. Being rationed on the interbank market thus leads to liquidity hoarding, similar to the mechanism described in the model of Heider et al. (2015). If the number of lenders who provide liquidity to a bank is reduced by one, the bank provides EUR 0.2m less liquidity to the euro area overnight interbank market. A one standard deviation reduction in a bank's betweenness centrality implies a EUR 6.8m lower provision of liquidity, a 2.1% reduction. The reduction of interbank liquidity provision is with 2% about the same size if a bank experiences a one standard deviation reduction in Katz centrality.

We study the impact of a bank's position in the interbank network on the price of liquidity in Table 20. The price of a loan is bilaterally negotiated between the borrower and the lender and depends on the borrower's opportunity costs and the lender's refinancing costs. In Panel A we show the volume-weighted spread a bank receives for its interbank liquidity. Banks with better access to the interbank market, i.e. banks with higher network centrality provide liquidity at cheaper prices. Banks that, for example, experience a one standard deviation increase in betweenness centrality provide liquidity on average 2.5bp cheaper. This is a sizeable effect, given that the mean spread in the pre-Lehman period was −3.2bp. In the pre-Lehman period, banks make a mean intermediation spread of about 90bp. Panel B in Table 20 shows that the volume-weighted intermediation spread is increased by about 30bp for banks that experience a one standard deviation increase in betweenness centrality, i.e. a 30% increase.

These effects are sizeable and show that a lending-bank's position in the interbank market implies a sizeable interbank lending channel, in particular for the price of liquidity. Our findings thus have direct consequences not only for financial stability, but also for the implementation of monetary policy.

6 Conclusion

A large number of papers study the interbank network structure to quantify the risk of contagion in interbank markets. Our paper is complementary to this literature, since we study the relation between the interbank network structure and banks' liquidity access and provision. The main result of our paper is that a bank's position in the interbank network, measured by various measures of centrality in networks, has a significant impact on both the access to liquidity and the provision thereof. Banks with higher network centrality obtain more liquidity and at cheaper prices. We find a similar but stronger effect for the provision of liquidity.

We study the overnight segment of the euro area interbank market rather than the term segment because our identification is cleaner for the overnight segment. However, our original data includes the term segment of the interbank market with maturities of up to one year. The dynamics in the term segment in the aftermath of the Lehman insolvency can help to understand the dynamics in the overnight segment. A substantial reduction in the maturity of interbank loans is reflected in a large drop in turnover in the term segment, accompanied by the documented increase in turnover in the overnight segment. It is likely that a similar effect can explain the dynamics of the fed funds market in September 2008. This provides the background for the somewhat surprising finding that the overnight interbank market did not freeze, despite the widely reported turmoil in interbank markets.

Our paper does not study whether the dynamics in the overnight interbank market is driven by counterparty risk concerns or liquidity hoarding. When analysing both the overnight and the term segment in a similar setup to Afonso et al. (2011), however, we find robust indication that banks had concerns about counterparty risk, even in the overnight segment. As a consequence, they start hoarding liquidity by shortening the maturity of their interbank lending. The essence of this mechanism is well captured by the model of Heider et al. (2015). A fruitful avenue for future research is to explore the interplay between the term and the overnight interbank market in more detail.

Our analysis provides cautionary evidence for central bank intervention. Following the switch from the variable-rate auction-based tender system to a full-allotment regime of monetary policy, the structure of the interbank network has changed such that the recently studied models of efficiency in networks indicate a lower efficiency. Substituting a large part of the interbank market, as the Eurosystem has as a reaction to the Lehman insolvency, has alleviated immediate liquidity shortages, the impact on market discipline and efficiency is unclear, but likely to be negative. This aspect of the Eurosystem's crisis measures has not been studied before but warrants attention, as the shift to a full-allotment regime of monetary policy is still in place and discussions about a "graceful exit" are ongoing.

A Appendix

A.1 Figures

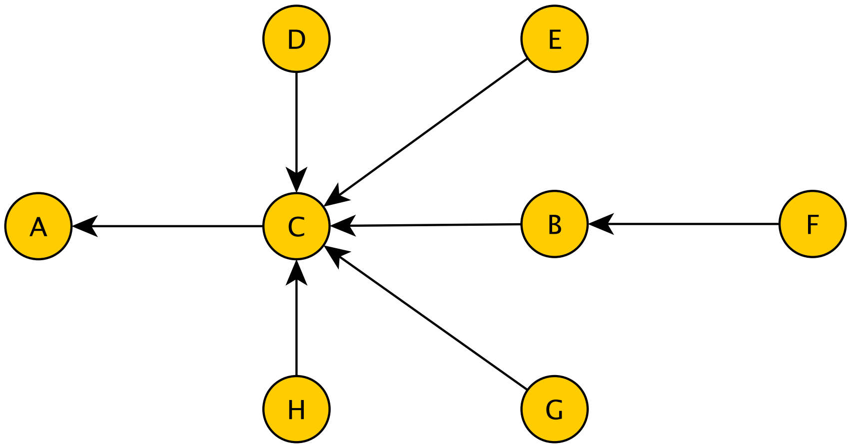


Figure 1: A highly stylized interbank network. Each circle represents a bank and each arrow a loan from one bank to another. All information is embedded in the structure of the network formed by the collection of banks and loans. The size of the circles and their (x, y) position carry no additionl information.

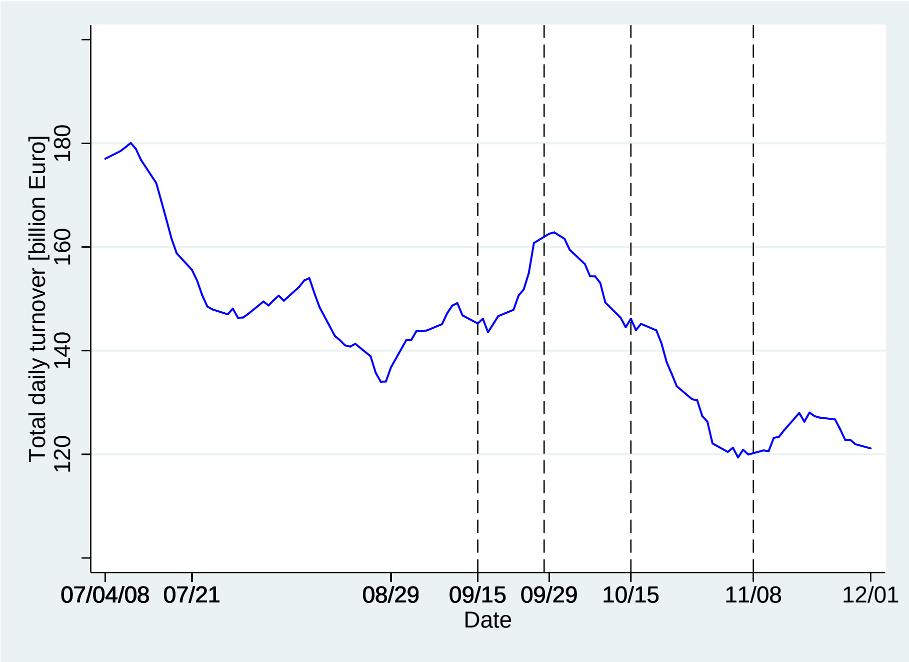


Figure 2: Daily turnover $\text{Amount}_{i,t}$ in the euroarea overnight interbank market during our sample period in billion Euros. Dashed vertical lines indicate key dates: 15 September - Lehman Brothers files for bankruptcy; 29 September - ECB conducts Special Refinancing Operation (SRO); 15 October - ECB moves from auction-based tender system to full-allotment regime; 08 November - Special Refinancing Operation matures. Our initial reference period is from 04 July until 21 July 2008.

