A Network View on Interbank Liquidity *

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Abstract

The euro area overnight interbank market is best described as a network of over-the-counter lending relationships. We study liquidity reallocation in this interbank network using a novel dataset of all interbank loans settled between European banks. We show the existence of a network pricing channel in over-the-counter markets: a bank's importance in the interbank network, measured by its centrality, has an economically significant effect on its liquidity provision and access. The effect is stronger for the price of liquidity than for the volume, and stronger for liquidity provision than for liquidity access.

Keywords: interbank networks, liquidity, network formation

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1 Introduction

The overnight interbank market is a decentralized over-the-counter (OTC) market for central bank reserves, and a major source of liquidity for euro area banks.[1] Consequently, 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. 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 is best described as a network of interbank loans amongst banks. However, contracts are bilaterally negotiated and information about trading partners, volumes, and prices is usually not available.[2]

We use a novel and uniquely detailed dataset of all interbank loans settled among any two euro area banks around the Lehman event to study the effect of the interbank network structure on the price and volume of banks' liquidity provision and access. To build some intuition, assume that the only difference between two banks is that the first is able to borrow from counterparties who, themselves, have more counterparties to borrow from. Even if both have the same number of counterparties, the first is at an advantage. If hit by a liquidity shock, it can obtain liquidity from counterparties who, in turn, can obtain liquidity from a larger number of possible lenders. We formalize this intuition and the notion of a pivotal bank using measures of a bank's network centrality. A bank's betweenness centrality, for example, is measured as the fraction of all shortest paths of liquidity intermediation between any two banks that pass through this bank.

Using loan-level data, and controlling for demand, we show in Section 4 that banks with a more pivotal position in the interbank network make significantly larger intermediation spreads and provide more liquidity. The effect is beconomically large: A one one standard deviation increase in

[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.

betweenness centrality, for example, leads to an almost 30% increase in the intermediation spread a bank is able to capture and a 2% increase in liquidity provision. In Section 5 we show that this *network pricing* channel of liquidity provision arises because banks with higher network centrality have access to more and cheaper liquidity. Using bank-level regressions with a bank's network centrality in a reference period–to avoid issues of reverse causality–as independent variable, we show that banks with a one standard deviation increase in betweenness centrality pay 34% less for their interbank borrowing.

Our main contribution is to the literature on trading in over-the-counter markets. Search models of OTC markets assume a continuum of atomistic agents that have a zero probability of meeting more than once (see, for example, Duffie et al. (2005), Duffie et al. (2007)). Such models abstract from the network character of the market. We show, however, that the network structure can have a sizeable effect on pricing. Our paper, therefore, mainly contributes to the growing literature on trading in OTC networks (see, for example, Gale and Kariv (2007), Gofman (2011), Condorelli and Galeotti (2012), Babus and Kondor (2014), Farboodi (2014), Manea (2016), and Malamud and Rostek (2016)).

While empirical evidence is still scarce, an emerging literature studies the network structure of municipal (Li and Schuerhoff (2014)) and corporate (di Maggio et al. (2015)) bond OTC markets. In line with our results, and the theoretical predictions of Babus and Kondor (2014), di Maggio et al. (2015) find that central dealers make larger intermediation spreads and intermediate more. Similarly, Li and Schuerhoff (2014) find that central dealers charge a higher spread but provide immediacy to customers. Our paper differs from this literature because we study the euro area overnight interbank market, which is not only crucial for financial stability, but also for the implementation of monetary policy in the euro area.

Our paper relates local liquidity provision, the formation of new lending relationships between banks, with the existing global structure of the interbank network, which, in addition to the reasons outlined above, is important for at least five 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)).

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.

As a first step in our analysis, we study the structure of the euro area overnight interbank market before and after the Lehman event in Section 3. Empirical studies show that domestic

[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 (2016). 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.

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 can be described as a core-periphery network, albeit with a higher error score than e.g. the German interbank network. There is substantial variation between the pre-Lehman and the post-Lehman interbank network structure–roughly 60% of all links change between those periods.

We find, somewhat surprisingly, a significant increase in interbank lending following the Lehman event. This can best be understood in the context of asymmetric information. Glode and Opp (2016) 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. We complement this analysis in Section 6 by directly comparing the price and volume dynamics in the euro area with the developments in the fed funds market, studied in Afonso et al. (2011). The increase in overnight interbank lending is accompanied by a slight decrease in interbank lending in the term segment for loans with a maturity longer than overnight and up to one year. Similarly to the US, lenders in the overnight market become sensitive to borrower characteristics, i.e. to counterparty risk. In the term segments, on the other hand, lending dropped irrespective of borrower or lender characteristics.

Our paper contributes to various other streams of literature. 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 provision and access 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

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

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 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 first. 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 bank i has given a loan to bank j and $g_{ij} = 0$ otherwise.[6] A loan from bank i to bank j on day t is denoted as $\text{Loan}_{ij,t}$ and interbank market turnover on day t is thus given as:

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

We study liquidity provision and access along four dimensions: access, amount, price, and number of counterparties. The extensive margin of liquidity access is given by $\text{Access}_{i,t}$, which

[6]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, since the weight is captured by $\text{Loan}_{ij,t}$.

equals one if we take a borrower perspective and bank i borrowed on the interbank market on day t, i.e.:

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

where the superscript b indicates access to interbank borrowing. If we take a lender perspective and bank i lends on the interbank market on day t we denote i's willingness to lend as $\text{Access}^{l}_{i,t} = \max_j\{g_{ij,t}\}$.

To study the intensive margin of liquidity access, we define the amount borrowed by bank i on day t as:

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

where $B_{i,t} = \{j|g_{ji,t} = 1\}$ is the set of banks j that lend to bank i on day t. Similarly, $L_{i,t} = \{j|g_{ij,t} = 1\}$ is the set of banks j to which bank i lends on day t.

Denote the price of a loan (i.e. the overnight interest rate) from i to j on day t as $\text{p}_{ij,t}$ and the volume-weighted average of prices bank i pays to its lenders on day t as $\widehat{\text{p}}_{ij,t}$:

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

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

$$\text{Spread}^{b}_{i,t} = \sum_{j\in L_{i,t}} \widehat{\text{p}}_{ji,t} - \widehat{\text{p}}_{t}. \tag{5}$$

where $\widehat{\text{p}}_t$ is the average interbank interest rate on day t, $\widehat{\text{p}}_t = \sum_i \sum_{j\in L_{i,t}} \widehat{\text{p}}_{ij,t}$. Finally, we use the number of counterparties of bank i using the nomenclature defined above. Bank i's asset-side diversification $\text{Degree}^{l}_{i,t}$ is defined as the number of counterparties j to which i has a loan on day t:

$$\text{Degree}^{l}_{i,t} = |L_{i,t}| \tag{6}$$

Equivalently, a bank's liability side diversification $\text{Degree}^{b}_{i,t}$ is given by the number of counterparties

j that have granted an interbank loan to i on day 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 weighted in-degree and the amount bank i lends to others as i's weighted out-degree.

Before we can address the question if a bank's position in the interbank network affects liquidity provision and access, we have to specify in more detail *which* network we are using. There are two ways to specify what it means for banks to be connected in a network. The first, and straightforward way, is to use the daily networks of newly established interbank loans G_t (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.[7] In this 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 liquidity provision and access 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 provide and obtain liquidity. Thus, all network measures in this paper are computed for a reference period:

$$G_\tau = \bigcup_{t \in \tau} G_t, \text{ with } g_{ij,\tau} = \sum_{t \in \tau} g_{ij,t} \tag{7}$$

where τ is one of the sample periods defined in Section 3. The elements of the adjacency matrix for the sample period $g_{ij,\tau}$ are thus the number of days during the sample period on which there existed a loan from bank i to bank j.

Network theory provides a wide variety of measures to quantify a node's position in a network

[7]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.

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 liquidity provision and access 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 path 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:

$$\overline{d_{i,\tau}} = \frac{\sum_{j \in B_{i,t}} d_{ji,\tau}}{|N| - 1} \tag{8}$$

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. The average shortest path length is a measure of the average length of liquidity intermediation chains, while the diameter measures the length of the longest liquidity intermediation chain.

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:

$$\rho_\tau = \frac{\#\text{Loans}_\tau}{\text{N}_\tau \times (\text{N}_\tau - 1)}. \tag{9}$$

The most natural interpretation of network density is that it provides a simple measure of market completeness, i.e. it is the probability that two randomly chosen banks can engage in interbank lending.

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

$$\text{Betweenness}_{i,\tau} = \frac{\sum_{j \in B_{i,t}} a_{jk,\tau|i}/a_{jk,\tau}}{(|N|-1) \times (|N|-2)} \tag{10}$$

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.[8] 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. 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:

$$\text{Katz}_{i,\tau} = \alpha \sum_{j \in B_{i,t}} g_{ji,\tau} + \beta \tag{11}$$

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.[9] Moreover, extra weight can be provided to immediate neighbours (lenders) of bank i through the parameter β, which

[8] 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.

[9] 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.

controls for the initial centrality.[10]

3 The Euro Area Interbank Market During the Financial Crisis

3.1 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).[11] 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

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

[11] 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.

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 gross settlement (RTGS) system owned and operated by the Eurosystem.[12] 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. 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).

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.[13] On 15 October 2008, the ECB adopted a *full-allotment*

[12] 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).

[13] 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.

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.

3.2 Stylized Facts About the euro area Interbank Market

Volume Dynamics. The measures defined in Section 2 can be used to quantify the change in the network structure of the euro area overnight interbank market. We use a difference-in-differences estimation to test our main hypothesis that banks with a higher network centrality provide more liquidity and at cheaper prices on the interbank market. For this analysis, we use the period aggregates for the interbank networks. However, test whether banks with a higher network centrality in a pre-determined reference period (i.e. centralities computed in an aggregated network) have better access to liquidity, we use daily turnover. We therefore present results on the volume dynamics of the interbank market using daily turnover.

Figure 1 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. For a better comparison, we have included not only the turnover in the overnight segment, but also in the term segment for loans with a maturity of up to one year. A slightly downward sloping trend lasts until 27 August and total daily turnover drops from around EUR182.6bn to EUR128.9bn. In the two weeks prior to the Lehman insolvency, turnover picks up again and is at EUR155.9bn on 12 September. Somewhat surprisingly, though, the Lehman insolvency did not lead to a breakdown of lending in the euro market.[14] Rather, a decrease in the daily turnover of term interbank lending from EUR36.8bn on 12 September to EUR24.9bn on 25 September is more than compensated for by an increase in daily turnover in the overnight interbank market from EUR119.2bn to EUR160.8bn in the same period. Thus, the volume dynamics alone provide an interesting insight in the euro area interbank market around the Lehman insolvency: there was, similarly to the US, *no* interbank market freeze. However, from

[14]This is well in line with the results by Afonso et al. (2011). Similarly, Perignon et al. (2016) document that there was no market-wide freeze in the wholesale funding market for ceertificates of deposit.

the time just before the ECB conducted the special refinancing operation on 29 September, to just before its maturity on 8 November 2008, the total daily turnover dropped by 34.5%. This reduction stems mostly from the overnight segment, since the term segment dropped from EUR25.19bn to EUR19.19bn in the same period, a 23.8% reduction.

