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The Role of Interbank Relationships and Liquidity Needs

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In this paper, we focus on the interconnectedness of banks and the price they pay for liquidity. We assess how the concentration of credit relationships and the position of a bank in the network topology of the system influence the bank's ability to meet its liquidity demand. We use quarterly data of bilateral interbank credit exposures between all German banks from 2000 to 2008 to measure interbank relationships and the network characteristics. We match these data with the bids placed by the individual banks in the European Central Bank's (ECB) weekly repo auctions. The bids measure each bank's willingness to pay for liquidity since they had variable rate tenders with a "pay-your-bid" price. Controlling for bank characteristics and the daily fulfillment of reserve requirements, we find that banks with a more diversified borrowing structure in the interbank market bid significantly less aggressively and pay a lower price for liquidity in the ECB's main refinancing operations. These findings suggest that incentives to diversify bank liquidity risk dominate the benefits of private information. When the network position of the bank is taken into account, we find that central lenders in the money market bid more aggressively in the auctions.

Keywords: Interbank markets, liquidity, relationship lending, networks

JEL Codes: G21, E58, D44, L14, D85

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1 Introduction

A key strategy of the G20 for strengthening financial stability is to focus tighter regulatory requirements on financial institutions considered to be too big or too connected to fail. The recommended regulatory changes strive to contain the moral hazard resulting from the implicit insurance for investors. Indicators of the systemic importance of a bank typically include both claims against the bank and claims that it holds against other financial institutions.[1] The failure of a bank clearly imposes costs on its creditors, but why should its failure also impose costs on its borrowers?

The key reason that borrowers in the interbank market can suffer from a failure of their lender lies in the fact that relationships and private information matter. As Rochet and Tirole (1996) argue, private information and peer monitoring play an important role in interbank markets. If private information acquired through lending relationships allows an interbank lender to better assess the credit risk of his counterparty, borrowers of good quality should receive cheaper funding from their interbank relationship lender than from other banks. The failure of an interbank relationship lender results in the loss of valuable private information. The borrower bank might not be able to receive funding in the interbank market from other sources or might be able to receive it only at a mark-up. This difficulty might ultimately even lead to the failure of the borrower. Thus if relationship lending prevails in interbank markets, financial contagion not only affects lenders through credit default, it also endangers the stability of borrowers through the loss of information about them. Questions on the extent of private information and relationships in the interbank market are central to assessing the costs of a systemic bank failure.

On the other hand, a borrower will receive liquidity at favourable rates from his relationship lender only if the lender has the excess liquidity to lend. Consequently, in order to

[1] See, for example, Basel Committee on Banking Supervision (2011).

ensure a higher probability of receiving liquidity from informed lenders, banks might prefer establishing multiple credit relationships.[2] Moreover, a more diversified network of relationship lenders can mitigate the lock-in that might lead to higher borrowing costs.[3]

Being connected has implications for a bank that extend beyond simple relationship structures and access to private information about the banks with which they are immediately connected. Borrowing from a lender with a well-diversified network of lenders might ensure that the lender can also provide liquidity even though he has no excess reserves available himself. He might serve as an intermediary in the interbank market borrowing liquidity to lend it to other counterparties. But this intermediation in the interbank market also bring about systemic risk: As Allen and Gale (2000), Furfine (1999 and 2003), and others point out, a lending relationship exposes a bank not only to its immediate counterparty, but also to those counterparties that the bank's counterparty is exposed to. While these secondary links are not subject to the same monitoring that the primary relationship loans are, both types of links will expose the bank's lenders to systemic risks that should add to the cost of borrowing on the interbank market.

In this paper, we focus on relationships and connectedness in the interbank market and the price banks pay for liquidity. We try to assess the extent to which the concentration of a particular relationship or the multitude of established credit relationships influence banks' costs of meeting their liquidity demand. Using the structure of the interbank credit network, we can also identify banks that are central to the interbank market. This allows us to study the extent to which banks can cover their liquidity needs more cheaply if they rely primarily on the liquidity provision of money center banks. Furthermore, we use the centrality measures to estimate whether a bank's exposure to systemic risk increases its borrowing costs.

[2] Ashcraft and Duffie (2007) provide evidence for this argument for the U.S. money market.
[3] See Petersen and Rajan (1995) for a framework of credit market competition in bank-firm relationships.

Our data are particularly well suited to the question of the value of relationships in interbank lending markets. First, we use credit register data, which show interbank exposures exceeding 500.000 € for long maturities as well as short maturities. These data have several advantages compared to lending data backed out from payments data using the Furfine (1999) approach. First, our data also comprise interbank exposures of smaller banks that are not directly participating in the payment system. These exposures are not captured by the Furfine approach. However, relationship lending and private information about counterparty credit risk is likely to play a more crucial role for small banks. Second, the Furfine approach misses loans of longer maturities. However, the longer maturities are especially good at indicating a relationship between a bank and its lenders. Since they expose lenders to greater credit risk, lenders will be more careful in granting longer-term loans. Furthermore, lenders can monitor borrowers over the longer course of the loans and get regular information about how the borrowers meet their obligations in a wide variety of conditions. Thus the information advantage of lenders increases through longer-term loans.

We match the quarterly data of bilateral interbank credit exposures between all German banks from 2000/6 to 2008/3, taken from the credit register data of the Deutsche Bundesbank, to the bids placed by the individual banks in the European Central Bank's (ECB) weekly repo auctions. Since the main refinancing operations were held during our sample period as variable rate tenders and "pay-your-bid" auctions, they reveal each individual bank's willingness to pay for liquidity. Indeed, an important contribution of our study is that our bidding data allows us to perfectly separate demand and supply side effects. The bidding data not only permit us to measure the individual demand for one-week collateralized liquidity from the central bank. Since this demand schedule also reflects the (expected) opportunity costs of obtaining liquidity in other markets, it gives us an insight into the bidding banks'

entire demand for short-run liquidity.[4] Obviously, due to arbitrage considerations, the expected rate a bank has to pay in the unsecured interbank money market in the week after the ECB auction should determine a bank's willingness to pay for liquidity in the repo auctions. Moreover, also the expected opportunity costs of borrowing unsecured rather than obtaining eligible collateral in order to participate in the ECB's main refinancing operations should be reflected in the demand schedule that banks submit to the auctions. Thus we can directly assess what determines the level and slope of each individual bank's liquidity demand schedule while other studies relying solely on bilateral interbank lending have difficulty separating demand and supply effects when studying, for instance, the impact of lending relationships.

We find that banks with more concentrated borrowing in the interbank market bid significantly more aggressively in the ECB's refinancing operations, controlling for bank characteristics. This suggests that more diversified lending relationships reduce the opportunity costs of obtaining liquidity in the interbank market more significantly than establishing a close lending relationship with one or very few counterparties. When the entire network with all of the connections are taken into account, banks with a higher centrality in lending, i.e. banks that lend to many banks that are themselves central to the money market, tend to bid more aggressively in auctions. This might suggest that due to their higher systemic risk exposure these banks pay a higher risk premium when facing a liquidity shortage themselves. However, central borrowers paid a lower price particularly during the recent financial crisis. This is consistent with the fact that established borrowing relationships with money center banks (that were likely too big to fail) ensured a better intermediated access to liquidity. Those banks with close borrowing relationships to money center banks faced lower

[4] Several contributions show that the bidding behaviour of banks is indeed driven by their willingness to pay for liquidity, rather than by strategic considerations as regards to the auction outcome. In other words, banks' bids do not only reflect the marginal rate at which they expect to receive liquidity in the auction, much rather do banks' opportunity costs of obtaining liquidity in interbank markets determine their bidding behaviour. See , Bindseil, Nyborg, and Strebulaev (2009), Cassola, Hortaçsu, and Kastl (2013), and Abbassi, Fecht, and Weber (2014).

opportunity costs of obtaining interbank liquidity and consequently bid less aggressively. The effects of network position, while statistically significant and generally robust to changes in specification, are usually very small, whereas the relationship effects of the direct links are larger and more consistent before and during the crisis.