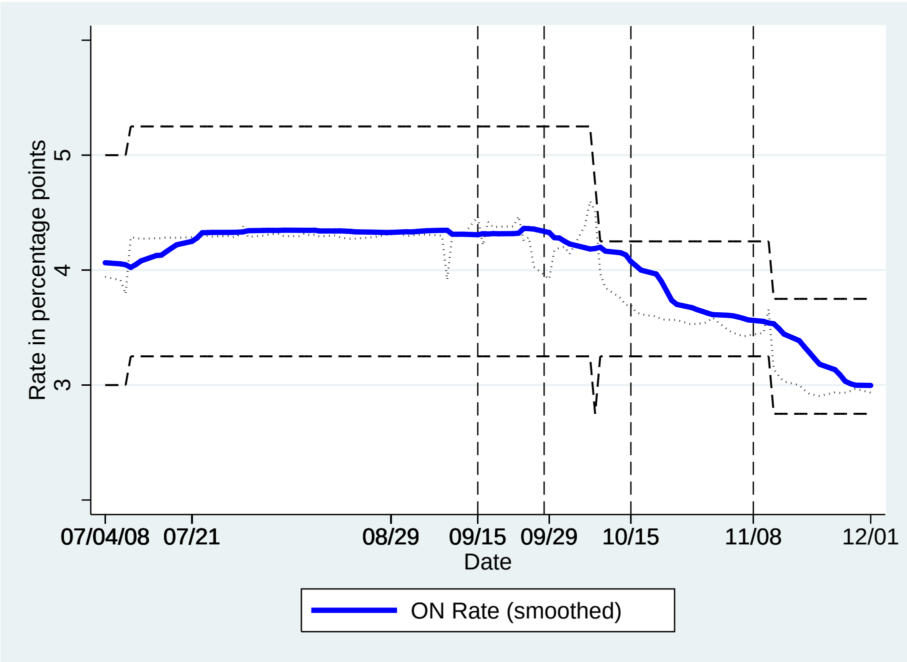


Figure 3: Daily price $\hat{p}_t$ of liquidity (dotted line) and price of liquidity smoothed with a 30 day moving average (blue line) in the euroarea overnight interbank market in our sample period in percentage points. Dashed horizontal curves are the ECB deposit facility (lower dashed curve) and marginal lending facility (upper dashed curve) rate. Dashed vertical lines indicate key dates: 15 September - Lehman Brothers files for bankruptcy; 29 September - ECB conducts Special Refinancing Operation (SRO); 15 October - ECB moves from auction-based tender system to full-allotment regime; 08 November - Special Refinancing Operation matures. Our initial reference period is from 04 July until 21 July 2008.

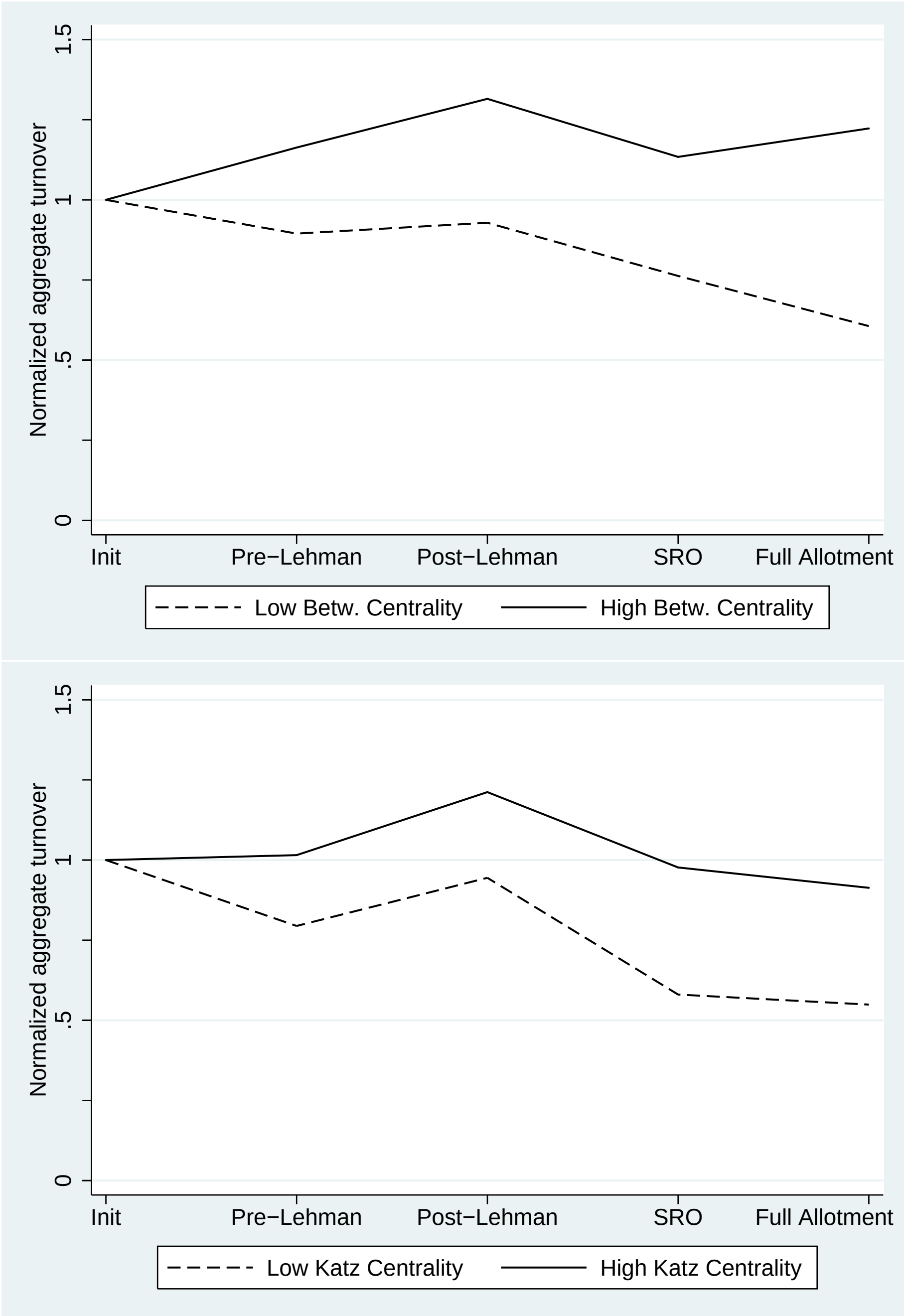


Figure 4: Normalized borrowing Amount$_{i,\tau}$ in the euroarea overnight interbank market during our sample period in billion Euros, aggregated for five periods. Init (04 July - 21 July); Pre-Lehman (01 September - 12 September) ; Post-Lehman (15 September - 29 September); SRO (30 September - 14 October); Full Allotment (15 October - 29 October). Turnover is computed separaetely for banks with high centrality, i.e. in the upper tercile in the Init period (solid black line) and low centrality, i.e. in the lower tercile in the Init period (dashed black line). Top figure shows Betweenness$_{i,\tau}$ centrality, bottom figure shows Katz$_{i,\tau}$ centrality. Normalization is done separately for both groups by dividing turnover in period τ by turnover in the Init period.