Table 1 provides further information on the the daily overnight interbank networks G_t. The aggregate picture for the turnover is reflected in the mean number of lenders, which increase by about 12% from the pre-Lehman to the post-Lehman period, and then drop by almost 30% in the full-allotment period.

Price Dynamics. The price of overnight interbank liquidity is shown in Table 1. The spread, defined as the volume-weighted price of liqudity in the interbank market minus the main refinancing rate set by the ECB, is smallest during the pre-Lehman period, 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.

Figure 2 also shows price dispersion, measured as the standard deviation of the daily price of liquidity. We show the smoothed average daily price of liquidity in the overnight and term segment for interbank loans with a maturity of more than three months and up to one year. In the term segment, the price of liquidity increases slightly after the Lehman insolvency on 15 September and until the ECB moved to a full-allotment regime of monetary policy on 15 October. Price dispersion is large, but roughly constant. Prices in the overnight segment are stable until the Lehman insolvency. Once the ECB conducted the first special refinancing operation with full-allotment, prices are volatile and price dispersion increases substantially. With the move to the full-allotment regime of monetary policy on 15 October the price continues to decrease and price dispersion remains high. In particular since 15 October the deposit facility rate is not a binding floor anymore, which is an indicator for abundant liquidity in the interbank market.[15]

Network Dynamics. In our regressions we use measures of network centrality defined on the networks aggregated over our sample periods. Table 2 shows summary statistics for a number of relevant network variables. The total number of loans increase from the pre-Lehman to the post-Lehman period by roughly 7% before it drops significantly in the SRO and full-allotment period. From the pre-Lehman to the post-Lehman period, the number of borrowers decreases by about 5%, 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, which is in line with the development in the fed funds market, studied by Afonso et al. (2011). While not the main focus of our paper, we expand this analysis in Section 6 and the Supplementary Information B.1.We show that the euro area overnight interbank market was characterized by lender concerns about borrower characteristics around the time of the Lehman insolvency.

As a result of this process, the network density ρ_τ slightly increases from the pre-Lehman to the post-Lehman period, 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 average shortest 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.

Using measures from network theory is only one possibility to quantify the change in the interbank network structure, though. Another possibility is to measure in how far the observed

[15]See Bech and Klee (2011) for a discussion of how abundant liquidity in the federal funds market can render the floor of the federal funds rate, implemented through interest on reserves akin to the Eurosystem's deposit facility rate, imperfect.

structure of the euro area overnight interbank market corresponds to other empirically observed interbank network structures. 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 core in the pre-Lehman period is 25 (and the size of the periphery thus 707). In the pre-Lehman period, there are 253 links within the core, 1650 links within the periphery, and 2033 links between the core and the 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, while the error score for the German interbank network has an error score of only 0.12.[16] In the post-Lehman period there are only 617 of the banks in the periphery active and there are 232 links within the core, 2070 links between the core and periphery, and 1755 links within the periphery. The error score slightly increases to 0.52 in the post-Lehman period. Both, the core and the periphery shrink between the pre-Lehman and the post-Lehman period, but the 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.[17] 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:

$$\mathrm{J}(L_\tau, L_{\tau'}) = \left| \frac{L_\tau \cap L_{\tau'}}{L_\tau \cup L_{\tau'}} \right|. \tag{12}$$

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.[18] The Jaccard-Index yields 0.4 for the comparison

[16] One difference between our data and the data used in Craig and von Peter (2014) is that we have daily data from payment systems and for the overnight interbank market, while the data for the German interbank market stems from the German large credit register and contains mostly term interbank lending, as Bluhm et al. (2016) show.

[17] The Jaccard index is defined for unweighted networks.

[18] 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.

between all links, 0.54 for the comparison of links within the identified core, 0.38 for links within the periphery, and 0.43 for links between the identified core and 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 core maintains the highest structural stability, while lending between banks in the identified periphery is the least structurally stable.

4 Liquidity Provision and Network Position

We argue in Section 3.2 that the euro area overnight interbank market changes significantly around the time of the Lehman insolvency. This provides us with an ideal setting to test our hypothesis that a bank's position in the interbank network does not affect how much liquidity the bank provides and at what price.

When estimating the effects of liquidity provision, one concern is that the demand for interbank liquidity could have been affected by the Lehman insolvency. Therefore, 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)). We start from the simplified balance sheet of bank i at time t:

$$\text{Other Liabilities}_{i,t} + \text{Interbank Funding}_{i,t} = \text{Other Assets}_{i,t} + \sum_{j \in L_{i,t}} L_{ij,t} \tag{13}$$

where Other $\text{Liabilities}_{i,t}$ includes demand deposits from households and firms, as well as bond and equity financing, and Other $\text{Assets}_{i,t}$ include loans to firms and households, as well as all assets other than interbank loans. Interbank $\text{Funding}_{i,t}$ is the total amount of interbank funding bank i receives at time t. Our measure of interbank liquidity provision of bank i to bank j is denoted $L_{ij,t}$. We assume that the demand and supply of interbank liquidity is linear in each period.

Taking the first difference between two points in time obtains the equilibrium values of L_{ij} because of the linear model setup. We use the post- and pre-Lehman periods defined in Section 3 and aggregate the daily interbank networks according to Equation (7). 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:

$$\Delta L_{ij} = \beta_j + \beta_1 \Delta \text{Interbank Funding}_i + \epsilon_{ij} \tag{14}$$

The assumption we make is that a bank's interbank funding depends linearly on its position in the interbank network, while its other liabilities and assets are fixed. Thus, $\text{Interbank Funding}_{i,\tau} \equiv \alpha \times \text{Network Position}_{i,\tau}$, where:

$$\text{Network Position}_{i,\tau} \in \{\text{Amount}^b_{i,\tau}, \text{Degree}^b_{i,\tau}, \text{Betweenness}_{i,\tau}, \text{Katz}_{i,\tau}\}. \tag{15}$$

The first two measures, $\text{Amount}^b_{i,\tau}$ and $\text{Degree}^b_{i,\tau}$, are local measures of a bank's position in the interbank network, i.e. they depend on a bank's in-neighborhood $B_{i,\tau}$ only. The other two are non-local measures that depend on the structure of the entire network. 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:

$$\text{Amount}^a_{i,\tau} = \log\left(1 + \sum_{j \in B_{i,\tau}} \text{Loan}_{ij,t}\right) \tag{16}$$

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 average intermediation spread bank i makes on loans to bank j in period τ:

$$\text{Intermediation Spread}_{ij,\tau} = \frac{1}{|\text{Loan}_{ij,t}|} \sum_{t \in \tau} \text{Intermediation Spread}_{ij,t} \tag{17}$$

where $|\text{Loan}_{ij,t}|$ denotes the number of days on which bank i has given a loan to bank j, and the intermediation spread for a loan on day t is defined as:

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

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 and at what price, we 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:

$$\text{Exit}_{ij} = \beta_j + \beta_1 \Delta \text{Interbank Funding}_i + \epsilon_{ij} \tag{19}$$

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 (19). 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 6. 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 a set of lender controls in model (2). We obtain the bank-specific control variables from bankscope and use the values reported for the end of 2007 to avoid any reverse causality issues. 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

$\text{Amount}_{i,t}/\text{Assets}_{i,2007}$.[19] 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, however.

One could 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 (see Section 3). 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) for comparison. All three events had massive impact on the liquidity reallocation in the euro area overnight interbank market, as Figure 1 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 participants in Europe.

Our main results are shown in model (2) and obtained when using 15 September 2008 as shock and when including lender controls. 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 liquidity provision and access. 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 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

[19] 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.

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 7 shows the results of regression (14) 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 8. 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, measured as the difference of the volume-weighted price of liquidity $\widehat{\text{p}}_{i,\tau}$ minus the ECB's main refinancing rate during period τ. 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 8 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.

5 Interbank Network Position and Access to Liquidity

One hypothesis why banks with a more central position in the interbank network provide more and cheaper liquidity to their counterparties is that they have access to more and cheaper liquidity themselves. A first indication for this hypothesis can be seen in Figures 3 and 4 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 3 we normalize the borrowing $\text{Amount}_{i,\tau}$ by borrowing in the initial period. The aggregate amount the two 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. We formalize this intuition and test the following hypothesis:

> Banks with higher betweenness and Katz centrality do not have better access to liquidity, measured as the amount and price of liquidity obtained, in the euro area overnight interbank market.

by estimating a simple OLS model:

$$\begin{aligned} A_{i,t} \quad = \quad & \beta_0(\text{Date}) + \beta_1\left(\text{Date} \times \text{Assets}_{i,2007}\right) + \beta_2\left(\text{Date} \times \text{Loan Loss Reserves}_{i,2007}\right) \\ & +\beta_3\left(\text{Date} \times \frac{\text{Amount}_{i,t}}{\text{Assets}_{i,2007}}\right) + \beta_4(\text{Date} \times \text{Network Position}_{i,\text{initial}}) \end{aligned} \tag{20}$$

where liquidity access, $A_{i,t}$, is measured along three dimensions, $\text{Amount}_{i,t}$, spread $\text{Spread}_{i,t}$, and the number of loans obtained, $\text{Degree}^{b}_{i,t}$. We introduce a time-period dummy, Date, for every period and use a set of bank-specific control variables which we obtain from bankscope.[20] The advantage of estimating such an OLS model is that it allows us to study the role of bank characteristics, which we could not do in the Diff-in-Diff setting in Section 4 because of the relatively smaller number of loans that can be used in the Diff-in-Diff setting.

Our main explanatory variable is $\text{Network Position}_{i,\text{initial}}$ and we use the network G_{initial}, i.e. the euro area overnight interbank network in the initial period. By using only pre-determined variables, we avoid issues of reverse causality. Our two main explanatory variables are $\text{Betweenness}_{i,\text{initial}}$, and $\text{Katz}_{i,\text{initial}}$ centrality. In the Supplementary Information B.1 we also use local measures of liquidity access, i.e. the weighted and unweighted in-degree of bank i in the reference period.

Tables (9) and (10) 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. Table (9) shows that, first, banks borrow significantly more in the post-Lehman period, and significantly less in the full-allotment period than in the initial period if we include borrower control times period fixed-effects. Second, larger banks obtain more liquidity than smaller banks. Third, riskier banks, i.e. banks with higher loan-loss reserves 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 pre-determined explanatory variables that describe a bank's centrality in the network are significant and positively correlated

[20]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.

with the amount of liquidity a bank obtains in the euro area overnight interbank market.

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.[21]

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 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.[22]

Overall, we find strong evidence to reject the hypothesis that banks with a more central position in the interbank network do not have better access to liquidity in the euro area overnight interbank market.

6 Do Borrower or Lender Characteristics Determine Liquidity Provision and Access?

We use the Lehman insolvency as exogenous shock to show that more pivotal banks not only provide more liquidity and at cheaper prices, but also have access to more and cheaper liquidity themselves. What remains to be seen, however, is whether the volume and price dynamics we describe in

[21] For a comparison with the effect of local network measures, i.e. the weighted and unweighted in-degree, as well as an analysis of access to liquidity measured by the number of borrowers, see the Supplementary Information (B.1).

[22] For comparison: 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.

