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Pricing in the Norwegian interbank market - the effects of liquidity and implicit government support

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Abstract

We investigate the effects of central bank liquidity and possible implicit government guarantees against default on Norwegian overnight interbank interest rates. We conduct an econometric study of these interest rates over the period 2006–2009, which includes the sharp fall in interbank trading during the financial crisis. Our findings suggest relatively lower funding costs for banks of systemic importance, particularly for banks with many and valuable linkages to other banks. Moreover, interest rates are found to depend not only on overall liquidity in the interbank market, but on its distribution among banks as well. There is also evidence of stronger effects on interest rates of systemic importance, creditworthiness and liquidity demand and supply factors during the financial crisis.

Keywords: *Interbank money market, Interest rates, Systemic importance.*

JEL Codes: *G21, E43, E58*

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1 Introduction

A well functioning money market is important for banks' payment and credit intermediation and trading for investment and risk management. It is also important for the effectiveness of the monetary policy transmission mechanism and achieving monetary policy objectives; see Acharya and Merrouche (2013) and Benos et al. (2014). Changes in the policy rates are generally transmitted to money market interest rates and thereby to lending and borrowing rates faced by firms and households, affecting their investment and consumption decisions and (thereby) macroeconomic target variables; see e.g. Acharya and Merrouche (2013). Central banks influence money market interest rates not only through their policy rates, but also by regulating the liquidity stance in money markets; see e.g. Nautz and Scheithauer (2009).

Analyses of interbank interest rates' response to various factors are required for managing money market liquidity and influencing money market rates. Such analyses are also of interest for credit-risk assessments and financial stability policies; see e.g. Rochet and Tirole (1996) and Furfine (2001). When overnight lending in the interbank market is uncollateralized, interest rates paid by a bank may indicate the solvency of the borrowing bank and the credit risk associated with corresponding loans. In particular, banks perceived to be of systemic importance may benefit from possible implicit government guarantees against default and thereby face relatively lower borrowing rates than their peers considered to lack systemic importance; see e.g. Passmore (2005), Gapen (2009), Reiss (2008) and Lucas and McDonald (2006). However, beneficiaries and benefits of such guarantees are usually ambiguous and depend generally on authorities and market's perceptions of the systemic importance of financial institutions.

We investigate econometrically the relationship between unsecured Norwegian overnight interbank interest rates and various market and bank characteristics, focusing especially on their variation with the aggregate level and the distribution of central bank liquidity and measures of banks' systemic importance. While an increase in overall liquidity in the interbank market is expected to lower interest rates, its effect can weaken if it becomes concentrated among a few banks. It has been argued that skewed liquidity distributions may give rise to higher interbank interest rates through exploitation of market power by banks with surplus liquidity; see e.g. Nyborg and Strebulaev (2004), Fecht et al. (2011) and Acharya et al. (2012). A skewed liquidity distribution could also reflect liquidity hoarding by banks in uncertain times and higher liquidity premia, which may become reflected in interbank interest rates; see Acharya and Merrouche (2013). Central banks can influence liquidity distribution among banks through altering the design and terms of central bank liquidity auctions and remuneration of banks' deposits at central banks. Empirical evidence on the possible importance of liquidity distribution for the level of interbank interest rates has therefore implications for the choice between alternative liquidity supply and remuneration schemes.

Our investigation of relationships between interbank interest rates and measures of banks' systemic importance tests for gains from systemic importance owing to a possible implicit government guarantee against default.[1] Possible gains from such guarantees may be detectable in the unsecured overnight interbank market despite the relatively short-term credit risk exposures as individual loans are relatively large and uncollateralized, in contrast with e.g. insured consumer deposits and mortgages. The unsecured interbank market is negligible for loans beyond the overnight maturity in many countries including Norway.[2]

As measures of a bank's systemic importance, we use its size and connectedness with other financial institutions through balance sheet linkages, as suggested by e.g. Financial Stability Board (2009), International Monetary Fund (2010) and Bank of England (2009). To represent connectedness, we employ centrality measures proposed in the growing literature on financial networks; see e.g. Allen and Babus (2009) and the references therein. A challenge is to disentangle the effects of a possible implicit government guarantee from those of other factors related to size

[1]The Norwegian government does not offer any explicit guarantee against default to any financial institution.

[2]Survey information for the Norwegian money market that has become available only recently suggest that more than 90% of uncollateralized lending takes place overnight and such lending beyond 1-week maturity is close to zero; see Norges Bank (2014, 2015).

and connectedness, such as portfolio diversification and relationships, that may also contribute to lower interest rates. We explicitly control for the effects of a number of bank characteristics associated with a bank's size and connectedness when testing for possible gains from systemic importance.

We conduct an econometric analysis based on a panel data set of banks active in the Norwegian interbank market over the period 9 October 2006 to 6 April 2009.[3] As data on actual interbank interest rates faced by individual banks is not publicly available, we employ the procedure suggested by Furfine (1999, 2001) to infer overnight interest rates from the real-time gross settlement (RTGS) system of Norges Bank, the central bank of Norway. By careful examination of the flows of funds between banks, fairly precise information can be obtained about amounts borrowed and overnight interest rates paid by banks; see e.g. Kovner and Skeie (2013) and Akram and Christophersen (2014) for some recent evidence. We have obtained a novel data set on each bank's daily liquidity position at Norges Bank over the sample period to study the possible effects of aggregate liquidity and its distribution among banks.

The data sample enables us to shed light on the importance of liquidity conditions and systemic importance before and during the financial crisis, particularly during the money market "freeze" in 2007–2008. Overall liquidity was substantially increased in response to the financial crisis while its distribution became relatively skewed, possibly because of liquidity hoarding; cf. Acharya and Merrouche (2013). The variation in liquidity conditions is informative for drawing inference on their importance. The financial crisis part of the sample is also informative about the value of a possible implicit government guarantee, which is likely to increase in a crisis. Therefore, to the extent that size and connectedness measure systemic importance of banks and implicit government guarantees to systemically important banks reduce credit premia, we expect possibly inverse relationships between banks' size and centrality and interest rates to become stronger in data samples including the financial crisis.

[3]Various restrictions on the availability of data has prevented us from using a longer data sample with more recent data. We expect our results to be valid post-sample, at least qualitatively.

To summarize our main findings: our analysis supports an inverse relationship between overall liquidity in the interbank market and interbank interest rates. Moreover, the analysis suggests that an increase in the inequality of liquidity distribution among banks is associated with higher interbank interest rates. Another key finding is that banks considered systemically important because of their financial linkages (centrality) are able to borrow in the overnight interbank market at relatively lower overnight rates than other banks. The relationship between bank size and overnight interest rate is found to be ambiguous, however, as its sign and statistical significance vary across the models and data samples considered. The observed relationship between interest rates and centrality has been found to be relatively strong during the recent financial crisis, consistent with the presence and expected increase in the value of an implicit government guarantee against default during a financial crisis.

This paper contributes to the relevant literature by being the first such econometric study of Norwegian overnight interbank interest rates and hence of particular interest to analysts of the Norwegian and comparable interbank markets. Our focus on the Norwegian interbank market is partly motivated by our privileged access to data sets required for such a study. Data from RTGS systems and banks' liquidity positions are not publicly and easily available. Even if available, it need not provide reliable information about the interbank market activity and prices. An advantage of studying a relatively small interbank market is that actual overnight interbank interest rates can be quite reliably inferred from RTGS data; see Akram and Christophersen (2014) for evidence based on Norwegian data. Large interbank markets with many banks acting as correspondent banks with frequent borrowing on behalf of other banks make such inference less reliable; cf. Armantier and Copeland (2012).

In terms of results, the paper contributes to the literature by demonstrating the robustness of an inverse relationship between interbank rates and systemic importance as measured by connectedness while such a relationship with size per se turns out to be model and sample dependent. So far there are a few studies using centrality measures based on the network literature models to represent systemic importance and account for variation in interbank interest rates; see e.g. Bech and

Atalay (2010) and Blasques et al. (2015). Our results supports the relevance of this variable to account for variation in interbank interest rates and its use as a measure of systemic importance, as recommended by Financial Stability Board (2009), International Monetary Fund (2010) and Bank of England (2009). In contrast, the use of banks' sizes has turned out to lack relevance when centrality is included in the model. This result goes against that of some earlier studies where size is included to represent systemic importance and assess possible gains from implicit government guarantees, such as e.g. Furfine (1999), but is consistent with Bernanke (2015, pp. 214–215). We also present new evidence on the importance of liquidity distribution among banks over and above its aggregate level for time variation in interbank interest rates. This result is consistent with both the exercise of market power by banks possessing relatively high shares of liquidity and with an increase in liquidity hoarding and liquidity premia in interbank market during turbulent periods. Irrespective of the exact mechanism, it points to the relevance of liquidity distribution for explaining deviations from central bank target interest rates.

The remaining paper is organised as follows. Section 2 presents the data and the method used for deriving overnight interest rates, while Section 3 discusses our measures of systemic importance and their possible relationship with interest rates. Section 4 presents the econometric analysis while Section 5 presents our main conclusions. Precise definitions of variables and a number of robustness tests of the main results are presented in the appendix.

2 Overnight interbank interest rates

This section explains how we derive overnight interbank interest rates from our sample of interbank payments data. We also present some key characteristics of the Norwegian interbank market including variation in market participation, loan sizes and overnight interest rates across the time and cross-sectional dimensions.

2.1 RTGS data and overnight interbank interest rates

During the sample period, about 140 banks, including branches and subsidiaries of foreign banks, have access to Norges Bank's real-time gross settlement (RTGS) system and around 30–40 banks use it on a daily basis. Most of the banks use the system for gross settlement of large-value and time-critical payments, such as those associated with overnight interbank loans. The RTGS system also receives clearings from the Norwegian Interbank Clearing System (NICS) and VPS, the Norwegian central securities depository, and payments sent to and from the Continuous Linked Settlement (CLS) system. We extracted a total of 428 708 transactions from the system, covering 609 business days over the period 9 October 2006 to 6 April 2009.[4] The average daily value of these transactions is NOK 128.4 billion (USD 21.7 billion). We have not included foreign exchange transactions settled via the CLS system or those arising from the central bank's transactions with the banks.[5] Transactions reflecting the netted positions settled via NICS and VPS were also excluded.

However, only a small share of these transactions is associated with interbank lending. We proceed as Furfine (1999, 2001) to separate overnight loans from all other RTGS transactions. In essence, the procedure classifies a pair of transactions between two banks on consecutive business days as an overnight loan if the amount transferred on a day (V_t) is a round number and the amount returned on the subsequent day (V_{t+1}) equals the transferred amount plus an amount that may be considered a payment for accrued overnight interest rates.[6] It is common to restrict the transferred amount to a round number as banks do not borrow non-round values by market convention. Specifically, we identify a pair of transactions as an overnight

[4] There was no available data from the RTGS system for 9 days in 2007 and for 2 days in 2008.

[5] As we only had access to the netted pay-outs and pay-ins to and from the CLS account, we were not in a position to consider the underlying individual FX transactions. The exclusion of individual CLS transactions substantially reduces, if not fully excludes, interbank loans obtained through foreign exchange swaps at tomorrow-next and longer maturities. One leg of overnight foreign exchange swaps generally appear as regular RTGS transactions, but are left out by the Furfine algorithm as they are unlikely to satisfy the round-value and the next-day return payment requirements; see footnote 11.

[6] It is not possible to extract information from the RTGS system indicating whether a loan has been initiated by a borrower or a lender. Nor does the system contain information on whether transacting banks are borrowing or lending themselves or just transacting on behalf of other banks or institutions that do not have direct access to the deposit and lending facilities at Norges Bank.

loan if the transferred value (V_t) is a round value in NOK million and the implied interest rate (ii):

$$ii_t = \left(\frac{V_{t+1}}{V_t} - 1\right) \times 365, \quad (1)$$

lies within a predefined band. The width of the band depends on what we consider to be reasonable variation in interbank interest rates. This consideration is based on how monetary policy is implemented by Norges Bank in the sample period, which is briefly described below.

The overnight interest rate on banks' deposit accounts at Norges Bank is the key policy rate. Banks that have deposit accounts with Norges Bank and can pledge sufficient eligible collateral may also borrow liquidity through Norges Bank's overnight overdraft facility. In general, the key policy rate acts as a floor for interbank overnight rates while the lending rate on overdrafts acts as a ceiling on interbank overnight interest rates. Occasionally, however, overnight interbank interest rates may not remain within the floor and ceiling defined by the central bank's interest rates. For example, foreign banks without deposit accounts at Norges Bank may deposit excess NOK liquidity with domestic banks at a lower interest rate than the central bank's deposit rate. Domestic banks can deposit excess liquidity with Norges Bank at its deposit rate and may therefore accept excess liquidity from foreign banks at a lower rate, as a charge for immediacy.[7] Overnight interest rates can also exceed the central bank's lending rate since interbank loans are uncollateralized whereas loans from the central bank are collateralized, and if there is a stigma associated with borrowing overnight from the central bank making interbank loans preferable to overdraft loans; see e.g. Goodhart (2009) and Bernanke (2015, pp. 148–149).