Our paper is most closely related to Braeuning and Fecht (2012). They also investigate the role of private information and interbank relationship lending for the access and price of liquidity in the German interbank market. But in contrast to our analysis they rely on bilateral overnight interbank loans retrieved with the Furfine approach from payment system data. Thus their analysis focuses on larger banks and shorter maturities for which private information about counterparty credit risk and relationship lending is likely to be less crucial. Furthermore, our paper is different from their study in that we focus on the effect that interbank lending relationships have on the demand schedules that banks submit to the ECB's liquidity auctions. Thus we can directly observe banks' liquidity demand schedules and better identify their determinants. In sum our data are better suited to provide comprehensive insights into the importance of relationship lending in the interbank market. Similarly, also other empirical studies that investigate the importance of private information and relationship lending in the interbank market for other countries rely on bilateral interbank loans. Cocco, Gomes, and Martins (2009) find with such data for the Portuguese interbank market that weaker banks rely more on lending relationships and pay lower rates for liquidity than they would otherwise when not borrowing from their relationship lenders. More recently Afonso, Kovner, and Schoar (2011) study relationship lending using bilateral interbank data from the federal funds market. They find that concentrated borrowers can easily get funds when needed and pay a significantly lower rate to their relationship lenders than they pay when borrowing from other market participants.

Our analysis builds largely on the approach taken by Fecht, Nyborg, and Rocholl (2011). They also examine German banks' willingness to pay for liquidity in the European Central Bank's (ECB) weekly repo auctions using the same set of bank characteristics and measures for individual liquidity shortages as we do but focussing only on the period before 2002. They also use this approach in order to study which banks expect higher opportunity costs of obtaining liquidity in other markets. However, in contrast to our analysis they do not consider bilateral interbank credit relationships and banks' positions in the interbank credit network as a determinant of banks' opportunity cost of obtaining liquidity.

A number of other papers study the determinants of banks' bidding behaviour in ECB auctions to assess banks' ability to obtain liquidity in other markets in a similar way. Craig and Fecht (2007) focus on the role of aggregate market conditions in various interbank markets for different banks' willingness to pay in the auctions. Linzert, Nautz, and Bindseil (2007) and Bindseil, Nyborg, and Strebulaev (2009) study the informational efficiency of the auction market with respect to the valuation of liquidity in subsequently interbank markets. Linzert, Nautz, and Breitung (2006) analyse how banks' characteristics relate to their bidding behaviour in auctions. In contrast to these papers we do not only include the role of connections in the interbank market as determinants for banks' bidding behaviour, we also study the bidding behaviour over a much longer period. This permits us to exploit in greater depth the time variation as well as to analyse the behaviour at the beginning of the subprime crisis.

Unfortunately there is no theoretical literature on the role of lending relationships in the interbank market. So we largely borrow from the theoretical models in a bank-firm context. Those models hypothesize that bank monitoring incentives lead to concentrated corporate borrowing (Holmstrom and Tirole (1997)) or to multiple banking whenever the benefit of greater diversification dominates the costs of free-riding (Carletti, Cerasi, and Daltung

(2007)). If concentrated borrowing leads to lower interbank borrowing rates (something we do not observe in our data), then by pure arbitrage considerations these lower opportunity costs of obtaining liquidity in the interbank market should be reflected in the lower rates that banks would be willing to bid for liquidity in the repo auctions held by the central bank. However, the borrowing structure is also determined by the financial health of the lender and her access to liquidity, where multiple banking relationships also allow borrowers to diversify their bank liquidity risk (see Detragiache, Garella, and Guiso (2000) and Ongena, Tümer-Alkan, and von Westernhagen (2012)). In this respect, diversification incentives would suggest an inverse (positive) relationship between borrowing concentration and banks' liquidity needs (as reflected in their willingness to bid). Having established several interbank credit relationships mitigates the dependency on an individual lender and might therefore improve access to interbank liquidity.

Finally, our paper is also related to the literature documenting increased systemic risk and contagion due to interbank linkages. Iyer and Peydro (2009), for instance, show that higher interbank exposure to a failed bank increases deposit withdrawals. The majority of the studies model the structure of the market by employing either payment data or balance sheet data to estimate interbank positions (see Furfine (2003), Bech and Atalay (2010), Upper and Worms (2004), and Degryse and Nguyen (2007) among others). Craig and von Peter (2010), on the other hand, develop a core-periphery model using German credit register data on bilateral interbank exposures. While our analysis does not make any inference on the contagion or systemic risk, we point to the implications of a bank being 'too connected-to-fail' and believe that it affects its liquidity needs and bidding behaviour. Our findings with the centrality measures also point to a conclusion where a higher degree of centrality in lending increases the willingness to bid. However, particularly during the crisis period, central borrowers in the money market bid less aggressively in the auctions, which might reflect the lower default probability due to being too-big-to-fail.

The remainder of the paper is organized as follows. In section 2, we introduce the institutional background of the German banking system and the European System of Central Banks (ESCB). In section 3, we describe the data, our empirical strategy, and our hypotheses. We investigate the impact of interbank relationships on bidding behaviour and present our findings in the fourth section. Section 5 concludes.

2 Institutional Background

The German universal banking system is structured along three pillars: commercial banks, cooperative banks, and public sector banks. By the end of 2007, German banks account for more than a quarter of the assets in the euro area-banking sector. There were 2,015 banks in the country, of which 1,234 were credit cooperatives, 458 public sector banks and 260 commercial banks. However, in terms of market shares, commercial banks account for 30 percent of all bank assets, whereas public sector banks account for 34.5 percent, and credit cooperatives together with their central institutions constitute only 10 percent.[5] While both the public and cooperative banks form a relatively closed giro system in which liquidity is reallocated, commercial banks rely to a larger extent on the liquidity provision of the formal interbank market.

Besides their need for working balances, banks' demand for liquidity in the euro area is driven be the required reserves that they have to hold as a monthly average with the European System of Central Banks (ESCB). All banks that are subject to these reserve requirements also have access to the ECB's standing facilities, i.e., the marginal lending facility as well as the deposit facility, and are eligible to participate in the ECB's repo auctions. During the period that we consider, these repo auctions were held as variable rate tenders. Each bank was

[5] Commercial banks include large commercial banks (Deutsche Bank, Dresdner Bank, Commerzbank, HypoVereinsbank), regional banks, and branches of foreign banks. The remaining 25.5% of the banking sector are mortgage banks, Bausparkassen (building and loan associations) and special purpose banks. However, all of those banks have very low reserve requirements and thus low demand for short-term liquidity. Therefore, we exclude them from our analysis.

allowed to place up to 10 bids in each auction, giving the interest rate the bank would be willing to pay for a loan of a certain size. The interest rate had to exceed a minimum bid rate, which was considered the key policy rate. The maturity of those collateralized short-term loans granted by the ECB was two weeks before March 2004 and one week thereafter. The ECB aggregated the individual demands for liquidity and calculated the marginal rate based on the market-wide demand and the amount the ECB intended to allocate. Bids at the marginal rate were served pro rata, bids with rates exceeding the marginal rate receive a full allotment, and bids lower than the marginal rate are not served. Banks in need of liquidity had an incentive to place a bid close to but slightly above the marginal bid rate. However, banks could not perfectly anticipate the marginal rate. Consequently, banks that must cover their liquidity needs in the auctions (rather than in the interbank market), placed higher bids to ensure that they received sufficient liquidity.[6]

At the marginal lending facility banks could borrow any amount overnight from the ECB, provided that they had sufficient collateral pledged with the ESCB. The deposit facility allows banks to deposit excess reserves with the ECB. In the period considered, the deposit rate is 100 bp lower than the minimum bid rate, and the marginal lending facility rate was 100 bp higher.

3 Data and Empirical Approach

3.1 Data Sources

We employ a unique dataset covering the period 2000 to 2008. The data are obtained by matching four major databases on the bank-date level. The databases are provided by the Deutsche Bundesbank and contain information on 1) German banks' bids placed in the ECB's

[6] Abassi et al. (2013) provide evidence that banks' bidding behavior reflects indeed their willingness to pay for liquidity rather than their ability to predict the marginal rate. They show that banks' bids are highly correlated with a banks' subsequent recourse to the marginal lending facility of the ECB (discount window).

weekly main refinancing operations, 2) interbank credit relationships derived from the German credit register, 3) balance sheet items from the Bundesbank's bank balance sheet statistics as well as 4) reserve holdings and reserve requirement for each German bank.