Section 3 are driven by borrower or lender characteristics. To remedy this, we directly compare the developments in euro area interbank market with those in the fed funds market in the US around the Lehman insolvency. Afonso et al. (2011) show that, while the overnight fed funds market did not freeze following the insolvency of Lehman brothers, it experienced considerable stress. The only evidence of an actual market freeze in the fed funds market is that on Monday 15 September banks borrowed significantly less from significantly fewer counterparties when borrower fixed effects are included. This finding is consistent with a market that is characterized by counterparty risk, i.e. lenders are sensitive to counterparty properties. However, the overall picture for the fed funds market does not suggest a massive market freeze in the overnight segment, at least from an aggregate perspective.

In this section, we use data consisting of transactions with maturities from overnight to 12 months, which allows us a more nuanced view at the developments in the euro area interbank market. We first look at the effect of the Lehman insolvency on borrowers in the overnight segment, shown in Table 12. The sample period runs from 04 July to 30 October 2008. Model (1) is a simple probit model with the dependent variable being equal to one if a bank accessed the interbank market on a given day and zero otherwise. The overnight segment shows a decrease in the probability of access relative to the initial reference period (i.e. relative to the period from 04 to 21 July) already in the pre-Lehman period. The reduction is stronger, though, in the two days following the Lehman insolvency. In the post-Lehman period, access is reduced, but not as strongly. Access is further reduced in the full-allotment period. In models (2) and (3) we estimate the amount a bank borrows on the interbank market in the various periods with and without borrower fixed effects. Without controlling for fixed borrower characteristics, and similar to the US, we do not see any significant reduction in trading in the overnight segment.

However, when borrower fixed effects are included, we see a significant reduction in the amount borrowed, but only once the ECB conducted the first full-allotment special refinancing operation and, more importantly, once full-allotment is implemented: in the latter case, the large point estimate suggests that certain banks reduced their recourse to interbank funding by more than

90%. Spreads are analyzed in models (4) and (5). They are computed as the difference between the volume-weighted average interest rate paid by a given borrower and the minimum bid rate of the Eurosystem's Main Refinancing Operations (MRO). Spreads were higher already in the pre-Lehman period, but substantially more so on 15 September, when banks paid on average 0.15 basis points more than in the initial reference period to obtain liquidity. Borrowing spreads increased by additional 0.05 basis points on 16 September, and are slightly higher when controlling for borrower characteristics. Then, starting in the post-Lehman period, spreads are reduced and significantly so during the full-allotment period. The number of counterparties a bank borrows from is shown in models (6) and (7). It is significantly lower in the pre-Lehman period and on Tuesday 16 September, when a bank could borrow from about one counterparty less than in the reference period, and then even more following the special refinancing operation, but only if borrower fixed effects are considered. This shows that immediately after the Lehman insolvency lenders in the overnight interbank market become indeed sensitive to counterparty properties. The effect is stronger with the onset of the ECB emergency measures. Then, especially after full-allotment, bank characteristics are important for the amount a bank borrows and the number of counterparties it borrows from. The overall picture for the overnight segment is thus very similar to the US, with the interbank market being stressed, but not frozen.

Was there no market freeze in Europe at all? A closer look at the term segment in Table 12 reveals a significant and sizeable impact of the Lehman insolvency. From Monday 15 September onwards, access is significantly reduced and neither the SRO nor full-allotment can restore market activity to pre-Lehman levels.[23] A similar picture emerges for the amount borrowed (models (2) and (3)), which is substantially reduced starting from Monday 15 September and in all periods. Spreads increased both on Monday 15 and Tuesday 16 September (models (4) and (5)), but on Monday 15 September the economic magnitude of such effect is about one fifth compared to the increase observed in the overnight spread.[24] However, differently from the overnight segment, spreads contin-

[23] de Andoain et al. (2014) study the liquidity provision by the ECB in more detail and show that central bank liquidity replaces the demand for liquidity by market participants.

[24] For each term maturity the term spread is computed as the difference between the weighted average interest paid by a borrower at that maturity and the average market rate for the same maturity. A unique spread is thereafter obtained by weigthing the various spreads with the turnover traded at the respective maturity.

ued to increase even after the ECB measures. Finally, the number of counterparties is significantly reduced on 15 and 16 September, and continues to decrease post-Lehman, with the implementation of the SRO and under the full allotment regime. In general, the effects are not sizeably different once we introduce borrower fixed effects and are not as large as in the overnight segment. Compared to what we observe for the overnight segment, this provides less convincing evidence of lenders' sensitiveness to borrower characteristics in the term market: the drop in turnover volume was so large that all borrowers saw a substantial decrease in their interbank funding. Another indication that borrower characteristics were more relevant in the overnight segment is that the explanatory power of our regressions when borrower fixed effects are introduced increases much more in the overnight than in the term regressions. All in all, the picture for the term segment points more clearly to a market freeze.

On the lending side, Table 13 shows that on Monday 15 and Tuesday 16 lenders participated less in the overnight segment and charged higher interest rates to borrowers, while we do not observe a significant reduction in amounts lent nor in the number of counterparties. A significant drop occurs only on Tuesday 09/16 in the term segment. Moreover, adding fixed effects for lenders does not change the point estimates remarkably, thus suggesting that the higher spreads where indeed driven by borrower rather than lender characteristics. Note, however, that this does not imply that banks were not trying to increase the liquidity of their balance sheet, it just implies that lender characteristics were not the driving force behind the increased liquidity preference.

In the Supplementary Information B.2, we extend our analysis and take a more disaggregate view on the interbank market by introducing in the former regressions a set of bank-specific controls and splitting the sample according to the size of the banks.

7 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 provision and access. 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 liquidity provision and access. Banks with higher network centrality provide more liquidity and at cheaper prices. We find a similar effect for the access to liquidity.

We mainly 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 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 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.

We 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), 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.

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A Appendix

A.1 Figures

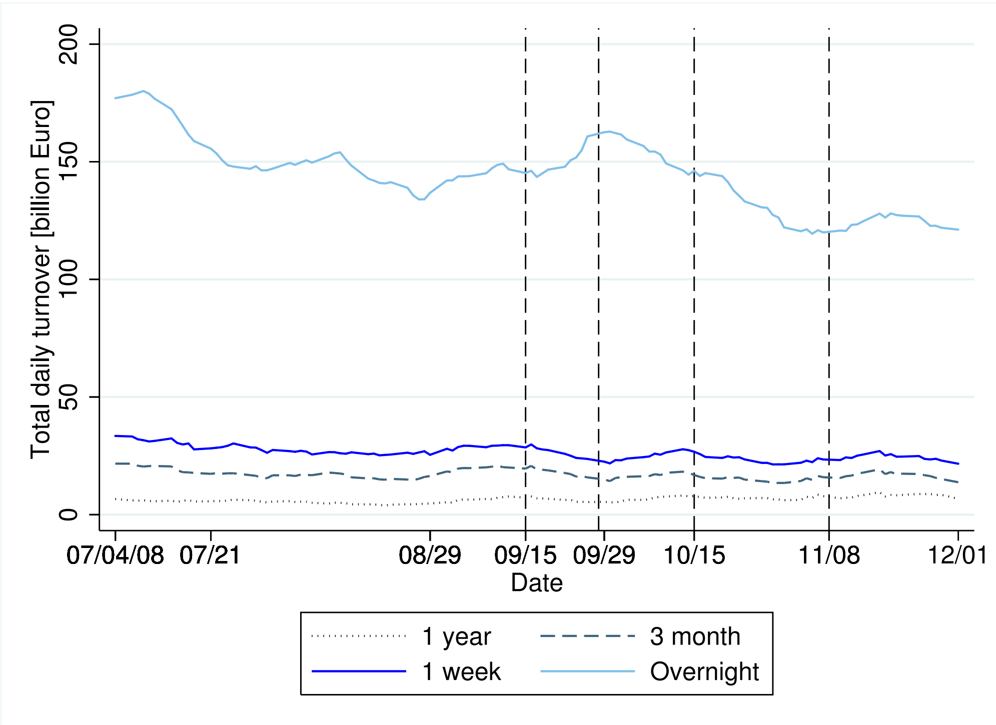

Figure 1: Stacked chart of daily turnover $\text{Amount}_{i,t}$ in the euro area interbank market during our sample period in billion Euros, broken down by maturity. Black dotted line includes loans with a maturity of more than three months, and up to one year. Dashed dark blue line includes loans with a maturity larger than one week and less than three months. Solid blue line includes loans with a maturity of more than overnight and up to one week. Solid light blue line denotes overnight interbank loans only. 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.

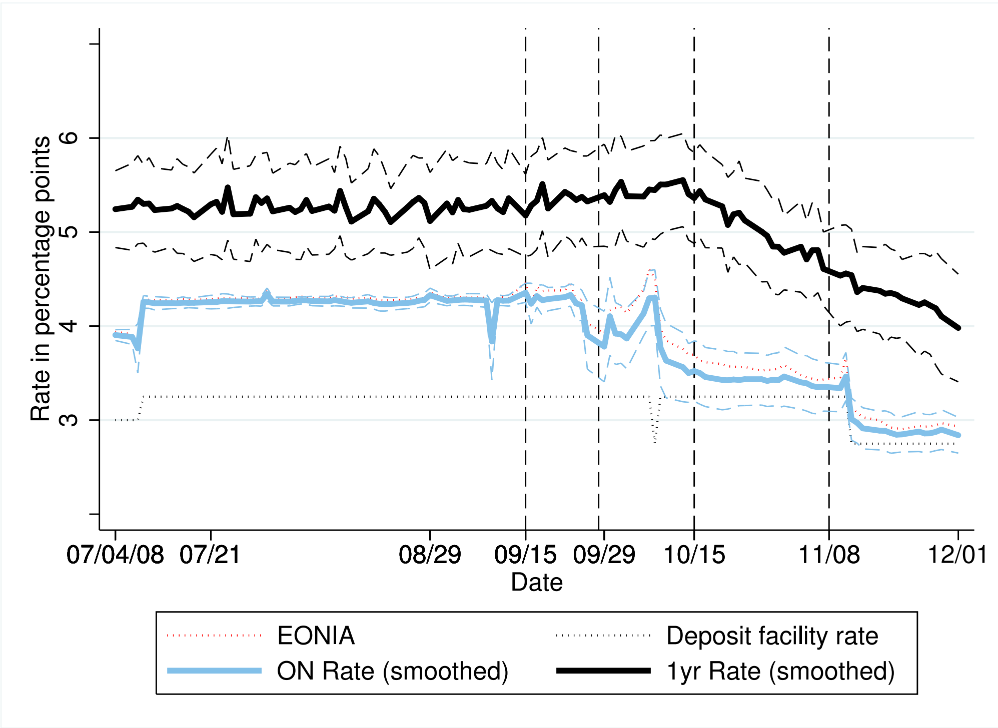

Figure 2: Smoothed mean daily price $\hat{p}_t$ of liquidity in the overnight (light blue line) and term segment (maturity more than three months, and up to one year; black line) of the euro area interbank market in our sample period in percentage points. Dashed black and light blue lines are the mean $\pm$ standard deviation of the daily price of liquidity in the overnight and term segment of the euro area interbank market. The dotted horizontal curve is the ECB deposit facility and dotted red line is the EONIA 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.