Our main analysis is based on values of implied interest rates (ii) that are between $i^b_{cb} - 0.1$ and $\max\{i^a_{cb} + 0.1, \text{NIBOR}_{t-1}\}$, where i^b_{cb} and i^a_{cb} are Norges Bank's overnight

[7]Such practice is not unusual. For example, US government sponsored entities (GSEs) do not receive interest on balances held with reserve banks. They therefore lend to other banks that are eligible to receive interest on their balances. The banks pay the GSEs interest rates below the interest rate paid on reserves; cf. Bech and Klee (2011). Although our data set does not allow us to isolate overnight loans on the basis of their purpose, we employ dummies to control for effects on interest rates that might be relevant for CLS and settlement banks in the empirical analysis as they are expected to carry out more transactions on behalf of others than other banks.

deposit and lending rates and NIBOR_{t-1} is the tomorrow-next rate the preceding day (for delivery "tomorrow" and repayment the "next" day).[8] That is, we let possible interest rates to fluctuate within an interest rate corridor that is usually 20 basis points wider than that defined by the central bank's overnight deposit and lending rates. In cases where the NIBOR exceeds the central bank's lending rate plus 10 basis points, the ceiling on overnight lending interest rate is determined by NIBOR.[9] Usually, NIBOR is below the rate on the overdraft facility, i^a_{cb}. During the financial crisis, however, it exceeded i^a_{cb}.

For the interest rate band specified, the algorithm identifies 18 760 overnight interbank loans among the payment transactions in our sample.[10] The identified transactions reflect uncollateralized loans in the NOK interbank market. Money market survey information suggests that uncollateralized overnight lending constitutes more than half of overnight lending while the rest of overnight lending occurs as foreign exchange swaps; overnight lending of NOK through repurchase agreements, i.e. with securities as collateral seems to be non-existent.[11]

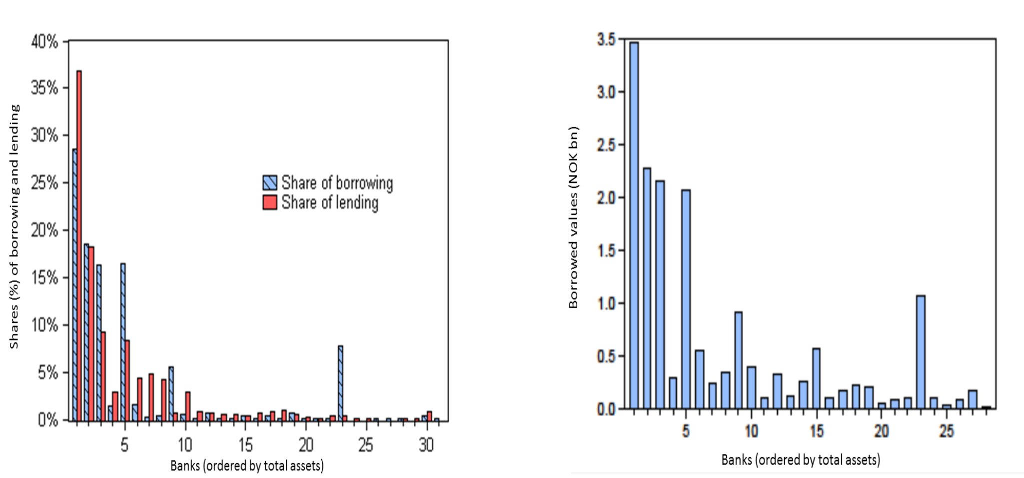
Some measurement errors in the number of interest rates due to misclassification of transactions as overnight loans are unavoidable. Our main conclusions are, how-

[8] We use quotes of NIBOR (Norwegian Interbank Offered Rate) published on Norges Bank's website. This rate is based on a 365-day convention, which is also the case for Norges Bank's lending and depositing rates. To ease comparison, we also use 365 days in Equation (1) to derive interest rates per annum.

[9] The adjustment factor (0.1) representing 10 basis points is based on our conversations with market participants. NIBOR is generally found to overestimate actual overnight rates in Norway; see Akram and Christophersen (2013). Using NIBOR to define the upper limit would therefore limit the risk of setting the ceiling too low.

[10] In a small number of cases, an outgoing transaction has been matched with more than one potential return transactions, resulting in two possible interest rates. In such cases, we have chosen the interest rate closer to the key policy rate.

[11] Interbank transactions reflecting foreign exchange swap deals that are settled outside the CLS system are unlikely to be captured by the Furfine algorithm because the initially exchanged amount from USD to NOK is unlikely to be a round value. And second, the inclusion of loans through the swap market among the transactions also depends on how each trade is carried out. For example, a bank can at time t borrow USD $\frac{1}{S^b}$ and sell it to obtain NOK 1. At the same time, it will agree to buy back USD $\frac{1}{S^b}$ for NOK $\frac{1}{S^b} \times F^a$ at time $t+1$ through a swap contract. In a separate deal, it could buy the accrued interest rates on the USD loan, $\frac{1}{S^b} i^{*,a}$, for NOK $\frac{F^a}{S^b} i^{*,a}$ through a forward contract or use available USD to pay for the accrued interest on the initial loan. Alternatively the borrowing bank may choose to include accrued interest in the forward contract; cf. Levi (2005, ch. 8). The procedure used requires that a loan is paid back with a single return transaction in NOK which includes the borrowed amount and the accrued interest. Hence, it would be able to infer the interest rate involved in the latter case, but not in the first case as there would be more than one return transactions involved.



(a) *Shares of overnight interbank borrowing and lending vs bank size*

(b) *Loan size vs bank size*

Figure 1: *(a) Shares (in %) of total overnight interbank lending and borrowing by the 31 banks over the sample period and (b) borrowed values (in* NOK *billion) by each of the 28 borrowing banks per day on average. Banks are ordered by total assets, from largest to smallest. Sample period: 9 October 2006 to 6 April 2009.*

ever, not sensitive to the values of the adjustment factors and alternative widths of the interest rate band; see Appendix B for evidence.

2.1.1 Interbank market activity

Our sample of overnight loans suggests that overnight lending takes place between 31 banks, constituting less than 1/4 of the banks that have access to the RTGS system. These banks are the largest Norwegian banks and branches and subsidiaries of foreign banks. Together they hold more than 75% of the total assets of banks established in Norway.

There are 28 lenders and 28 borrowers among the 31 banks as three of the banks do not lend to other banks while three do not borrow from other banks during the sample period. The number of market participants varies across trading days. There are 3 to 15 different borrowers and 3 to 20 lenders on a day during our sample period. About half of the banks are active on more than 1/4 of the days in the data set, whereas 3 banks are active on more than 95% of the days. A bank may have several overnight loans with different counterparts on a day.

The number of overnight loans in the Norwegian interbank market, their values and corresponding overnight interest rates vary substantially over time. In our sample, the number of overnight loans varies between 5 and 56 on different days while the value of a single loan varies from NOK 1 million to NOK 2.1 billion. Overnight borrowing by different banks varies in the range NOK 2 million to NOK 14.1 billion over the sample period. Interbank market activity experienced a marked decline in October–December of 2008 with a gradual recovery in 2009. The relatively low market activity in October–December of 2008 may be associated with the defaults of a number of financial institutions including Lehman Brothers in mid-September and two Icelandic banks (Glitnir and Kaupthing), which also had presence in Norway, on 29 September and 12 October 2008, respectively.

Figure 1a presents shares of overnight interbank borrowing and lending activity by banks of different sizes over the sample period. The figure suggests that almost 75% of the loans were borrowed or lent by the 5 largest borrowers. The shares of the amount borrowed and lent vary substantially across different borrowers and tend to increase with banks' assets. The obvious exceptions from this pattern can be ascribed to borrowing and lending by branches of larger foreign banks which have relatively few assets in Norway, such as bank number 23 in the figure. Similarly, foreign branches with relatively large assets are not necessarily as active as domestic banks of comparable assets in the Norwegian overnight market and hence have relatively low borrowing and lending, such as bank number 4. Overall, branches of foreign banks account for a large share of the volume in the overnight market, contributing more than 40% of the volume borrowed. Figure 1b suggests that banks with a high share of borrowing also tend to borrow relatively large loans.

2.1.2 Overnight interest rates

Figure 2 plots interest rates associated with all of the identified overnight loans over the sample period. A circle represents an overnight interbank interest rate, ii, while the solid and dashed lines represent the central bank's overnight deposit and lending interest rates, respectively. As shown, almost all of the overnight interbank interest rates are within the central bank's interest rate corridor. Moreover, most of the

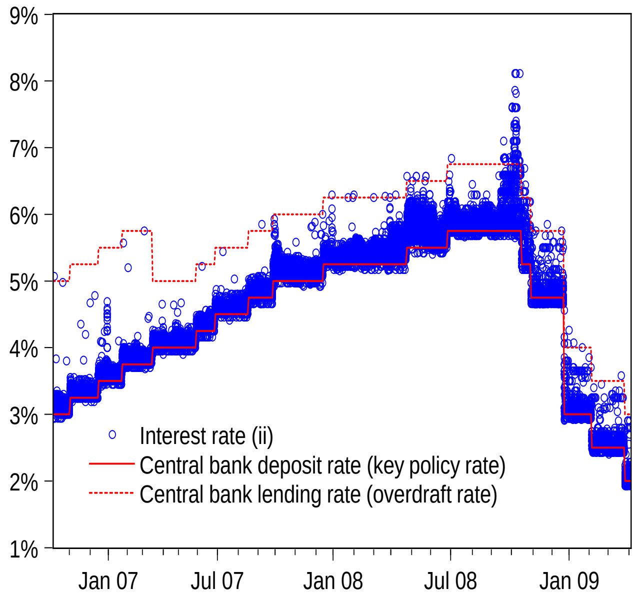


Figure 2: *Interest rates on identified loans (ii) and the central bank's deposit and lending rates. The spread between the latter interest rates has been one percentage point since 16 March 2007. Daily observations over the period 9 October 2006 to 6 April 2009. Interest rates in % per annum.*

overnight interbank interest rates are closer to the central bank's deposit rate than to its lending rate.[12]

There are, however, a non-negligible number of interest rates outside the central bank's interest rate corridor, mostly below the deposit rate. Interest rates below the central bank's deposit rate may refer to foreign banks (without a subsidiary or a branch in Norway) depositing excess NOK liquidity with banks that have deposit accounts at Norges Bank. Figure 2 also shows 90 observations of loans with interest rates above the central bank's lending rate. Most of these observations refer to the period between 15 September 2008 and the end of the year 2008.[13] One interpretation of such observations is that banks in need of liquidity prefer borrowing from their peers to borrowing from the central bank. This could be due to banks' wish to avoid signaling that they are unable to obtain (unsecured) overnight funds in the market. Another reason could be that banks economize on the use of collateral

[12] Akram and Christophersen (2013) provide a brief description of the monetary policy implementation framework in Norway and the floor system in place during the sample period.

[13] The NIBOR also exceeded the central bank's lending rate during this period. However, identified overnight interest rates generally remained below the central bank's lending rate.

required for borrowing from the central bank, especially in times of relatively large uncertainty regarding own liquidity demand.

There is a relatively large variation in overnight interest rates across different loans within any given day, and this was particularly the case at the height of the financial crisis. The difference in interest rates across loans is mostly below 15 basis points.[14] Particularly large differences in interest rates across loans refer to the spring and the autumn of 2008. They may therefore be related to uncertainty during the bail-out of Bear Stearns in mid-March 2008 and the defaults of a number of financial institutions in the autumn of 2008.

3 Systemic importance and funding costs

We measure the systemic importance of banks by their size and connectedness with other financial institutions through balance sheets linkages, as proposed by international and national policy institutions; see e.g. Financial Stability Board (2009), International Monetary Fund (2010) and Bank of England (2009). We represent a bank's size by the log of its total assets in its quarterly balance sheets and a bank's connectedness with other banks in the overnight loans market by the often used network centrality measure of Bonacich (1987). This measure takes into account the (overnight) borrowing and lending activity of each of the banks and their counterparts. Banks with a relatively large number of counterparts and which are counterparts to other such banks, obtain a higher centrality score. Thus, a bank with a high centrality score would be a bank that is itself active in the interbank market and trades with other banks that also participate actively in the market; see Appendix A for more details.

The relevant literature suggests several centrality measures; for a review, see Borgatti (2005). Our results are, however, robust to the use of alternative centrality measures including the 'inter-centrality' measure suggested by Ballester et al.

[14] We found that the spread between the (value-weighted) averages of banks' borrowing and lending rates on a day is mostly positive. While this may be consistent with arbitrage opportunities, it is difficult to conclude as some of the banks may also borrow and lend on behalf of other banks, and we were not able to identify a clear pattern.

(2006), as various measures of centrality tend to be highly correlated with the one used in our main analysis; see Appendix C1. The 'inter-centrality' measure evaluates the importance of a specific network participant by assessing disruption in the network activity when the participant is excluded from the network. Removal of the most important participant results in the maximal decrease in overall network activity. Accordingly, banks are ranked in accordance with the disruption in interbank transactions their withdrawal from the interbank market could cause.

Figure 3 suggests that centrality of a financial institution, though likely to correlated with its size, may be considered distinct from it. The figure shows a cross plot of banks' sizes in terms of log values of their total assets in NOK and their (Bonacich) centrality. Large banks tend to be highly connected in our sample, but the correlation is far from perfect. Figure 3 shows relatively large dispersion in centrality scores between banks of comparable sizes. A possible relationship between the centrality of a financial institution and interest rates it faces may therefore be considered distinct from a possible relationship between its size and interest rates.