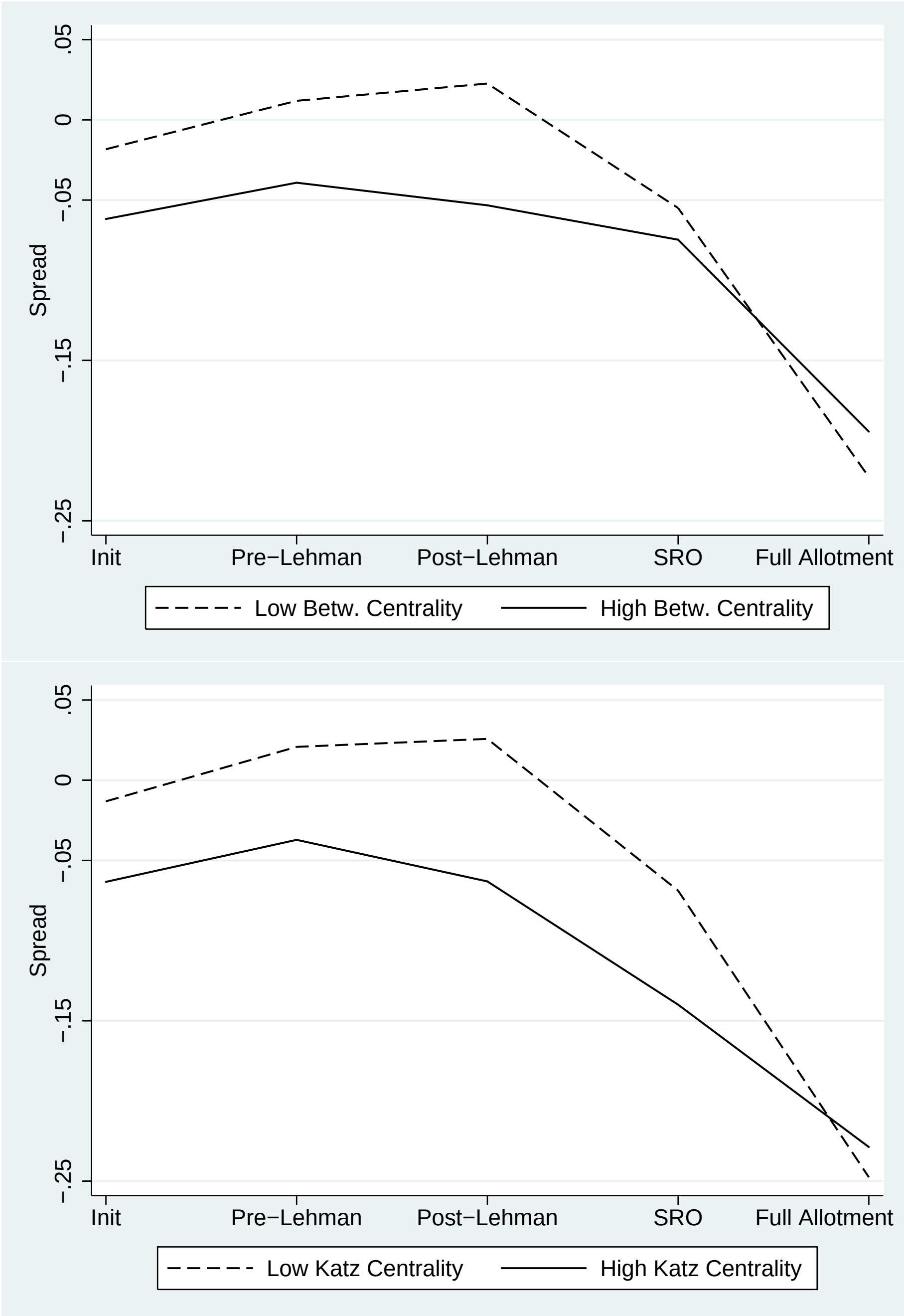


Figure 5: Volume-weighted $\text{Spread}_{i,\tau}$ banks pay for borrowing liquidity in the euroarea overnight interbank market during our sample period in percentage points, averaged over five periods. Init (04 July - 21 July); Pre-Lehman (01 September - 12 September) ; Post-Lehman (15 September - 29 September); SRO (30 September - 14 October); Full Allotment (15 October - 29 October). Turnover is computed separaetely for banks with high centrality, i.e. in the upper tercile in the Init period (solid black line) and low centrality, i.e. in the lower tercile in the Init period (dashed black line). Top figure shows $\text{Betweenness}_{i,\tau}$ centrality, bottom figure shows $\text{Katz}_{i,\tau}$ centrality.

A.2 Tables

Table 1: Summary Statistics for Borrowers in Daily Networks G_t.

	Amount Borrowed [mEUR]			#Lender			Spread		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Init	648.343	160.0	1143.485	6.806	3.0	8.376	-0.032	-0.014	0.155
Pre-Lehman	590.146	130.0	1104.222	6.335	3.0	7.589	-0.015	0.02	0.184
Post-Lehman	671.273	150.0	1178.385	7.113	3.0	8.781	-0.064	0.0	0.267
SRO	570.355	165.0	1092.479	6.174	3.0	7.615	-0.076	-0.109	0.404
Full Allotment	505.625	150.0	944.405	5.087	3.0	5.767	-0.246	-0.309	0.247

Note: Summary statistics for the daily networks during the sample periods. We take a borrower perspective, so that Amount is the total interbank borrowing; #Lender is the number of lenders a bank borrows from; and Spread is the difference of the volume-weighted price of liquidity to the main refinancing rate. Averages are computed over all days $t \in \tau$ and over all banks in the network. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

Table 2: Summary Network Statistics for Aggregate Networks G_τ.

	Init	Pre-Lehman	Post-Lehman	SRO	Full Allotment
Volume [mEUR]	408,204.04	371,208.01	402,656.92	329,777.31	260,312.01
# Loans [#]	4185.0	3936.0	4221.0	3562.0	2798.0
# Borrowers [#]	331.0	318.0	302.0	298.0	278.0
# Lenders [#]	670.0	667.0	670.0	635.0	578.0
Density [#]	0.0078	0.0074	0.0077	0.0073	0.0066
Avg. Shortest Path Length [#]	2.9	2.97	2.91	3.0	3.11
Diameter [#]	8.0	9.0	7.0	7.0	7.0
Largest Component Size [#]	734.0	716.0	730.0	689.0	638.0

Note: Summary statistics for network variables in the different sample periods. We aggregate daily interbank networks for all days in a period to obtain the aggregate interbank network G_τ. Volume is the total amount of interbank turnover. The number of loans per period is given by $\#Loans$, the number of borrowers by $\#Borrowers$, and the number of lenders by $\#Lenders$. The density is the number of links divided by the possible number of links. The average shortest path length is average length of all shortest paths between any two nodes in the network. The Diameter is the length of the shortest path in the network and the largest component size is the number of nodes in the largest connected component of the network. The unit for each variable is given in square brackets after the variable. A # indicates that a variable is a number and has no unit. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 3: Summary statistics for dependent variables in the aggregate networks G_τ.

	Total Lending [mEUR]			Avg. Spread [%]			Avg. Int. Spread [%]			N
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	
Init	325.051	99.200	837.594	-0.060	-0.025	0.141	0.793	0.372	1.587	4779
Pre-Lehman	315.657	90.000	1015.544	-0.032	0.02	0.214	0.891	0.573	2.709	4481
Post-Lehman	314.722	90.000	886.796	-0.060	0.000	0.257	0.818	0.441	1.707	4846
SRO	320.547	70.000	1115.231	-0.168	-0.200	0.379	0.773	0.344	1.595	4016
Full Allotment	396.304	80.000	1379.824	-0.350	-0.408	0.268	0.649	0.212	1.306	3160

Note: Total lending is the total value of overnight interbank loans outstanding on a given day in a sub-sample. The average spread is the difference of the rate of an overnight interbank loan outstanding in a sub-sample to the main refinancing rate. The average intermediation spread is the volume-difference between the average volume-weighted price a bank charges for an overnight interbank loan minus the average volume-weighted price it pays for an overnight interbank loan in a sub-sample. Units are given in square brackets next to the variable. % indicates that the value is in percentage points. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 4: Summary statistics with percentiles for independent variables.

	In-Degree [#]					Out-Degree [#]					
	Mean	25%	50%	75%	SD	Mean	25%	50%	75%	SD	N
Init	22.837	0.000	3.000	21.000	40.659	17.606	7.000	14.000	25.000	14.031	4779
Pre-Lehman	20.236	0.000	3.000	23.000	35.200	16.241	6.000	14.000	23.000	12.329	4481
Post-Lehman	20.195	0.000	3.000	27.000	35.077	17.110	7.000	14.000	24.000	12.597	4846
SRO	13.643	0.000	1.000	15.000	26.568	13.162	6.000	11.000	18.000	9.061	4016
Full Allotment	10.933	0.000	1.000	12.000	20.019	11.600	4.000	10.000	17.000	8.463	3160

	In-Volume [kEUR]					Out-Volume [kEUR]					
	Mean	25%	50%	75%	SD	Mean	25%	50%	75%	SD	N
Init	2654.065	0.000	54.500	2023.800	5497.146	2460.717	166.900	836.100	2740.000	3749.334	4779
Pre-Lehman	2269.227	0.000	56.500	1603.150	4418.506	2163.824	144.000	800.500	2553.000	3191.358	4481
Post-Lehman	2300.567	0.000	29.000	1704.150	4533.040	2260.481	179.100	793.000	3482.500	3153.263	4846
SRO	1400.958	0.000	20.000	671.590	3504.695	1546.409	126.825	539.000	2140.000	2303.424	4016
Full Allotment	1168.517	0.000	4.000	563.900	2732.696	1243.422	111.500	388.000	1754.200	1776.251	3160

Note: In-Degree is the average (unweighted) number of lenders a bank borrows from in a sub-sample. Out-Degree is the average (unweighted) number of borrowers a bank lends to in a sub-sample. In-Volume is the average amount of overnight interbank loans a bank receives in a sub-sample. Out-Volume is the average amount of overnight interbank loans a bank provides in a sub-sample. Units are given in square brackets next to the variable name. # indicates that the unit is a dimensionless number. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 5: Summary statistics for independent variables.

	Betweenness Centrality [#]					Katz Centrality [#]					
	Mean	25%	50%	75%	SD	Mean	25%	50%	75%	SD	N
Init	0.006	0.000	0.000	0.006	0.012	0.048	0.001	0.011	0.061	0.078	4779
Pre-Lehman	0.006	0.000	0.000	0.005	0.011	0.046	0.001	0.013	0.049	0.075	4481
Post-Lehman	0.005	0.000	0.000	0.005	0.009	0.048	0.002	0.013	0.056	0.072	4846
SRO	0.004	0.000	0.000	0.003	0.008	0.035	0.001	0.008	0.031	0.068	4016
Full Allotment	0.004	0.000	0.000	0.004	0.009	0.036	0.001	0.006	0.041	0.062	3160

Note: The betweenness centrality of a bank is measured as the number of shortest paths of liquidity transfer in a network that pass through this bank. The Katz centrality measures the relative influence of a bank within a network by measuring the number of its immediate neighbors and also the number of neighbors of all other banks in the network that lend to and borrow from the bank through these immediate neighbors. Units are given by square brackets next to the variable name. # indicates that the unit is a dimensionless number. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 6: Amount Borrowed and Lent explained by Degree.