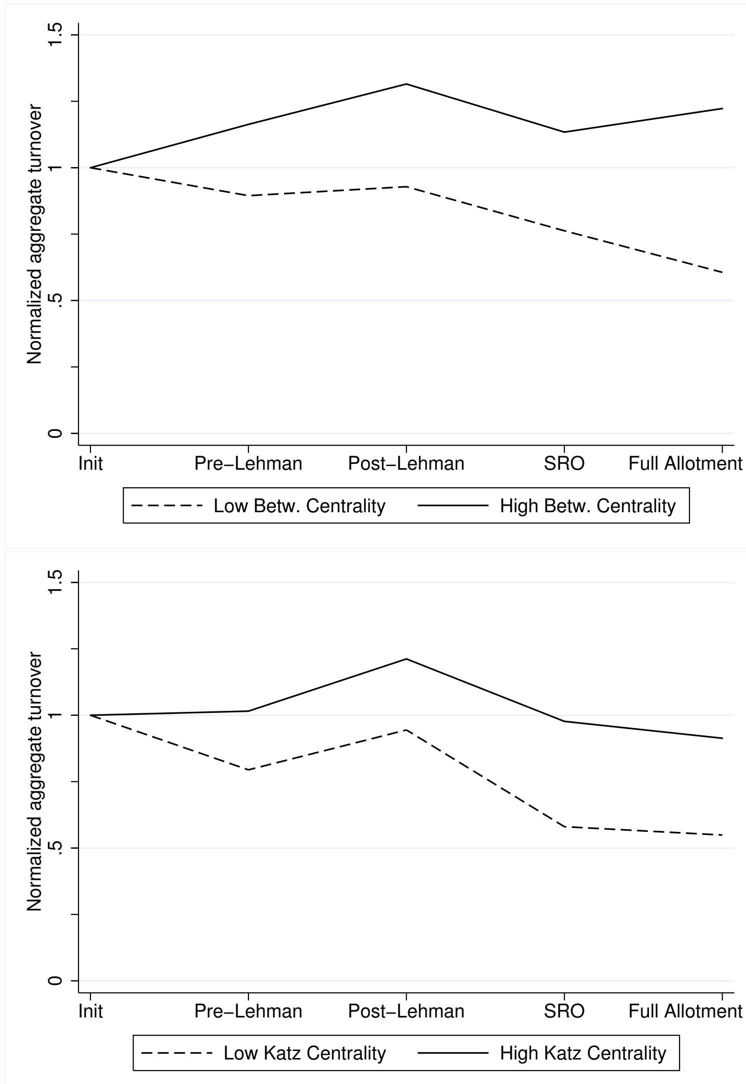

Figure 3: Normalized borrowing Amount$_{i,\tau}$ in the euro area overnight interbank market during our sample period in billion Euros, aggregated for five periods. Init (04 July - 21 July); Pre-Lehman (01 September - 12 September) ; Post-Lehman (15 September - 29 September); SRO (30 September - 14 October); 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.

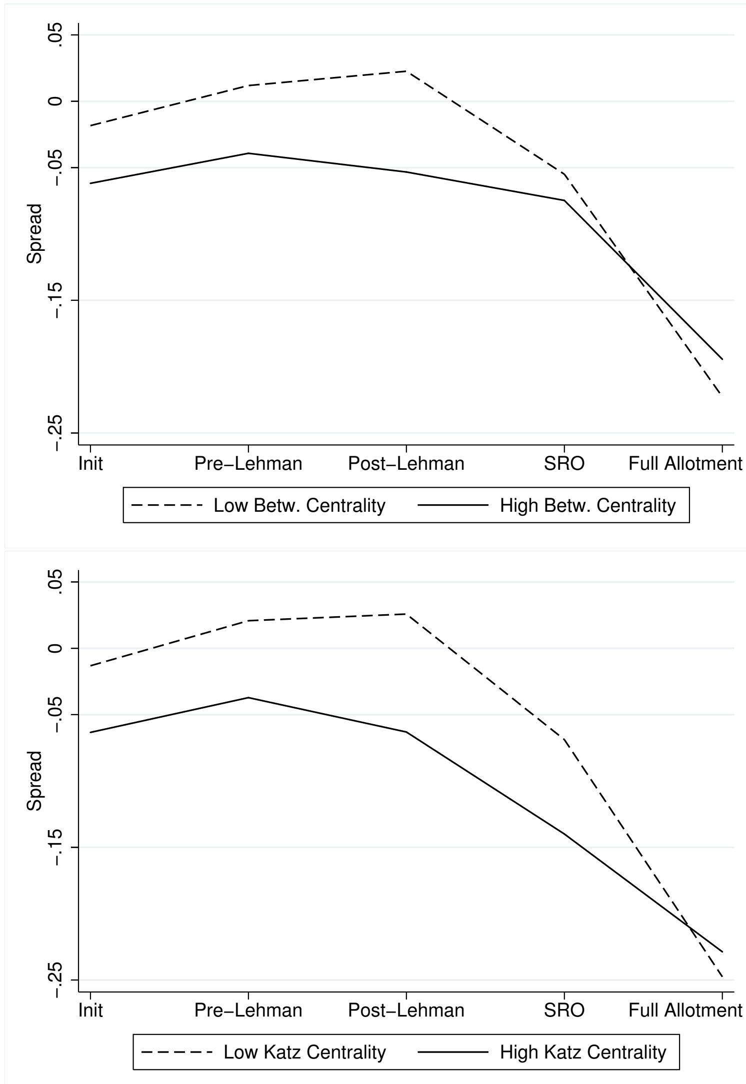

Figure 4: Volume-weighted Spread$_{i,\tau}$ banks pay for borrowing liquidity in the euro area overnight interbank market during our sample period in percentage points, averaged over five periods. Init (04 July - 21 July); Pre-Lehman (01 September - 12 September) ; Post-Lehman (15 September - 29 September); 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 Betweenness$_{i,\tau}$ centrality, bottom figure shows Katz$_{i,\tau}$ centrality.

A.2 Tables

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

	#Lender			Spread		
	Mean	Median	SD	Mean	Median	SD
Init	6.806	3.0	8.376	-0.032	-0.014	0.155
Pre-Lehman	6.335	3.0	7.589	-0.015	0.02	0.184
Post-Lehman	7.113	3.0	8.781	-0.064	0.0	0.267
SRO	6.174	3.0	7.615	-0.076	-0.109	0.404
Full Allotment 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 #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 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: 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 7: 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 8: 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.

Table 9: Amount Borrowed explained by Network Centrality

	Betweenness Centrality				Katz Centrality			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	4.144	2.979	17.085	41.273	5.959	5.819	2.423	38.930
	(43.949)	(43.976)	(37.042)	(38.677)	(26.498)	(26.352)	(27.579)	(26.330)
Post-Lehman	47.794	46.590	193.475***	117.080**	37.115	38.039	39.874	69.211*
	(48.461)	(48.506)	(56.851)	(52.655)	(46.934)	(46.617)	(48.324)	(38.619)
SRO	-64.534	-64.337	-65.149	0.776	-7.391	-5.526	-3.518	74.618***
	(65.112)	(65.010)	(65.812)	(60.031)	(34.314)	(34.151)	(34.876)	(23.151)
Full Allotment	-187.973**	-187.861**	-79.924	-4.739	-64.760*	-63.485*	-60.413	56.460**
	(73.647)	(73.710)	(62.765)	(63.004)	(38.551)	(38.154)	(39.142)	(23.226)
Relative Size	268.559***	170.202**	216.371**	-5.951	7.588**	6.759**	11.726	21.449***
	(95.026)	(68.952)	(100.112)	(48.032)	(3.827)	(3.386)	(8.761)	(6.625)
Loan Loss Reserves	-0.004	-0.005	-0.063***	-0.089***	-0.001	0.000	-0.001	0.000
	(0.004)	(0.005)	(0.021)	(0.026)	(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)
Centrality		36470.5***		37531.0***		6789.673***		8255.118***
		(7978.657)		(7172.540)		(870.122)		(1091.424)
(Centrality × Date)								
Pre-Lehman				-6796.209				-1147.377
				(5829.444)				(1260.523)
Post-Lehman				9015.173**				-825.757
				(3642.151)				(2232.239)
SRO				-16056.1***				-2329.405*
				(4901.424)				(1259.648)
Full Allotment				-19084.278*				-3480.702***
				(10021.6)				(1156.095)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	4348	7750	4348	4348
R^2 (within)	0.021	0.020	0.016	0.030	0.005	0.005	0.006	0.034
R^2 (between)	0.000	0.304	0.159	0.520	0.003	0.594	0.004	0.601
R^2 (overall)	0.019	0.193	0.219	0.349	0.003	0.362	0.004	0.373

Note: Models (1) - (4) use Betweenness as Centrality, while Models (5) - (8) use Katz as Centrality. The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. The centrality of bank i is computed during an initial reference period. 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 Spread explained by Network Centrality

	Betweenness Centrality				Katz Centrality			
	(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	-0.008
	(0.011)	(0.011)	(0.013)	(0.014)	(0.009)	(0.009)	(0.009)	(0.011)
SRO	-0.041	-0.041	-0.013	-0.023	-0.062***	-0.063***	-0.058	-0.076***
	(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)
Centrality		-1.870		-1.848***		0.352***		0.125*
		(1.174)		(0.713)		(0.116)		(0.066)
(Centrality × Date)								
Pre-Lehman				0.009				-0.010
				(0.349)				(0.053)
Post-Lehman				-1.672*				0.129
				(0.924)				(0.105)
SRO				1.978				0.551**
				(2.409)				(0.235)
Full Allotment				0.611				0.603**
				(3.196)				(0.257)
Controls × date	No	No	Yes	Yes	No	No	Yes	Yes
N	4348	4348	4348	4348	4348	4348	4348	4348
R^2 (within)	0.160	0.160	0.166	0.168	0.140	0.140	0.144	0.149
R^2 (between)	0.172	0.178	0.181	0.190	0.165	0.168	0.164	0.150
R^2 (overall)	0.131	0.134	0.140	0.145	0.121	0.127	0.123	0.132

Note: Models (1) - (4) use Betweenness as Centrality, while Models (5) - (8) use Katz as Centrality. 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. The centrality of bank i is computed during an initial reference period. 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: Summary Statistics for Section 6

Panel A – ON Segment

	Amount			#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	590.146	130.0	1104.222	6.335	3.0	7.589	-0.015	0.02	0.184
Monday 09/15	659.092	158.5	1243.87	7.018	4.0	8.209	0.123	0.102	0.11
Tuesday 09/16	642.428	173.9	1044.085	6.804	3.0	7.678	0.016	0.02	0.199
Post	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	505.625	150.0	944.405	5.087	3.0	5.767	-0.246	-0.309	0.247

Panel B – Term Segment

	Amount			#Lender			Spread			Maturity		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Init	150.04	33.2	341.768	2.547	2.0	2.797	0.04	0.007	0.093	36.488	19.0	50.758
Pre	132.666	30.74	271.567	2.366	1.0	2.813	0.047	0.008	0.11	38.802	17.568	56.591
Monday 09/15	93.262	22.0	201.497	1.941	1.0	1.741	0.06	0.019	0.119	69.769	30.0	90.054
Tuesday 09/16	60.979	30.0	85.024	2.0	1.0	1.675	0.071	0.014	0.143	39.994	24.25	51.728
Post	85.39	25.0	166.505	2.106	1.0	2.554	0.057	0.01	0.114	30.342	9.0	52.711
SRO	104.312	25.0	394.382	2.016	1.0	1.844	0.105	0.034	0.166	27.901	7.0	48.752
Full	88.516	28.5	169.046	2.005	1.0	1.824	0.068	0.006	0.139	35.797	8.333	61.607

Note: We take a borrower perspective, so that #Lender is the number of lender a bank borrows from. Spread is measured as the difference of average interest rate to the main refinancing rate. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

Table 12: The Impact of the Lehman Event on Borrowers.