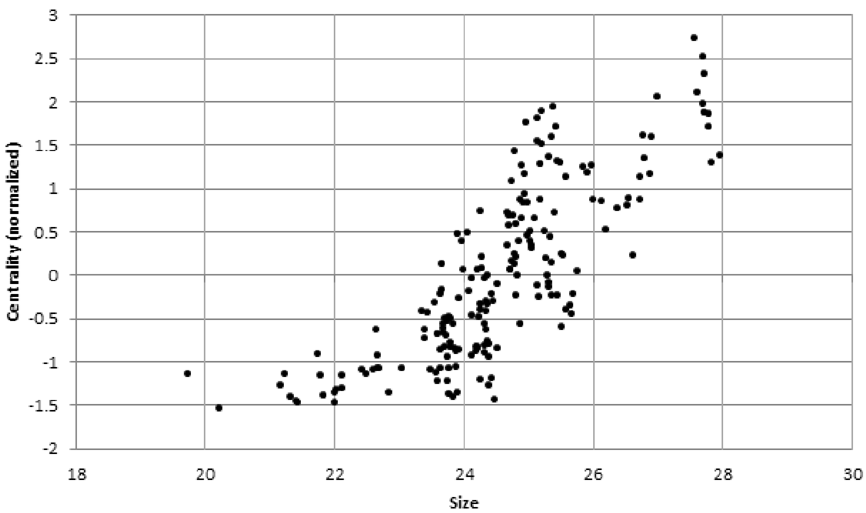


Figure 3: *Cross plot of centrality and size; the correlation is 0.80. Asset values in logs measured at end of each quarter over the period 9 October 2006 to 6 April 2009.*

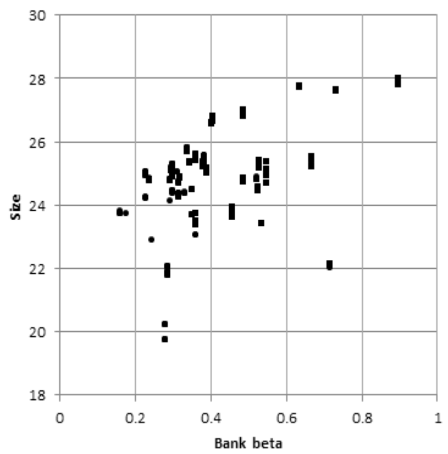
In several studies, relatively large banks and banks with extensive financial linkages (high centrality) have been found to pay lower interest rates than relatively smaller banks and/or banks with relatively lower centrality; see e.g. Furfine (2001) and Bech and Atalay (2010). This is consistent with the argument that systemically important banks may face lower funding costs because of implicit government guarantees against default.

However, the size and centrality of a bank may affect its risks and funding costs for other reasons than a possible implicit government guarantee. The latter interpretation of the inverse relationship requires that the employed model controls for variables correlated with banks' size and centrality that may also influence their funding costs. We undertake both bivariate and multivariate analyses that aim to rule out some alternative explanations of the importance of size and centrality for banks' funding costs. We particularly consider the following alternative explanations for possible inverse relationships between banks' size and centrality and funding costs.

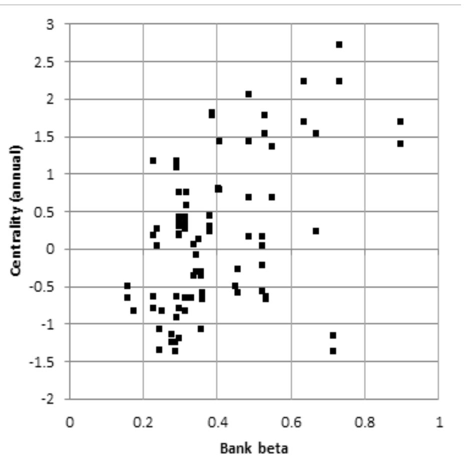
First, our analysis aims to avoid that a possible negative relationship between banks' sizes and their funding costs reflect lower risk owing to their portfolio choices. It has been argued that large banks could have more diversified portfolios than relatively smaller banks and hence lower risk; see e.g. Demsetz and Strahan (1997). Some recent empirical studies, however, does not support such a negative relationship between banks' size and their portfolio risk; see e.g. Baker and Wurgler (2015) and Laeven et al. (2014). One interpretation of such evidence is that when the expected private downside for a bank of any risky bet is limited by an implicit government guarantee, it may take on more risk than it would otherwise have taken; see e.g. Boyd and Runkle (1993) and Gropp et al. (2011).

Banks' portfolio risk may be represented by their (CAPM) beta estimates. Returns on equity of banks holding riskier assets is expected to vary more with market return than those of banks holding less risky assets, resulting in relatively higher beta estimates for the former banks' equity returns.

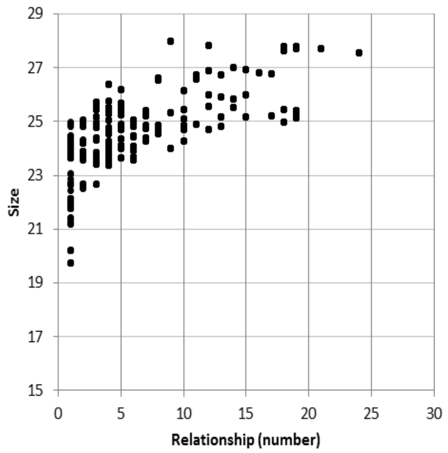
Figures 4a and 4d, top row, gives an impression of the relationship between banks' portfolio risk and size and centrality. They plot estimated beta values of banks against their size and connectedness. Estimates of the beta values are based on banks' equity returns and market returns using the CAPM model. The beta estimates are only calculated for banks whose equity is publicly traded and market



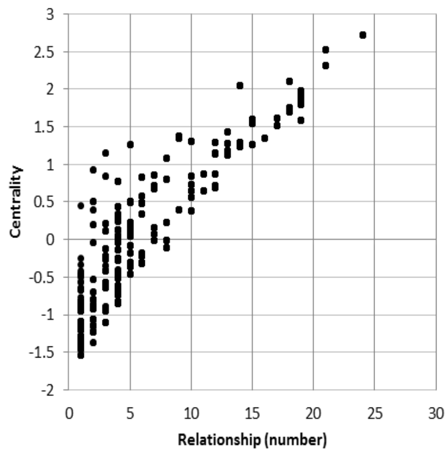
(a) *Plot of beta and size*



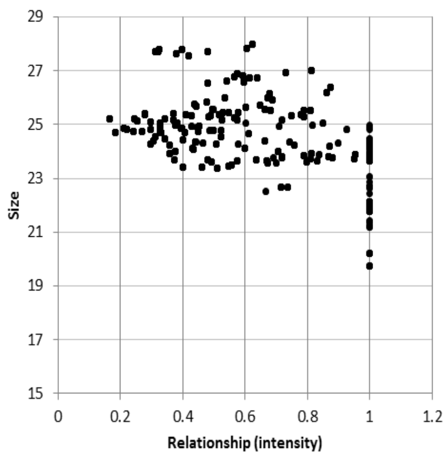
(d) *Plot of beta and centrality*



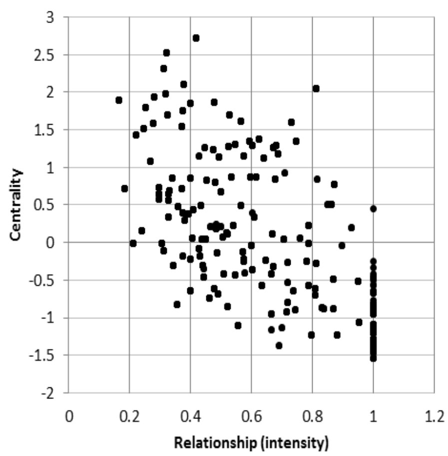
(b) *Plot of counterparts and size*



(e) *Plot of counterparts and centrality*



(c) *Plot of relationships and size*



(f) *Plot of relationships and centrality*

Figure 4: *Cross plots of centrality and size against bank beta, counterparts (relationship number) and relationship intensity, respectively. Asset values in logs measured at the end of each quarter. A bank's relationship intensity is defined as the share of its borrowing from its largest lender, while counterparts is defined as the number of banks from which funds were borrowed (measured quarterly). In order to ease the comparison with bank beta, centrality is presented as annual averages in plot (d).*

prices are available, in total 18 banks. Moreover, since the equity of many of the banks is infrequently traded, we have estimated the betas using the method proposed by Dimson (1979) to avoid bias which may be present in conventional beta estimates in such cases. The adjusted betas are calculated for each calendar year using a rolling window of returns from the preceding 4 years against the market returns on the Oslo Stock Exchange.

The cross plots in Figures 4a and 4d indicate positive relationships between estimated beta values and banks' size and connectedness. Although one can not draw firm conclusions from bivariate cross plots, it is at least not obvious that relatively large and well connected banks in our sample have relatively lower portfolio risk, e.g. because of better diversification of assets and liabilities. Actually, the positive correlations between indicators of systemic risk and portfolio risk are consistent with the argument that an implicit government guarantee to systemically important banks can lead to excessive risk taking. In the multivariate analysis we control for the possible effects of portfolio risk as represented by our beta estimates.

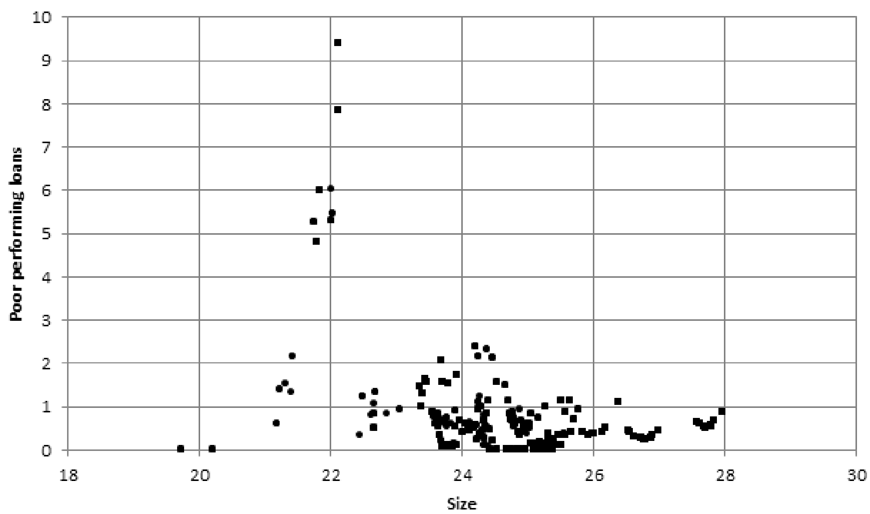


Figure 5: *Cross plot of non-performing loans and size (log of assets in* NOK*). Asset values measured at end of each quarter over the period 9 October 2006 to 6 April 2009.*

In addition, we also take into account banks' credit risk of their lending to households and non-financial institutions as represented by shares of their poor performing loans. Such loans are defined as loans that are past-due for a period exceeding 3 months. Loans to customers make up by far the largest share of assets on balance sheets of the banks in our sample. Shares of poor-performing loans may therefore be a suitable measure of the creditworthiness of banks. Figure 5 indicates that relatively large banks have relatively smaller shares of poor performing loans than their relatively smaller peers.[15] Our multivariate analysis controls for the effects of the relatively higher creditworthiness of larger banks as represented by their relatively lower shares of poor performing loans on their funding costs.

Second, the multivariate analysis addresses the concern that an inverse relationship between the systemic importance indicators and interest rates could be a reflection of interbank relationships. One could argue that a bank scoring high on centrality and/or size measures could be obtaining favorable rates because of the form and extent of their relationships. Banks with relatively high degree of connectedness have by definition more intensive and extensive banking relationships than other banks. It is well known that borrowing terms may depend on past relationships between lenders and borrowers; see e.g. Cocco et al. (2009). Such relationships help reduce the asymmetric information problem facing lenders and thereby also credit risk. Moreover, numerous relationships enable banks to get several reasonable interest rate quotes to choose from and thereby reduce their funding costs; see e.g. Stigum and Crescenzi (2007). Furthermore, one can argue that banks scoring high on the centrality score obtain lower rates from their extensive relationships as they can spread their borrowing needs on many counterparts to avoid possible price impact of their borrowing. It is well known that financial market participants in centralized as well as over-the-counter markets may split large trades into smaller trades to avoid price impact.

The overall impression from Figures 4e and 4f is consistent with the latter ('price impact') hypothesis and less so with relatively central banks preferring to borrow from one or a few counterparts. Figure 4e shows a positive relationship between the centrality of banks and the number of their counterparts while Figure 4f suggests

[15] At the face value, the impression from Figure 5 is in contrast with some of the literature implying a positive relationship between poor performing loans and bank size. Accordingly, large banks can have higher share of poor performing loans than smaller banks due to relaxed standards of screening new loan applications and monitoring of existing loans. Such relaxations may be due to relatively larger 'distance' between decision-makers and information collectors in relatively large banks; see e.g. Stein (2002), Acharya et al. (2006) and Liberti and Mian (2009).

that banks with high degree of centrality tend to borrow relatively small shares of their total borrowing from their largest lenders. It also suggests that several banks with relatively low degree of centrality borrow exclusively from their biggest counterpart. Overall, there is a negative relationship between banks' centrality and their shares of borrowing from their largest counterparts. For example, the top four scores of centrality coincide with 0.30–0.42 as maximum borrowing shares from banks' largest lenders in Figure 4f and 17–24 number of counterparts in Figure 4e, that is, close to all of the participants in the interbank market. The coincidence of high centrality scores, relatively large number of counterparts and relatively small share of borrowing from the largest lenders does not accord well with the hypothesis of more connected banks asking around and borrowing exclusively or mainly from those offering relatively low rates. In the latter case, one could have expected a coincidence between high centrality score and high shares of borrowing from the largest lenders. In the multivariate analysis we control for the possible effects of the extensive and intensive interbank relationships on banks' funding costs.

