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Interbank overnight interest rates – gains from systemic importance

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Interbank overnight interest rates – gains from systemic importance*

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July 23, 2010

Abstract

We study overnight interbank interest rates paid by banks in Norway over the period 2006–2009. We observe large variations in interest rates across banks and over time. During the financial crisis, the interest rates are found to be substantially below indicative quotes of interest rates provided by major banks. Our econometric model attributes the interest rate variation partly to differences in banks' characteristics including relative size and connectedness, implying favorable terms for banks of systemic importance. Moreover, interest rates are found to depend not only on overall liquidity in the interbank market, but possibly on its distribution among banks as well, suggesting exploitation of market power by banks with surplus liquidity. There is also evidence of stronger effects on interest rates of systemic importance, credit ratings and liquidity demand and supply since the start of the current financial crisis.

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

JEL Codes: *G21, E42, E43, E58*

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1 Introduction

A well functioning money market is important for banks' funding for their credit and payment intermediation, as underscored by the recent financial crisis. Disruptions in the money market can affect the credit supply to firms and households and payment services provided by banks. Volatility in even short-term money market rates may have macroeconomic effects. Shifts in short-term money market interest rates are generally transmitted to longer-term money market rates and thereby to lending and borrowing rates faced by firms and households, affecting their investment and consumption decisions; see e.g. Acharya and Merrouche (2009).

Information about interbank interest rates and their determination is required for active management of money market liquidity and short-term money market rates. Central banks influence money market interest rates through their deposit and lending rates and by regulating the liquidity stance in the money markets; see e.g. Nautz and Scheithauer (2009). Information about actual interest rates is also of interest from a financial stability perspective; see e.g. Rochet and Tirole (1996) and Furfine (2001). As overnight lending in the interbank market is uncollateralized, actual interest rates paid by a bank may indicate the solvency of the borrowing bank and the credit risk associated with the corresponding loan. In particular, banks perceived to enjoy an implicit government guarantee against default due to their possible systemic importance could face relatively lower overnight interest rates. The systemic importance of a bank is often gauged by a bank's size. Banks that are highly interconnected with other financial and non-financial institutions through their balance sheet linkages are often considered to be of systemic importance as well.

However, actual interbank overnight interest rates are generally not public information, as a loan's terms are agreed upon bilaterally between borrowing and lending banks. One indicator of actual overnight interest rates is indicative lending and borrowing rates quoted by major banks acting as market makers.[1] However, indicative quotes may deviate from actual overnight interbank rates depending on borrower and lender characteristics and other factors related to the liquidity stance in the money market; see e.g. Acharya and Merrouche (2009). Hence, precise monitoring of interbank interest rates and a careful study of the determination of overnight interest rates paid by different banks is generally not possible unless banks report overnight loans. Still, there can be a need to cross check information provided by banks as they can have incentives to under-report their borrowing costs.[2]

A central bank can, however, infer actual interest rates in real time from interbank transactions recorded in its real-time gross settlement (RTGS) system. RTGS data is available to central banks

[1] Money market interest rates used as reference values such as NIBOR or LIBOR are usually some average of lending and borrowing rates quoted by selected banks. While they may offer sufficient information about the overall market liquidity situation, they may be inadequate for watching the liquidity needs of individual banks and for learning about an individual bank's liquidity and solvency status.

[2] It has been argued that e.g. LIBOR has not been a reliable indicator of the interbank interest rates as some of the banks in the LIBOR-panel could have underreported interest rates they faced in the interbank market; cf. McAndrews et al. (2008).

due to their provision of clearing and settlement services to other banks. By careful examination of funds between banks one may get fairly precise information about amounts borrowed and overnight interest rates paid by banks; see Furfine (1999, 2001). Several recent studies have inferred the overnight interest rates from RTGS data; see e.g. Bech and Atalay (2008) and Rørdam and Bech (2009).