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	4.144	2.281	17.085	82.695*	5.959	4.276	2.423	12.683
	(43.949)	(43.863)	(37.042)	(42.716)	(26.498)	(26.436)	(27.579)	(39.619)
Post-Lehman	47.794	46.028	193.475***	138.676***	37.115	35.685	39.874	-31.274
	(48.461)	(48.557)	(56.851)	(52.917)	(46.934)	(46.671)	(48.324)	(63.391)
SRO	-64.534	-64.118	-65.149	153.333***	-7.391	-8.693	-3.518	24.549
	(65.112)	(65.235)	(65.812)	(53.861)	(34.314)	(34.273)	(34.876)	(36.868)
Full Allotment	-187.973**	-187.423**	-79.924	167.726**	-64.760*	-66.988*	-60.413	68.532
	(73.647)	(73.800)	(62.765)	(68.119)	(38.551)	(38.597)	(39.142)	(49.357)
Relative Size	268.559***	141.206**	216.371**	-125.722*	7.588**	11.783***	11.726	19.798***
	(95.026)	(58.392)	(100.112)	(70.645)	(3.827)	(3.957)	(8.761)	(6.955)
Loan Loss Reserves	-0.004	-0.005	-0.063***	-0.075***	-0.001	0.000	-0.001	0.000
	(0.004)	(0.004)	(0.021)	(0.024)	(0.001)	(0.000)	(0.001)	(0.001)
Assets	0.000	0.000	0.001***	0.001***	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Degree		9.535***		11.090***		28.198***		29.520***
		(1.732)		(1.676)		(5.159)		(6.371)
(Degree × Date)								
Pre-Lehman				-2.278				-0.930
				(1.399)				(4.767)
Post-Lehman				1.055				5.678
				(1.428)				(8.354)
SRO				-6.855***				-2.173
				(1.852)				(4.888)
Full Allotment				-8.493***				-9.850*
				(2.303)				(5.811)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.021	0.020	0.016	0.043	0.009	0.009	0.014	0.032
R^2 (between)	0.000	0.355	0.159	0.549	0.006	0.092	0.006	0.096
R^2 (overall)	0.019	0.212	0.219	0.363	0.005	0.052	0.006	0.058

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the amount a bank i lends on the interbank market on day t. The explanatory variable is the number of banks bank i borrows from (borrower perspective) and to (lender perspective) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 7: Amount Borrowed and Lent explained by Volume

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	4.144	3.215	17.085	50.328	5.959	5.285	2.423	36.522
	(43.949)	(43.837)	(37.042)	(35.425)	(26.498)	(26.245)	(27.579)	(30.543)
Post-Lehman	47.794	47.216	193.475***	164.558***	37.115	38.606	39.874	61.142
	(48.461)	(48.538)	(56.851)	(51.169)	(46.934)	(46.516)	(48.324)	(44.626)
SRO	-64.534	-62.792	-65.149	112.429**	-7.391	-4.500	-3.518	78.120***
	(65.112)	(65.056)	(65.812)	(48.760)	(34.314)	(34.092)	(34.876)	(25.003)
Full Allotment	-187.973**	-185.630**	-79.924	95.413*	-64.760*	-62.920*	-60.413	66.992***
	(73.647)	(73.663)	(62.765)	(49.950)	(38.551)	(38.020)	(39.142)	(23.869)
Relative Size	268.559***	84.895*	216.371**	-286.201**	7.588**	6.388**	11.726	19.238***
	(95.026)	(47.955)	(100.112)	(140.891)	(3.827)	(3.043)	(8.761)	(6.045)
Loan Loss Reserves	-0.004	-0.004	-0.063***	-0.034	-0.001	0.000	-0.001	0.000
	(0.004)	(0.004)	(0.021)	(0.021)	(0.001)	(0.000)	(0.001)	(0.000)
Assets	0.000	0.000	0.001***	0.001***	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Volume		0.065***		0.070***		0.151***		0.180***
		(0.015)		(0.016)		(0.019)		(0.020)
(Volume × Date)								
Pre-Lehman				-0.009				-0.022
				(0.011)				(0.029)
Post-Lehman				0.009				-0.011
				(0.014)				(0.051)
SRO				-0.045***				-0.047*
				(0.016)				(0.028)
Full Allotment				-0.060***				-0.074***
				(0.016)				(0.024)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.021	0.019	0.016	0.038	0.005	0.005	0.006	0.037
R^2 (between)	0.000	0.418	0.159	0.569	0.003	0.657	0.004	0.660
R^2 (overall)	0.019	0.251	0.219	0.374	0.003	0.405	0.004	0.417

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the amount a bank i lends on the interbank market on day t. The explanatory variable is i's total interbank borrowing volume (borrower perspective) and interbank lending volume (lender perspective) during an initial reference period, i.e. i's in- and out-volume. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 8: Amount Borrowed and Lent explained by Betweenness Centrality

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	4.144	2.979	17.085	41.273	5.959	5.479	2.423	-21.594
	(43.949)	(43.976)	(37.042)	(38.677)	(26.498)	(26.425)	(27.579)	(23.290)
Post-Lehman	47.794	46.590	193.475***	117.080**	37.115	37.154	39.874	-20.196
	(48.461)	(48.506)	(56.851)	(52.655)	(46.934)	(46.821)	(48.324)	(40.513)
SRO	-64.534	-64.337	-65.149	0.776	-7.391	-6.996	-3.518	-34.790
	(65.112)	(65.010)	(65.812)	(60.031)	(34.314)	(34.201)	(34.876)	(33.639)
Full Allotment	-187.973**	-187.861**	-79.924	-4.739	-64.760*	-64.706*	-60.413	-44.951
	(73.647)	(73.710)	(62.765)	(63.004)	(38.551)	(38.482)	(39.142)	(39.351)
Relative Size	268.559***	170.202**	216.371**	-5.951	7.588**	8.078**	11.726	6.321
	(95.026)	(68.952)	(100.112)	(48.032)	(3.827)	(3.726)	(8.761)	(8.943)
Loan Loss Reserves	-0.004	-0.005	-0.063***	-0.089***	-0.001	0.000	-0.001	-0.001
	(0.004)	(0.005)	(0.021)	(0.026)	(0.001)	(0.001)	(0.001)	(0.001)
Assets	0.000	0.000	0.001***	0.001***	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Betweenness		36470.5***		37531.0***		28673.9***		23245.183***
		(7978.657)		(7172.540)		(8396.064)		(7328.308)
(Betweenness × Date)								
Pre-Lehman				-6796.209				6804.311
				(5829.444)				(4715.130)
Post-Lehman				9015.173**				17992.146
				(3642.151)				(10991.2)
SRO				-16056.1***				9455.821**
				(4901.424)				(4687.787)
Full Allotment				-19084.278*				-4439.997
				(10021.6)				(8925.257)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.021	0.020	0.016	0.030	0.005	0.005	0.006	0.022
R^2 (between)	0.000	0.304	0.159	0.520	0.003	0.194	0.004	0.198
R^2 (overall)	0.019	0.193	0.219	0.349	0.003	0.138	0.004	0.147

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the amount a bank i lends on the interbank market on day t. The explanatory variable is the betweenness centrality of bank i (both perspectives) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 9: Amount Borrowed and Lent explained by Katz-Centrality

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	4.144	2.034	17.085	18.149	5.959	5.819	2.423	38.930
	(43.949)	(43.961)	(37.042)	(39.016)	(26.498)	(26.352)	(27.579)	(26.330)
Post-Lehman	47.794	46.529	193.475***	33.359	37.115	38.039	39.874	69.211*
	(48.461)	(48.206)	(56.851)	(49.746)	(46.934)	(46.617)	(48.324)	(38.619)
SRO	-64.534	-66.592	-65.149	-92.448	-7.391	-5.526	-3.518	74.618***
	(65.112)	(64.366)	(65.812)	(67.657)	(34.314)	(34.151)	(34.876)	(23.151)
Full Allotment	-187.973**	-188.813***	-79.924	-117.406*	-64.760*	-63.485*	-60.413	56.460**
	(73.647)	(73.042)	(62.765)	(63.204)	(38.551)	(38.154)	(39.142)	(23.226)
Relative Size	268.559***	239.944***	216.371**	218.136**	7.588**	6.759**	11.726	21.449***
	(95.026)	(84.999)	(100.112)	(90.727)	(3.827)	(3.386)	(8.761)	(6.625)
Loan Loss Reserves	-0.004	-0.004	-0.063***	-0.054***	-0.001	0.000	-0.001	0.000
	(0.004)	(0.003)	(0.021)	(0.020)	(0.001)	(0.000)	(0.001)	(0.000)
Assets	0.000	0.000	0.001***	0.001***	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Katz		5218.313***		2651.334***		6789.673***		8255.118***
		(1151.290)		(813.595)		(870.122)		(1091.424)
(Katz × Date)								
Pre-Lehman				-165.116				-1147.377
				(761.622)				(1260.523)
Post-Lehman				3774.526***				-825.757
				(1125.350)				(2232.239)
SRO				1149.217				-2329.405*
				(1316.249)				(1259.648)
Full Allotment				1396.224				-3480.702***
				(1233.937)				(1156.095)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.021	0.021	0.016	0.033	0.005	0.005	0.006	0.034
R^2 (between)	0.000	0.272	0.159	0.416	0.003	0.594	0.004	0.601
R^2 (overall)	0.019	0.165	0.219	0.270	0.003	0.362	0.004	0.373

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the amount a bank i lends on the interbank market on day t. The explanatory variable is the Katz centrality of bank i (both perspectives) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 10: Borrowing and Lending Spread explained by In-Degree.