Third, by controlling for the possible effects of interbank relationships we also take into account possible reductions in large banks' funding costs due to any economies of scale at relatively large lenders, or due to relatively small banks' preferences to lend to specific large banks. One could argue that if large banks borrow predominantly from other large banks, their funding costs can be lower because large lenders may be able to offer lower borrowing rates due to possible cost savings arising from economies of scale; see e.g. Berger et al. (2005), Hughes and Mester (2013) and Kovner et al. (2014). The evidence of economies of scale in banking industry is mixed, however; see Benston et al. (1982) and Laeven et al. (2014) and references therein. Large banks may on the other hand borrow more cheaply from relatively smaller banks as smaller banks' gains from placing small amount of excess liquidity may not be sufficiently large to justify costs of an active investment strategy in the interbank market. Relatively small banks may therefore be complacent with obtaining interest rates slightly above the central bank deposit rate or even equal to it; see e.g. (Stigum and Crescenzi, 2007, ch. 12). Especially large banks acting as settlement banks for numerous small banks may obtain cheaper funding through such a role.

Figures 4c suggests that there is no positive or negative correlation between banks' size and the shares of funds obtained from their dominant counterpart in a quarter. Overall, shares of banks' borrowing from their largest counterparts vary widely for banks of different sizes. However, many relatively small banks tend to transact exclusively with a single counterpart. Figure 4b shows that the number of banks' counterparts tend to increase somewhat with their size. In particular, relatively small banks have just one counterpart over the sample period. Moreover, a large number of medium-sized banks also have one or relatively few counterparts. The biggest banks have the largest number of counterparts (29), but some of the relatively large banks have less than ten counterparts. Our multivariate analysis controls for relatively large bank's potential advantage from acting as settlement banks for numerous banks by using dummy variables for settlement banks.

And finally, our multivariate analysis aims to rule out in various ways a potential endogeneity problem as a possible explanation of our main conclusions. One could argue that it is not the centrality of a bank that would contribute to lower its interest rates, but the other way around. To address this possible concern we redo our main analysis using lagged values of centrality and size. In addition, we also calculate the (Bonacich) centrality measure based on a sample of relatively longer maturity interbank loans. The latter refers to cross holdings of Norwegian banks' certificates and bonds at maturities of one month and more. These interbank liabilities are measured at the end of each quarter. A potential endogeneity problem is likely to be less important in a model of overnight interest rates with a centrality measure based on the latter data set than with a centrality measure derived from overnight interbank liabilities. Our results using the alternative centrality measure are in line with those from the main analysis in the next section; see Appendix C1.

4 Bank characteristics, liquidity conditions and interest rates

In the following, we model daily variation in overnight interest rates across banks and over different sample periods within our data set covering the period 9 October 2006 to 6 April 2009. The interest rate model allows for the effects of several bank characteristics and market conditions on overnight interest rates. In particular, we investigate whether possible relationships between interest rates and measures of systemic importance (size and centrality) are robust to accounting for other bank characteristics and market conditions including the recent financial crisis.

4.1 The model and key variables

We specify an econometric model of overnight interbank interest rates paid by different banks over the sample period. The model is estimated on a panel data set, which is unbalanced as every bank does not participate in the market every day. There are 28 different borrowers on the cross-sectional dimension and 609 business days on the time dimension in our full data sample. To take into account both time and cross-sectional variation in the data, we use pooled OLS to estimate the model in our main analysis. We also estimate the model with a number of alternative specifications and estimation methods to examine the robustness of our main results. This includes estimation of the model with either bank-specific or period fixed effects and alternative standard error estimates. As shown, our main conclusions are found to be quite robust.

In our main analysis, we employ the following model:

$$\begin{aligned} ii^m_{j,t} - i^b_{cb,t} \quad &= \quad \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi'} \boldsymbol{B}_{j,t} \\ &\quad + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi'} \boldsymbol{M}_t + \varepsilon_{j,t}, \qquad (2) \end{aligned}$$

where $ii^m_{j,t}$ denotes the loan-size weighted mean of (derived) interest rates (iis) paid by bank j on day t. We use the means of interest rates on a day, as a bank may have several overnight loans with different interest rates on the same day. We model the deviation of interest rates (in basis points) from the central bank's deposit rate as the latter is contemporaneously reflected in the overnight interest rates; this is supported by preliminary analysis. Thus, we are able to take into account any step-variations induced by policy changes. In addition, the spread $(ii^m_{j,t} - i^b_{cb,t})$ is likely to be stationary over the sample period.[16]

Variables representing bank-specific characteristics are indexed by subscripts j and t, while variables representing market characteristics are indicated by subscript t only. Greek letters represent parameters, except for the variable $\varepsilon_{j,t}$, which represents an independent and identically distributed stochastic error term that is bank- and period-specific. Vectors $\boldsymbol{B}_{j,t}$ and $\boldsymbol{M}_t$ contain sets of bank-specific and market-specific control variables, respectively.[17] Appendix A provides precise definitions of the variables used in the model. Our variables of main interest are defined as follows.

The systemic importance of a bank j is represented by its size and centrality. The size is measured by the log value of a bank's total assets at the end of a quarter while the centrality of a bank is based on the network measure proposed by Bonacich (1987) employing data on the overnight borrowing and lending activity of each of the banks and their counterparts during a quarter. The centrality measure is calculated on the basis of a matrix representing the links (i.e. overnight loans) between the banks each quarter. As the centrality scores are based on the number of counterparties as well as the direction of the transactions in each quarter, the sum of centrality scores and the variance between banks would depend on the total interbank activity that quarter. We therefore normalize the centrality scores for each quarter by subtracting the mean and dividing by the standard deviation to make the variance in scores more consistent over time.

[16] The augmented Dickey-Fuller (ADF) test strongly rejects the null hypothesis that the panel contain unit roots for the spread $(ii^m_{j,t} - i^b_{cb,t})$ with an inverse normal Z statistic of -10.07 for the most active banks. ADF tests for banks that are occasionally active were not feasible.

[17] We have not included interactions of the variables in $\boldsymbol{B}_{j,t}$ and $\boldsymbol{M}_t$ in order to limit the number of parameters in the models.

Liquidity conditions are accounted for by the log level of overall liquidity (*liq*) and its distribution among banks (*liqdist*). Overall liquidity on a day is measured as the sum of all banks' deposits with Norges Bank on the beginning of that day. A relatively high level of liquidity is expected to place downward pressure on interest rates; cf. Hamilton (1997). Distribution of overall liquidity can also matter as a relatively unequal distribution may contribute to higher interest rates due to e.g. the exercise of market power by banks with relatively high shares of liquidity. To represent liquidity distribution among banks on a daily basis, we employ the Gini coefficient, the popular measure of income and wealth distribution. The Gini coefficient ranges from 0 to 1 and increases with the degree of inequality in the distribution of overall liquidity; 0 indicates an even distribution, while 1 indicates complete inequality. Daily values of the Gini coefficients are based on the distribution of all banks' deposits with Norges Bank on the beginning of each day.

While investigating the effects on interest rates of differences in the systemic importance of banks and those of liquidity conditions, we control for the possible effects of a number of variables. Vector $\boldsymbol{B}_{j,t}$ includes measures of portfolio risk, credit risk, borrowing amount, interbank relationships and bank-type dummy variables. In our main analysis, we include beta estimates for banks' equity returns and their poor-performing loans, as shares of their total outstanding amount of loans to the public, to represent their portfolio risk and credit risk. In Appendix C, we replace the shares of non-performing loans with banks' core capital as a share of their risk-weighted assets and find that the main results are largely unchanged.[18]

As large banks tend to borrow relatively larger amounts than small banks which may affect their loan terms, we control for the amounts borrowed (over a month) by each bank. Effects on interest rates stemming from amounts borrowed have previously been documented by Furfine (2001). Interbank relationships are often proxied by the number and/or values of transactions between two counterparts; see e.g. Cocco et al. (2009). We use a related measure termed relationship intensity; see

[18]Two alternative measures of creditworthiness would be credit rating or CDS spreads. Credit ratings are not available for most of the banks in our sample, however, as only a few banks in Norway are rated by international rating agencies. The same applies to CDS spreads, which are only available for a few banks for parts of our sample (see also footnote 20 in Appendix C).

Craig et al. (2015). It is defined as above in Section 3 as the value of funds obtained from a bank's biggest counterparty each quarter divided by its total borrowing the same quarter.

Vector $\boldsymbol{B}_{j,t}$ includes four binary dummy variables to control for heterogeneity among the banks in our sample. Two of the dummy variables allow for different intercepts for settlement banks and banks active in the settlement of foreign exchange trades (CLS banks), as such banks are more likely to be correspondent banks for other relatively smaller banks and foreign banks without access to the central bank's deposit facilities. The latter banks can be willing to lend funds in the interbank market via their correspondent banks at concessionary rates. Such lending would appear as lending from the correspondent bank to the foreign bank's counterpart. Direct transactions between foreign banks and their correspondent banks in Norway do not appear in our data set as they are dealt with outside the RTGS system.

The other two dummy variables in vector $\boldsymbol{B}_{j,t}$ are associated with branches and subsidiaries of foreign banks, respectively, allowing their intercepts to differ from those of domestic banks. One may argue that branches of foreign banks could be perceived to be supported by their main office abroad when in need and therefore to be less riskier borrowers than implied by their local characteristics. In contrast, subsidiaries of foreign banks may not be expected to be supported by their foreign mother banks.

To take into account overall market conditions, vector $\boldsymbol{M}_t$ includes payment activity and dummy variables for petroleum tax payment dates, the financial crisis and calendar effects. A number of studies show that an increase in payment activity is associated with higher interbank interest rates; see e.g. Acharya and Merrouche (2013) and Furfine (2000). Higher payment activity raises transaction demand for liquidity as well as precautionary demand for liquidity. This is because each bank's liquidity position becomes more uncertain on days with a high turnover in the payment system. To account for the effects of payment activity we include the log level of gross settlements in the RTGS system in vector $\boldsymbol{M}_t$.

Overall liquidity in the Norwegian money market is affected on the petroleum tax dates because of the Norwegian government's account with Norges Bank. Payments to the government's account remove liquidity from banks' accounts at Norges Bank, reducing overall liquidity. Relatively large turnover in the payment system on these days tends to put upward pressure on interest rates, possibly due to precautionary liquidity demand stemming from uncertainty about end-of-day positions. To reduce such pressure on interest rates, Norges Bank provides additional liquidity to banks on petroleum tax payment dates. By including dummies for the payment dates, we control for the possible effects on interest rates beyond those represented by the payment activity measure and overall liquidity, liq. To reduce possible interest rate effects of relatively high liquidity demand and reduction in overall liquidity, the number of due dates for petroleum taxes per year was increased from 2 to 6 in 2008. We use two different dummy variables to allow for the two tax payment regimes.

Furthermore, to account for possible effects of the recent financial crisis on overnight interest rates, the relevant dummy variable takes on the value of 1 from 15 September to 15 October 2008 and 0 otherwise. The period is chosen to take into account effects immediately following the collapse of Lehman Brothers in mid-September and two Icelandic banks on 29 September and 12 October, respectively.

Finally, two binary dummy variables control for the possible influence of end-of-year and end-of-month effects on overnight interest rates. In Norway, there are no reserve requirements that banks have to meet at the end of months and which could lead to calendar effects. However, regulatory capital requirements and banks' annual fee to the Norwegian Banks' Guarantee Fund are affected by their interbank lending, but not by their deposits at the central bank carrying zero risk weight. Therefore, at the end of periods, especially quarters and years, when banks' balance sheets receive relatively more attention than otherwise, banks may prefer to have excess liquidity deposited overnight at the central bank than lent out to other banks. This may coincide with increased demand for liquidity from banks experiencing liquidity withdrawals from customers for e.g. adjusting their balance sheets at the end of periods. Consequently, a fall in interbank activity can lead to higher interbank rates at the end of periods. Calendar effects on overnight interest rates have been reported in previous studies; see e.g. Fecht et al. (2007).

4.2 Results

Table 1 presents parameter estimates of model (2) on three different sample periods to examine their sample dependence, especially the effects of the financial crisis. Column (1) presents the parameter estimates of a benchmark model which includes only *size* as a measure of systemic importance while those in Columns (2)–(4) are of a model that includes both *size* and *centrality* of banks. The estimates in Columns (1) and (2) are based on the full data sample (9 October 2006 to 6 April 2009) while those in Columns (3) and (4) are based on subsamples. The estimates in Column (3) are based on a sample containing only observations after the onset of the recent financial crisis, i.e. after 9 August 2007 when activity in money markets fell substantially; cf. Acharya and Merrouche (2013). Column (4) presents estimation results based on data from from 9 August 2007 until 24 November 2008, covering the height of the financial crisis and the period before the Norwegian government's main program for liquidity support to banks was implemented; cf. Norges Bank (2008). The program enabled banks to swap mortgage-backed covered bonds with treasury bills for sale or use as safe collateral when borrowing from private or public counterparts.