In this paper, we follow the procedure used by these studies and infer overnight interest rates from transactions going through the RTGS system of Norges Bank (the central bank of Norway). We have obtained exclusive RTGS data for the period October 2006–April 2009, which includes the period before and after the height of the recent financial crisis. The data set also enables us to shed light on the activity in the Norwegian money market. In particular, the RTGS system data reveals that 28 banks regularly borrow and lend funds overnight in the Norwegian interbank market. We investigate the effects of banks' characteristics and conditions in the interbank market on the overnight interest rates paid by these banks. We have also 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 the liquidity stance in the interbank market. We construct a panel data set and employ an appropriate econometric model to exploit available information efficiently and take into account relevant factors. This is the first such study based on Norwegian data. The Norwegian money market has some features distinctive from the UK, US and Euro area money markets, which have been the subject of previous studies. These include its relatively smaller size and extensive reliance on the US dollar (USD) exchange rate and short-term interest rates.

In particular, we investigate the possible effects of a bank's systemic importance on the interest rates it faces in the interbank market. The effects of a bank's systemic importance is tested by investigating effects of both size and connectedness with other banks. To measure connectedness, we employ a measure of centrality suggested by the growing literature on financial networks; see e.g. Allen and Babus (2009) and the references therein. Previously, Bech and Atalay (2008) have reported that banks gain from their centrality, but the study does not take into account possible effects of other explicit measures of credit risk associated with a borrowing bank and its borrowing/lending relationship with its counterparts as well as market liquidity conditions. It should be noted that favorable rates obtained by banks considered systemically important due to their size and/or centrality need not reflect lower credit risk owing to any implicit government guarantee against default. It could also reflect higher bargaining power and/or lower credit risk through more diversified portfolios; cf. Bech and Atalay (2008). We make an effort to control for such effects by including explicit indicators for credit risk and factors partly determining bargaining power such as relatively large liquidity holdings.

We also investigate the effects on interbank interest rates of aggregate liquidity in the interbank market and its distribution among banks. Effects of aggregate liquidity shed light on the interest rate response to the central bank's liquidity supply measures; see e.g. Acharya and Merrouche (2009) on UK data. Arguably, a more even liquidity distribution may reduce liquidity risk as more banks can act as possible counterparts when in need of liquidity. This may also reduce the scope for exploiting possible market power in liquidity supply. A number of theoretical studies including Nyborg and Strebulaev (2004) and Acharya et al. (2009) have pointed out that skewed liquidity distributions may give rise to higher interbank interest rates through exploitation of market power by banks with surplus liquidity. Previously, Acharya and Merrouche (2009) have studied the relationship between liquidity and overnight interest rates using a sample of UK data over the period January 2007–June 2008. They find that such a relation was virtually absent in the period before the crisis, but emerged during the crisis. Using a different data set that includes more observations from the recent financial crisis may help examine the generality of their finding.

Possible effects of liquidity distribution while controlling for the overall level of liquidity are also of interest in the light of the controversy regarding the effectiveness of the Fed's term auction facility (TAF), which was initiated during the financial crisis. This facility as well as some other liquidity facilities aim to resolve possible misallocation of liquidity in money market without changing the total supply of reserves in the system. The empirical analyses by Wu (2009) and McAndrews et al. (2008) suggest that a more efficient allocation of liquidity helps reduce interbank interest rates while Taylor and Williams (2009) do not find significant evidence of such effects. While these studies undertake their examination using interest rates of 1-month and/or 3-month maturities, we offer evidence based on Norwegian overnight interbank interest rates.

The paper is organized as follows. The next section, 2, briefly describes key institutional features of the very short term Norwegian money market. Section 3 presents the data and the method employed for identifying overnight interbank loans and the associated overnight interest rates from interbank payments and their main features. Section 4 investigates the relationship between characteristics of banks and market conditions and overnight interest rates. Section 5 presents our main conclusions. Precise definitions of variables and robustness tests of the main results are presented in the appendices.

2 The Norwegian interbank market

Transactions between banks due to e.g. loans between banks and transfers between customers of different banks are settled across the books of a settlement bank. Banks need to have short-term liquidity available with their settlement bank to cover their debit positions. Such liquidity generally consists of drawing rights and deposits on banks' accounts with their settlement bank.