Panel A: Overnight Segment

	Access	Amount		Spread		Counterparties	
	Probit	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pre-Lehman	-0.063*	-58.197	-90.941*	0.017**	0.023***	-0.471	-0.749**
	(0.033)	(50.054)	(48.808)	(0.007)	(0.005)	(0.328)	(0.320)
Monday 09/15	-1.546***	10.749	-56.962	0.155***	0.161***	0.212	-0.213
	(0.048)	(82.476)	(79.808)	(0.009)	(0.008)	(0.479)	(0.435)
Tuesday 09/16	-1.606***	-5.915	-99.624	0.047***	0.053***	-0.002	-0.774*
	(0.050)	(86.159)	(86.777)	(0.017)	(0.016)	(0.469)	(0.410)
Post-Lehman	-0.156***	22.931	18.294	-0.032***	-0.028***	0.307	0.334
	(0.033)	(63.386)	(63.810)	(0.010)	(0.010)	(0.387)	(0.387)
SRO	-0.142***	-77.988	-149.345*	-0.044**	-0.059***	-0.632	-1.071*
	(0.043)	(75.493)	(83.554)	(0.021)	(0.021)	(0.584)	(0.627)
Full-allotment	-0.230***	-142.718	-270.051***	-0.215***	-0.223***	-1.719***	-2.624***
	(0.048)	(88.907)	(101.591)	(0.022)	(0.021)	(0.557)	(0.635)
Fixed Effects	No	No	Yes	No	Yes	No	Yes
N	7,834	6,385	6,385	6,385	6,385	6,385	6,385
Adjusted R^2		0.002	0.533	0.096	0.384	0.006	0.628

Panel B: Term Segment

	Access	Amount		Spread		Counterparties	
	Probit	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pre-Lehman	0.042	-17.520	-17.849	0.009*	0.006	-0.183	-0.120
	(0.035)	(16.341)	(16.479)	(0.005)	(0.004)	(0.119)	(0.129)
Monday 09/15	-1.326***	-56.778**	-49.000**	0.031**	0.027*	-0.606***	-0.347**
	(0.062)	(23.959)	(24.324)	(0.015)	(0.016)	(0.181)	(0.148)
Tuesday 09/16	-1.610***	-89.061***	-92.879***	0.043**	0.043**	-0.547**	-0.533**
	(0.072)	(24.368)	(28.155)	(0.020)	(0.021)	(0.224)	(0.239)
Post-Lehman	-0.209***	-64.792***	-69.635***	0.019***	0.018***	-0.443**	-0.418*
	(0.036)	(21.292)	(23.635)	(0.006)	(0.006)	(0.187)	(0.225)
SRO	-0.174***	-45.204**	-55.014**	0.060***	0.056***	-0.530***	-0.554**
	(0.041)	(21.424)	(25.030)	(0.006)	(0.006)	(0.195)	(0.232)
Full-allotment	-0.116***	-60.446**	-75.820***	0.029***	0.028***	-0.506**	-0.619***
	(0.040)	(23.570)	(26.890)	(0.008)	(0.008)	(0.200)	(0.225)
Fixed Effects	No	No	Yes	No	Yes	No	Yes
N	5,450	3,646	3,646	3,646	3,646	3,646	3,646
Adjusted R^2		0.007	0.162	0.030	0.236	0.006	0.331

Note: Panel A (top) shows the reaction of the overnight segment of the interbank market to the Lehman insolvency, Panel B (bottom) the reaction of the term ($1d \leq$ maturity $\leq 1yr$) segment. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

Table 13: The Impact of the Lehman Event on Lenders.

Panel A: Overnight Segment

	Access	Amount		Spread		Counterparties	
	Probit	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pre-Lehman	-0.065**	-4.796	-1.885	0.084***	0.078***	-0.147	-0.148
	(0.032)	(22.871)	(24.657)	(0.004)	(0.005)	(0.131)	(0.129)
Monday 09/15	-1.563***	-8.827	-24.880	0.223***	0.222***	-0.102	-0.206
	(0.050)	(48.948)	(52.237)	(0.007)	(0.009)	(0.191)	(0.202)
Tuesday 09/16	-1.660***	-12.281	-2.338	0.049***	0.056***	-0.014	-0.200
	(0.050)	(55.425)	(51.206)	(0.015)	(0.016)	(0.187)	(0.191)
Post-Lehman	-0.144***	22.140	38.514	0.035***	0.040***	0.204	0.252
	(0.035)	(41.777)	(42.720)	(0.008)	(0.009)	(0.171)	(0.170)
SRO	-0.189***	11.673	-9.023	-0.227***	-0.233***	0.035	-0.109
	(0.038)	(37.332)	(36.659)	(0.016)	(0.016)	(0.157)	(0.159)
Full-allotment	-0.179***	-15.658	-42.869	-0.703***	-0.707***	-0.066	-0.219
	(0.040)	(31.809)	(37.056)	(0.017)	(0.017)	(0.188)	(0.196)
Fixed Effects	No	No	Yes	No	Yes	No	Yes
N	13,295	11,172	11,172	11,172	11,172	11,172	11,172
Adjusted R^2		−0.000	0.541	0.502	0.597	0.001	0.604

Panel B: Term Segment

	Access	Amount		Spread		Counterparties	
	Probit	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pre-Lehman	-0.041	3.949	2.339	0.026	0.038	-0.014	-0.018
	(0.042)	(14.294)	(12.705)	(0.038)	(0.042)	(0.081)	(0.086)
Monday 09/15	-1.485***	3.339	18.707	0.039	0.075	-0.055	-0.012
	(0.072)	(30.052)	(30.551)	(0.067)	(0.073)	(0.184)	(0.187)
Tuesday 09/16	-1.598***	-62.604***	-57.046*	-0.110	-0.080	-0.284**	-0.233*
	(0.077)	(17.507)	(29.449)	(0.071)	(0.075)	(0.144)	(0.140)
Post-Lehman	-0.377***	-11.797	-1.563	-0.011	0.029	-0.144	-0.149
	(0.051)	(19.898)	(14.231)	(0.040)	(0.049)	(0.099)	(0.104)
SRO	-0.289***	10.632	18.704	0.051	0.065	-0.182*	-0.106
	(0.050)	(22.536)	(21.499)	(0.043)	(0.047)	(0.104)	(0.079)
Full-allotment	-0.179***	-31.793*	0.189	-0.405***	-0.364***	-0.167**	-0.131*
	(0.053)	(16.683)	(12.205)	(0.041)	(0.045)	(0.076)	(0.078)
Fixed Effects	No	No	Yes	No	Yes	No	Yes
N	5,773	3,279	3,279	3,279	3,279	3,279	3,279
Adjusted R^2		0.002	0.344	0.069	0.188	0.002	0.183

Note: Panel A (top) shows the reaction of the overnight segment of the interbank market to the Lehman insolvency, Panel B (bottom) the reaction of the term ($1d \leq$ maturity $\leq 1yr$) segment. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

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B Supplementary Information – Not for Publication

B.1 Comparison of Direct and Indirect Access to Liquidity

While we are interested in studying the effect of a bank's network centrality on its access to liquidity, it is instructive to compare the effect of an increase in a global measure, such as network centrality, with the effect of an increase in local network measures, such as a bank's weighted and unweighted in-degree. All network variables are computed in an initial reference period to avoid issues of reverse causality.

Tables (14) - (17) show the estimates for model 20. 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 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.

As a robustness check, we also study access to liquidity measured as the number of counterparties a bank borrows from on a given day. We use model 20 and show the results of this estimation in Tables (18) - (21). 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.

Table 14: Amount Borrowed explained by In-Degree.

	(1)	(2)	(3)	(4)
Pre-Lehman	4.144	2.281	17.085	82.695*
	(43.949)	(43.863)	(37.042)	(42.716)
Post-Lehman	47.794	46.028	193.475***	138.676***
	(48.461)	(48.557)	(56.851)	(52.917)
SRO	-64.534	-64.118	-65.149	153.333***
	(65.112)	(65.235)	(65.812)	(53.861)
Full Allotment	-187.973**	-187.423**	-79.924	167.726**
	(73.647)	(73.800)	(62.765)	(68.119)
Relative Size	268.559***	141.206**	216.371**	-125.722*
	(95.026)	(58.392)	(100.112)	(70.645)
Loan Loss Reserves	-0.004	-0.005	-0.063***	-0.075***
	(0.004)	(0.004)	(0.021)	(0.024)
Assets	0.000	0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Degree		9.535***		11.090***
		(1.732)		(1.676)
(Degree × Date)				
Pre-Lehman				-2.278
				(1.399)
Post-Lehman				1.055
				(1.428)
SRO				-6.855***
				(1.852)
Full Allotment				-8.493***
				(2.303)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.021	0.020	0.016	0.043
R^2 (between)	0.000	0.355	0.159	0.549
R^2 (overall)	0.019	0.212	0.219	0.363

Note: The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. The explanatory variable is the number of banks bank i borrows from during an initial reference period. 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: Amount Borrowed explained by Weighted In-Degree

	(1)	(2)	(3)	(4)
Pre-Lehman	4.144	3.215	17.085	50.328
	(43.949)	(43.837)	(37.042)	(35.425)
Post-Lehman	47.794	47.216	193.475***	164.558***
	(48.461)	(48.538)	(56.851)	(51.169)
SRO	-64.534	-62.792	-65.149	112.429**
	(65.112)	(65.056)	(65.812)	(48.760)
Full Allotment	-187.973**	-185.630**	-79.924	95.413*
	(73.647)	(73.663)	(62.765)	(49.950)
Relative Size	268.559***	84.895*	216.371**	-286.201**
Loan Loss Reserves	-0.004	-0.004	-0.063***	-0.034
	(0.004)	(0.004)	(0.021)	(0.021)
Assets	0.000	0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Weighted In-Degree		0.065***		0.070***
		(0.015)		(0.016)
(Weighted In-Degree × Date)				
Pre-Lehman				-0.009
				(0.011)
Post-Lehman				0.009
				(0.014)
SRO				-0.045***
				(0.016)
Full Allotment				-0.060***
				(0.016)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.021	0.019	0.016	0.038
R^2 (between)	0.000	0.418	0.159	0.569
R^2 (overall)	0.019	0.251	0.219	0.374

Note: The dependent variable is $\text{Amount}_{i,t}$, i.e. the amount a bank i borrows on the interbank market on day t. The explanatory variable is i's total interbank borrowing Weighted In-Degree during an initial reference period. 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: Borrowing and Lending Spread explained by In-Degree.