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	0.025***	0.026***	0.024***	0.024***	0.023***	0.023***	0.024***	0.022***
	(0.005)	(0.005)	(0.006)	(0.008)	(0.005)	(0.005)	(0.006)	(0.008)
Post-Lehman	0.010	0.011	0.015	0.033**	-0.005	-0.006	-0.003	-0.034**
	(0.011)	(0.011)	(0.013)	(0.015)	(0.009)	(0.009)	(0.009)	(0.014)
SRO	-0.041	-0.041	-0.013	-0.001	-0.062***	-0.063***	-0.058	-0.110***
	(0.026)	(0.026)	(0.031)	(0.036)	(0.018)	(0.018)	(0.019)	(0.027)
Full Allotment	-0.246***	-0.246***	-0.229	-0.197***	-0.259***	-0.259***	-0.249	-0.320***
	(0.029)	(0.029)	(0.036)	(0.043)	(0.019)	(0.019)	(0.020)	(0.029)
Relative Size	0.007	0.011**	0.011*	0.002	-0.009*	-0.008	0.010*	0.008
	(0.006)	(0.006)	(0.006)	(0.013)	(0.005)	(0.005)	(0.006)	(0.006)
Loan Loss Reserves	0.000*	0.000***	0.000	0.000	0.000	0.000***	0.000***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000	0.000	0.000	0.000***	0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Degree		-0.001***		0.000		0.003***		0.001***
		(0.000)		(0.000)		(0.001)		(0.000)
(Degree × Date)								
Pre-Lehman				0.000				0.000
				(0.000)				(0.000)
Post-Lehman				-0.001***				0.002***
				(0.000)				(0.001)
SRO				0.000				0.004**
				(0.001)				(0.002)
Full Allotment				-0.001				0.005***
				(0.001)				(0.001)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.160	0.160	0.166	0.170	0.140	0.140	0.144	0.152
R^2 (between)	0.172	0.187	0.181	0.192	0.165	0.185	0.164	0.155
R^2 (overall)	0.131	0.142	0.140	0.152	0.121	0.138	0.123	0.146

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Spread}_{i,t}$, i.e. the volume-weighted spread a bank i pays for liquidity on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the volume-weighted spread a bank i charges for liquidity on the interbank market on day t. The explanatory variable is the number of banks bank i borrows from (borrower perspective) and to (lender perspective) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 11: Borrowing and Lending Spread explained by Volume

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	0.025***	0.025***	0.024***	0.026***	0.023***	0.023***	0.024***	0.023***
	(0.005)	(0.005)	(0.006)	(0.007)	(0.005)	(0.005)	(0.006)	(0.006)
Post-Lehman	0.010	0.011	0.015	0.027*	-0.005	-0.005	-0.003	-0.010
	(0.011)	(0.011)	(0.013)	(0.014)	(0.009)	(0.009)	(0.009)	(0.011)
SRO	-0.041	-0.041	-0.013	-0.012	-0.062***	-0.063***	-0.058	-0.081***
	(0.026)	(0.026)	(0.031)	(0.033)	(0.018)	(0.018)	(0.019)	(0.021)
Full Allotment	-0.246***	-0.246***	-0.229	-0.214***	-0.259***	-0.259***	-0.249	-0.274***
	(0.029)	(0.029)	(0.036)	(0.038)	(0.019)	(0.019)	(0.020)	(0.023)
Relative Size	0.007	0.011*	0.011*	0.002	-0.009*	-0.008	0.010*	0.009
	(0.006)	(0.006)	(0.006)	(0.014)	(0.005)	(0.005)	(0.006)	(0.006)
Loan Loss Reserves	0.000*	0.000***	0.000	0.000	0.000	0.000***	0.000***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000	0.000	0.000	0.000***	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Volume		-4.2e-06**		0.000		9.1e-06***		3.4-e06***
		(0.000)		(0.000)		(0.000)		(0.000)
(Volume × Date)								
Pre-Lehman				0.000				0.000
				(0.000)				(0.000)
Post-Lehman				-3.7e-06**				0.000
				(0.000)				(0.000)
SRO				0.000				1.3e-05***
				(0.000)				(0.000)
Full Allotment				0.000				1.4e-05**
				(0.000)				(0.000)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.160	0.160	0.166	0.168	0.140	0.140	0.144	0.150
R^2 (between)	0.172	0.184	0.181	0.190	0.165	0.175	0.164	0.158
R^2 (overall)	0.131	0.140	0.140	0.148	0.121	0.129	0.123	0.135

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Spread}_{i,t}$, i.e. the volume-weighted spread a bank i pays for liquidity on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the volume-weighted spread a bank i charges for liquidity on the interbank market on day t. The explanatory variable is i's total interbank borrowing volume (borrower perspective) and interbank lending volume (lender perspective) during an initial reference period, i.e. i's in- and out-volume. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 12: Borrowing and Lending Spread explained by Betweenness Centrality

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	0.025***	0.025***	0.024***	0.024***	0.023***	0.023***	0.024***	0.024***
	(0.005)	(0.005)	(0.006)	(0.007)	(0.005)	(0.005)	(0.006)	(0.006)
Post-Lehman	0.010	0.011	0.015	0.024*	-0.005	-0.005	-0.003	-0.014
	(0.011)	(0.011)	(0.013)	(0.014)	(0.009)	(0.009)	(0.009)	(0.010)
SRO	-0.041	-0.041	-0.013	-0.023	-0.062***	-0.062***	-0.058	-0.084***
	(0.026)	(0.026)	(0.031)	(0.034)	(0.018)	(0.018)	(0.019)	(0.020)
Full Allotment	-0.246***	-0.246***	-0.229	-0.232***	-0.259***	-0.259***	-0.249	-0.270***
	(0.029)	(0.029)	(0.036)	(0.038)	(0.019)	(0.019)	(0.020)	(0.022)
Relative Size	0.007	0.009	0.011*	0.017	-0.009*	-0.009*	0.010*	0.009
	(0.006)	(0.006)	(0.006)	(0.010)	(0.005)	(0.005)	(0.006)	(0.006)
Loan Loss Reserves	0.000*	0.000**	0.000	0.000	0.000	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000	0.000	0.000	0.000***	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Betweenness		-1.870		-1.848***		4.082***		1.494***
		(1.174)		(0.713)		(0.783)		(0.448)
(Betweenness × Date)								
Pre-Lehman				0.009				-0.016
				(0.349)				(0.545)
Post-Lehman				-1.672*				3.024***
				(0.924)				(0.766)
SRO				1.978				7.831***
				(2.409)				(2.142)
Full Allotment				0.611				5.914***
				(3.196)				(1.686)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.160	0.160	0.166	0.168	0.140	0.140	0.144	0.152
R^2 (between)	0.172	0.178	0.181	0.190	0.165	0.181	0.164	0.169
R^2 (overall)	0.131	0.134	0.140	0.145	0.121	0.133	0.123	0.142

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Spread}_{i,t}$, i.e. the volume-weighted spread a bank i pays for liquidity on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the volume-weighted spread a bank i charges for liquidity on the interbank market on day t. The explanatory variable is the betweenness centrality of bank i (both perspectives) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 13: Borrowing and Lending Spread explained by Katz-Centrality