Norges Bank is the ultimate settlement bank in Norway. All banks established in Norway including branches and subsidiaries of foreign banks may have deposit accounts at Norges Bank.

The overnight deposit rate on these accounts is Norges Bank's key policy interest rate. The lending rate on overnight overdrafts has been one percentage point above the deposit rate since 16 March 2007; it was two percentage points above the deposit rate before that.

Norges Bank aims to ensure that the deposit rate prevails in the money market and that banks have adequate liquidity to meet their short-term obligations stemming from day to day activities. To this aim, it targets a level of aggregate liquidity considered consistent with its objectives. The aggregate liquidity is measured as the sum of banks' deposits in Norges Bank from one business day to the next.

Norges Bank offers banks that have deposit accounts with it and can pledge sufficient collateral, short-term liquidity through auctions and its overdraft facility.[3] The overdraft facility primarily aims to enable banks to honour their debts in the payment settlements. Such overdrafts are interest-free if repaid before the end of the day.

2.1 Interbank overnight interest rates

The lending rate on overdrafts usually acts as a ceiling on interest rates on interbank overnight loans. Banks would rather borrow from other banks in the overnight interbank market than pay the central bank lending rate on overnight overdrafts. As the banking system as a whole would be in a deposit position overnight due to fixed maturity loans provided by Norges Bank, some banks will have deposits in Norges Bank which they may lend to other banks at an interest rate higher than the key policy rate. Overnight loans in the interbank market are not secured through collateral. Hence, banks would rather deposit at the central bank than lend to other banks in the overnight interbank market at a rate lower or equal to the central bank deposit rate. Therefore, the key policy rate usually acts as a floor for interbank overnight rates.

Overnight interbank interest rates usually vary across banks and over time within the floor and ceiling defined by central bank interest rates on overnight deposits and loans. Their levels depend on short-term liquidity available in the market and banks' characteristics determining e.g. liquidity and credit risks associated with their interbank loans.

Occasionally, however, overnight interbank interest rates may not remain within the floor and ceiling defined by the central bank interest rates. For example, foreign banks with no deposit account at Norges Bank may deposit excess NOK liquidity in the interbank market at a lower interest rate than the central bank deposit rate. This can be the case at e.g. the end of a trading day when a foreign bank with excess NOK liquidity is facing the prospect of keeping it on an account with its correspondent bank, possibly at zero interest rate. Norwegian banks would be willing to accept such excess liquidity at a lower rate than the central bank deposit rate at which

[3] Norges Bank auctions loans with fixed interest rates and fixed maturities, usually ranging from a few days to a month. Successful bidders receive loans at their interest rate bids, which are usually just above the key policy rate. Auctions are scheduled when actual or predicted aggregate liquidity falls short of operational targets for aggregate liquidity.

they can deposit it overnight. The deposit rate offered to the foreign bank can be lower, the greater the amount of foreign bank's excess liquidity.

One reason for interbank overnight lending rates exceeding the central bank lending rate could be the possible stigma associated with borrowing overnight from the central bank. That is, if a bank fears that an overnight overdraft at the central bank would be interpreted as a sign of a bank's failure to obtain funding from its peers in the interbank market because of their perception of excessive credit risk associated with lending to the needy bank, it may be willing to borrow at a higher interbank rate than the overnight overdraft rate at the central bank. Another reason for rates exceeding the central bank lending rate is that interbank loans are uncollateralized whereas central bank loans are collateralized.

Furthermore, as explained below, Norwegian interbank interest rates, especially the reference rate NIBOR, may be quite sensitive to exchange rate fluctuations and USD money market rates. Thus they need not always remain strictly within the interest rate corridor defined by central bank interest rates.