The estimation results suggest that banks considered to be relatively large and/or financially well connected may borrow at relatively lower overnight interest rates. This was especially the case during the financial crisis for banks with high centrality score. In the benchmark model of Column (1), the coefficient estimate associated with *size* has a negative sign and is statistically significant at the 1% level, indicating lower interest rates for large banks, aligning our results with previous studies; cf. Furfine (2001), Cocco et al. (2009). Taken at face value, the coefficient estimate indicates a difference in interest rates of between 1.5 and 4.8 basis points between small and medium-sized banks. When *centrality* is included in the model, it also enters significantly at the 1% level with a negative coefficient estimate; see Column

Table 1: ***Main econometric analysis***

$$ii^{m}_{j,t} - i^{b}_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)	(4)
Size	-1.64***	-1.15***	-0.51	-1.11*
	(0.30)	(0.31)	(0.53)	(0.60)
Centrality		-3.10***	-5.76***	-9.96***
		(0.45)	(0.73)	(1.08)
Relationship intensity	-4.64***	-8.42***	-15.17***	-10.93***
	(1.51)	(1.58)	(2.05)	(3.86)
Bank beta	31.38***	29.81***	39.57***	41.38***
	(2.18)	(2.14)	(3.09)	(3.74)
Poor performing loans	5.69***	5.52***	5.95***	4.08***
	(0.23)	(0.24)	(0.33)	(0.63)
Monthly borrowing	0.33	0.45**	1.01***	1.30***
	(0.22)	(0.21)	(0.31)	(0.38)
Liquidity	-3.39***	-2.92***	-4.36***	-2.05**
	(0.53)	(0.52)	(0.68)	(0.98)
Liquidity distribution	10.75**	9.56**	16.94**	15.51**
	(4.42)	(4.38)	(6.82)	(7.14)
Payments turnover	3.24***	3.06***	3.29**	4.47***
	(0.86)	(0.85)	(1.28)	(1.39)
Oil tax (2x)	6.18**	5.91**	6.04*	5.20*
	(2.49)	(2.43)	(3.10)	(2.83)
Oil tax (6x)	-0.28	-0.42	-1.20	0.91
	(3.92)	(3.80)	(3.62)	(4.63)
Financial crisis dummy	19.08***	19.14***	17.84***	16.30***
	(3.54)	(3.54)	(3.73)	(3.54)
End of year dummy	41.52***	41.12***	22.27***	33.83***
	(12.19)	(12.36)	(6.94)	(2.46)
End of month dummy	3.15	3.27*	5.77*	3.32
	(1.94)	(1.94)	(3.03)	(2.34)
CLS dummy	-4.23***	-0.32	-3.08***	5.00***
	(0.69)	(0.81)	(1.06)	(1.43)
Settlement bank dummy	0.51	0.38	1.01	1.12
	(0.73)	(0.72)	(1.55)	(1.55)
Foreign branch dummy	-3.53***	-4.57***	-6.37***	-8.43***
	(0.49)	(0.47)	(0.81)	(0.85)
Foreign subsidiary dummy	8.95***	6.98***	12.05***	8.47***
	(0.88)	(0.85)	(1.41)	(1.35)
Observations	3,845	3,845	2,418	1,920
Adjusted R-squared	0.43	0.44	0.49	0.39

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension; see Petersen (2009). Columns (1) and (2) present results estimated on the full sample (9 October 2006 to 6 April 2009). Column (3) presents results when the model is estimated on a sample starting 9 August 2007 and the results in Column (4) are based on the sample period from 9 August 2007 to 24 November 2008. Here and elsewhere in this paper, estimates are obtained using Stata version 13 and asterisks indicate levels of statistical significance: *** p<0.01, ** p<0.05, * p<0.1.

(2). It follows that even relatively small but well connected banks may face relatively lower funding costs.

As we place more weight on observations from the financial crisis by reducing our sample, we observe that the coefficient estimate associated with *centrality* becomes more significant, numerically and statistically; see Columns (3)–(4). The largest effect of *centrality* is estimated when we use the data sample only including observations from the financial crisis; see Column (4). This is consistent with a possible implicit government guarantee being more valuable during the financial crisis.

The significance of the network centrality measure while controlling for measures of bank size, i.e. assets (*size*) and even monthly borrowing amount, indicates that a bank's size may not reflect all aspects of its systemic importance. Actually, *size* does not remain statistically significant at the 5% level when we change the sample period as in e.g. Columns (3)–(4) or alter the model specification e.g. by using core captial instead of beta estimates as in Appendix B.

The coefficient estimates of *centrality* in Columns (2)–(4) imply that an increase in centrality of the same magnitude as that which would separate the quartiles of banks with the lowest and highest centrality is associated with a reduction in interest rates by almost 5 basis points in normal times and between 9 and 15 basis points during the recent financial crisis. Although such reductions contribute only to modest savings overnight due to the short maturity of overnight loans, an average reduction of say 5 basis points may accumulate to a more substantial reduction in costs over time for banks that frequently borrow overnight.

The signs of the coefficient estimates of the numerous control variables representing different bank characteristics suggest their effects to be as expected and consistent with existing studies. Notably, the estimated coefficients suggest lower rates when banks borrow from their main lenders and have low portfolio risk. We note that average daily interest rates paid by a bank may decline with relationship intensity, an increase in the share of borrowing from its largest counterpart, consistent with e.g. Furfine (2001) and Cocco et al. (2009). Interestingly, the importance of relationship intensity tend to increase after the onset of the financial crisis. Portfolio risk and credit risk are represented by beta estimates and shares of poor performing loans. An increase in a bank's beta and its share of poor performing loans leads to significantly higher borrowing rates. While the effects of the poor performing loans are stable across the sample periods, those of the beta estimates increase substantially in the samples from the financial crisis. The latter estimates suggest steep increase in interest rates during the financial crisis for banks with a relatively high portfolio risk.

Estimates of the dummy variables associated with settlement banks suggest that settlement-bank status does not affect the interest rates they pay; the associated coefficient estimate is statistically insignificant at the 10%. There are also ambiguous effects of any gains for banks denoted as CLS banks; the sign and size is model and sample dependent. We find subsidiaries of foreign banks to face relatively higher rates than domestic banks while branches of foreign banks obtain relatively lower rates. The results are however model dependent as shown in the appendix.

Turning to the effects of overall liquidity, we find overnight interest rates to decline when overall liquidity increases. Furthermore, there is evidence that the distribution of liquidity also matters. Our results suggest upward pressure on interest rates in periods with an uneven liquidity distribution, consistent with the evidence in e.g. Bindseil et al. (2004). In particular, the relatively higher coefficient estimate associated with liquidity distribution in subsamples from the financial crisis period suggests that an uneven liquidity distribution matter more during the financial crisis. This is in contrast with the coefficient estimate of overall liquidity which offer mixed evidence. The coefficient estimates associated with overall liquidity is higher when observations from the start of the financial crisis and onwards are used, while it becomes smaller, but comparable to the full sample estimate, when only observations during the financial crisis are used; see Columns (3)–(4).

Regarding estimated effects of control variables representing market conditions, we find an increase in payment activity to place upward pressure on interest rates as in Acharya and Merrouche (2013). Moreover, even when controlling for payment activity, there is a significant reduction in the effects of the due dates for petroleum taxes when they are changed from two to six times a year. This implies that an increase in the number of due dates has helped reduce pressure on interest rates in connection with payments of petroleum taxes.

As expected, the results suggest higher interest rates during the financial crisis. There was a significant increase in overnight interest rates that can be related to bank defaults in September–October 2008. We also observe a significant end-of-year effect on the interest rates. The relatively large coefficient estimates associated with the end-of-year dummy suggest relatively high borrowing rates at the end of a year.

This effect could be ascribed to particularly low turnover in the interbank market in the final days of a year owing to e.g. regulatory reasons and portfolio adjustments overall. On average, turnover on the last business days of the years are close to 1/3 of the daily turnover in our sample. At the end of months, however, there is only weak evidence of such effects as the associated dummies are statistically significant at the 10% level at most.

4.3 A summary of our robustness analysis

Our main conclusions are robust to several alternative data samples, centrality measures and model specifications. A summary of selected robustness tests is provided in Table 2 while details and some additional robustness tests are presented in Appendix C.[19] In particular, our main findings are robust to calculating the centrality based on longer-term interbank loans (bonds) and to using an alternative, but related, measure of centrality; see Columns (1)–(2), respectively. Moreover, we find that our conclusions remain robust to using the core capital ratio as an alternative measure of riskiness instead of beta in Column (3). The conclusions are also robust to various model specifications including lagged size and centrality instead of their contemporaneous values and to including lags of the left-hand-side variable (interest rate), see Columns (4)–(5), respectively. Using bank-level fixed effects, however, leads to weaker evidence of the importance of centrality, as especially the standard error of the coefficient estimate increases substantially leading to a statistically insignificant effect in the relevant model specification in Column (6). A possible reason is that a fixed effect model only employs within-firm varation over time to estimate the coefficients, in contrast to our other model specifications which also take advantage of variation between banks. Finally, we note that our results regarding the effects

[19] In order to limit the number of robustness tests presented in this paper, we have chosen not to present the results of some robustness tests where the results were largely similar to those presented for the main models. In particular, we also tested that our results were robust to the use of rolling samples for the calculation of certain variables such as centrality (calculated using 90 and 60-days rolling windows) and borrowed amount (calculated using 30-days rolling windows). We found that the main results are robust to these changes, despite the reductions in the number of observations stemming from the use of rolling windows. We also found that our results are generally robust to alternative dating of the right-hand-side variables (using lags of the bank-specific variables).

of total liquidity and liquidity distribution are statistically significant in at least all of the different model specifications considered in Table 2.

Table 2: *Summary of robustness tests*

$$ii^m_{j,t} - i^b_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Size	-1.60***	-1.37***	0.09		-0.46*	0.14
	(0.30)	(0.31)	(0.35)		(0.26)	(6.28)
Size (lagged)				-0.47		
				(0.37)		
Centrality			-4.10***		-1.24***	-2.15
			(0.41)		(0.40)	(2.39)
Centrality (LM)	-2.65***					
	(0.42)					
Centrality (lagged)				-2.47***		
				(0.45)		
Intercentrality		-1.74***				
		(0.37)				
Interest rate (one lag)					0.51***	
					(0.05)	
Relationship intensity	-8.01***	-6.48***	-4.55***	-7.47***	-3.02**	-13.96***
	(1.50)	(1.60)	(1.02)	(1.67)	(1.36)	(4.64)
Bank beta	35.28***	31.24***		32.82***	15.61***	41.18***
	(2.45)	(2.19)		(2.43)	(2.12)	(13.66)
Core capital (log)			-2.37			
			(1.46)			
Core capital (log) x Foreign branch			14.73***			
			(1.79)			
Poor performing loans	5.46***	5.60***	5.37***	5.89***	2.80***	3.24*
	(0.24)	(0.23)	(0.22)	(0.27)	(0.34)	(1.80)
Monthly borrowing	0.28	0.41*	0.99***	0.47**	0.28	1.79**
	(0.21)	(0.21)	(0.19)	(0.23)	(0.18)	(0.71)
Liquidity	-3.10***	-2.81***	-2.28***	-3.39***	-1.93***	-2.66**
	(0.52)	(0.52)	(0.35)	(0.54)	(0.41)	(1.08)
Liquidity distribution	10.43**	9.69**	7.08***	12.03***	5.64*	9.45**
	(4.36)	(4.43)	(2.50)	(4.53)	(3.25)	(3.87)
Payments turnover	3.04***	3.23***	2.78***	3.60***	3.35***	2.90**
	(0.84)	(0.86)	(0.63)	(1.06)	(0.89)	(1.10)
Oil tax (2x)	6.00**	6.00**	8.31***	5.82**	6.12***	5.30**
	(2.64)	(2.52)	(2.59)	(2.60)	(1.96)	(2.24)
Oil tax (6x)	-0.69	-0.19	1.39	-0.62	0.26	-0.76
	(3.77)	(3.86)	(2.50)	(3.94)	(2.35)	(2.15)
Financial crisis dummy	19.24***	19.32***	19.38***	18.88***	9.84***	18.89***
	(3.59)	(3.55)	(2.18)	(3.57)	(2.28)	(5.71)
End of year dummy	41.79***	41.21***	45.56***	24.39***	40.87***	41.83***
	(12.44)	(12.16)	(7.09)	(6.95)	(11.71)	(9.87)
End of month dummy	3.11	3.18	3.95***	3.80*	3.86**	3.27***
	(1.92)	(1.95)	(1.14)	(2.09)	(1.75)	(0.96)
CLS dummy	-4.16***	-1.79**	3.97***	-2.36**	-0.83	
	(0.70)	(0.84)	(0.79)	(0.93)	(0.76)	
Settlement bank dummy	0.40	0.47	5.69***	-0.34	-0.41	
	(0.74)	(0.73)	(0.83)	(0.89)	(0.60)	
Foreign branch dummy	-8.10***	-4.15***	-30.49***	-3.99***	-2.27***	
	(0.78)	(0.47)	(3.76)	(0.54)	(0.45)	
Foreign subsidiary dummy	8.74***	7.71***	2.13***	7.03***	3.36***	
	(0.88)	(0.85)	(0.72)	(0.84)	(0.85)	
Observations	3,845	3,845	5,112	3,423	3,828	3,845
Adjusted R-squared	0.44	0.44	0.38	0.45	0.59	0.25
Number of bankid						17

Note: All columns present results estimated on the full sample (9 October 2006 to 6 April 2009). Columns (1) and (2) present results when the model is estimated using different calculations of centrality (long-term loans and intercentrality, respectively). Column (3) employs core capital instead of bank level beta. Column (4) presents the model estimated with size and centrality lagged once. The results in Column (5) are estimated using bank-level fixed effects.

5 Conclusions

Our findings suggest that banks that may be considered systemic because of their financial linkages (centrality) are able to borrow in the unsecured overnight interbank market at relatively lower overnight rates than other banks. The relationship between bank size and overnight interest rate is found to be ambiguous, however, as its sign and statistical significance vary across the models and data samples considered. Possible effects of centrality could reflect lower credit risk owing to a perception of an implicit government guarantee against default for banks with extensive financial linkages. The observed relationship between interest rates and centrality has been found to be relatively strong during the recent financial crisis. This is consistent with an increase in the value of an implicit government guarantee against default during a financial crisis. Estimated gains to highly interconnected, and usually sizable, banks due to the perception of government guarantees against default suggest the need for appropriate regulation and close monitoring of such banks to discourage such perceptions, prevent excessive risk taking and thereby limit potential spillovers to monetary and fiscal policy.

The other notable result is that while an increase in overall liquidity in the interbank market contributes to lower interest rates, its effectiveness can be reduced if it is unevenly distributed among banks. The latter effect could be due to the exercise of market power of banks with a relatively large share of overall liquidity. For central banks in particular, this finding suggests that the monetary policy transmission mechanism in the interbank market may be enhanced by attention to the distribution of liquidity in the interbank market, in addition to overall liquidity.