	(1)	(2)	(3)	(4)
Pre-Lehman	0.025***	0.026***	0.024***	0.024***
	(0.005)	(0.005)	(0.006)	(0.008)
Post-Lehman	0.010	0.011	0.015	0.033**
	(0.011)	(0.011)	(0.013)	(0.015)
SRO	-0.041	-0.041	-0.013	-0.001
	(0.026)	(0.026)	(0.031)	(0.036)
Full Allotment	-0.246***	-0.246***	-0.229	-0.197***
	(0.029)	(0.029)	(0.036)	(0.043)
Relative Size	0.007	0.011**	0.011*	0.002
	(0.006)	(0.006)	(0.006)	(0.013)
Loan Loss Reserves	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)
Degree		-0.001***		0.000
		(0.000)		(0.000)
(Degree × Date)				
Pre-Lehman				0.000
				(0.000)
Post-Lehman				-0.001***
				(0.000)
SRO				0.000
				(0.001)
Full Allotment				-0.001
				(0.001)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.160	0.160	0.166	0.170
R^2 (between)	0.172	0.187	0.181	0.192
R^2 (overall)	0.131	0.142	0.140	0.152

Note: The dependent variable is $\text{Spread}_{i,t}$, i.e. the Weighted In-Degree-weighted spread a bank i pays for liquidity on the interbank market on day t. The explanatory variable is the number of banks bank i borrows from during an initial reference period. 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: Borrowing and Lending Spread explained by Weighted In-Degree

	(1)	(2)	(3)	(4)
Pre-Lehman	0.025***	0.025***	0.024***	0.026***
	(0.005)	(0.005)	(0.006)	(0.007)
Post-Lehman	0.010	0.011	0.015	0.027*
	(0.011)	(0.011)	(0.013)	(0.014)
SRO	-0.041	-0.041	-0.013	-0.012
	(0.026)	(0.026)	(0.031)	(0.033)
Full Allotment	-0.246***	-0.246***	-0.229	-0.214***
	(0.029)	(0.029)	(0.036)	(0.038)
Relative Size	0.007	0.011*	0.011*	0.002
	(0.006)	(0.006)	(0.006)	(0.014)
Loan Loss Reserves	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)
Weighted In-Degree		-4.2e-06**		0.000
		(0.000)		(0.000)
(Weighted In-Degree × Date)				
Pre-Lehman				0.000
				(0.000)
Post-Lehman				-3.7e-06**
				(0.000)
SRO				0.000
				(0.000)
Full Allotment				0.000
				(0.000)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.160	0.160	0.166	0.168
R^2 (between)	0.172	0.184	0.181	0.190
R^2 (overall)	0.131	0.140	0.140	0.148

Note: The dependent variable is $\text{Spread}_{i,t}$, i.e. the Weighted In-Degree-weighted spread a bank i pays for liquidity on the interbank market on day t. The explanatory variable is i's total interbank borrowing Weighted In-Degree during an initial reference period. 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: Number of Loans Obtained and Provided explained by Degree.

	(1)	(2)	(3)	(4)
Pre-Lehman	-0.335	-0.339	-0.350	-0.192
	(0.261)	(0.259)	(0.257)	(0.248)
Post-Lehman	0.328	0.323	0.302	0.337
	(0.268)	(0.267)	(0.310)	(0.317)
SRO	-0.056	-0.061	-0.242	0.718*
	(0.453)	(0.452)	(0.444)	(0.414)
Full Allotment	-0.736*	-0.737*	-0.739	0.654
	(0.440)	(0.440)	(0.513)	(0.438)
Relative Size	1.070***	0.636**	0.909***	-0.131
	(0.342)	(0.274)	(0.341)	(0.291)
Loan Loss Reserves	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)
Degree		0.062***		0.079***
		(0.014)		(0.015)
(Degree $\times$ Date)				
Pre-Lehman				-0.006
				(0.008)
Post-Lehman				-0.006
				(0.009)
SRO				-0.031***
				(0.009)
Full Allotment				-0.047***
				(0.009)
Controls $\times$ date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.015	0.015	0.041	0.082
R^2 (between)	0.003	0.397	0.002	0.317
R^2 (overall)	0.001	0.221	0.001	0.197

Note: 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. The explanatory variable is the number of banks bank i borrows from during an initial reference period. 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 19: Number of Loans Obtained and Provided explained by Weighted In-Degree

	(1)	(2)	(3)	(4)
Pre-Lehman	-0.335	-0.338	-0.350	-0.310
	(0.261)	(0.260)	(0.257)	(0.244)
Post-Lehman	0.328	0.325	0.302	0.430
	(0.268)	(0.268)	(0.310)	(0.297)
SRO	-0.056	-0.061	-0.242	0.285
	(0.453)	(0.453)	(0.444)	(0.418)
Full Allotment	-0.736*	-0.739*	-0.739	0.016
	(0.440)	(0.441)	(0.513)	(0.482)
Relative Size	1.070***	0.855***	0.909***	-0.130
	(0.342)	(0.305)	(0.341)	(0.306)
Loan Loss Reserves	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)
Weighted In-Degree		0.0003***		0.0004***
		(0.000)		(0.000)
(Weighted In-Degree × Date)				
Pre-Lehman				0.000
				(0.000)
Post-Lehman				-8.5e-5*
				(0.000)
SRO				-0.0002***
				(0.000)
Full Allotment				-0.0003***
				(0.000)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.015	0.015	0.041	0.074
R^2 (between)	0.003	0.165	0.002	0.091
R^2 (overall)	0.001	0.074	0.001	0.046

Note: 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. The explanatory variable is i's total interbank borrowing Weighted In-Degree during an initial reference period. 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 20: Number of Loans Provided and Obtained explained by Betweenness Centrality

	(1)	(2)	(3)	(4)
Pre-Lehman	-0.335	-0.336	-0.350	-0.313
	(0.261)	(0.260)	(0.257)	(0.260)
Post-Lehman	0.328	0.327	0.302	0.165
	(0.268)	(0.267)	(0.310)	(0.287)
SRO	-0.056	-0.059	-0.242	0.042
	(0.453)	(0.452)	(0.444)	(0.434)
Full Allotment	-0.736*	-0.737*	-0.739	-0.350
	(0.440)	(0.439)	(0.513)	(0.456)
Relative Size	1.070***	0.676**	0.909***	0.304
	(0.342)	(0.287)	(0.341)	(0.285)
Loan Loss Reserves	0.000	0.000	0.000*	-0.001*
	(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)
Betweenness		253.659***		297.845***
		(64.621)		(68.367)
(Betweenness × Date)				
Pre-Lehman				-10.101
				(31.786)
Post-Lehman				2.065
				(27.173)
SRO				-65.490*
				(38.226)
Full Allotment				-99.634**
				(41.214)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.015	0.015	0.041	0.057
R^2 (between)	0.003	0.389	0.002	0.323
R^2 (overall)	0.001	0.229	0.001	0.215

Note: 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. The explanatory variable is the betweenness centrality of bank i (both perspectives) during an initial reference period. 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 21: Number of Loans Obtained and Provided explained by Katz-Centrality

	(1)	(2)	(3)	(4)
Pre-Lehman	-0.335	-0.339	-0.350	-0.199
	(0.261)	(0.261)	(0.257)	(0.274)
Post-Lehman	0.328	0.325	0.302	0.237
	(0.268)	(0.268)	(0.310)	(0.301)
SRO	-0.056	-0.062	-0.242	-0.059
	(0.453)	(0.452)	(0.444)	(0.439)
Full Allotment	-0.736*	-0.741*	-0.739	-0.686
	(0.440)	(0.440)	(0.513)	(0.509)
Relative Size	1.070***	1.063***	0.909***	0.850***
	(0.342)	(0.333)	(0.341)	(0.330)
Loan Loss Reserves	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)
Katz		15.970***		16.394**
		(4.848)		(7.580)
(Katz × Date)				
Pre-Lehman				-7.322
				(5.495)
Post-Lehman				-0.103
				(5.216)
SRO				-7.751
				(7.388)
Full Allotment				-3.037
				(7.168)
Controls × date	No	No	Yes	Yes
N	4348	4348	4348	4348
R^2 (within)	0.015	0.015	0.041	0.045
R^2 (between)	0.003	0.048	0.002	0.013
R^2 (overall)	0.001	0.016	0.001	0.003

Note: 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. The explanatory variable is the Katz centrality of bank i (both perspectives) during an initial reference period. 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.

B.2 Do Borrower or Lender Characteristics Determine Liquidity Access or Provision?

Since we are interested in bank's access to liquidity via the interbank market during times of distress, we focus on those bank-specific measures that possibly affect how much liquidity a bank is able to obtain. The most straightforward such measures are a bank's balance sheet characteristics, introduced in Section 5. We focus on a bank total asset size and the amount of loan loss reserves, both measured at the end of 2007 and obtained from Bankscope.

Following Afonso et al. (2011) we estimate the following specifications:

$$\text{Access}_{i,t} = \beta(\text{Date}) + \delta(\text{Date} \times \text{Loan Loss Reserves}_{i,2007}) + \gamma(\text{Date} \times \text{Assets}_{i,2007}) + \epsilon_{i,t} \quad (21)$$

where $\text{Access}_{i,t}$ equals one if bank i borrowed on the interbank market on day t, i.e.:

$$\text{Access}_{i,t} = \max_j \{g_{ij,t}\}. \quad (22)$$

$\text{Assets}_{i,2007}$ are the assets of bank i at the end of 2007, and $\text{Loan Loss Reserves}_{i,2007}$ is the amount of loan loss reserves at the end of 2007.[25]

We also estimate an OLS regression for both maturity segments m (i.e. overnight and term, where term denotes all loans with a maturity longer than overnight and up to one year) with dependent variable $F^m_{i,t} = \{$amount borrowed, spread to the mean interbank interest rate, number of counterparties$\}$. The amount borrowed by bank i in maturity segment m at time t is defined as:

$$\text{Amount}^{\text{m}}_{i,t} = \sum_{j \in B_{i,t}} \text{Loan}^{\text{m}}_{ji,t}. \quad (23)$$

The amount of interbank liquidity is only one aspect of the intensive margin of obtaining interbank

[25] Loan loss reserves provide information on the perceived riskiness by banks of their loan portfolio: banks anticipating higher losses should hold higher liquidity buffers. We also used the ratio of non-performing to total loans and our results were qualitatively unchanged. The coverage of loan loss reserves is slightly better, though, so we use it in our main regressions.

liquidity. The other aspect is the price a bank pays for liquidity, measured as the spread to the main refinancing rate (in the overnight segment) or the average interbank interest rate (for the maturity segments). For each point in time t and each maturity segment we have a network G_t^{m}. Denote the price of a loan from i to j at time t with maturity m as $p_{ij,t}^m$ and the volume-weighted price in maturity segment m as $\widehat{\mathrm{p}}_{ij,t}^m$. Then:

$$\widehat{\mathrm{p}}_{ij,t}^m = p_{ij,t}^m \times \frac{\mathrm{Loan}_{ij,t}^m}{\sum_{j \in B_{i,t}} \mathrm{Loan}_{ij,t}^m}. \tag{24}$$