2.2 The FX SWAP market and the Norwegian money market

Major banks in Norway mainly borrow Norwegian krone (NOK) through the NOK-USD foreign exchange swap market, rather than directly in the Norwegian money market. The NOK-USD swap market is an important market for financing and investing for large Norwegian banks and institutional investors. It is also important for oil companies who need to exchange their revenues in USD for NOK for payment of petroleum taxes; see e.g. Fidjestøl (2007). Partly because of these factors, the NOK-USD swap market is more liquid than the Norwegian money market where one borrows and lends directly in NOK.

Due to the importance of the USD market for the funding of Norwegian banks, the main reference rate for Norwegian overnight interest rates, the Norwegian interbank offered interest rate (NIBOR), depends on the USD lending interest rate ($i^{*,a}$) and the NOK-USD swap exchange rate ($F^a - S^b$), where F^a is the outright forward exchange rate for buying USD while S^b is the spot exchange rate for selling USD:

$$i^a_{swap} = i^{*,a} + \frac{(F^a - S^b) \times (1 + i^{*,a})}{S^b}. \tag{1}$$

Superscripts 'a' and 'b' refer to ask and bid quotes, respectively.[4]

Ignoring differences in interest rates across banks and between indicative and tradable quotes, to borrow one krone at time t, a bank borrows $1/S^b$ USD at interest rate $i^{*,a}$ and then sells the

[4]The formula used by market participants to obtain overnight interest rates in percents is: $i^a = i^{*,a} + \frac{(F^a - S^b)\times(360\times100+i^{*,a})}{10^4\times S^b}$, where $(F^a - S^b)$ refers to market quotations of the swap exchange rate in pips, which are divided by 10^4.

$1/S^b$ USD to obtain one krone. To clear its debt (that would amount to $\frac{1}{S^b}(1+i^{*,a})$ USD) at time $t+1$, the bank simultaneously agrees to buy $\frac{1}{S^b}(1+i^{*,a})$ USD for $\frac{1}{S^b}(1+i^{*,a})F^a$ NOK at time $t+1$. Thus, for one NOK borrowed at time t, the bank pays $\frac{1}{S^b}(1+i^{*,a})F^a$ NOK at time $t+1$. The implied NOK interest rate for borrowing i^a_{swap} is therefore $\frac{1}{S^b}(1+i^{*,a})F^a - 1$, which can be rewritten as (1).

Large Norwegian banks quote lending and borrowing rates for tomorrow/next transactions throughout the day in light of (1). The reference rate, NIBOR, is the average of the ask quotes after the highest and lowest rates have been disregarded. Since NIBOR is an average of indicative ask quotes, it generally differs from prices at which banks actually trade.

Not all banks have access to the USD market, however. A large number of smaller Norwegian banks are mainly active in the Norwegian money market. Larger banks are generally active in both. Still, the implied NOK interest rate for borrowing (and lending) through the USD market must remain close to the corresponding interest rate in the market for direct interbank borrowing (and lending) in NOK. Possible differences may diminish relatively fast depending on the arbitrage pressure; see Akram et al. (2009). Banks and other market participants in need of funds would borrow directly in the interbank market for NOK if it is cheaper than borrowing through the NOK-USD swap market and vice versa. In a state of equilibrium, the interest rate for overnight borrowing via the swap market should equal the interest rate for borrowing directly in the interbank NOK market.

Actual interest rates faced by banks are not directly observable, however. The next section explains briefly how actual interest rates can be inferred from data available to the central bank owing to its role as the ultimate settlement bank.

3 Data

We infer interest rates paid by Norwegian banks from interbank transactions recorded in Norges Bank's real-time gross settlement (RTGS) system. More than 140 banks have access to the system and between 30 and 40 banks are active in the system daily. Most of the active banks use the system for gross settlement of large value and time-critical payments, such as the in- and out-legs of overnight interbank loans. The system is also used for the settlement of transactions that have been cleared in other systems before reaching Norges Bank (e.g. retail payments). Such transactions accounted for less than 7% of the turnover in the RTGS in terms of volume in 2007 and 2008; cf. Norges Bank (2009). Transactions between relatively small banks that are settled through systems operated by a few large private banks are not recorded in this system.