We have undertaken a number of sensitivity analyses and found our main results to be quite robust. Yet, given the lack of precise measures of key variables including systemic importance, liquidity distribution and even actual overnight interest rates, more research on the topic is required, especially on the relationship between interest rates on longer maturity loans and systemic importance.

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Appendix

Appendix A provides a detailed description of the variables in the model. Appendices B and C show the robustness of our main results to changes in the data sample and model specification, respectively.

Appendix A. Data definitions

Table 3: *Description of variables*

Variables	Description
Bank characteristics	
Size	A bank's total assets at the end of a quarter. Log of values in NOK billion (bn).
Centrality	Measure of centrality proposed in Bonacich (1987). The centrality measure is calculated on the basis of a matrix identifying the links (i.e. overnight loans in the main analysis, while longer-maturity loans are used in Appendix C) between the banks each quarter. Defining this matrix as W, the Bonacich centrality, c is defined as $c(N, \beta, W) = N[I - \beta W]^1 \times W1$ where N is a scaling parameter equal to the number of banks in the network, I is the identity matrix and 1 is a vector of ones. The parameter β is a factor that defines to what extent the centrality of a bank is affected by the centrality of its counterparts. It can take values between $[-\frac{1}{\lvert L\rvert}, \frac{1}{\lvert L\rvert}]$ where L is the largest eigenvalue of W. For $\beta = 0$, the centrality of a bank is not affected by the centrality of it counterparts. We have chosen a β of 0.05 to allow the centrality of one bank to be affected by its counterparts'. Selecting other reasonable (positive) values of β does not affect our conclusions. As the centrality scores are based on the number of counterparties as well as the direction of the transactions in each quarter, the sum of centrality scores and the variance between banks would depend on the total interbank activity that quarter. We therefore normalize the centrality scores for each quarter by subtracting the quarterly mean and dividing by the quarterly standard deviation.
Monthly amount	Monthly amount borrowed by each bank. Log of NOK bn.
Relationship intensity	Value of funds obtained from a bank's biggest counterparty each quarter divided by its total borrowing the same quarter, cf. Craig et al. (2015)
Relationship number	Number of banks from which funds were borrowed (measured quarterly)
Poor performing loans	Loans that are past-due for a period exceeding 3 months as a percentage of total outstanding amount of loans to the public. In %.
Core capital	Core capital ratio (Tier 1 capital over risk weighted assets) measured quarterly. In %.
Bank beta	Beta values based on the CAPM estimated using the method proposed by Dimson (1979). The adjusted betas are estimated each calendar year using a rolling window of banks' returns data from the preceding 4 years against the market returns on the Oslo Stock Exchange. Data available for 18 banks in our sample.
Bank dummies	Four dummy variables indicating CLS-banks, settlement banks, foreign branches and subsidiaries of foreign banks.
Market conditions	
Liquidity	Amount of NOK liquidity available to banks, i.e. the aggregate of their position towards Norges Bank at the beginning of each day. Log of NOK bn.
Liquidity distribution	Gini coefficient is calculated from the each bank's available liquidity per day.
Payments turnover	Gross payment systems turnover in the RTGS-system on each day. Log of NOK bn.
Oil tax	Binary dummy variables indicating due dates for the payment of petroleum taxes under the previous regime with two dues dates in a year (2x) and the current regime with six due dates (6x). The last half-yearly payment was on 1 April 2008 and the first due date under the new regime was 1 August 2008.
Financial crisis time dummy	A binary dummy variable with a value of 1 from 15 September 2008 to 15 October 2008 and 0 otherwise.
End-of-period dummy	A binary dummy variable indicating the end of each period: year or month.

Appendix B. Robustness to data samples

B1. Applying alternative band widths for the Furfine algorithm

One faces the risk of overestimating the number of interbank loans with a predefined band for possible (derived) interest rates (ii) that is too wide, but underestimating it by choosing a band that is too narrow; see Section 2.1. In the following, we show that our results are robust to a narrower and a wider band for possible interest rates than the one used in the main analysis. The results are presented in Table 4, where Columns (1)–(3) show results based on possible interest rates within a relatively narrow band, which only allows values of ii between i_{cb}^{b} and NIBOR_{t-1}. Columns (4)–(6) present results based on a relatively wide band, which allows values of ii between $i_{cb}^{b} - 0.2$ and $\max\{i_{cb}^{a} + 0.2, \text{NIBOR}_{t-1}\}$; i_{cb}^{b} and i_{cb}^{a} are Norges Bank's deposit and lending rates, respectively.

The initial number of interbank payments transactions was 428 708. When we imposed Furfine-restrictions to identify interbank overnight loans among these, we were left with 18 760 transactions classified as likely interbank loans. When we imposed implied interest rates to be part of the narrower interest rates band, the number of likely interbank overnight loans was reduced to 17 057, while the number increased to 19 294 when the relatively wider band was imposed.

Table 4 shows that the results are comparable to those in the main analysis for most of the variables. In particular, the coefficient estimates associated with *Centrality* are close to those presented in the main analysis and statistically significant at the 1% level; see Table 1. The coefficient estimate associated with *size* has negative sign in all but one of the six samples, but it is significant at the 1% level when estimated on the full sample based on observations conditional on the narrow band. Overall liquidity's coefficient estimate remains negative and statistically significant at the 1% in all but one of the samples. Liquidity distribution's coefficient estimate is positive and mostly significant at the 5% level. The results for almost all of the control variables are also qualitatively as in the main analysis. The sign and size of the coefficient estimate associated with settlement-bank status dummy are quite sample dependent, however, turning out to be significantly positive in three samples conditional on a narrow band, but statistically insignificant in the three wide-band samples.

Table 4: *Econometric analysis with different bands for allowed interest rates*

$$ii^{m}_{j,t} - i^{b}_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Size	-1.13***	-0.55	-1.12*	-0.63	0.18	-0.76
	(0.30)	(0.51)	(0.59)	(0.41)	(0.63)	(0.63)
Centrality	-3.06***	-6.01***	-9.49***	-2.75***	-5.45***	-9.67***
	(0.39)	(0.68)	(1.11)	(0.51)	(0.79)	(1.17)
Relationship intensity	-3.49**	-9.98***	-2.58	-8.58***	-15.80***	-17.36***
	(1.46)	(2.05)	(3.84)	(1.65)	(2.08)	(4.06)
Bank beta	25.68***	33.72***	36.83***	29.91***	41.54***	39.77***
	(2.12)	(3.10)	(3.81)	(2.43)	(3.29)	(3.93)
Poor performing loans	4.49***	4.90***	2.88***	5.86***	6.42***	4.81***
	(0.25)	(0.33)	(0.61)	(0.30)	(0.46)	(0.67)
Monthly borrowing	0.96***	1.39***	1.79***	0.15	0.73**	0.69*
	(0.20)	(0.29)	(0.39)	(0.23)	(0.33)	(0.37)
Liquidity	-1.49***	-2.57***	0.16	-3.79***	-5.40***	-3.99***
	(0.48)	(0.67)	(0.92)	(0.59)	(0.76)	(1.08)
Liquidity distribution	6.25	14.12**	13.08*	10.19**	17.15**	15.88**
	(4.09)	(6.87)	(7.18)	(4.86)	(7.32)	(7.71)
Payments turnover	3.62***	4.77***	6.14***	3.26***	3.19**	4.37***
	(0.92)	(1.42)	(1.64)	(0.87)	(1.30)	(1.51)
Oil tax (2x)	5.84**	5.83*	5.00*	6.09**	6.48**	5.77*
	(2.75)	(3.15)	(2.86)	(2.44)	(3.30)	(3.11)
Oil tax (6x)	-0.66	-1.67	-0.29	-1.91	-2.45	0.38
	(3.67)	(3.57)	(4.66)	(4.12)	(3.88)	(5.11)
Financial crisis dummy	20.20***	18.89***	16.87***	21.22***	19.93***	19.79***
	(3.78)	(3.90)	(3.67)	(3.78)	(3.89)	(3.87)
End of year dummy	35.99**	13.54***	8.71***	41.10***	22.08***	34.34***
	(15.07)	(3.33)	(2.50)	(12.08)	(7.35)	(3.28)
End of month dummy	1.59	2.48	2.57	4.20	7.60*	4.37
	(1.38)	(2.18)	(2.35)	(2.63)	(4.11)	(3.20)
CLS dummy	-0.07	-1.55*	4.61***	-1.43	-4.43***	3.93**
	(0.67)	(0.91)	(1.59)	(0.92)	(1.21)	(1.55)
Settlement bank dummy	1.83***	3.27***	4.04***	-0.13	-0.87	0.68
	(0.61)	(1.17)	(1.45)	(0.90)	(2.02)	(1.62)
Foreign branch dummy	-3.86***	-4.66***	-6.25***	-3.45***	-5.69***	-7.80***
	(0.44)	(0.76)	(0.85)	(0.68)	(0.90)	(0.89)
Foreign subsidiary dummy	6.05***	11.81***	8.39***	8.06***	12.99***	11.12***
	(0.75)	(1.22)	(1.34)	(0.88)	(1.59)	(1.44)
Observations	3,690	2,266	1,855	3,873	2,445	1,938
Adjusted R-squared	0.40	0.42	0.38	0.39	0.47	0.37

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension. Columns (1) to (3) presents results using a narrow band for allowed interest rates. Columns (4) to (6) present results from a sample based on a wide band for allowed interest rates. Columns (1) and (4) present results estimated on the full sample (9 October 2006 to 6 April 2009). Columns (2) and (5) present results when the model is estimated on a sample starting 9 August 2007 and the results in Columns (3) and (6) are based on the sample period from 9 August 2007 to 24 November 2008.

B2. Excluding usually inactive banks

As noted earlier, not all banks are present in the interbank market daily. Only about half of the banks are active on more than 1/4 of the days in the data set, whereas three banks are active on more than 95% of the days. We have therefore re-estimated the model using data only for the three relatively active banks to ensure that our results are not driven by banks which are usually not active in the interbank market. Table 5 presents results based on the re-estimated model. As shown, our main results remain qualitatively the same for almost all of the variables. Many of the variables loose statistical significance, however, given the reductions in observations of more than 50% relative to those used in Table 1.

Notably, an increase in *size*, *centrality* and overall liquidity is associated with lower interest rates while a more unequal liquidity distribution goes together with higher interest rates. The coefficient estimate of *size* is not statistically significant in the full sample while it is numerically and statistically significant in the two subsamples.

Table 5: *Econometric analysis excluding non-active banks*

$$ii^m_{j,t} - i^b_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)
Size	-2.55	-20.79***	-21.58**
	(2.95)	(7.44)	(9.85)
Centrality	-2.33***	-3.84***	-1.90
	(0.61)	(1.00)	(2.96)
Relationship intensity	-17.17***	-16.07***	3.11
	(2.73)	(4.66)	(6.82)
Bank beta	43.82***	53.62***	51.17***
	(5.38)	(6.05)	(6.37)
Poor performing loans	-18.40***	6.07	38.58*
	(5.82)	(7.25)	(21.91)
Monthly borrowing	1.75**	3.73***	8.14***
	(0.77)	(0.89)	(1.36)
Liquidity	-2.10**	-3.97***	-2.11*
	(0.83)	(0.93)	(1.11)
Liquidity distribution	8.18	6.82	10.27
	(6.50)	(8.97)	(9.19)
Payments turnover	0.76	1.51	3.61**
	(1.03)	(1.63)	(1.76)
Oil tax (2x)	6.81	8.55	6.84
	(5.02)	(6.95)	(7.05)
Oil tax (6x)	-1.85	-2.96	-1.14
	(3.27)	(3.29)	(5.36)
Financial crisis dummy	24.58***	24.09***	20.93***
	(4.85)	(4.85)	(4.53)
End of year dummy	37.06***	22.57***	31.30***
	(11.60)	(4.37)	(2.67)
End of month dummy	2.22	3.62	1.66
	(1.95)	(2.66)	(2.41)
Foreign branch dummy	-17.96**	-52.79***	-33.50*
	(7.72)	(16.11)	(19.14)
Foreign subsidiary dummy	5.98*	-1.96	5.68
	(3.26)	(6.52)	(7.61)
Observations	1,783	1,188	934
Adjusted R-squared	0.29	0.36	0.35

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension. Column (1) presents results estimated on the full sample (9 October 2006 to 6 April 2009). Column (2) presents results when the model is estimated on a sample starting 9 August 2007 and the results in Column (3) are based on the sample period from 9 August 2007 to 24 November 2008.

B3. Low interest rates due to arbitrage?

The NOK-USD swap market is available for financing and investing for Norwegian banks and institutional investors. Banks in Norway can borrow Norwegian krone (NOK) through the NOK-USD foreign exchange swap market, rather than directly in the Norwegian money market. Not all banks choose to access the USD market for funds, however. A large number of smaller Norwegian banks are mainly active in the Norwegian money market. Larger banks are generally active in both.

It is possible that relatively low interest rates are obtained by relatively large banks because they borrow directly in the interbank market for NOK if it is cheaper than borrowing through the NOK-USD swap market and vice versa.

However, when the model is estimated for only the most active banks, the results become comparable to those in Table 5 based on a data sample for the three banks, which may regularly access both the NOK-USD swap market and the pure NOK market. The results are qualitatively the same as in the main analysis where all banks are included in the estimation sample.