We use the bids a bank placed in the European Central Bank's (ECB) weekly repo auctions to derive measures for its willingness to pay for liquidity. The data on German banks are compiled by the Deutsche Bundesbank, as all monetary operations in the Eurosystem are conducted at the national level. We include the complete set of bids for all main refinancing operations (MROs) that are variable rate tenders held in our sample period.[7] The sample of auctions consists of 409 main refinancing operations with maturities of seven and fourteen days.

The Deutsche Bundesbank's credit register reports for each German bank all large exposures to individual financial and non-financial firms. Large exposures are defined as exposures of 1.5 million euros (formerly 3 million DM) and above. German banks are required to report exposures exceeding this threshold to the Deutsche Bundesbank on a quarterly basis.[8] We are able to identify both the borrower and the lender with a full counter-party breakdown, borrower identity, location, industry, legal form, and the date of bankruptcy (if applicable). Moreover, we can distinguish short-term exposures for interbank loans (up to one year) as well as on-balance sheet and off-balance sheet items. Since we are interested in bilateral bank relationships, we include only exposures to banks, and investigate at each borrower level in order to observe borrowing patterns in the interbank market. In addition to investigating direct exposures, we include information on financial networks in order to

[7] The ECB decided to change its auction procedure to a fixed-rate tender on 8 October 2008.
[8] For a more detailed definition, see Section 14 of the Banking Act (Deutsche Bundesbank, 2001). If the sum of the exposures to firms in a borrower unit exceeds the threshold, the individual exposures in that borrower unit are reported, even if it is a small exposure. For claims existing during the reporting period but partly or fully repaid, the remaining exposure is reported even if the amount is zero. This helps us to identify the existing bilateral relationships.

account for systemic importance in terms of both intermediation and tiering in the interbank market (see Craig and von Peter, 2010).

We match this dataset of borrower banks and their relationship structure to bank balance sheet data (*BISTA*), which include all banks in the German banking system. Finally, we employ reserve data for all German financial institutions in the industry available from 2004 to 2008. The data include each bank's cumulative reserve holdings on a daily basis and the reserve requirement for each maintenance period.

3.2 The Model

We explore the impact of interbank relationships on pricing by estimating

$$Pricing_{it} = \sum_{k=1}^{K} \beta_{1k} Relationship\ \&\ Centrality_{k,it-1} + \sum_{n=1}^{N} \beta_{2n} Accounting_{n,it-1} + \sum_{p=1}^{P} \beta_{3p} Liquidity_{p,it} + \beta_4 Auction_{jt} + \alpha_i + \varepsilon_{it} \quad (1)$$

where *Pricing* is measured by the bidding behavior (*Overbid*) and the price paid (*Overpricing*), respectively.

A potential problem with the identification strategy is that our *Relationship* and *Centrality* variables are endogenous and may capture banks' unobserved characteristics that would determine both this interconnectedness and banks' bidding behavior. We take advantage of information on bids from multiple points in time to use within group variation to control for individual bank effects. These panel methods help to eliminate the bias related to the omission of unobserved bank characteristics. We further exploit the differences in bank ownership, mainly focusing on state-owned banks in our OLS estimations. Due to implicit government guarantees for state-owned banks omitted variables that reflect the health of a bank play less of role. With a government guarantee, a change in the perceived riskiness of a

state-owned bank should not impede the banks' access to the interbank market. The increased riskiness should not force state owned banks to borrow more extensively from the ECB.

3.3 Variable Definitions

All variable definitions are displayed in Table 1. We categorize the set of dependent variables as *Pricing*; explanatory variables as '*Relationship* and *Centrality'*, *Bank variables* (*Accounting* and *Liquidity needs*) and *Auction* characteristics as presented in our empirical model.

3.3.1 Pricing measures

Our major interest is to measure the bidding behaviour, particularly its aggressiveness, of banks in repo auctions. By constructing our variables, we mainly follow the approach by Fecht, Nyborg, and Rocholl (2011), who explain auction pricing with bank and market characteristics.

We employ two measures computed using the bidding data. First, we calculate the *Overbid* (*Overpricing*) for each bidder by subtracting the Eonia swap rate from the weighted average rate bid (paid). The *Overbid* proxies for the willingness to pay, whereas the *Overpricing* is determined by the success of the bidding strategy, as it measures the price paid by bidders benchmarked by the market rate.

3.3.2 Relationship and Centrality Measures

We start by borrowing measures from the relationship lending literature to identify interbank relationships. Several proxies are used in empirical work to distinguish between relationship lenders and transactional lenders. These are the duration of the relationship between the firm and the bank, various loan categories, the number of creditors, and concentration of

borrowing[9] (see Boot (2000) and Petersen and Rajan (1994) among others; and Degryse and Ongena (2008) and Degryse, Kim, and Ongena (2009) for reviews). Studies on interbank relationships consider similar measures as in Furfine (2001) and Cocco, Gomes and Martins (2009). First, we measure banks' concentration of borrowing using the largest share of financing. We compute the share as the largest amount borrowed by bank *i* in quarter *t* relative to the overall amount borrowed by bank *i*. This measure gives us the information on the asymmetry in financing and the intensity of the relationship lending. We have information on the largest share in "on-and off balance sheet (BS) loans", in "on-BS loans", and "in short-term loans (up to one year)". We chose to report the results using on-balance sheet exposures, *MaxShare_onBS*, as our findings are mainly similar. Our second concentration measure is the Herfindahl-Hirschman Index (*HHI*) that captures the entire distribution of shares.

Our alternative measure for lending relationships is the number of lenders in the interbank market. *Number* is defined as the lagged value of the natural log number of lenders observed in on-and-off-balance sheet exposures. We also estimate our model using only on-balance sheet short-term exposures in the first part of the analysis, but we report only the former for brevity in the rest of our estimations. We take the lag of these measures in order to deal with the differences in the frequency of data.[10]

We hypothesize that banks that cannot benefit from relationships in interbank lending will turn to the primary market for their liquidity needs and bid more aggressively compared with other banks. If the same mechanism operates as in bank-firm relationships, that is close ties facilitate monitoring, then the degree of the intensity of relationships, i.e., a lower *Number* or higher *MaxShare_onBS* and *HHI*, should lead to lower bid rates. On the other hand, if for example screening costs are prior to invested fixed costs, then all that matters is that there is a

[9] Elsas (2005) finds evidence of a strong connection between the share of financing and the probability of (self-assessing) being the relationship lender.

[10] Pricing variables are measured on a weekly basis, whereas balance sheet variables are monthly, and the credit register consists of quarterly data. We further take the four consecutive lags of the largest share to take the average on a rolling window. Results remain unchanged.

relationship and not its intensity. The *Number* should have a negative impact on banks willingness to pay for liquidity in the ECB's auctions.

These measures of interbank relationships indicate the degree of direct connectivity of a bank with other banks. But they do not really capture the connections with the rest of the system through banking intermediaries. With our information about all of the bilateral exposures among all German banks, we can construct the entire network of interbank credit relations, and study not only the impact of direct but also indirect interbank lending relations.[11]

To measure the connectivity of an individual bank to the rest of the interbank network, we calculate for each bank a classic centrality measure first introduced by Bonacich (1987). This measure adds the number of interbank credit relationships (weighted by the amount of the bilateral exposures) through which the bank is connected to every other bank in the system. A bank is more central the more interbank credit chains link it to other banks. Consequently, a bank is considered as more central if it is linked to other more central banks (see Appendix A for a more detailed description of the Bonacich centrality measure).

Obviously, the interbank network is a directed network since each credit relationship involves a borrower and a lender. We can define centrality measures for both borrowing and lending. A high *Bonacich in* centrality figure for a particular bank suggests that this bank borrows from many banks that are also centrally located in the network, i.e., these are lenders that borrow themselves in the interbank market and borrow mostly from other banks that also serve as intermediaries in the interbank market. In contrast, a high *Bonacich out* centrality measure for a bank indicates that this bank lends heavily to banks that are themselves lending to those banks that function as intermediaries in the interbank market.

[11] See Craig and von Peter (2010) for a detailed explanation on the network structure of German banks.

Although the *Bonacich in* and *out* measures have distinct concepts, they are both driven by banks that serve as intermediaries in the interbank market. So it is not surprising that they have a fairly high correlation coefficient. We use this measure because it has an interpretation in terms of intermediation exposure (see Bonacich (1987) for other examples of flows and connection that the measures illustrate.)