Notably, the RTGS system does not record information indicating whether a loan has been initiated by a borrower or a lender. Neither does it 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 such facilities at Norges Bank. For example, a transaction between two Norwegian banks could refer to a foreign bank (without a branch in Norway) placing NOK liquidity with a Norwegian bank through its Norwegian correspondent bank. Branches and subsidiaries of foreign banks in Norway, however, use the RTGS system and have direct access to the central bank deposit and overdraft facilities.

From the RTGS system, we extract a record of transactions for 620 business days over the period 9 October 2006 to 6 April 2009. This enables us to base our analysis on 428 708 transactions for gross settlement in Norges Bank.[5] The average daily value of these transactions is about NOK 128.4 billion.[6]

However, only a small share of these transactions are associated with interbank lending. We need to separate these transactions from the other transactions to infer overnight interest rates.

3.1 Identifying overnight loans and interest rates

We employ the procedure used by Furfine (1999, 2001) to extract overnight loans from all of the RTGS transactions over the sample period.[7] 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. It is common to restrict the transferred amount to a round number as banks do not usually borrow non-round values; cf. Furfine (2001).

Specifically, we identify a pair of transactions as an overnight loan if the transferred value is a round value in NOK million and the implied interest rate (ii):

$$ii = \left(\frac{V_{t+1}}{V_t} - 1\right) \times 365, \quad (2)$$

lies within a predefined band. The width of the band depends on what we consider to be reasonable variation in interbank interest rates. The number of transactions identified as loans increases with the width of the band. The transactions could refer to loans in the NOK market or to transactions reflecting interbank loans through the foreign exchange swap market.[8]

[5] There was no available data from the RTGS system on 9 days in 2007 and on 2 days in 2008, so the resulting data set of interbank loans is over 609 days.

[6] This is lower than the average daily gross turnover reported in Norges Bank (2009) since transactions to and from several special purpose accounts (such as the account for Continuous Linked Settlement (CLS) and market operations accounts) are excluded from our data set.

[7] An open-source implementation of the Furfine algorithm developed as part of this project is available on FinancialNetworkAnalysis.com.

[8] However, if a bank conducts two separate transactions to honour its debt obligation, a procedure looking at individual bilateral transactions in NOK would not be able to infer the interest rate involved. For example, a bank can at time t sell $\frac{1}{S^b}$ USD for one NOK and then at time $t+1$ buy back $\frac{1}{S^b}$ USD for $\frac{1}{S^b} \times F^a$ NOK through a swap contract. In a separate deal, it could buy the accrued interest rates $\frac{1}{S^b} i^{*,a}$ for $\frac{F^a}{S^b} i^{*,a}$ NOK through a forward contract. The procedure could also erroneously identify pure foreign exchange swap transactions as overnight loans

In our main analysis, we only consider values of ii that are between $i_{cb}^{b} - 0.1$ and $\max\{i_{cb}^{a} + 0.1$, NIBOR$\}$, where i_{cb}^{b} and i_{cb}^{a} are Norges Bank's deposit and lending rates, respectively, while the adjustment factor 0.1, representing 10 basis points, is based on our conversations with market participants. That is, we allow possible interest rates to fluctuate within an interest rate corridor that is usually 20 basis points wider than that defined by the central bank deposit and lending rates to take into account interbank loans on behalf of foreign banks and to avoid lending from the central bank due to stigma. In cases where the NIBOR exceeds the central bank lending rate plus 10 basis points, the ceiling on overnight lending interest rate is determined by NIBOR. NIBOR is generally believed to overestimate actual interest rates paid by the major banks. It is generally below the rate on the overdraft facility, i_{cb}^{a}. During the financial crisis, however, it exceeded i_{cb}^{a}, as shown later.