We do not have precise information about the extent of foreign exchange swap dealings as a substitute for direct dealing in the NOK market during our sample. However, recently available survey evidence for 2013 and 2014 suggests that a relatively small share of foreign exchange swaps, 7%–15%, are used for overnight borrowing and lending; see Norges Bank (2014, 2015). Moreover, a relatively small share of such foreign exchange swaps dealing, 15%–20%, are between banks located in Norway with access to Norges Bank's RTGS system. Most of the foreign exchange swap dealings are with banks abroad.

Appendix C. Robustness to changes in model specifications

In the following, we show the robustness of our main conclusions to alternative model specifications. Specifically, we test the robustness of the model to: alternative centrality and creditworthiness measures, allowance for unobserved individual hetereogeneity and period fixed effects, use of two-way clustered standard errors, use of lagged size and centrality measures to address a concern for endogeneity, and finally, the inclusion of lags of the left-hand side variable to acount for the influence of potentially omitted variables.

C1. Alternative centrality measures

First, we calculate the Bonacich (1987) measure of centrality based on a data set of interbank loans at a relatively longer maturity, i.e. certificates and bonds at maturities of one month and more. The interbank liabilities are measured at the end of each quarter. The data set has been provided by Statistics Norway. The sample correlation between the two Bonacich (1987) measures based on long and overnight maturities of interbank liabilities is about 0.6. The estimation results based on the former centrality measure are presented in Table 6, Columns (1)–(3).

And second, we estimate a model based on the centrality measure proposed by Ballester et al. (2006) on the data set of overnight loans used in the main analysis. This measure, which is known as intercentrality, evaluates the importance of a specific network participant by assessing disruption in the network when the participant is excluded from the network. Removal of the most important participant results in the maximal decrease in overall network activity. In our data set on overnight interbank loans, the correlation between the Bonacich centrality and the centrality measures suggested by Ballester et al. (2006) is relatively high: 0.99. The relevant estimation results are presented in Table 6, Columns (4)–(6).

C2. Using additional measure of credit riskiness

In Table 7 we show the robustness of our main conclusions to the inclusion of the ratio of a bank's core capital instead of of their beta estimates, as a measure of their credit riskiness. As core capital ratios are available for all of the banks, in contrast with the beta measures, the number of observations increase by more than 30%. Core capital ratios for branches of foreign banks are not measured for the Norwegian branch only, since this measure would be somewhat arbitrary. Instead, we use core capital ratios as reported by the owning foreign bank in these cases.

Table 6: ***Econometric analysis with different centrality measures***

$$ii^{m}_{j,t} - i^{b}_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Size	-1.60***	-1.28**	-1.60***	-1.37***	-0.77	-1.12*
	(0.30)	(0.55)	(0.59)	(0.31)	(0.53)	(0.60)
Centrality (LM)	-2.65***	-4.06***	-7.30***			
	(0.42)	(0.69)	(0.83)			
Intercentrality				-1.74***	-3.94***	-6.65***
				(0.37)	(0.60)	(0.92)
Relationship intensity	-8.01***	-13.01***	-9.88**	-6.48***	-12.49***	-4.52
	(1.50)	(1.94)	(3.95)	(1.60)	(2.07)	(3.97)
Bank beta	35.28***	45.81***	51.31***	31.24***	40.22***	43.77***
	(2.45)	(3.80)	(4.35)	(2.19)	(3.16)	(3.88)
Poor performing loans	5.46***	5.91***	4.87***	5.60***	6.12***	4.59***
	(0.24)	(0.34)	(0.59)	(0.23)	(0.32)	(0.59)
Monthly borrowing	0.28	0.76**	1.27***	0.41*	0.95***	1.55***
	(0.21)	(0.31)	(0.37)	(0.21)	(0.31)	(0.38)
Liquidity	-3.10***	-4.60***	-1.71*	-2.81***	-4.02***	-1.42
	(0.52)	(0.67)	(0.94)	(0.52)	(0.69)	(0.98)
Liquidity distribution	10.43**	18.25***	16.26**	9.69**	16.24**	14.80**
	(4.36)	(6.87)	(7.14)	(4.43)	(7.02)	(7.48)
Payments turnover	3.04***	3.27**	4.21***	3.23***	3.44***	4.74***
	(0.84)	(1.30)	(1.37)	(0.86)	(1.32)	(1.45)
Oil tax (2x)	6.00**	6.38*	5.49	6.00**	6.33**	5.54**
	(2.64)	(3.69)	(3.63)	(2.52)	(2.85)	(2.47)
Oil tax (6x)	-0.69	-1.50	0.62	-0.19	-0.77	1.50
	(3.77)	(3.64)	(4.56)	(3.86)	(3.70)	(4.95)
Financial crisis dummy	19.24***	18.10***	16.41***	19.32***	18.26***	16.60***
	(3.59)	(3.80)	(3.64)	(3.55)	(3.77)	(3.57)
End of year dummy	41.79***	23.17***	35.45***	41.21***	22.66***	33.69***
	(12.44)	(7.12)	(2.50)	(12.16)	(6.63)	(2.58)
End of month dummy	3.11	5.49*	3.08	3.18	5.66*	3.21
	(1.92)	(3.00)	(2.41)	(1.95)	(3.05)	(2.43)
CLS dummy	-4.16***	-9.63***	-9.39***	-1.79**	-4.38***	1.21
	(0.70)	(0.96)	(1.05)	(0.84)	(1.04)	(1.45)
Settlement bank dummy	0.40	2.00	3.00*	0.47	1.61	1.08
	(0.74)	(1.64)	(1.60)	(0.73)	(1.56)	(1.49)
Foreign branch dummy	-8.10***	-11.12***	-16.51***	-4.15***	-5.72***	-6.92***
	(0.78)	(1.08)	(1.28)	(0.47)	(0.82)	(0.88)
Foreign subsidiary dummy	8.74***	12.30***	12.69***	7.71***	12.40***	8.90***
	(0.88)	(1.43)	(1.55)	(0.85)	(1.42)	(1.33)
Observations	3,845	2,418	1,920	3,845	2,418	1,920
Adjusted R-squared	0.44	0.49	0.40	0.44	0.49	0.38

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension. In Columns (1) to (3) the estimation is based on the Bonacich (1987) centrality measure calculated on longer-maturity loans (LM). In Columns (4) to (6), the measure of centrality is based on the inter-centrality measure proposed in Ballester et al. (2006). Columns (1) and (4) present results estimated on the full sample (9 October 2006 to 6 April 2009). Columns (2) and (5) present results when the model is estimated on a sample starting 9 August 2007 and the results in columns (3) and (6) are based on the sample period from 9 August 2007 to 24 November 2008.

Accordingly, we allow different effects on interest rates by core capital ratios for branches of foreign banks and Norwegian banks (or subsidiaries of foreign banks) by letting a bank's core capital interact with a dummy variable indicating a foreign branch. For subsidiaries of foreign banks, which are in effect stand-alone banks, core capital ratios are measured for the subsidiary registered in Norway.

We note that the effects of core capital are significant with the expected sign for domestic banks and subsidiaries of foreign banks in the two subsamples. For branches of foreign banks, however, the core capital ratio has the opposite sign.

Table 7: *Econometric analysis with core capital*

$$\begin{aligned} ii^{m}_{j,t} - i^{b}_{cb,t} &= \alpha_j + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} \\ &+ \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t} \end{aligned}$$

VARIABLES	(1)	(2)	(3)
Size	0.09	0.25	-0.15
	(0.35)	(0.61)	(0.73)
Centrality	-4.10***	-5.11***	-8.45***
	(0.41)	(0.60)	(0.93)
Relationship intensity	-4.55***	-8.94***	-7.45***
	(1.02)	(1.44)	(2.01)
Poor performing loans	5.37***	6.02***	4.52***
	(0.22)	(0.28)	(0.53)
Monthly borrowing	0.99***	1.38***	1.91***
	(0.19)	(0.30)	(0.35)
Core capital (log)	-2.37	-9.84***	-9.80***
	(1.46)	(2.59)	(2.72)
Core capital (log) x Foreign branch	14.73***	25.38***	20.00***
	(1.79)	(2.71)	(2.73)
Liquidity	-2.28***	-3.98***	-0.80
	(0.35)	(0.44)	(0.64)
Liquidity distribution	7.08***	12.79***	9.41**
	(2.50)	(3.76)	(3.96)
Payments turnover	2.78***	3.48***	4.60***
	(0.63)	(1.04)	(1.18)
Oil tax (2x)	8.31***	8.35**	7.45**
	(2.59)	(3.38)	(3.14)
Oil tax (6x)	1.39	0.47	3.46
	(2.50)	(2.49)	(3.16)
Financial crisis dummy	19.38***	18.55***	16.81***
	(2.18)	(2.18)	(2.12)
End of year dummy	45.56***	26.57***	27.82**
	(7.09)	(9.46)	(11.08)
End of month dummy	3.95***	6.53***	5.11***
	(1.14)	(1.89)	(1.81)
CLS dummy	3.97***	4.07***	10.10***
	(0.79)	(1.12)	(1.75)
Settlement bank dummy	5.69***	7.52***	6.93***
	(0.83)	(1.69)	(1.96)
Foreign branch dummy	-30.49***	-54.04***	-45.35***
	(3.76)	(5.73)	(5.69)
Foreign subsidiary dummy	2.13***	2.33**	0.04
	(0.72)	(1.14)	(1.20)
Observations	5,112	3,165	2,590
Adjusted R-squared	0.38	0.42	0.32

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension. Column (1) presents results estimated on the full sample (9 October 2006 to 6 April 2009). Column (2) presents results when the model is estimated on a sample starting 9 August 2007 and the results in Column (3) are based on the sample period from 9 August 2007 to 24 November 2008.

This might be due to the fact that core capital ratios are not measured for the Norwegian branch only, as discussed above. We also considered using CDS spreads as an additional measure of credit risk. However, we found that the number of banks with CDS traded with sufficient frequency was not large enough to include CDS spreads in our analysis. [20]

[20]CDS-data covering the whole or parts of the sample period is only available for a small minority of the banks in our sample. Moreover, even when CDS-data is available, the frequency of trading and price fixing is often very low, especially in the beginning of the sample period.

C3. Allowing for (unobserved) individual heterogeneity and period fixed effects

Table 8: ***Econometric analysis including fixed effects***

$$ii^{m}_{j,t} - i^{b}_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi' B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi' M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)
Size	0.14	-0.17	-1.01***
	(6.28)	(8.68)	(0.32)
Centrality	-2.15	-5.99	-1.88***
	(2.39)	(3.99)	(0.39)
Relationship intensity	-13.96***	-12.50	-2.79*
	(4.64)	(11.39)	(1.52)
Bank beta	41.18***	61.77***	21.69***
	(13.66)	(13.77)	(2.28)
Poor performing loans	3.24*	-1.77	5.79***
	(1.80)	(6.57)	(0.24)
Monthly borrowing	1.79**	3.56**	0.31*
	(0.71)	(1.39)	(0.18)
Liquidity	-2.66**	-2.13*	
	(1.08)	(1.08)	
Liquidity distribution	9.45**	16.20**	
	(3.87)	(5.94)	
Payments turnover	2.90**	3.94***	
	(1.10)	(1.08)	
Oil tax (2x)	5.30**	4.29	
	(2.24)	(2.79)	
Oil tax (6x)	-0.76	0.16	
	(2.15)	(2.68)	
Financial crisis dummy	18.89***	16.03***	
	(5.71)	(5.15)	
End of year dummy	41.83***	35.61*	
	(9.87)	(16.59)	
End of month dummy	3.27***	3.11**	
	(0.96)	(1.38)	
CLS dummy			-0.21
			(0.76)
Settlement bank dummy			2.42***
			(0.73)
Foreign branch dummy			-3.13***
			(0.55)
Foreign subsidiary dummy			6.30***
			(0.87)
Observations	3,845	1,920	3,852
Number of bankid	17	14	
Adjusted R-squared	0.25	0.24	0.57

Note: Values in parentheses are cross-sectional robust standard errors. The results in Columns (1) - (2) are estimated with bank-specific fixed effects. Columns (1) and (3) presents results estimated on the full sample (9 October 2006 to 6 April 2009). Column (2) is based on a restricted sample period from 9 August 2007 to 24 November 2008. The model in Column (3) is estimated with fixed effects along the time dimension (daily).

To test the robustness to alternative model set-ups, we assume there is (unobserved) individual heterogeneity across banks, which is captured by allowing for different intercepts for each bank. We assume, however, that the slope coefficients are equal across banks. The intercept parameter α is given a subscript j to indicate different banks; cf. model (2). The parameter α_j is assumed to control for time-invariant bank-specific characteristics not included in the model. The first two columns of Table 8 present the results of this estimation based on two different sample periods, including bank level beta as in our main model. The coefficient estimates associated with *centrality* maintain their negative signs, but are not significant mainly due to the sizable increase in the estimated values of the robust standard erros. Part of the reason for this might be that the fixed effect model only employs within-bank variation over time to estimate the coefficients, in contrast to our other model specifications which also take advantage of variation between banks.

However, the market variables, liquidity and liquidity distribution, remain significant, supporting our findings regarding the impact of liquidity conditions in the unsecured interbank market.

Finally, we estimate a model based on a simple model specification with period fixed effects; see Column (3) of Table 8. Introducing period fixed effects allows us to account for changes along the time dimension in our relatively large-T data set without explicitly accounting for variables representing market conditions that are included in the main analysis. The model now includes explicitly only variables representing bank characteristics. Here, the effects of both *size* and *centrality* are statistically significant at the 5% and 1% level of significance, respectively.