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	0.025***	0.026***	0.024***	0.025***	0.023***	0.023***	0.024***	0.024***
	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)
Post-Lehman	0.010	0.011	0.015	0.021	-0.005	-0.005	-0.003	-0.008
	(0.011)	(0.011)	(0.013)	(0.013)	(0.009)	(0.009)	(0.009)	(0.011)
SRO	-0.041	-0.040	-0.013	-0.005	-0.062***	-0.063***	-0.058	-0.076***
	(0.026)	(0.026)	(0.031)	(0.033)	(0.018)	(0.018)	(0.019)	(0.020)
Full Allotment	-0.246***	-0.246***	-0.229	-0.224***	-0.259***	-0.259***	-0.249	-0.270***
	(0.029)	(0.029)	(0.036)	(0.038)	(0.019)	(0.019)	(0.020)	(0.022)
Relative Size	0.007	0.007	0.011*	0.009	-0.009*	-0.009	0.010*	0.009
	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)
Loan Loss Reserves	0.000*	0.000***	0.000	0.000	0.000	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000	0.000	0.000	0.000***	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Katz		-0.560***		-0.376**		0.352***		0.125*
		(0.161)		(0.149)		(0.116)		(0.066)
(Katz × Date)								
Pre-Lehman				-0.050				-0.010
				(0.081)				(0.053)
Post-Lehman				-0.176				0.129
				(0.109)				(0.105)
SRO				-0.336				0.551**
				(0.306)				(0.235)
Full Allotment				-0.218				0.603**
				(0.300)				(0.257)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.160	0.160	0.166	0.167	0.140	0.140	0.144	0.149
R^2 (between)	0.172	0.200	0.181	0.201	0.165	0.168	0.164	0.150
R^2 (overall)	0.131	0.144	0.140	0.149	0.121	0.127	0.123	0.132

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\text{Spread}_{i,t}$, i.e. the volume-weighted spread a bank i pays for liquidity on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is the volume-weighted spread a bank i charges for liquidity on the interbank market on day t. The explanatory variable is the Katz centrality of bank i (both perspectives) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 14: Number of Loans Obtained and Provided explained by Degree.

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	-0.335	-0.339	-0.350	-0.192	-0.178	-0.182	-0.211	0.203
	(0.261)	(0.259)	(0.257)	(0.248)	(0.126)	(0.127)	(0.131)	(0.165)
Post-Lehman	0.328	0.323	0.302	0.337	0.184	0.181	0.224	0.529^{**}
	(0.268)	(0.267)	(0.310)	(0.317)	(0.147)	(0.147)	(0.153)	(0.210)
SRO	-0.056	-0.061	-0.242	0.718^{*}	0.077	0.074	0.117	0.622^{***}
	(0.453)	(0.452)	(0.444)	(0.414)	(0.130)	(0.130)	(0.133)	(0.174)
Full Allotment	-0.736^{*}	-0.737^{*}	-0.739	0.654	-0.208	-0.214	-0.177	0.520^{**}
	(0.440)	(0.440)	(0.513)	(0.438)	(0.166)	(0.167)	(0.172)	(0.247)
Relative Size	1.070^{***}	0.636^{**}	0.909^{***}	-0.131	0.142^{**}	0.151^{**}	0.187^{***}	0.266^{***}
	(0.342)	(0.274)	(0.341)	(0.291)	(0.071)	(0.070)	(0.063)	(0.072)
Loan Loss Reserves	0.000	0.000	0.000^{*}	0.000^{*}	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000^{*}	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Degree		0.062^{***}		0.079^{***}		0.126^{***}		0.153^{***}
		(0.014)		(0.015)		(0.031)		(0.038)
(Degree × Date)								
Pre-Lehman				-0.006				-0.033^{*}
				(0.008)				(0.020)
Post-Lehman				-0.006				-0.024
				(0.009)				(0.021)
SRO				-0.031^{***}				-0.039^{**}
				(0.009)				(0.016)
Full Allotment				-0.047^{***}				-0.053^{**}
				(0.009)				(0.023)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.015	0.015	0.041	0.082	0.009	0.009	0.014	0.027
R^2 (between)	0.003	0.397	0.002	0.317	0.006	0.308	0.006	0.307
R^2 (overall)	0.001	0.221	0.001	0.197	0.005	0.225	0.006	0.227

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\#\text{Loans}_{i,t}$, i.e. the number of interbank loans a bank i obtains on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is number of loans a bank i provides on the interbank market on day t. The explanatory variable is the number of banks bank i borrows from (borrower perspective) and to (lender perspective) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 15: Number of Loans Obtained and Provided explained by Volume

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	-0.335	-0.338	-0.350	-0.310	-0.178	-0.180	-0.211	-0.056
	(0.261)	(0.260)	(0.257)	(0.244)	(0.126)	(0.126)	(0.131)	(0.122)
Post-Lehman	0.328	0.325	0.302	0.430	0.184	0.183	0.224	0.359**
	(0.268)	(0.268)	(0.310)	(0.297)	(0.147)	(0.146)	(0.153)	(0.157)
SRO	-0.056	-0.061	-0.242	0.285	0.077	0.076	0.117	0.476***
	(0.453)	(0.453)	(0.444)	(0.418)	(0.130)	(0.130)	(0.133)	(0.125)
Full Allotment	-0.736*	-0.739*	-0.739	0.016	-0.208	-0.210	-0.177	0.172
	(0.440)	(0.441)	(0.513)	(0.482)	(0.166)	(0.166)	(0.172)	(0.166)
Relative Size	1.070***	0.855***	0.909***	-0.130	0.142**	0.145**	0.187***	0.232***
	(0.342)	(0.305)	(0.341)	(0.306)	(0.071)	(0.071)	(0.063)	(0.067)
Loan Loss Reserves	0.000	0.000	0.000*	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000*	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Volume		0.0003***		0.0004***		0.0003***		0.0004***
		(0.000)		(0.000)		(0.000)		(0.000)
(Volume × Date)								
Pre-Lehman				0.000				0.000
				(0.000)				(0.000)
Post-Lehman				-8.5e-5*				0.000
				(0.000)				(0.000)
SRO				-0.0002***				-0.0002***
				(0.000)				(0.000)
Full Allotment				-0.0003***				-0.0002***
				(0.000)				(0.000)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.015	0.015	0.041	0.074	0.009	0.009	0.014	0.033
R^2 (between)	0.003	0.165	0.002	0.091	0.006	0.109	0.006	0.112
R^2 (overall)	0.001	0.074	0.001	0.046	0.005	0.059	0.006	0.065

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\#\text{Loans}_{i,t}$, i.e. the number of interbank loans a bank i obtains on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is number of loans a bank i provides on the interbank market on day t. The explanatory variable is i's total interbank borrowing volume (borrower perspective) and interbank lending volume (lender perspective) during an initial reference period, i.e. i's in- and out-volume. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 16: Number of Loans Provided and Obtained explained by Betweenness Centrality

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	-0.335	-0.336	-0.350	-0.313	-0.178	-0.179	-0.211	-0.152
	(0.261)	(0.260)	(0.257)	(0.260)	(0.126)	(0.127)	(0.131)	(0.113)
Post-Lehman	0.328	0.327	0.302	0.165	0.184	0.184	0.224	0.249
	(0.268)	(0.267)	(0.310)	(0.287)	(0.147)	(0.147)	(0.153)	(0.153)
SRO	-0.056	-0.059	-0.242	0.042	0.077	0.078	0.117	0.161
	(0.453)	(0.452)	(0.444)	(0.434)	(0.130)	(0.130)	(0.133)	(0.141)
Full Allotment	-0.736*	-0.737*	-0.739	-0.350	-0.208	-0.209	-0.177	-0.124
	(0.440)	(0.439)	(0.513)	(0.456)	(0.166)	(0.166)	(0.172)	(0.174)
Relative Size	1.070***	0.676**	0.909***	0.304	0.142**	0.143**	0.187***	0.196***
	(0.342)	(0.287)	(0.341)	(0.285)	(0.071)	(0.071)	(0.063)	(0.064)
Loan Loss Reserves	0.000	0.000	0.000*	-0.001*	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000*	0.000*	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Betweenness		253.659***		297.845***		107.905**		117.742**
		(64.621)		(68.367)		(45.073)		(52.447)
(Betweenness × Date)								
Pre-Lehman				-10.101				-16.942
				(31.786)				(23.370)
Post-Lehman				2.065				-6.920
				(27.173)				(25.479)
SRO				-65.490*				-12.498
				(38.226)				(17.218)
Full Allotment				-99.634**				-15.236
				(41.214)				(28.587)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.015	0.015	0.041	0.057	0.009	0.009	0.014	0.015
R^2 (between)	0.003	0.389	0.002	0.323	0.006	0.109	0.006	0.108
R^2 (overall)	0.001	0.229	0.001	0.215	0.005	0.089	0.006	0.090

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\#\text{Loans}_{i,t}$, i.e. the number of interbank loans a bank i obtains on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is number of loans a bank i provides on the interbank market on day t. The explanatory variable is the betweenness centrality of bank i (both perspectives) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 17: Number of Loans Obtained and Provided explained by Katz-Centrality