3.3.3 Control variables

We control for bank characteristics using balance sheet variables and reserve data. To control for potential size effects we use *Size*, defined as Log of total assets. We include *Interbank_borrowing*, defined as overall interbank borrowing to total assets, in order to capture banks' dependency on funding from the interbank markets. As measures for bank health we include *Equity* ratio, which is based on the monthly balance sheet statistic. In addition, we use the *ROA* and *NPL*. However, these variables are only available on an annual basis. To account for the liquidity position, we make use of the daily fulfillment of reserves one day before the auction, normalized by the number of days left to the end of the maintenance period.

$$fulfill_{ijp} = \frac{\left[daily\ holding_{ijp} \Big/ cumulative\ required\ reserves_{ijp} \right]}{days\ left_{jp}} \qquad (2)$$

where *fulfill* is measured for bank *i*, auction *j* and maintenance period *p*. We also control for the liquid assets the bank holds (as a fraction of its Total Assets), denoted as *Security Holdings*.

In addition, we control for *due*, the maturing repo amount of the previous auction divided by total assets of the bank. Finally, we include *announced*, defined as the natural logarithm of the amount that the ECB announced before the MRO to allot in the auction. This should capture the price and quantity expectations of the participants.

3.4 Summary Statistics

The first set of (pooled) summary statistics are displayed in Table 2. We observe certain distinct features of bidder banks in comparison to the entire sample. They are larger on average, borrow more in the interbank market and hold a higher fraction of liquid assets. Not surprisingly, bidder banks have a higher number of interbank relationships and are slightly more concentrated in borrowing when the largest share is taken into account.

Table 3 presents information on the bidding behavior and relationships over time. Mean values for bid rates and price paid increase significantly in 2008, while from 2001 to 2007 banks tend to bid below the Eonia swap rate on average. Concerning relationships, the variation in Number is quite large both over time and cross-section. Concentration measures do not vary much over time, while slightly increasing in the last two years.

We further explore the banking groups in Table 4. Commercial banks have a higher number of relationships and are also less concentrated than state-owned banks and cooperative banks where the latter two groups tend to have concentration measures that are normally distributed.

4 Results

Table 5 reports the fixed-effects panel estimation results explaining *Overbid.*[12] The first set of specifications (the first four columns) cover the entire period from 2000 to 2008. The second set (starting with column 5) covers the period from 2004 to 2008, since these specifications include two new variables in the model that are only available after 2004: *fulfill*, daily fulfilment of reserves, and *announced*, the announced amount to be allotted before the

[12] We also estimate our model using a pooled panel. The results are unaffected.

auction. We focus our discussion on the second set of results since these two variables are important determinants of the liquidity needs of banks.

In the first specifications, we investigate the impact of concentration of borrowing by employing *MaxShare_onBS,* (the largest share in on-BS loans), *Number* (number of lenders for all relationships) and *HHI*. The results are not in line with the relationship lending literature, where close relationships imply a higher credit availability, which would decrease the willingness to pay/bid for liquidity in this framework. Having a more concentrated borrowing structure or a lower number of lenders leads to a higher bid rate on average. For instance, one standard deviation increase in the concentration of borrowing (number of lenders) increases the bid rate by 0.3 to 0.4 basis points (4.2 basis points) over the swap rate. This finding suggests that banks may prefer to diversify. Having a larger number of relationship lenders increases the chances that one of the lenders indeed has excess liquidity that it could lend. Moreover, increasing the number of credit relationships reduces the lenders' market power. Since monitoring intensity is expected to be higher with a more concentrated borrowing structure, the lock-in is more severe and the lender might charge a mark-up, inducing her to bid also more aggressively in an ECB auctions.

We further take the overall interconnectedness of the nodes into account using the *Bonacich* centrality measure. As described above, this measure rates how central a node is through the number of connections (weighted by the amount of bilateral exposures to other connected banks). We include *Bonacich in* and *Bonacich out* measures as alternative measures to our relationship variables in the fourth specification. We find that only *Bonacich out,* measuring centrality in lending, is significantly positive in explaining *Overbid*. In other words, being a well connected lender who lends to borrowers that are themselves central lenders increases the willingness to bid for a bank. This is what we would expect in terms of the increased systemic risk faced by banks that are exposed to banks that are themselves

exposed to more borrowers. Because of these central exposures, the lenders must themselves pay a higher price for liquidity. The estimated coefficient indicates that banks with a substantial exposure to systemic risk must pay a higher risk premium when covering their own liquidity needs.

In the last three specifications, we examine the interbank position for a given borrowing structure by including centrality measures together with our relationship variables. [13] Moreover, we would like to account for multiple banking relationships with asymmetric financing since we believe that the share of financing and the number of bank relationships do not necessarily capture the same characteristics of a borrowing structure.[14] Therefore we include them together in Specification 9 . We also consider the fact that our alternative concentration measure *HHI* is a function of both "shares in financing" and "number of relationships". Hence we choose the model that includes *HHI* as our benchmark model in the rest of the analysis.

Most coefficients support the results in previous specifications. However, the share of financing is no longer significant while *Number* remains unaffected in this new specification. Banks with a higher *HHI* bid higher rates in an ECB auction. The increase in the willingness to pay for liquidity in the auctions due to lending to more systemically relevant banks remains stable when controlling for the positive diversification effect of direct lending relationships. This confirms our reading that it is indeed the exposure to systemic risk why the *Bonacich out* matters for the banks' opportunity costs of obtaining liquidity.

With respect to our bank control variables we find that banks that refinance a larger share of their balance sheet in the interbank market pay less for liquidity. Seemingly this also reflects the fact that these banks have a better access to the interbank market and are less

[13] Considering that *Bonacich in* and *out* are highly correlated as well, we reestimate the same model with the share of financing and *Bonacich out* only. The results remain unaffected.
[14] The variables are not highly correlated.

dependent on liquidity obtained from the ECB.[15] Banks with a large portfolio of marketable (and thus in principle liquid) securities have a lower willingness to pay for liquidity. Rather than borrowing from the ECB or in the unsecured interbank market these banks can obtain liquidity through asset sales or secured interbank borrowing involving no credit risk premium. These results are all consistent with what we would expect from our explanation above. Somewhat surprising is though our finding that better capitalized and larger banks pay more for liquidity. However, this can be explained in terms of an endogenous capital ratio. Riskier banks might need a higher equity ratio at the same time that they pay an elevated credit risk premium in the interbank market. This increases their willingness to pay for liquidity in the auctions. There remains only one control variable that is difficult to explain. It is still puzzling that banks with more non-performing loans pay less for liquidity.

The higher the maturing repo amount, the more aggressive the bank will bid in an auction. Moreover, when short in liquidity to fulfil their reserve requirements, banks place significantly higher bids. Having a concentrated borrowing structure increases this effect (see column 9 and 10). We also include the volatility of the Eonia rate, as it potentially influences the ability of anticipating the final auction outcome. This allows us to control for bid-shading effects that might distort the information content of a bank's submitted demand schedule about its borrowing costs in the market. Indeed our results indicate that a higher uncertainty about the interbank rate is associated with a higher willingness to pay for liquidity in the auctions. In addition, we control for the effect of the crisis, which includes the period from July 2007 to the first quarter of 2008.[16] Not surprisingly, we document that both higher volatility and being in the crisis period have a positive impact on the bid rate. We also interact the *HHI* with the crisis dummy to investigate the role of borrowing relationships during the

[15] While the results are statistically less significant for the bidding behavior, they are more robust for the overpricing.
[16] In July 2007, IKB announced that it had been affected by the subprime mortgage crisis in the U.S. and had to be bailed out in August 2007. Hence, we take the end of July as the starting point of the turmoil in the German market.

crisis. The result suggests that the impact is much stronger in adverse times. More concentrated borrowing increased the value of liquidity during the crisis.

Table 6 presents the results explaining *Overpricing*, defined as a weighted average rate paid minus the swap rate. The results are in line with the previous finding, suggesting that banks end up paying higher interest rates when they rely on concentrated borrowing. However, the centrality measure does not determine the price paid. We also note that *Overpricing* is determined by the bidding strategy and the auction outcome together. In other words, while it also reflects the bidding behaviour, it is an equilibrium value and is affected by several factors, including the ECB's policy and other participants' bidding strategies that are endogenous. Thus, we believe that *Overbid* is a better and a cleaner measure to identify the aggressiveness of the bidders related to their liquidity needs.