The interest rate corridor specified in our main analysis implies 18 760 overnight interbank loans among the transactions in our sample.[9] The actual number of overnight loans during the sample period could be higher than 18 760. We assume that overnight loans identified over the sample period are sufficient to provide reasonable estimates of actual interest rates paid by different banks. Some measurement errors in the number of interest rates due to misclassification of transactions as overnight loans are unavoidable. However, we show that reasonable changes in the width of the corridor for permissible interest rates increases or decreases the number of possible interest rates by merely 1 to 3%. Notably, our main conclusions are not sensitive to the values of the adjustment factors and alternative widths of the interest rate corridor; see Appendix B for evidence.

3.2 Interbank market activity

Our sample of overnight loans identified during the sample period (9 October 2006 to 6 April 2009) show that overnight lending takes place between 31 banks, constituting less than a quarter of the banks that have access to the RTGS system. These banks are the largest Norwegian banks and branches and subsidiaries of foreign banks. In terms of assets, the 31 banks constitute more than 75% of the total banking market 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 differ 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 1/3 of the days in the data set, whereas four banks are active on more than 90% of the days. Figure 1 shows the average number of borrowers and lenders per day in different months over the sample period. There are relatively low numbers of borrowers and

when the interest rate for the foreign currency in the swap (i.e. the USD-rate) is very close to zero.

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

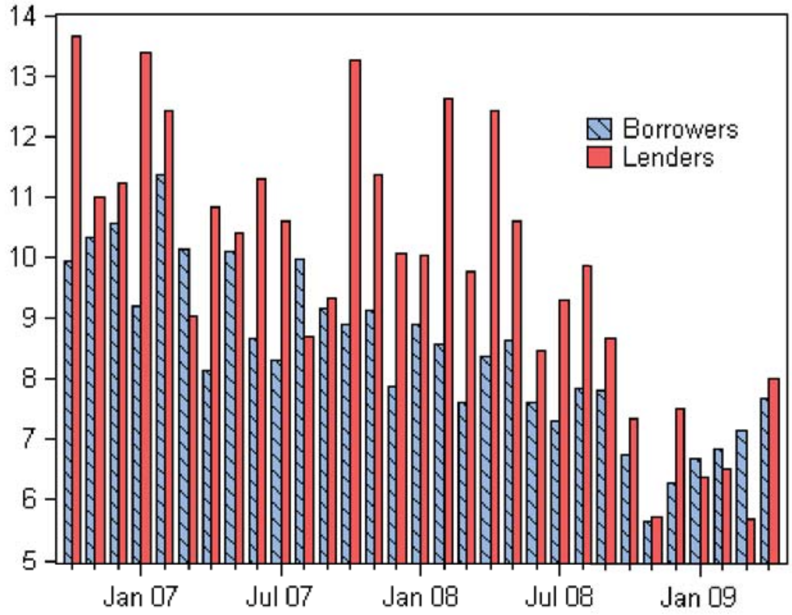


Figure 1: *Borrowers and lenders per day on average in different months of the sample period (9 October 2006 to 6 April 2009).*

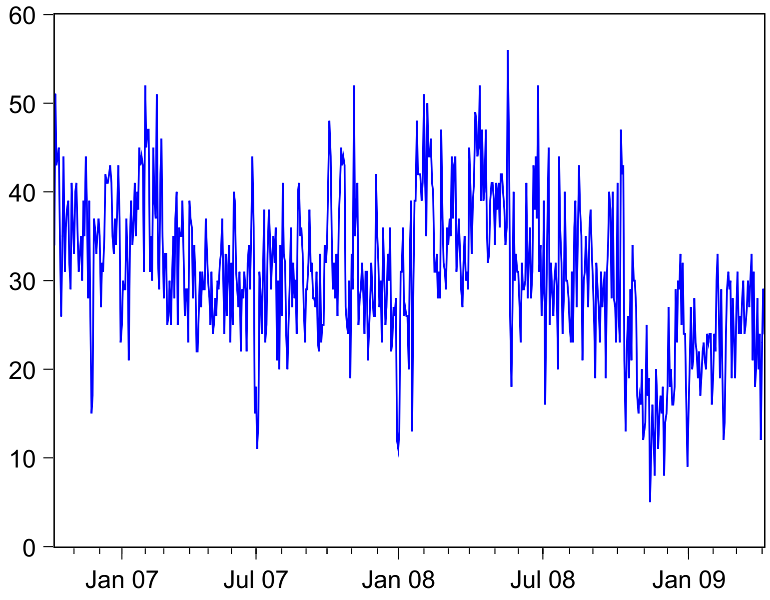
lenders in October–December of 2008, especially in November, after which the market participation gradually increases. The figure also reveals a larger number of lenders than borrowers, in general; the exceptions are in March 2007 and January-March 2009. A bank may have several overnight loans with different counterparts on a day. The relatively low market activity in October–December of 2008 may be associated with defaults of a number of financial institutions including the default of Lehman Brothers in mid-September and those of two Icelandic banks (Glitnir and Kaupthing), which also had branches in Norway, on 29. September and 12. October 2008, respectively.