	Borrower				Lender			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	-0.335	-0.339	-0.350	-0.199	-0.178	-0.179	-0.211	-0.068
	(0.261)	(0.261)	(0.257)	(0.274)	(0.126)	(0.126)	(0.131)	(0.119)
Post-Lehman	0.328	0.325	0.302	0.237	0.184	0.183	0.224	0.349**
	(0.268)	(0.268)	(0.310)	(0.301)	(0.147)	(0.146)	(0.153)	(0.151)
SRO	-0.056	-0.062	-0.242	-0.059	0.077	0.076	0.117	0.450***
	(0.453)	(0.452)	(0.444)	(0.439)	(0.130)	(0.130)	(0.133)	(0.123)
Full Allotment	-0.736*	-0.741*	-0.739	-0.686	-0.208	-0.210	-0.177	0.145
	(0.440)	(0.440)	(0.513)	(0.509)	(0.166)	(0.166)	(0.172)	(0.163)
Relative Size	1.070***	1.063***	0.909***	0.850***	0.142**	0.145**	0.187***	0.231***
	(0.342)	(0.333)	(0.341)	(0.330)	(0.071)	(0.071)	(0.063)	(0.066)
Loan Loss Reserves	0.000	0.000	0.000*	0.000*	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Assets	0.000	0.000	0.000*	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Katz		15.970***		16.394**		13.294***		18.502***
		(4.848)		(7.580)		(3.531)		(3.654)
(Katz × Date)								
Pre-Lehman				-7.322				-4.419
				(5.495)				(2.776)
Post-Lehman				-0.103				-3.648
				(5.216)				(4.691)
SRO				-7.751				-10.108***
				(7.388)				(2.316)
Full Allotment				-3.037				-9.619***
				(7.168)				(2.909)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	7750	7750	7750	7750
R^2 (within)	0.015	0.015	0.041	0.045	0.009	0.009	0.014	0.032
R^2 (between)	0.003	0.048	0.002	0.013	0.006	0.092	0.006	0.096
R^2 (overall)	0.001	0.016	0.001	0.003	0.005	0.052	0.006	0.058

Note: Models (1) - (4) show the borrower perspective. The dependent variable is $\#\text{Loans}_{i,t}$, i.e. the number of interbank loans a bank i obtains on the interbank market on day t. Models (5) - (8) show the lender perspective where the dependent variable is number of loans a bank i provides on the interbank market on day t. The explanatory variable is the Katz centrality of bank i (both perspectives) during an initial reference period, i.e. i's in- and out-degree. We use the following bank-specific controls, all reported at the end of 2007. The relative size is the amount of interbank lending during the initial reference period divided by the total asset size. The Loan Loss Reserves are a proxy for the bank's riskiness and Assets is the total asset size. Date indicates a period dummy that is one in the respective period, and zero otherwise. The dates for the periods are as follows. Init: 04 July - 21 July; Pre-Lehman: 28 August - 12 September; Post-Lehman: 15 September - 29 September; SRO: 30 September - 14 October; Full Allotment: 15 October - 30 October.

Table 18: The Interbank Lending Channel - Extensive Margin

PANEL A - ENTRY

	Post - Pre		SRO - Post	Full - Post
	(1)	(2)	(3)	(4)
Borrowing	-0.438	-0.522	-0.423	-0.365
	(0.032)	(0.078)	(0.022)	(0.022)
	-13.680	-6.710	-18.910	-16.460
#Lender	-0.108	-0.113	-0.042	-0.027
	(0.019)	(0.030)	(0.004)	(0.002)
	-5.730	-3.710	-10.570	-11.130
Betweenness	-145.117	-165.747	-153.668	-179.978
	(17.102)	(32.173)	(17.891)	(23.743)
	-8.490	-5.150	-8.590	-7.580
Katz	-16.814	-16.777	-14.880	-15.069
	(2.637)	(4.637)	(3.716)	(2.890)
	-6.380	-3.620	-4.000	-5.210
Controls	No	Yes	No	No
N	5977	2697	5977	5568

PANEL B - EXIT

	Post - Pre		SRO - Post	Full - Post
	(1)	(2)	(3)	(4)
Borrowing	0.506	0.516	0.454	0.498
	(0.034)	(0.049)	(0.027)	(0.039)
	14.750	10.520	16.920	12.730
#Lender	0.078	0.075	0.108	0.191
	(0.008)	(0.011)	(0.016)	(0.029)
	9.540	6.700	6.980	6.520
Betweenness	265.441	250.723	197.339	171.289
	(62.441)	(87.024)	(24.022)	(17.633)
	4.250	2.880	8.210	9.710
Katz	16.274	19.294	14.287	18.056
	(1.608)	(3.552)	(3.150)	(2.505)
	10.120	5.430	4.540	7.210
Controls	No	Yes	No	No
N	6133	2772	5898	5437

Note: The dependent variable in Panel A is Exit_{ij}, which equals one if a loan existed in the pre-sample, but is not renewed in the post-sample. The dependent variable in Panel B is Entry_{ij}, which equals one if a loan that exists in the post-sample did not exist in the pre-sample. *Borrowing* is the change in log amount borrowed by bank i, *# Lenders* is the change in the number of lender a bank i borrows from, *Betweenness* is bank i's change in betweenness centrality, and *Katz* is bank i's change in Katz centrality. Changes are always computed as post-period value minus pre-period value. The pre-period in models (1) and (2) is the pre-Lehman period. The post-period in models (1) and (2) is the post-Lehman period. The pre- and post-period in model (3) are the post-Lehman and SRO period, respectively. The pre- and post-period in model (4) are the post-Lehman and full-allotment period, respectively. Controls in model (2) include the total asset size, relative size of lender i on the interbank market, and loan loss reserves of lender i. All regressions have borrower fixed-effects and the sample is restricted to loans where the borrower bank borrows from at least two lender banks.

Table 19: The Interbank Lending Channel - Intensive Margin, amount

	Post - Pre		SRO - Post	Full - Post
	(1)	(2)	(3)	(4)
Borrowing	2.002	2.071	1.952	1.868
	(0.036)	(0.052)	(0.035)	(0.039)
	56.400	39.770	56.190	48.370
#Lender	0.176	0.198	0.170	0.150
	(0.009)	(0.019)	(0.009)	(0.008)
	19.840	10.590	18.910	18.330
Betweenness	554.159	620.073	584.355	508.034
	(40.168)	(93.168)	(40.041)	(35.969)
	13.800	6.660	14.590	14.120
Katz	85.542	85.827	77.349	80.667
	(7.709)	(14.377)	(9.039)	(6.722)
	11.100	5.970	8.560	12.000
Controls	No	Yes	No	No
N	6567	3070	6456	6200

Note: The dependent variable is Amount_{ij}, i.e. the change in the log of borrowing from bank i to bank j. *Borrowing* is the change in log amount borrowed by bank i, *# Lenders* is the change in the number of lender a bank i borrows from, *Betweenness* is bank i's change in betweenness centrality, and *Katz* is bank i's change in Katz centrality. Changes are always computed as post-period value minus pre-period value. The pre-period in models (1) and (2) is the pre-Lehman period. The post-period in models (1) and (2) is the post-Lehman period. The pre- and post-period in model (3) are the post-Lehman and SRO period, respectively. The pre- and post-period in model (4) are the post-Lehman and full-allotment period, respectively. Controls in model (2) include the total asset size, relative size of lender i on the interbank market, and loan loss reserves of lender i. All regressions have borrower fixed-effects and the sample is restricted to loans where the borrower bank borrows from at least two lender banks.

Table 20: The Interbank Lending Channel - Intensive Margin, spreads

PANEL A - SPREAD

	Post - Pre		SRO - Post	Full - Post
	(1)	(2)	(3)	(4)
Borrowing	-0.009	-0.008	-0.011	-0.024
	(0.001)	(0.002)	(0.002)	(0.001)
	-7.780	-5.430	-6.760	-16.980
#Lender	-0.001	-0.001	-0.001	-0.002
	(0.000)	(0.000)	(0.000)	(0.000)
	-4.360	-3.620	-3.860	-8.880
Betweenness	-1.899	-2.231	-2.700	-6.361
	(0.382)	(0.525)	(0.805)	(0.736)
	-4.970	-4.250	-3.350	-8.640
Katz	-0.492	-0.383	-0.550	-1.243
	(0.065)	(0.083)	(0.141)	(0.134)
	-7.590	-4.640	-3.900	-9.300
Controls	No	Yes	No	No
N	6567	3070	6456	6200

PANEL B - INTERMEDIATION SPREAD

	Post - Pre		SRO - Post	Full - Post
	(1)	(2)	(3)	(4)
Borrowing	0.070	0.120	-0.011	0.078
	(0.032)	(0.039)	(0.002)	(0.016)
	2.200	3.120	-6.760	5.030
#Lender	0.006	0.007	-0.001	0.006
	(0.002)	(0.003)	(0.000)	(0.002)
	3.740	2.160	-3.860	3.370
Betweenness	23.005	27.610	-2.700	23.064
	(4.916)	(9.741)	(0.805)	(5.107)
	4.680	2.830	-3.350	4.520
Katz	14.805	16.383	-0.550	12.138
	(2.305)	(3.546)	(0.141)	(2.058)
	6.420	4.620	-3.900	5.900
Controls	No	Yes	No	No
N	6567	3070	6456	12400

Note: The dependent variable in Panel A is Spread_{ij}, i.e. the volume-weighted spread bank i charges for lending to bank j. The dependent variable in Panel B is Intermediation Spread_{ij}, i.e. the intermediation spread bank i makes on the interbank loan to bank j. *Borrowing* is the change in log amount borrowed by bank i, *# Lenders* is the change in the number of lender a bank i borrows from, *Betweenness* is bank i's change in betweenness centrality, and *Katz* is bank i's change in Katz centrality. Changes are always computed as post-period value minus pre-period value. The pre-period in models (1) and (2) is the pre-Lehman period. The post-period in models (1) and (2) is the post-Lehman period. The pre- and post-period in model (3) are the post-Lehman and SRO period, respectively. The pre- and post-period in model (4) are the post-Lehman and full-allotment period, respectively. Controls in model (2) include the total asset size, relative size of lender i on the interbank market, and loan loss reserves of lender i. All regressions have borrower fixed-effects and the sample is restricted to loans where the borrower bank borrows from at least two lender banks.