All of the results in this section and in the subsequent section have been subjected to considerable robustness checks. For example, we included only those bids that were made at the end of the quarter so that they match up more exactly with the quarterly data from the credit register. These results are reported in Table 9 at the end of the paper. Based on a sample more than ten times smaller than the original sample, we lose significance for our relationship variables and most bank characteristics. However, banks still place significantly higher bids in the auctions when short on liquidity to fulfill their reserve requirements. Having a concentrated borrowing structure continues to increase this effect.

Other robustness checks include using only a subsample of banks whose interbank lending from foreign sources is less than 30% of their interbank lending (to account for the fact that our sample only includes domestic lending sources.) They also include a different

liquidity measure that aggregates both cash and securities. All of these results remain substantially the same as those reported here in spite of fairly large changes in the sample.[17]

4.1 Selection Model

In this section, we consider a bank's decision to participate in an auction since it is very likely that this decision is not random and may be determined by certain bank characteristics including banking groups. Therefore, we would like to correct for a potential selection bias by estimating a standard Heckman (1979) selection model. Table 7 presents our findings on both *Overbid* and *Overpricing*.

Starting from this point, we use only the *HHI* as our relationship measure. In the first stage, we estimate a *probit* model for the decision to participate in an auction. In the second stage, i.e., the selected sample, we explain bidding behaviour using our benchmark model and include the inverse Mills ratio obtained from the first stage to correct for any selection bias. We find that *HHI* and network variables do not have any influence on the decision to participate. In the second stage, before reporting the fixed effects estimations, we also report OLS results. The OLS approach permits us to include variables that are not varying over time, such as bank type. The German banking system consists of three pillars with commercial banks, state-owned banks and cooperative banks.[18] Moreover there exist several other subcategories like regional banks as well. However, we would like to focus on the role of state ownership due to differences in solvency risk, and include a single dummy, *state-owned banks*, equal to one if the bank is a state-owned bank, and zero otherwise.[19]

[17] These results are available from the authors on request. We thank an anonymous referee who suggested some of the robustness checks.
[18] See Section 2 for detailed information.
[19] In a previous version of this paper, we included more subcategories, such as regional banks, savings banks, Landesbanken and cooperative banks. We found that main influence on the bidding behavior is determined by state-owned banks.

In line with previous results, banks with a more concentrated borrowing structure bid significantly more aggressively, contradicting again the findings of studies on the importance of relationships in the interbank market. Centrality measures seem to matter only in fixed effects estimations. *Bonacich in* inversely affects both pricing measures, while the magnitude is close to zero. *Bonacich out* is consistent with previous results.

Larger banks with a higher level of interbank borrowing and security holdings are more likely to participate in auctions. State-owned banks are less likely to participate and tend to bid lower rates compared to commercial banks. Liquidity needs also play a role in the decision to participate, not different than the influence on the bidding behavior. The signs and statistical significance for most of the parameters in the second stage remain almost unchanged compared to the previous section. We find that a higher volatility in the market increases the willingness to participate as well.

4.2 State-owned banks and the crisis

In this section, we explore how the bank type would affect the link between interbank relationships and the bidding behaviour. We follow the same approach in the previous section and include a dummy for state-owned banks in the model and interact it with *HHI*. We do so in order to assess the relevance of an omitted variable bias. In contrast to other banking groups, state-owned banks are government guaranteed. Thus changes in their perceived credit risk should not matter for their availability and pricing of interbank credit. Thus when the health of state-owned banks weakens it should not force the bank to rely more on its interbank relationship borrower while at the same time also borrowing more extensively from the ECB.[20] The results are reported in the first two columns of Table 8. While being a state-owned bank mitigates the effect of concentrated borrowing on the willingness to pay before

[20] A problem with this argument though is that because of state guarantees, relationship specific information about the borrowers' quality does not play an important role. Thus we might find that relationship variables matter less for state-owned banks.

the crisis, state-owned banks bid still more aggressively if they have a concentrated borrowing structure. Summing up the coefficient of the interaction term and the coefficient of *HHI* gives for both estimates an overall positive effect. Thus while possibly contributing to the magnitude of our previous results an omitted variable bias cannot explain our findings entirely. This is further confirmed if we look at the split sample (see columns 3 & 4 and 5 & 6, respectively). During the financial crisis when omitted variable problems should have been most severe the bidding behaviour of state owned bank was not significantly differently affected by changes in the concentration in the borrowing structure. In addition we find that concentration of borrowing has a stronger impact on Overbid during the crisis. However it no longer determines the price paid in the crisis. *Bonacich out*, measuring centrality in lending, is significantly positive in explaining *Overbid* , and this effect seems to be driven by the crisis. This is in line with our previous findings and consistent with the idea that centrality in lending measures a bank's exposure to systemic risk, and affects its ability to obtain liquidity. Banks that are more exposed to systemic risk bid relatively more aggressively during the crisis.

5 Conclusion

During the financial crisis, several developments affected institutional structures in the interbank market. The increase in counterparty risks led to a substantial rise in secured interbank lending relative to uncollateralized interbank loans. The ECB temporarily decided to reduce the difference in interest rates between the two standing facilities. Moreover, due to the ECB's massive liquidity injections, the ECB became a major intermediary for the euro area interbank market. While these developments presumably reduced the risk of domino effects in the banking sector, their overall welfare implications are far from being fully understood. As a single example, it is still unclear to what extent these developments weakened market discipline in the interbank market.

In this paper, we try to contribute to a more profound understanding of these issues. In particular, we study to what extent relationship lending prevails in the German interbank market. To our knowledge, only a few papers investigated relationship lending in the interbank market so far. Cocco, Gomes and Martins (2009), for instance, find that relationships affect banks' ability to borrow in the interbank market.

We find that having established lending relationships with many lenders in the interbank markets provides borrowers with a more diversified source for liquidity. In addition, a more equal distribution of borrowing across lenders also improves borrowers' diversification. Both foster banks' access to liquidity and lead to lower bid rates of banks that participate in an ECB's refinancing operations. The observation that established relationships matter for the price banks pay for liquidity suggests that indeed private information available to relationship lenders plays an important role in the allocation of liquidity and the price banks pay for covering their liquidity needs.

When the network structure of the interbank market as a whole is taken into account, we find that banks that lend not only to many banks but particularly to banks that themselves lend to many other interbank lenders tend to pay more in the ECB's auctions. This reflects that systemically important banks pay a premium for liquidity. We also find some evidence that banks borrowing from lenders who have a broad network of lenders pay less for liquidity, suggesting also that the indirect access to liquidity through an intermediary in the money market matters with the availability of liquidity.

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Table 1 Variable Definitions

		Data source	*frequency*
Bank specific auction variables		ECB repo auctions	
Number of bidders	Number of bidders		
Overbid	weighted bid minus swap		*weekly*
Overpricing	weighted rate minus swap		*weekly*
Relationship & Centrality variables		Credit Register	*quarterly*
All banks			
Number	number of lenders		
Number interbank	number of lenders-for short term loans		
MaxShare_all	largest share in on-and off BS loans		
MaxShare_onBS	largest share in on-BS loans		
MaxShare_ST	largest share in short term loans		
HHI	Herfindahl Index of relationships		
Bonacich in	Bonacich centrality in		
Bonacich out	Bonacich centrality out		
Liquidity variables			
fulfill	fulfillment /number of days left	Reserve data available after 2004	*daily*
due	due amount to Total Assets	ECB repo auctions	*weekly*
Bank variables		Bank financial statements-BISTA	
Interbank_borrowing	Interbank borrowing to Total Assets		*monthly*
Equity	Equity ratio		*monthly*
Security Holdings	Treasury bills and bonds to Total Assets		*monthly*
Total Assets	Total Assets (mln Euros)		*monthly*
ROA	Return on Assets		*annual*
NPL	Nonperforming Loans to Total Loans		*annual*