Overnight loans and corresponding overnight interest rates as well as the values of loans vary substantially over the sample period. Figure 2.a shows that the number of overnight loans varies between 5 and 56 on different days while Figure 2.b shows variation in loan size from 1 mill to about 2.1 billion. The figures also shows that the number of loans per day and their values experienced a marked decline in October–December of 2008 which recovered gradually during 2009. The number of loans and their values were particularly low in November 2008.

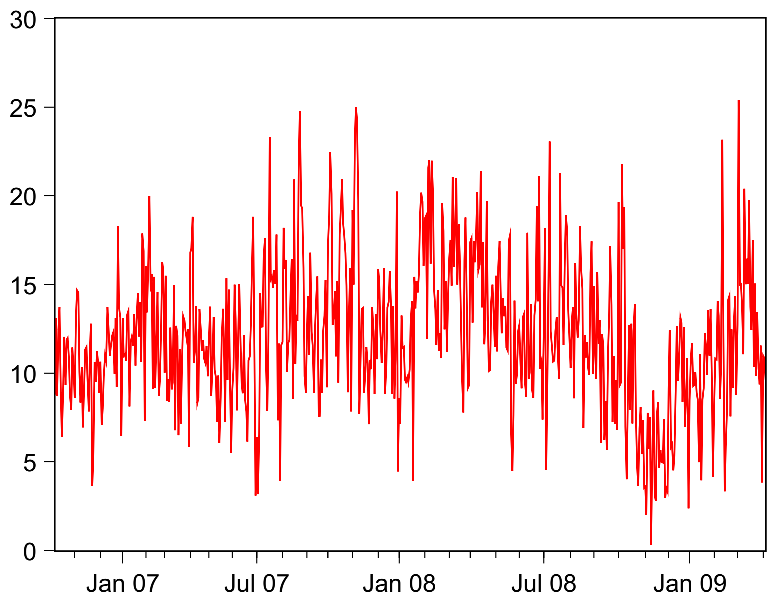
Table 1: ***Turnover in the overnight interbank market***

	Individual loans	Daily borrowing by banks	Total daily turnover
Mean	393	1 430	12 100
Median	270	780	11 800
Std. Dev.	400	1 690	4 240
Min	1	2	309
Max	2 120	14 100	25 400

Note: The unit is NOK million. The descriptive statistics is based on the sample period 9 October 2006 to 6 April 2009.