B Supplementary Information – Not for Publication

B.1 Can Nodes Influence their own Centrality?

In Khwaja and Mian (2008) banks experience an exogenous liquidity shock due to sanctions imposed on Pakistan following an unannounced nuclear weapon's test. This exogenous shock is crucial for identification and begs the question whether a change in a node's network centrality can be seen as exogenous. We use three shocks in this paper: the insolvency of the US investment bank Lehman Brothers on 15 September 2008 (our main specification), the first full-allotment special refinancing operation on 29 September, and the decision by the Eurosystem to move from a variable-rate auction-based regime of monetary policy to a full-allotment regime on 15 October 2008. Our main hypothesis is that banks in a more central position within the network have easier access to more and cheaper liquidity. We show in Section 3 that the interbank network structure changes significantly between the different sample periods. This aggregate change causes substantial change in individual banks' network position (measured by their degree, volume, and centralities). We test the hypothesis that this change in bank i's network position leads to a change in i's access to liquidity using a diff-in-diff setting similar to Khwaja and Mian (2008).

However, one concern could be that banks can strategically choose their network position. A change in their network position would thus not be an exogenous shock. In this section we thus test whether banks can indeed strategically choose a certain value of their centrality. Intuitively, we expect this not to be the case because a bank's centrality depends on the entire network structure, while the bank can only decide about its immediate neighborhood (i.e. whether to form a link with other banks and thus add them to the neighborhood). While there is no easy analytical proof of our intuition, we can test it numerically.

Consider the following simple algorithm with seven steps:

1. Select an undirected random network with N nodes. Since interbank networks are typically of core-periphery type, we draw N_G core-periphery networks G with N nodes. [17].

2. Select N_r random reference nodes r.

3. Calculate the initial centrality of the reference node C_r^i where $C \in \{\text{Betweenness}, \text{Katz}\}$.

4. Add N_m random links to/from the reference node r.

5. Allow the rest of the network to change: select N_{-r} random nodes in the network and change a random number of links of these, that are not to/from the reference node r.

6. Now calculate the updated centrality of the reference node C_r^u and compute the absolute change in the centrality (relative to the initial centrality):

$$\Delta C_r = \left| \frac{C_r^u - C_r^i}{C_r^i} \right| .$$

7. Calculate the mean of ΔC_r.[18].

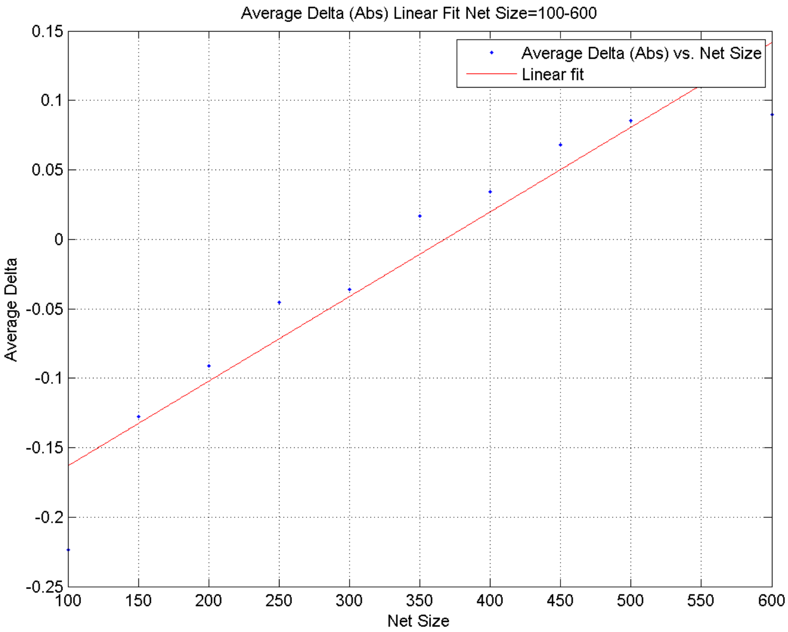
We perform the numerical simulation both for core-periphery network configuration and for Erdös-Rényi network with rewiring probability equal to 0.8. Choosing a

[17] In line with the evidence commonly found in the empirical literature on interbank networks, we set the number of cores for each network randomization to be chosen randomly between $10 - 20\%$ of the total number of nodes

[18] Technically, in the numerical simulation we compute three averages. First, we calculate the average change in the reference node centrality induced by others' links change over N_m different links randomizations of the reference node r. The calculation of this average is performed for N_r random reference nodes selected (using the same initial network configuration selected in step 1.) and the mean of these averages is calculated over N_G random configurations of the network. This last average gives the value for ΔC_r for each given number of nodes.

high value for the last parameter, we aim to reflect the empirical evidence that interbank market structure is relatively tightly knit. As it has been argued by Haldane (2009) indeed, the financial sector has undergone increasing levels of homogeneity. Moreover, several empirical papers show that bank networks feature a core-periphery structure with a core of big and densely connected banks and a periphery of smaller banks. Our hypothesis aims therefore to capture the opportunity for banks in this core to change their network position.

In Figure 6 we show the change in the centrality measures of node r in a log scale and do linear fit, which corresponds to an exponential increase in the mean of ΔC_r. We obtain in general a good level of the linear fit of the two series in log scale, as shown by the R-square values of 0.92 and 0.72 calculated respectively for the core-periphery and the Erdös-Rényi network. This implies that increasing network size, the change in a node r's centrality due to changes outside of the neighborhood of r increases more than the change in r's centrality due to changes in the neighborhood of r. Accordingly, the results of the analysis support our intuition that nodes cannot influence their centrality and strategically choose their network position.



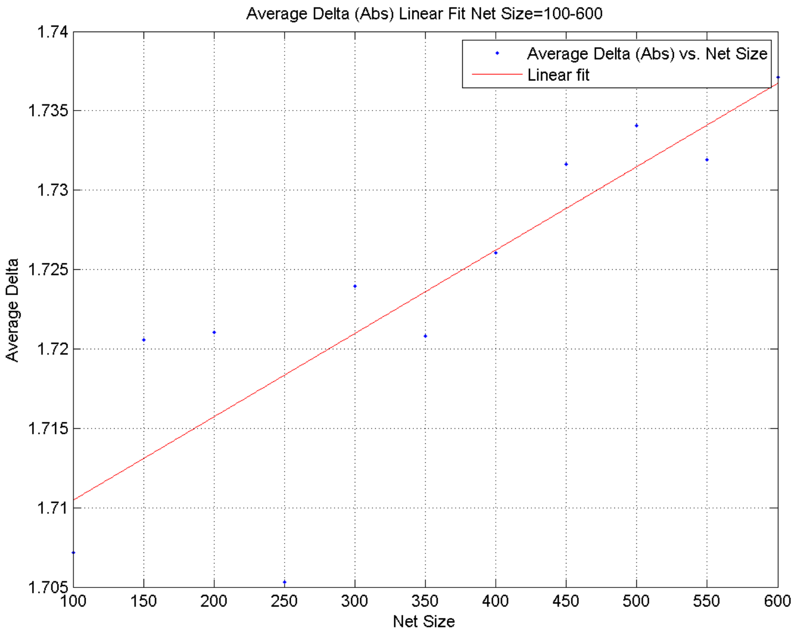


Figure 6: Mean relative change ΔC_r in node r's centrality versus network size. Mean is computed over $N_G = 100$ random draws, $N_r = 10$ random reference nodes that can randomly change $N_m = 10$ links, and $N_{-r} = 1$ random changes of links outside r's neighborhood. We use core-periphery network (top) and Erdös-Rényi network with rewiring probability equal to 0.8 (bottom).

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