Table 2 Summary Statistics

	Obs	Mean	Std. Dev.	p25	p50	p75
Bank specific auction variables						
Number of bidders	409	356.7433	100.3644	298	345	381
Overbid	83,208	-0.0015	0.0638	-0.0250	-0.0100	0.0083
Overpricing	75,614	0.0036	0.0612	-0.0200	-0.0080	0.0100
Relationship & Centrality measures						
All banks						
Number	65,664	31.5300	146.6890	4	5	10
Number interbank	63,380	10.7459	53.8459	2	3	4
MaxShare_all	65,664	0.4923	0.2299	0.2731	0.4747	0.6818
MaxShare_onBS	65,664	0.4888	0.2307	0.2691	0.4703	0.6775
MaxShare_ST	65,664	0.6052	0.3190	0.3019	0.6000	0.9586
HHI	65,664	0.3791	0.2001	0.2500	0.3238	0.4977
Bonacich in	64,444	0.3827	2.1731	-0.0040	0.0010	0.0330
Bonacich out	64,444	0.2477	1.9776	-0.0050	0.0000	0.0020
Bidder banks						
Number	10,538	90.5114	262.0520	5	11	24
Number interbank	10,470	28.7062	100.4742	2	4	7
MaxShare_all	10,538	0.5196	0.2377	0.3333	0.5343	0.7148
MaxShare_onBS	10,538	0.5107	0.2409	0.3239	0.5204	0.7082
MaxShare_ST	10,538	0.6263	0.2946	0.3839	0.6305	0.9244
HHI	10,538	0.3718	0.2249	0.2091	0.3413	0.5297
Bonacich in	10,306	0.9322	3.2821	-0.0016	0.0251	0.1269
Bonacich out	10,306	0.5984	2.8737	-0.0211	-0.0015	0.0064
Liquidity variables						
fulfill	45,086	0.0090	0.0170	0.0014	0.0024	0.0062
due	83,853	0.2419	0.3501	0.0069	0.1442	0.3212
Bank variables						
All banks						
Interbank_borrowing	176,785	0.1628	0.1127	0.0947	0.1401	0.1994
% Domestic IB Overnight	175,668	0.4844	0.3298	0.2020	0.4332	0.7785
% Domestic IB 1Year	175,668	0.1813	0.2550	0.0000	0.0152	0.3140
Equity	176,785	0.0569	0.0419	0.0440	0.0515	0.0606
Security Holdings	176,785	0.1780	0.1047	0.1074	0.1648	0.2332
Total Assets (mln Euros)	176,785	2,897.7450	18,200.0000	138.5170	354.1150	1,002.7890
ROA	16,642	0.0041	0.0147	0.0020	0.0043	0.0066
NPL	16,616	0.0471	0.0420	0.0238	0.0411	0.0611
Bidder banks						
Interbank_borrowing	25,859	0.2285	0.1290	0.1397	0.2026	0.2886
Equity	25,859	0.0460	0.0198	0.0380	0.0448	0.0523
Security Holdings	25,859	0.2090	0.1109	0.1344	0.1883	0.2619
Total Assets (mln Euros)	25,859	12,800.0000	42,600.0000	632.5310	1,493.6510	3,608.9450
ROA	3,245	0.0039	0.0049	0.0017	0.0038	0.0059
NPL	3,242	0.0459	0.0329	0.0250	0.0418	0.0606

Table 3 Bidding and Relationships over Time

		Overbid	Overpricing	Number	MaxShare_onBS	HHI	Bonacich in	Bonacich out
200103	*mean*	-0.047	-0.039	79.243	0.502	0.354	1.001	0.622
	sd	0.077	0.068	244.763	0.224	0.205	3.696	2.674
200203	*mean*	-0.009	0.002	88.930	0.490	0.344	1.205	0.724
	sd	0.031	0.024	259.715	0.231	0.214	3.937	3.031
200303	*mean*	-0.023	-0.019	99.489	0.489	0.351	1.055	0.761
	sd	0.056	0.057	268.202	0.248	0.224	3.673	3.208
200403	*mean*	-0.011	-0.010	93.696	0.501	0.358	0.846	0.531
	sd	0.026	0.026	272.574	0.235	0.216	2.775	2.828
200503	*mean*	-0.003	-0.002	100.048	0.505	0.368	0.931	0.517
	sd	0.014	0.013	273.708	0.245	0.231	2.782	2.764
200603	*mean*	-0.016	-0.014	93.626	0.517	0.381	0.799	0.464
	sd	0.015	0.013	262.569	0.246	0.231	2.621	2.786
200703	*mean*	-0.003	-0.001	92.997	0.531	0.402	0.714	0.514
	sd	0.017	0.016	262.694	0.251	0.238	2.644	2.789
200803	*mean*	0.143	0.161	90.301	0.538	0.418	0.655	0.477
	sd	0.064	0.053	261.176	0.261	0.246	2.232	2.681

Table 4 Banking Groups and Relationships

Commercial banks					
	mean	sd	p25	p50	p75
Number	191.335	327.981	22.000	50.000	133.000
MaxShare_onBS	0.300	0.223	0.136	0.236	0.411
HHI	0.187	0.204	0.051	0.109	0.256
Bonacich in	3.343	5.677	0.000	0.525	4.521
Bonacich out	2.283	5.211	-0.003	0.013	1.124
State owned					
	mean	sd	p25	p50	p75
Number	65.632	197.213	8.000	13.000	24.000
MaxShare_onBS	0.536	0.230	0.363	0.544	0.728
HHI	0.385	0.224	0.210	0.347	0.554
Bonacich in	0.564	1.979	0.011	0.066	0.177
Bonacich out	0.408	2.527	-0.048	-0.012	0.005
Cooperative banks					
	mean	sd	p25	p50	p75
Number	26.342	157.633	4.000	5.000	9.000
MaxShare_onBS	0.565	0.204	0.412	0.581	0.723
HHI	0.431	0.188	0.294	0.403	0.552
Bonacich in	0.134	1.263	-0.006	0.002	0.015
Bonacich out	0.144	1.447	-0.004	0.000	0.003

Table 5 Bidding Behaviour

The table reports the fixed effects panel estimation results. The dependent variable is *Overbid*, defined as weighted bid rate minus swap rate. All variable definitions are presented in Table 1. Robust standard errors are in parentheses. ***,**, * significant at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Relationship & Centrality											
MaxShare_onBS	0.012***				0.011**				0.008		
	[0.004]				[0.005]				[0.005]		
Number		-0.016***				-0.026***			-0.026***		
		[0.002]				[0.004]			[0.004]		
HHI			0.018***				0.020***			0.022***	0.012**
			[0.004]				[0.006]			[0.006]	[0.006]
Bonacich in				0.000				0.000	0.000	0.000	-0.001
				[0.000]				[0.001]	[0.001]	[0.001]	[0.001]
Bonacich out				0.001***				0.001***	0.001***	0.001***	0.001**
				[0.000]				[0.000]	[0.000]	[0.000]	[0.000]
Bank variables											
Interbank_borrowing	-0.028**	-0.013	-0.027**	-0.028**	-0.015	-0.001	-0.013	-0.022	-0.006	-0.020	-0.018
	[0.013]	[0.015]	[0.014]	[0.011]	[0.018]	[0.019]	[0.019]	[0.018]	[0.020]	[0.019]	[0.019]
Equity	0.221***	0.203***	0.222***	0.232***	0.469***	0.504***	0.475***	0.485***	0.523***	0.492***	0.486***
	[0.050]	[0.050]	[0.050]	[0.056]	[0.093]	[0.094]	[0.093]	[0.095]	[0.097]	[0.097]	[0.098]
Security Holdings	-0.014	-0.012	-0.013	-0.012	-0.072***	-0.066***	-0.071***	-0.073***	-0.066***	-0.071***	-0.067***
	[0.012]	[0.012]	[0.011]	[0.012]	[0.020]	[0.019]	[0.020]	[0.020]	[0.020]	[0.020]	[0.020]
Size	0.022***	0.027***	0.022***	0.024***	0.058***	0.067***	0.058***	0.063***	0.071***	0.062***	0.062***
	[0.004]	[0.005]	[0.004]	[0.004]	[0.009]	[0.008]	[0.009]	[0.010]	[0.009]	[0.010]	[0.010]
ROA	-0.265***	-0.343***	-0.275***	-0.251**	0.101	0.061	0.089	0.136	0.077	0.103	0.116
	[0.095]	[0.097]	[0.095]	[0.102]	[0.141]	[0.136]	[0.142]	[0.136]	[0.135]	[0.142]	[0.141]
NPL	-0.077***	-0.083***	-0.078***	-0.077***	-0.253***	-0.244***	-0.251***	-0.248***	-0.245***	-0.251***	-0.246***
	[0.020]	[0.019]	[0.020]	[0.020]	[0.058]	[0.051]	[0.057]	[0.058]	[0.051]	[0.057]	[0.057]