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

$$\mathrm{Spread}_{i,t}^{m,b} = \sum_{j \in B_{i,t}} \widehat{\mathrm{p}}_{ij,t}^m - \widehat{\mathrm{p}}_t^m. \tag{25}$$

where $\widehat{\mathrm{p}}_t^m$ is the average interbank interest rate in maturity segment m at time t, $\widehat{\mathrm{p}}_t^{\mathrm{m}} = \sum_i \sum_{j:i} \widehat{\mathrm{p}}_{ij,t}^m$.[26]

Using these definitions, we can specify OLS estimations that take borrower properties into account as:

$$\begin{aligned} F_{i,t} \quad = \quad & \beta(\mathrm{Date}) + \delta(\mathrm{Date} \times \mathrm{Loan\ Loss\ Reserves}_{i,2007}) + \gamma(\mathrm{Date} \times \mathrm{Assets}_{i,2007}) \\ & +\Theta\left(\frac{\mathrm{Amount}_{i,t}}{\mathrm{Assets}_{i,2007}}\right) + \alpha_i + \epsilon_{i,t} \end{aligned} \tag{26}$$

where $\mathrm{Amount}_{i,t}$ is the amount borrowed by bank i in both maturity segments and α_i are bank fixed effects. As before, the sample period runs from 04 July 2008 to 30 October 2008. In Tables (22) to (25) we split our sample in two subsamples based on banks' asset size. Large banks are in the upper tercile of the asset size distribution, while small banks are in the lower tercile. Furthermore, interacting the period dummies with borrower quality, measured by a bank i's loan loss reserves yields a triple difference-in-difference estimation that tests whether the interbank market has become

[26]The computation for the average interest rate was done in three maturity segment separately to ensure comparable results across maturities. Loans in the three segments have maturity m with: 1day $< m \leq$ 1week ; 1week $< m \leq$ 3month ; 3month $< m <$ 1year.Differently from the term maturities, the spread for the overnight maturity is defined relative to the main refinancing rate.

sensitive to bank characteristics post-crisis and whether the sensitivity is greater for large or small banks.

As pointed out by Afonso et al. (2011), if lenders respond to the crisis by hoarding liquidity, we would expect to find an aggregate decrease in amounts lent and worse performing banks lending less. If instead uncertainty about counterparty risk increases after a shock but banks can still discriminate between risks, then we would expect to find a large shift in the distribution of funds and rates in the cross section of borrowers and worse performing banks borrowing less and/or paying higher rates. The aggregate view of market developments taken so far allows us to exclude an aggregate decrease in amounts lent after the bankruptcy of Lehman (with the only exception of the reduction on Tuesday 09/16 in the term segment). Moreover, in Table 12 we saw that bank-specific characteristics drove a relatively high increase in overnight and term borrowing rates and a reduction in the number of counterparties from which banks could obtain liquidity. Only in the term segment these developments are associated to a generalized decrease in borrowed amounts. This overall picture seems consistent with an increase in counterparty risk in the euro area interbank market around the Lehman event, especially in the ovenight segment, and a more pronounced market freeze only in the term segment.

Tables (22) and (23) corroborate and shed further light on this picture. Access to the market is reduced on Monday 15 and Tuesday 16, and especially so for small borrowers and for the overnight segment (models (1) and (2)). In models (3) and (4) we add interactions of the period dummies with loan loss reserves as a proxy for borrower quality. The interaction terms reveal that large borrowers whose loan portfolio is riskier pre-crisis access the overnight market less, both around the Lehman event and afterwards. No such effect is visible for small borrowers. In contrast, in the term segment large, worse performing borrowers are found to actually increase their participation pre-Lehman and especially on Tuesday 16 September (model (7)). Evidence from Table (23) confirms that there was no decrease in amounts borrowed overnight around Lehman, not even for the worse performing banks. The significant and large coefficient on the large banks for the full-allotment period in model (3) tells us that it was large borrowers who strongly reduced their interbank funding after the Eurosystem switched to full-allotment operations in mid-October 2008. It were small banks that reduced their interbank funding in the term segment on Monday 15 September and in the full-allotment regime, instead.

Table (24) shows that both large and small banks see an increase in overnight spreads on Monday 15 September. However, the increase persists only for small banks on Tuesday 16 September, while large banks actually start borrowing at a discount, relative to the initial reference period, both in the post-Lehman period and especially after the ECB measures (SRO and full-allotment). When we add interactions of the period dummies with loan loss reserves, models (3) and (4), we still observe the increase in spreads on Monday 15 September (larger for small banks), but we do not see a significant deterioration of borrowing terms for small worse performing banks immediately after the Lehman event. The only significant and positive coefficient appears for the interaction between loan loss reserves and the SRO period dummy, which suggests that small banks with a riskier loan portfolio pre-crisis could not obtain all the liquidity they needed at the Eurosystem's special refinancing operation. For the term segment, models (5) to (8) show that immediately after the crisis the relationship between spreads and borrower quality was not significantly different from that for the pre-crisis period, i.e. interest rates in the term segment did not become increasingly sensitive to measures of borrower quality.

We find similar evidence in Table (25) for the number of counterparties a bank borrows from. The results do not provide strong evidence of a changed market sensitivity of to borrower size, nor to borrower quality immediately after the Lehman insolvency. The only significant and economically sizeable effect can be observed after the adoption of the full-allotment regime on 15 October, when large banks reduce the number of counterparties from which they borrow (-2.6 counterparties in model (1) and -3.4 in model (3)). A similar effect is found in the term segment, again for large banks, but this effect is not as large as in the overnight segment.

Overall, these tables do not show a drastic change in the distribution of loans and rates in the cross section of borrowers depending on borrower pre-crisis quality, at least not immediately after the Lehman insolvency. This does not mean, however, that the market was not sensitive to counterparty risks, as we have shown in the aggregate perspective in Table (12). In a situation of stress, lenders may rather start to manage their unsecured interbank exposures by the amount they lend to a particular bank or even whether they lend to a given bank at all. Bank-to-bank relationships may actually become more important for the lenders' decision because they convey *soft* information that cannot be otherwide obtained from pre-crisis balance sheets. But this means that a more granular analysis of bilateral links between banks is needed. This motivates our network view in the rest of the paper.

Table 22: Impact of Lehman Event on Borrower Access

	Overnight				Term			
	Large	Small	Large	Small	Large	Small	Large	Small
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	-0.107	-0.125*	-0.193**	-0.141	0.041	0.090	0.131	0.062
	(0.066)	(0.073)	(0.084)	(0.134)	(0.071)	(0.074)	(0.082)	(0.105)
Monday 09/15	-1.332***	-1.678***	-1.393***	-1.569***	-1.226***	-1.401***	-1.078***	-1.342***
	(0.112)	(0.098)	(0.131)	(0.154)	(0.129)	(0.121)	(0.174)	(0.173)
Tuesday 09/16	-1.409***	-1.760***	-1.484***	-1.784***	-1.669***	-1.639***	-1.437***	-1.462***
	(0.120)	(0.088)	(0.139)	(0.144)	(0.117)	(0.154)	(0.149)	(0.211)
Post-Lehman	-0.145*	-0.171**	-0.283***	-0.127	-0.182***	-0.156**	-0.251***	-0.089
	(0.080)	(0.071)	(0.094)	(0.126)	(0.065)	(0.075)	(0.072)	(0.102)
SRO	-0.055	-0.176**	-0.141	-0.108	-0.174**	-0.106	-0.181	0.002
	(0.097)	(0.088)	(0.115)	(0.139)	(0.080)	(0.081)	(0.114)	(0.117)
Full-allotment	-0.239**	-0.275***	-0.336***	-0.237	-0.060	-0.166*	-0.073	-0.188
	(0.106)	(0.096)	(0.128)	(0.162)	(0.083)	(0.093)	(0.114)	(0.134)
Pre-Lehman×Loan Loss Reserves			-0.00001**	-0.001			0.00002***	0.001
			(0.000)	(0.001)			(0.000)	(0.001)
Monday 09/15×Loan Loss Reserves			-0.00004*	-0.003			0.000	0.003
			(0.000)	(0.002)			(0.000)	(0.002)
Tuesday 09/16×Loan Loss Reserves			-0.00004**	-0.002			0.00005***	-0.001
			(0.000)	(0.002)			(0.000)	(0.002)
Post-Lehman×Loan Loss Reserves			-0.00001***	-0.001			0.000	-0.001
			(0.000)	(0.001)			(0.000)	(0.001)
SRO×Loan Loss Reserves			-0.00001**	-0.001			-0.000	0.001
			(0.000)	(0.001)			(0.000)	(0.001)
Full-allotment×Loan Loss Reserves			-0.00001***	-0.001			0.000	-0.000
			(0.000)	(0.002)			(0.000)	(0.001)
Fixed Effects	No	No	No	No	No	No	No	No
N	2,617	2,618	2,617	2,618	1,828	1,838	1,828	1,838

Note: Impact of the Lehman event on borrowers. Term segment includes all loans with a maturity of longer than one day and up to one year. Large (small) banks are in the upper (lower) tercile of $Assets_{2007}$. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

Table 23: Impact of Lehman Event on Amount Borrowed

	Overnight				Term			
	Large (1)	Small (2)	Large (3)	Small (4)	Large (5)	Small (6)	Large (7)	Small (8)
Pre-Lehman	-15.897	-31.272	-121.607	-19.971	-11.781	0.013	0.597	-1.826
	(83.580)	(27.379)	(122.829)	(44.188)	(20.781)	(3.789)	(24.867)	(4.006)
Monday 09/15	50.663	-44.416	162.055	4.311	-28.681	-7.505*	22.506	-11.111*
	(146.412)	(31.025)	(146.990)	(36.883)	(29.299)	(4.345)	(29.048)	(6.472)
Tuesday 09/16	-118.438	-62.499	270.409	-49.364	-25.449	-5.061	-26.910	-6.057
	(138.670)	(46.566)	(188.503)	(70.471)	(24.296)	(6.718)	(24.563)	(8.063)
Post-Lehman	99.841	-19.466	115.431	-19.180	-28.564	-3.491	-27.411	-5.027
	(101.786)	(27.104)	(107.064)	(37.730)	(23.021)	(3.947)	(23.565)	(3.719)
SRO	102.118	-41.257	-57.506	-13.249	-11.825	-5.289	-3.275	-6.106
	(108.614)	(32.738)	(105.887)	(42.819)	(24.458)	(3.808)	(28.265)	(4.552)
Full-allotment	-75.521	-46.039	-331.0**	-36.074	-30.793	-2.969	-6.050	-14.609***
	(125.772)	(27.985)	(134.859)	(40.637)	(31.499)	(3.707)	(28.912)	(5.524)
Pre-Lehman×Loan Loss Reserves			-0.004	0.008			0.001	0.014
			(0.021)	(0.205)			(0.005)	(0.051)
Monday 09/15×Loan Loss Reserves			-0.033	-0.272			-0.005	0.009
			(0.026)	(0.240)			(0.004)	(0.046)
Tuesday 09/16×Loan Loss Reserves			-0.056	0.139			-0.004	-0.008
			(0.042)	(0.316)			(0.006)	(0.157)
Post-Lehman×Loan Loss Reserves			-0.005	0.200			0.000	0.009
			(0.021)	(0.186)			(0.005)	(0.060)
SRO×Loan Loss Reserves			-0.004	0.044			-0.003	0.030
			(0.022)	(0.191)			(0.006)	(0.065)
Full-allotment×Loan Loss Reserves			-0.005	0.062			0.001	0.140*
			(0.022)	(0.199)			(0.006)	(0.081)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2,409	1,810	2,409	1,810	1,560	874	1,560	874
Adjusted R^2	0.770	0.595	0.776	0.645	0.757	0.545	0.761	0.545