C4. Two-way clustering of standard errors

The standard errors in the main model are clustered by the time dimension (i.e. the more frequent cluster) to account for potential cross-correlation in the standard errors. In general, this approach should yield results that are close to those obtained by clustering by both bank and time, see Petersen (2009). We have, however, also estimated the main model allowing for clusters by both bank and time as part of our robustness checks. The results are reported for the main model in Table 9, and does not affect our findings, especially those about centrality, total liquidity and liquidity distribution. There is somewhat weaker evidence that levels of liquidity and its distribution also affected interest rates, but both variables remain significant in the main model including centrality.

Table 9: ***Main analysis with two-way clustering of standard errors***

$$ii^{m}_{j,t} - i^{b}_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)
Size	-1.15	-0.51	-1.11
	(1.01)	(1.54)	(1.66)
Centrality	-3.10*	-5.76***	-9.96***
	(1.76)	(2.10)	(2.54)
Relationship intensity	-8.42*	-15.17*	-10.93
	(4.67)	(8.66)	(10.10)
Bank beta	29.81***	39.57***	41.38***
	(9.32)	(8.81)	(8.30)
Poor performing loans	5.52***	5.95***	4.08**
	(0.70)	(1.05)	(1.80)
Monthly borrowing	0.45	1.01	1.30*
	(0.38)	(0.62)	(0.73)
Liquidity	-2.92***	-4.36***	-2.05**
	(0.70)	(0.66)	(0.96)
Liquidity distribution	9.56**	16.94**	15.51**
	(4.59)	(7.16)	(7.51)
Payments turnover	3.06**	3.29**	4.47***
	(1.20)	(1.35)	(1.33)
Oil tax (2x)	5.91***	6.04***	5.20**
	(1.70)	(2.24)	(2.14)
Oil tax (6x)	-0.42	-1.20	0.91
	(3.50)	(3.42)	(4.34)
Financial crisis dummy	19.14***	17.84***	16.30***
	(6.04)	(5.68)	(5.09)
End of year dummy	41.12***	22.27**	33.83***
	(12.81)	(10.53)	(8.35)
End of month dummy	3.27*	5.77**	3.32*
	(1.73)	(2.77)	(1.93)
CLS dummy	-0.32	-3.08**	5.00
	(1.93)	(1.27)	(3.39)
Settlement bank dummy	0.38	1.01	1.12
	(1.51)	(3.60)	(4.58)
Foreign branch dummy	-4.57***	-6.37***	-8.43***
	(1.61)	(1.47)	(1.35)
Foreign subsidiary dummy	6.98***	12.05***	8.47**
	(2.26)	(4.08)	(3.39)
Observations	3,845	2,418	1,920
Adjusted R-squared	0.44	0.49	0.39

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time and bank dimension. Column (1) presents results estimated on the full sample (9 October 2006 to 6 April 2009). Column (2) presents results when the model is estimated on a sample starting 9 August 2007 and the results in Column (3) are based on the sample period from 9 August 2007 to 24 November 2008.

C5. Endogeneity: Lagged size and centrality

One could argue that it is not the centrality of a bank that would contribute to lower its interest rates, but the other way around. To address this possible concern we re-estimate our main model with centrality and size lagged once (instead of using the contemporaneous values). We find that all our main results are robust to these changes in specifications. We also refer to the analysis shown in Appendix C1 where we calculate the (Bonacich) centrality measure based on a sample of relatively longer maturity interbank loans. The latter refers to cross holdings of Norwegian banks' certificates and bonds, at maturities of one month and more. A potential endogeneity problem is likely to be less important in a model of overnight interest rates with a centrality measure based on the latter data set than with a centrality measure derived from overnight interbank liabilities.

Table 10: *Lagged size and centrality*

$$
\begin{aligned}
ii^m_{j,t} - i^b_{cb,t} &= \alpha + \beta_1 size_{j,t-1} + \beta_2 centrality_{j,t-1} + \boldsymbol{\varphi'B}_{j,t} \\
&+ \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi'M}_t + \varepsilon_{j,t}
\end{aligned}
$$

VARIABLES	(1)	(2)	(3)
Size (lagged)	-0.47	-0.44	-0.65
	(0.37)	(0.51)	(0.57)
Centrality (lagged)	-2.47***	-3.86***	-3.73***
	(0.45)	(0.66)	(0.74)
Relationship intensity	-7.47***	-11.20***	-0.43
	(1.67)	(1.90)	(3.76)
Bank beta	32.82***	38.14***	39.47***
	(2.43)	(3.12)	(3.77)
Poor performing loans	5.89***	6.17***	5.09***
	(0.27)	(0.31)	(0.58)
Monthly borrowing	0.47**	0.88***	1.70***
	(0.23)	(0.31)	(0.38)
Liquidity	-3.39***	-4.94***	-2.61**
	(0.54)	(0.70)	(1.03)
Liquidity distribution	12.03***	19.51***	18.57**
	(4.53)	(7.01)	(7.46)
Payments turnover	3.60***	3.43**	4.71***
	(1.06)	(1.33)	(1.43)
Oil tax (2x)	5.82**	6.59**	5.79**
	(2.60)	(3.23)	(2.90)
Oil tax (6x)	-0.62	-1.07	1.11
	(3.94)	(3.83)	(5.31)
Financial crisis dummy	18.88***	17.90***	15.69***
	(3.57)	(3.75)	(3.51)
End of year dummy	24.39***	23.27***	35.39***
	(6.95)	(7.04)	(2.61)
End of month dummy	3.80*	5.64*	3.33
	(2.09)	(3.01)	(2.51)
CLS dummy	-2.36**	-3.67***	-3.86***
	(0.93)	(1.01)	(1.16)
Settlement bank dummy	-0.34	0.89	1.02
	(0.89)	(1.54)	(1.44)
Foreign branch dummy	-3.99***	-5.43***	-5.23***
	(0.54)	(0.84)	(0.87)
Foreign subsidiary dummy	7.03***	9.86***	8.56***
	(0.84)	(1.30)	(1.31)
Observations	3,423	2,418	1,920
Adjusted R-squared	0.45	0.48	0.37

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time and firm dimension. Columns (1) presents results estimated on the full sample (9 October 2006 to 6 April 2009). Column (2) presents results when the model is estimated on a sample starting 9 August 2007 and the results in Column (3) are based on the sample period from 9 August 2007 to 24 November 2008.

C6. Including lags of the left-hand-side variable

We also estimate the model with lags of the left-hand-side variable entering into the regression. This is intended to mop up the effects of omitted variables and reduce the chance of omitted variable bias in our parameters of interest. We estimate two model specifications, including one and two lags of the dependent variable, respectively. We find that centrality remains with its negative sign and statistical significance in both specifications. Liquidy, another variable of key interest, also retains a negative sign, and statistically significant coefficient estimate, while the distribution of liquidity only enters significantly at the 10% level in the specification with one lag.

Table 11: *Including lags of the left-hand-side variable*

$$\begin{aligned} ii^{m}_{j,t} - i^{b}_{cb,t} &= \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} \\ &\quad + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t} \end{aligned}$$

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Interest rate spread (1 lag)	0.51***	0.54***	0.55***	0.38***	0.40***	0.41***
	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)
Interest rate spread (2 lags)				0.26***	0.25***	0.26***
				(0.05)	(0.04)	(0.05)
Size	-0.46*	-0.05	-0.43	-0.31	0.05	-0.32
	(0.26)	(0.48)	(0.54)	(0.24)	(0.47)	(0.53)
Centrality	-1.24***	-2.38***	-4.54***	-0.70*	-1.70***	-3.48***
	(0.40)	(0.59)	(0.85)	(0.36)	(0.56)	(0.79)
Relationship intensity	-3.02**	-5.81***	-5.52*	-1.41	-3.72**	-4.60
	(1.36)	(1.86)	(2.91)	(1.31)	(1.82)	(2.88)
Bank beta	15.61***	19.10***	19.83***	11.71***	15.31***	15.86***
	(2.12)	(2.90)	(3.48)	(1.75)	(2.68)	(3.12)
Poor performing loans	2.80***	2.87***	2.01***	2.10***	2.25***	1.62**
	(0.34)	(0.42)	(0.68)	(0.31)	(0.42)	(0.69)
Monthly borrowing	0.28	0.59**	0.52*	0.30*	0.52*	0.32
	(0.18)	(0.28)	(0.30)	(0.17)	(0.27)	(0.28)
Liquidity	-1.93***	-2.49***	-1.79***	-1.66***	-2.37***	-2.04***
	(0.41)	(0.48)	(0.66)	(0.36)	(0.47)	(0.61)
Liquidity distribution	5.64*	7.97*	7.79	2.49	5.88	5.65
	(3.25)	(4.64)	(4.77)	(2.61)	(4.43)	(4.55)
Payments turnover	3.35***	3.14***	3.87***	3.25***	2.66**	3.46***
	(0.89)	(1.15)	(1.28)	(0.81)	(1.09)	(1.17)
Oil tax (2x)	6.12***	6.47***	6.01***	7.41***	8.23***	7.89***
	(1.96)	(2.06)	(2.23)	(1.74)	(1.25)	(1.32)
Oil tax (6x)	0.26	0.01	1.67	0.96	0.78	2.35
	(2.35)	(2.15)	(2.48)	(1.94)	(1.82)	(1.95)
Financial crisis dummy	9.84***	8.61***	8.07***	7.81***	6.99***	6.70***
	(2.28)	(2.16)	(2.14)	(2.15)	(2.12)	(2.08)
End of year dummy	40.87***	22.11***	33.32***	40.69***	21.67***	33.21***
	(11.71)	(6.23)	(1.96)	(11.80)	(6.35)	(1.96)
End of month dummy	3.86**	6.42**	3.96**	4.09**	6.68**	4.29**
	(1.75)	(2.81)	(1.86)	(1.78)	(2.88)	(1.88)
CLS dummy	-0.83	-2.14**	2.17*	-1.11	-2.03**	1.66
	(0.76)	(0.99)	(1.31)	(0.74)	(0.98)	(1.31)
Settlement bank dummy	-0.41	-0.61	0.06	-0.59	-1.00	-0.19
	(0.60)	(1.38)	(1.37)	(0.58)	(1.37)	(1.34)
Foreign branch dummy	-2.27***	-3.18***	-3.92***	-1.74***	-2.56***	-3.11***
	(0.45)	(0.72)	(0.80)	(0.41)	(0.71)	(0.76)
Foreign subsidiary dummy	3.36***	4.99***	3.98***	2.03***	3.57***	3.12**
	(0.85)	(1.34)	(1.33)	(0.73)	(1.32)	(1.33)
Observations	3,828	2,418	1,920	3,812	2,417	1,919
Adjusted R-squared	0.59	0.64	0.59	0.65	0.66	0.62

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension. Columns (1) and (4) present results estimated on the full sample (9 October 2006 to 6 April 2009). Columns (2) and (5) present results when the model is estimated on a sample starting 9 August 2007 and the results in Column (3) and (6) are based on the sample period from 9 August 2007 to 24 November 2008.

C7. Alternative measure of relationships

Instead of considering the intensity and potential gains from maintaining closer relationships with counterparties, we also estimate the model with relationships defined simply as the number of counterparties. The number of counterparts (relationship) enters significantly but with a positive sign. We interpret this as consistent with our finding that maintaining few, but strong relationships may be beneficial when obtaining unsecured funding once we control for the effects of size and centrality. Our finding regarding the other variables, especially size, centrality, liquidity and liquidity distribution, are not substantially affected.

Table 12: *Relationships as number of lenders*

$$ii^{m}_{j,t} - i^{b}_{cb,t} = \alpha + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \varepsilon_{j,t}$$

VARIABLES	(1)	(2)	(3)
Size	-0.82***	-0.32	-1.51**
	(0.29)	(0.56)	(0.59)
Centrality	-7.38***	-10.25***	-12.98***
	(0.89)	(1.19)	(1.98)
Relationship (number)	0.95***	1.15***	0.84***
	(0.13)	(0.15)	(0.29)
Bank beta	30.40***	42.30***	41.50***
	(2.19)	(3.17)	(3.87)
Poor performing loans	4.97***	5.00***	3.06***
	(0.21)	(0.33)	(0.57)
Monthly borrowing	0.50***	1.13***	1.41***
	(0.18)	(0.30)	(0.33)
Liquidity	-2.85***	-4.41***	-2.08**
	(0.56)	(0.71)	(1.03)
Liquidity distribution	9.82**	18.64***	16.41**
	(4.36)	(6.77)	(7.17)
Payments turnover	2.53***	2.95**	4.30***
	(0.82)	(1.27)	(1.41)
Oil tax (2x)	5.63**	5.90*	5.20*
	(2.26)	(3.23)	(2.91)
Oil tax (6x)	-0.35	-1.16	0.88
	(3.61)	(3.54)	(4.59)
Financial crisis dummy	18.73***	17.40***	16.33***
	(3.56)	(3.74)	(3.61)
End of year dummy	40.91***	21.96***	34.69***
	(12.76)	(7.75)	(2.43)
End of month dummy	3.51*	5.89*	3.42
	(1.91)	(3.04)	(2.34)
CLS dummy	-3.39***	-7.06***	1.84
	(0.80)	(0.97)	(1.49)
Settlement bank dummy	-1.99***	-2.10	-0.07
	(0.75)	(1.68)	(1.77)
Foreign branch dummy	-6.87***	-9.18***	-10.54***
	(0.55)	(0.92)	(1.20)
Foreign subsidiary dummy	4.77***	7.65***	6.00***
	(0.82)	(1.33)	(1.38)
Observations	3,845	2,418	1,920
Adjusted R-squared	0.45	0.50	0.39

Note: Values in parentheses are robust standard errors, adjusted for clusters along the time dimension. Column (1) presents results estimated on the full sample (9 October 2006 to 6 April 2009). Column (2) presents results when the model is estimated on a sample starting 9 August 2007 and the results in Column (3) are based on the sample period from 9 August 2007 to 24 November 2008.