Table 5- continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
liquidity needs											
due	0.008***	0.006***	0.008***	0.006***	0.012***	0.011***	0.012***	0.011***	0.010***	0.012***	0.011***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.003]	[0.003]	[0.003]
fulfill					-0.226***	-0.223***	-0.226***	-0.220***	-0.119***	-0.153***	-0.228***
					[0.028]	[0.028]	[0.028]	[0.029]	[0.044]	[0.039]	[0.030]
fulfill * RL									-0.262***	-0.271***	
									[0.064]	[0.075]	
auction variables											
announced					-0.064***	-0.066***	-0.064***	-0.064***	-0.066***	-0.064***	-0.063***
					[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
market variables											
volatility	0.072***	0.076***	0.073***	0.067***	0.276***	0.270***	0.275***	0.273***	0.274***	0.279***	0.274***
	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]	[0.007]	[0.007]	[0.008]
crisis	0.119***	0.118***	0.119***	0.119***	0.079***	0.077***	0.079***	0.079***	0.076***	0.079***	0.068***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.004]
crisis * RL											0.026***
											[0.008]
Observations	72823	72823	72823	71700	43525	43525	43525	42760	42434	42434	42434
R-squared	0.31	0.312	0.311	0.311	0.541	0.543	0.541	0.542	0.544	0.542	0.543
Number of banks	723	723	723	703	576	576	576	556	554	554	554

Table 6 Overpricing

The table reports the fixed effects panel estimation results. The dependent variable is *Overpricing*, defined as weighted paid rate minus swap rate. All variable definitions are presented in Table 1. Robust standard errors are in parentheses. ***,**, * significant at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Relationship & Centrality											
MaxShare_onBS	0.008**				0.005				0.002		
	[0.003]				[0.004]				[0.004]		
Number		-0.015***				-0.028***			-0.028***		
		[0.002]				[0.004]			[0.004]		
HHI			0.013***				0.012**			0.015***	0.010**
			[0.004]				[0.005]			[0.005]	[0.005]
Bonacich in				-0.000**				-0.001	0.000	0.000	-0.001
				[0.000]				[0.001]	[0.000]	[0.001]	[0.001]
Bonacich out				0.000*				0.001*	0.001	0.001	0.001
				[0.000]				[0.000]	[0.000]	[0.000]	[0.000]
Bank variables											
Interbank_borrowing	-0.032***	-0.016	-0.031***	-0.033***	-0.045**	-0.027	-0.043**	-0.051***	-0.032	-0.049***	-0.049***
	[0.011]	[0.013]	[0.011]	[0.010]	[0.017]	[0.020]	[0.017]	[0.018]	[0.020]	[0.018]	[0.018]
Equity	0.184***	0.166***	0.185***	0.192***	0.576***	0.616***	0.581***	0.601***	0.633***	0.601***	0.603***
	[0.042]	[0.048]	[0.042]	[0.045]	[0.091]	[0.091]	[0.091]	[0.094]	[0.094]	[0.095]	[0.095]
Security Holdings	-0.011	-0.009	-0.011	-0.01	-0.065***	-0.057***	-0.064***	-0.066***	-0.058***	-0.064***	-0.063***
	[0.010]	[0.010]	[0.010]	[0.010]	[0.017]	[0.016]	[0.017]	[0.017]	[0.017]	[0.017]	[0.017]
Size	0.021***	0.025***	0.021***	0.022***	0.074***	0.083***	0.074***	0.079***	0.087***	0.078***	0.078***
	[0.003]	[0.004]	[0.003]	[0.004]	[0.010]	[0.009]	[0.010]	[0.010]	[0.010]	[0.010]	[0.011]
ROA	-0.311***	-0.388***	-0.318***	-0.323***	0.232*	0.188	0.225	0.260*	0.201	0.236*	0.241*
	[0.090]	[0.094]	[0.091]	[0.097]	[0.139]	[0.134]	[0.140]	[0.138]	[0.135]	[0.141]	[0.141]
NPL	-0.062**	-0.067**	-0.063**	-0.060**	-0.242***	-0.231***	-0.241***	-0.233***	-0.229***	-0.237***	-0.235***
	[0.025]	[0.026]	[0.025]	[0.026]	[0.053]	[0.047]	[0.052]	[0.053]	[0.047]	[0.052]	[0.052]

Table 6- continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
liquidity needs											
due	0.002	0	0.002	0.001	0.006***	0.004**	0.006***	0.006***	0.004**	0.006***	0.006***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
fulfill					-0.267***	-0.264***	-0.267***	-0.262***	-0.124**	-0.167***	-0.271***
					[0.037]	[0.037]	[0.037]	[0.038]	[0.057]	[0.050]	[0.039]
fulfill * RL									-0.351***	-0.368***	
									[0.079]	[0.094]	
auction variables											
announced					-0.081***	-0.084***	-0.081***	-0.081***	-0.084***	-0.081***	-0.081***
					[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
market variables											
volatility	0.167***	0.170***	0.167***	0.163***	0.315***	0.308***	0.315***	0.312***	0.314***	0.320***	0.313***
	[0.008]	[0.008]	[0.008]	[0.008]	[0.009]	[0.009]	[0.009]	[0.009]	[0.007]	[0.007]	[0.009]
crisis	0.134***	0.133***	0.134***	0.134***	0.090***	0.087***	0.089***	0.089***	0.086***	0.089***	0.086***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.003]
crisis * RL											0.005
											[0.006]
Observations	67204	67204	67204	66006	41113	41113	41113	40420	40108	40108	40108
R-squared	0.354	0.356	0.355	0.356	0.609	0.612	0.609	0.612	0.615	0.612	0.611
Number of banks	709	709	709	688	566	566	566	546	544	544	544

Table 7 Selection Model

The table reports the two-stage estimation results using the Heckman (1979) selection model; the first column reports the first-stage probit results for the probability participating in an auction, the remainder of the columns reports OLS and fixed-effects panel estimations explaining Overbid and Overpricing respectively. All variable definitions are presented in Table 1. All estimations include a constant. Robust standard errors are in parentheses. ***,**, * significant at 1%, 5% and 10%, respectively.

	Participate	**Overbid**	**Overbid**	**Overpricing**	**Overpricing**
	probit	OLS	FE	OLS	FE
Relationship & Centrality					
HHI	0.130	0.014***	0.022***	0.012***	0.015***
	[0.111]	[0.002]	[0.003]	[0.002]	[0.003]
Bonacich in	-0.019	0.000	-0.000*	0.000	-0.000**
	[0.018]	[0.000]	[0.000]	[0.000]	[0.000]
Bonacich out	0.032	0.000	0.001***	0.000	0.001**
	[0.020]	[0.000]	[0.000]	[0.000]	[0.000]
Bank variables					
Interbank_borrowing	1.213***	-0.020***	-0.020**	-0.013***	-0.049***
	[0.294]	[0.004]	[0.008]	[0.003]	[0.008]
Equity	-1.796	0.01	0.501***	0.004	0.593***
	[1.247]	[0.011]	[0.030]	[0.009]	[0.030]
Security Holdings	1.285***	-0.013***	-0.071***	-0.011***	-0.064***
	[0.250]	[0.004]	[0.008]	[0.003]	[0.008]
Size	0.200***	-0.002***	0.061***	-0.001**	0.078***
	[0.022]	[0.000]	[0.004]	[0.000]	[0.003]
ROA	-4.219	-0.162	0.118	-0.148	0.222**
	[3.801]	[0.102]	[0.099]	[0.099]	[0.090]
NPL	1.362*	-0.060***	-0.252***	-0.060***	-0.236***
	[0.725]	[0.016]	[0.023]	[0.015]	[0.021]
State owned banks	-0.142**	-0.006***		-0.004***	
	[0.058]	[0.001]		[0.001]	
due	10.741***	0.007***	0.009***	0.005***	0.008***
	[0.265]	[0.002]	[0.001]	[0.001]	[0.001]
fulfill	-3.640***	-0.153***	-0.152***	-0.172***	-0.168***
	[0.454]	[0.046]	[0.019]	[0.057]	[0.022]
fulfill * RL		-0.308***	-0.274***	-0.406***	-0.366***
		[0.086]	[0.046]	[0.105]	[0.050]
auction variables					
announced	-0.006	-0.053***	-0.064***	-0.065***	-0.081***
	[0.048]	[0.003]	[0.002]	[0.003]	[0.002]
market variables					
volatility	1.023***	0.309***	0.280***	0.361***	0.319***
	[0.202]	[0.007]	[0.008]	[0.008]	[0.008]
crisis	0.132***	0.094***	0.079***	0.107***	0.089***
	[0.036]	[0.002]	[0.001]	[0.002]	[0.002]
Mills		-0.003***	-0.002***	0.001	0.002***
		[0.001]	[0.001]	[0.001]	[0.000]
Observations	163,871	42,434	42,434	40,108	40,108
R-squared		0.577	0.542	0.646	0.612