Note: Impact of the Lehman event on borrowers. Term segment includes all loans with a maturity of longer than one day and up to one year. Large (small) banks are in the upper (lower) tercile of Assets_{2007}. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

Table 24: Impact of Lehman Event on Spreads

	Overnight				Term			
	Large (1)	Small (2)	Large (3)	Small (4)	Large (5)	Small (6)	Large (7)	Small (8)
Pre-Lehman	0.024***	0.020*	-0.000	0.049**	0.006	0.006	0.011	0.006
	(0.008)	(0.012)	(0.020)	(0.021)	(0.008)	(0.007)	(0.011)	(0.013)
Monday 09/15	0.157***	0.158***	0.142***	0.165***	0.005	0.064	0.008	0.092
	(0.011)	(0.021)	(0.026)	(0.037)	(0.011)	(0.056)	(0.015)	(0.095)
Tuesday 09/16	-0.021	0.133***	-0.007	0.125***	0.041	0.026	0.083	0.035
	(0.026)	(0.026)	(0.035)	(0.045)	(0.031)	(0.017)	(0.062)	(0.028)
Post-Lehman	-0.076***	0.025	-0.123***	0.018	0.017**	0.030**	0.030*	0.009
	(0.017)	(0.017)	(0.027)	(0.029)	(0.008)	(0.013)	(0.011)	(0.014)
SRO	-0.132***	0.061	-0.224***	-0.006	0.052***	0.061***	0.056***	0.070***
	(0.031)	(0.039)	(0.035)	(0.062)	(0.009)	(0.012)	(0.012)	(0.019)
Full-allotment	-0.296***	-0.126***	-0.358***	-0.119	0.031**	0.011	0.042**	-0.000
	(0.020)	(0.043)	(0.026)	(0.083)	(0.013)	(0.010)	(0.016)	(0.013)
Pre-Lehman×Loan Loss Reserves			0.000	-0.0003**			-0.000	-0.000
			(0.000)	(0.000)			(0.000)	(0.000)
Monday 09/15×Loan Loss Reserves			0.000	0.000			-0.000	-0.000
			(0.000)	(0.000)			(0.000)	(0.000)
Tuesday 09/16×Loan Loss Reserves			-0.000	0.000			-0.000005*	-0.000
			(0.000)	(0.000)			(0.000)	(0.000)
Post-Lehman×Loan Loss Reserves			0.000	0.000			-0.000001*	0.000
			(0.000)	(0.000)			(0.000)	(0.000)
SRO×Loan Loss Reserves			0.000	0.001**			-0.000	-0.000
			(0.000)	(0.000)			(0.000)	(0.000)
Full-allotment×Loan Loss Reserves			0.000	-0.000			-0.00002***	0.000
			(0.000)	(0.001)			(0.000)	(0.000)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2,409	1,810	2,409	1,810	1,560	874	1,560	874
Adjusted R^2	0.333	0.480	0.346	0.488	0.207	0.410	0.206	0.418

Note: Impact of the Lehman event on borrowers. Term segment includes all loans with a maturity of longer than one day and up to one year. Large (small) banks are in the upper (lower) tercile of Assets_{2007}. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

Table 25: Impact of Lehman Event on Number of Counterparties

	Overnight				Term			
	Large	Small	Large	Small	Large	Small	Large	Small
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pre-Lehman	-0.615	0.117	-1.206	0.550	-0.262	0.183	-0.056	0.408
	(0.468)	(0.576)	(1.053)	(1.163)	(0.185)	(0.304)	(0.261)	(0.591)
Monday 09/15	0.201	0.034	1.242	0.606	-0.566**	-0.143	-0.155	-0.026
	(0.780)	(0.621)	(0.895)	(1.153)	(0.219)	(0.303)	(0.260)	(0.489)
Tuesday 09/16	-1.316*	-0.283	0.430	0.128	-0.420	-0.032	-0.402	0.317
	(0.715)	(0.515)	(1.015)	(0.778)	(0.423)	(0.386)	(0.550)	(0.741)
Post-Lehman	0.628	0.450	-0.582	0.962	-0.585*	0.190	-0.298	0.580
	(0.457)	(0.363)	(0.983)	(0.687)	(0.298)	(0.467)	(0.277)	(0.838)
SRO	-0.551	0.415	-1.564	1.074	-0.858**	-0.098	-0.230	0.112
	(1.063)	(0.467)	(0.824)	(0.847)	(0.352)	(0.167)	(0.337)	(0.339)
Full-allotment	-2.615***	-0.081	-3.393***	0.450	-0.748**	-0.329	-0.453	-0.543
	(0.849)	(0.536)	(1.261)	(1.099)	(0.334)	(0.265)	(0.322)	(0.446)
Pre-Lehman×Loan Loss Reserves			0.000	-0.004			0.000	-0.002
			(0.000)	(0.006)			(0.000)	(0.003)
Monday 09/15×Loan Loss Reserves			-0.000	-0.006			-0.000	-0.001
			(0.000)	(0.007)			(0.000)	(0.003)
Tuesday 09/16×Loan Loss Reserves			-0.000	-0.004			-0.000	-0.005
			(0.000)	(0.004)			(0.000)	(0.005)
Post-Lehman×Loan Loss Reserves			0.000	-0.005			0.000	-0.005
			(0.000)	(0.004)			(0.000)	(0.005)
SRO×Loan Loss Reserves			0.000	-0.005			0.000	-0.002
			(0.000)	(0.004)			(0.000)	(0.002)
Full-allotment×Loan Loss Reserves			0.000	-0.005			0.00005**	0.002
			(0.000)	(0.006)			(0.000)	(0.003)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2,409	1,810	2,409	1,810	1,560	874	1,560	874
Adjusted R^2	0.735	0.722	0.738	0.724	0.453	0.275	0.494	0.267

Note: Impact of the Lehman event on borrowers. Term segment includes all loans with a maturity of longer than one day and up to one year. Large (small) banks are in the upper (lower) tercile of Assets_{2007}. The dates for the periods are as follows. Init: 04 July - 21 July; Pre: 28 August - 12 September; Monday: 15 September; Tuesday: 16 September; Post: 17 September - 29 September; SRO: 30 September - 14 October; Full: 15 October - 30 October.

B.3 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 2 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 liquidity provision and access 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. [27].

[27] 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

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):

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

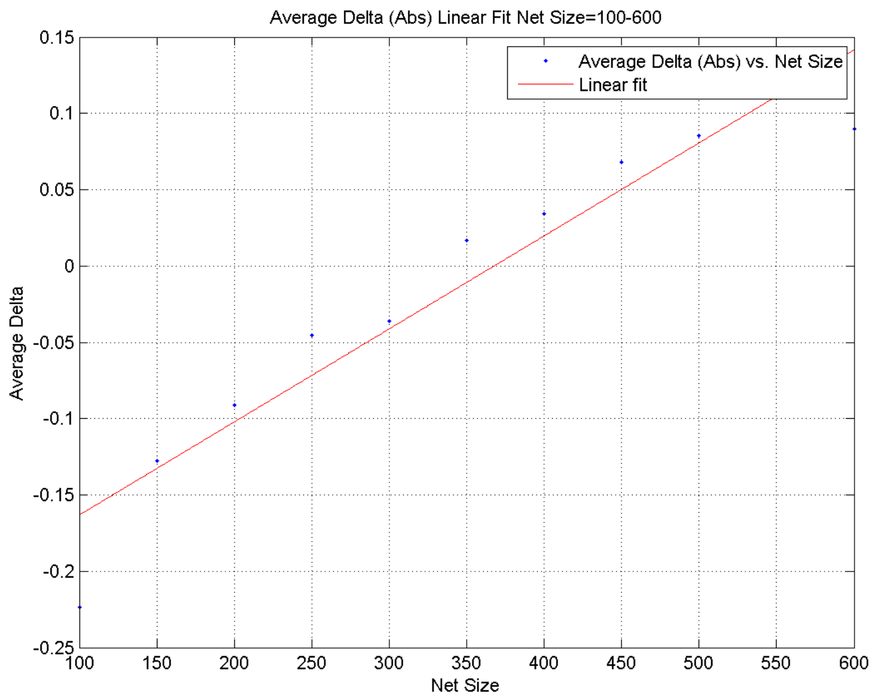
7. Calculate the mean of ΔC_r.[28].

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 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 5 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

[28]Technically, in the numerical simulation we compute three averages. First, we calculate the average change in the reference node centrality induced by othersâĂŹ 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.

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.



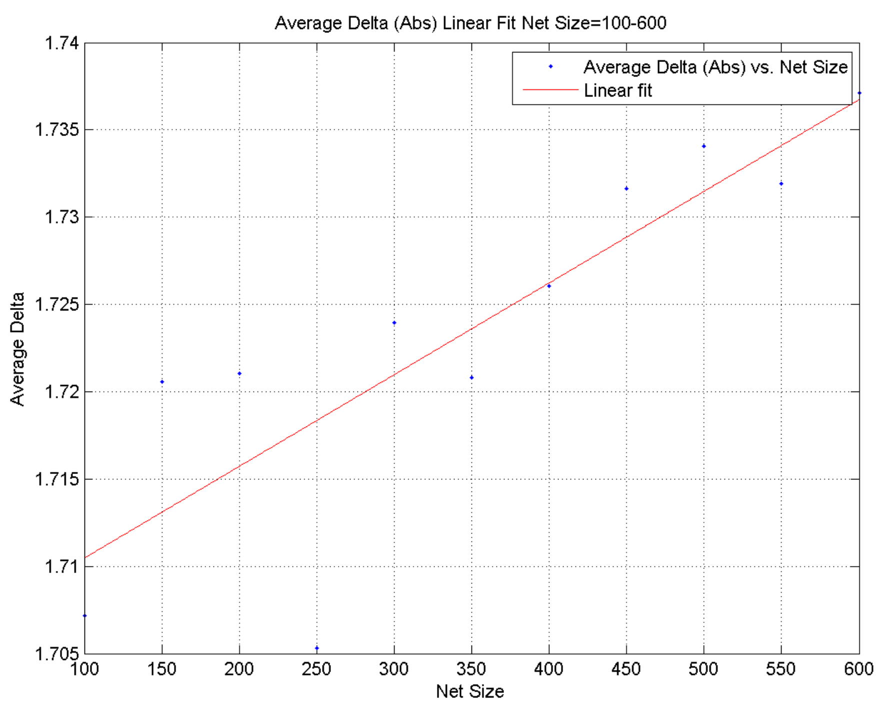


Figure 5: Mean relative change ΔC_r in node r's centrality versus network size. Mean is computed over $N_G = 100$ random draws, $N_r = 10$ random reference nodes that can randomly change $N_m = 10$ links, and $N_{-r} = 1$ random changes of links outside r's neighborhood. We use core-periphery network (top) and Erdös-Rényi network with rewiring probability equal to 0.8 (bottom).