Table 8 Role of Bank Type in Different Periods

The table reports the OLS estimation results explaining Overbid and Overpricing for the entire sample, pre/crisis and crisis periods respectively. All variable definitions are presented in Table 1. All estimations include a constant. Robust standard errors are in parentheses. ***,**, * significant at 1%, 5% and 10%, respectively.

			pre-crisis		*Crisis*	
	Overbid	**Overpricing**	**Overbid**	**Overpricing**	**Overbid**	**Overpricing**
Relationship & Centrality						
HHI	0.021***	0.015***	0.012***	0.008***	0.021***	0.003
	[0.001]	[0.001]	[0.001]	[0.001]	[0.005]	[0.005]
Bonacich in	0.000	0.000	0.000	0.000	0.000	-0.001*
	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.001]
Bonacich out	0.000***	0.000	0.000	0.000	0.001***	0.000
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Bank variables						
Interbank_borrowing	-0.020***	-0.012***	-0.008***	-0.006***	-0.055***	-0.003
	[0.002]	[0.002]	[0.001]	[0.001]	[0.009]	[0.009]
Equity	0.008	0.007	-0.004	-0.003	-0.019	-0.005
	[0.009]	[0.008]	[0.006]	[0.006]	[0.030]	[0.030]
Security Holdings	-0.012***	-0.010***	-0.005***	-0.004**	-0.01	-0.014
	[0.002]	[0.002]	[0.001]	[0.001]	[0.010]	[0.009]
Size	-0.001***	-0.001***	-0.001***	-0.001***	-0.003***	0.002*
	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.001]
ROA	-0.176***	-0.149***	-0.059*	-0.081**	-0.576**	-0.114
	[0.048]	[0.045]	[0.034]	[0.033]	[0.289]	[0.283]
NPL	-0.052***	-0.057***	-0.024***	-0.028***	-0.025	0.007
	[0.008]	[0.008]	[0.006]	[0.006]	[0.049]	[0.046]
State owned banks	0.000	0.000	0.001	0.000	-0.018***	-0.007*
	[0.001]	[0.001]	[0.001]	[0.001]	[0.004]	[0.004]
State owned * HHI	-0.017***	-0.013***	-0.008***	-0.006***	-0.007	-0.008
	[0.002]	[0.002]	[0.001]	[0.001]	[0.008]	[0.008]
liquidity needs						
due	0.011***	0.005***	0.005***	0.003***	0.036***	0.001
	[0.001]	[0.001]	[0.000]	[0.000]	[0.003]	[0.003]
fulfill	-0.238***	-0.284***	-0.197***	-0.198***	0.254***	0.094**
	[0.016]	[0.019]	[0.014]	[0.014]	[0.060]	[0.044]
auction variables						
announced	-0.053***	-0.066***	0.022***	0.025***	-0.130***	-0.191***
	[0.002]	[0.002]	[0.001]	[0.001]	[0.004]	[0.003]
market variables						
volatility	0.301***	0.353***	0.181***	0.210***	0.577***	0.629***
	[0.008]	[0.009]	[0.008]	[0.008]	[0.026]	[0.029]
crisis	0.093***	0.106***				
	[0.001]	[0.001]				
Observations	42434	40108	36024	35164	6410	4944
R-squared	0.577	0.646	0.066	0.073	0.266	0.440

Table 9 Auctions at Quarter Ends

The table reports the OLS estimation results explaining Overbid and Overpricing for the auctions at quarter ends. All variable definitions are presented in Table 1. All estimations include a constant. Robust standard errors are in parentheses. ***,**, * significant at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)
	Overbid	**Overpricing**	**Overbid**	**Overpricing**
Relationship & Centrality				
MaxShare_onBS	0.012	-0.007		
	[0.012]	[0.012]		
Number	-0.001	0.001		
	[0.008]	[0.007]		
HHI			0.015	-0.009
			[0.014]	[0.013]
Bonacich in	0.000	0.001	0.000	0.001
	[0.001]	[0.001]	[0.001]	[0.001]
Bonacich out	0.001**	0.000	0.001**	0.000
	[0.000]	[0.001]	[0.000]	[0.001]
Bank variables				
Interbank_borrowing	-0.007	-0.041	-0.009	-0.042
	[0.039]	[0.035]	[0.038]	[0.034]
Equity	-0.268	-0.289**	-0.271	-0.290**
	[0.194]	[0.139]	[0.191]	[0.138]
Security Holdings	0.008	-0.015	0.009	-0.015
	[0.033]	[0.027]	[0.034]	[0.027]
Size	0.003	-0.008	0.003	-0.007
	[0.014]	[0.011]	[0.014]	[0.011]
ROA	-0.796	-0.265	-0.782	-0.242
	[0.561]	[0.419]	[0.562]	[0.418]
NPL	0.152*	0.320***	0.153*	0.322***
	[0.078]	[0.075]	[0.079]	[0.075]
liquidity needs				
due	0.013*	0.006	0.013*	0.006
	[0.007]	[0.005]	[0.007]	[0.005]
fulfill	-4.288***	-4.374***	-4.542***	-4.470***
	[1.361]	[1.227]	[1.201]	[1.095]
fulfill * RL	-8.293***	-6.124**	-10.774***	-8.255***
	[2.779]	[2.564]	[3.143]	[2.903]
auction variables				
announced	0.056***	0.073***	0.057***	0.073***
	[0.008]	[0.008]	[0.008]	[0.008]
market variables				
volatility	1.248***	1.483***	1.250***	1.483***
	[0.046]	[0.041]	[0.046]	[0.041]
crisis	0.105***	0.174***	0.105***	0.174***
	[0.007]	[0.006]	[0.007]	[0.006]
Constant	-0.752***	-0.802***	-0.761***	-0.814***
	[0.194]	[0.158]	[0.196]	[0.158]
Observations	3346	3113	3346	3113
R-squared	0.37	0.50	0.371	0.50
Number of banks	466	452	466	452

Appendix A

The Bonacich centrality measure is a measure that depends on two parameters, a scaling parameter, α, and a measure of the centrality of the closer neighbors to the bank, β. The Bonacich centrality measure is defined as

$$c(\alpha,\beta) = \alpha A * \mathbf{1} * (I - \beta A)^{-1} \qquad \text{(A.1)}$$

where A is the adjacency matrix, **1** is a vector of ones, and I is the identity matrix. The scaling parameter is chosen to normalize the centrality measures so that their norm is the total number of nodes in the adjacency matrix for the interbank network, A. For $\beta = 0$, then c is just the weighted out-links centrality measure. For β increasing between 0 and $1/\lambda$, where λ is the largest eigenvalue of A, the centrality measure can be interpreted as a recursion which puts greater weight on those nearby links which are more central, themselves. This can be seen in Bonacich's original definition, which explicitly uses the centrality measure of adjacent links:

$$c(\alpha,\beta) = \sum_j (\alpha + \beta_j c_j) A_{ij}$$

For β decreasing between 0 and $-1/\lambda$, more central banks are penalized in the centrality measure. For this paper, we report the extreme values for $\beta = .999/\lambda$, which measures the centrality of banks that lend to other central banks. We follow Rodan (2011), in that we report extreme values, although clearly not the most extreme value at $\beta = 1/\lambda$, where the matrix $(I - \beta A)^{-1}$ would be singular.

Although the original measure was designed for symmetric adjacency matrices, in our case, the exposures are clearly asymmetric. So we define a separate measure of centrality, where A_{ij} in the above equations are replaced with A_{ji} which we call the in-centrality. In this case, a bank is more central if it is lent to by more central banks.

To summarize our centrality measure, we chose a measure that was related to links, but also incorporated exposures to the systemic, connected banks in the networks, to distinguish it from the aspects of relationship lending embodied in the link measures.