(a) Number of loans

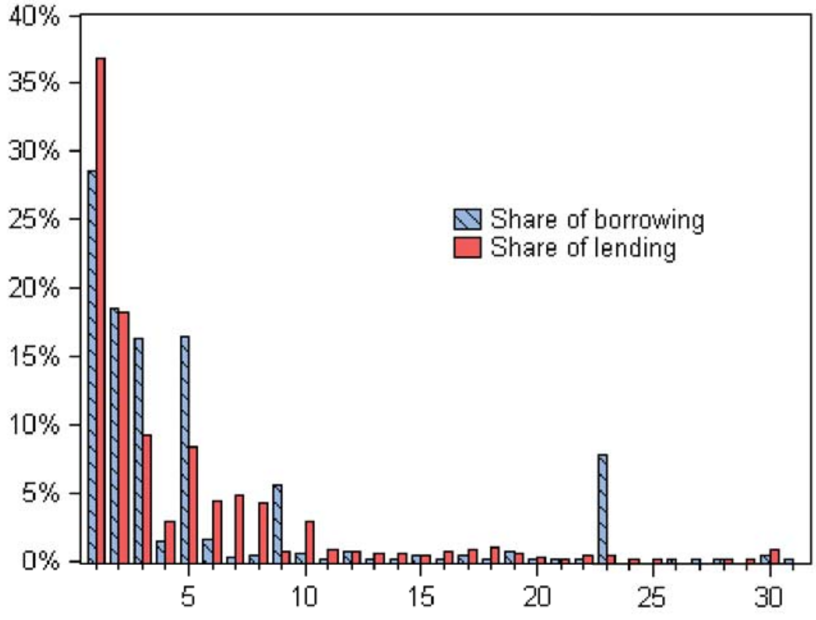


(b) Value of loans

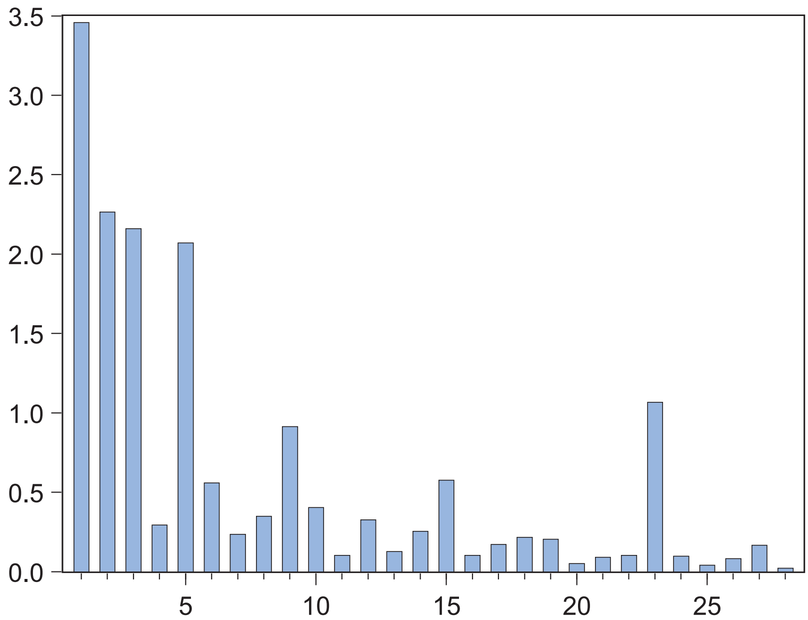
Figure 2: *(a) Number of loans per day, and (b) the size of loans per day over the sample period; (in* NOK *billion).*

Table 1 provides more details on the size of loans. The table shows that the value of a loan varies from NOK 1 million to NOK 2.1 billion while total overnight borrowing by each bank varies from 2 million to 14.1 billion NOK over the sample period. The table also shows that daily turnover in the overnight market ranges from NOK 309 million to NOK 25.4 billion.

Figure 3.a displays shares of borrowing and lending activity by banks of different sizes over the sample period. The figure suggests that almost 75% of the loans have been borrowed or lent



(a) Shares of borrowing and lending vs bank size



(b) Loan size vs bank size

Figure 3: *(a) Shares (in %) of total lending and borrowing over the sample period. The 31 banks are ordered by asset size, from largest to smallest. (b) Borrowed values (in* NOK *billion) by each of the 28 borrowing banks per day on average, calculated over the sample period.*

by the 5 largest borrowers. The shares of the amount borrowed and lent vary substantially across different borrowers and tend to increase with a bank's assets. The obvious exceptions from the pattern can be ascribed to borrowing and lending by branches of larger foreign banks who have relatively few assets in Norway, such as bank number 23. 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 3.b suggests that banks with a high share of borrowing also tend to borrow relatively large loans.

3.3 Overnight interest rates

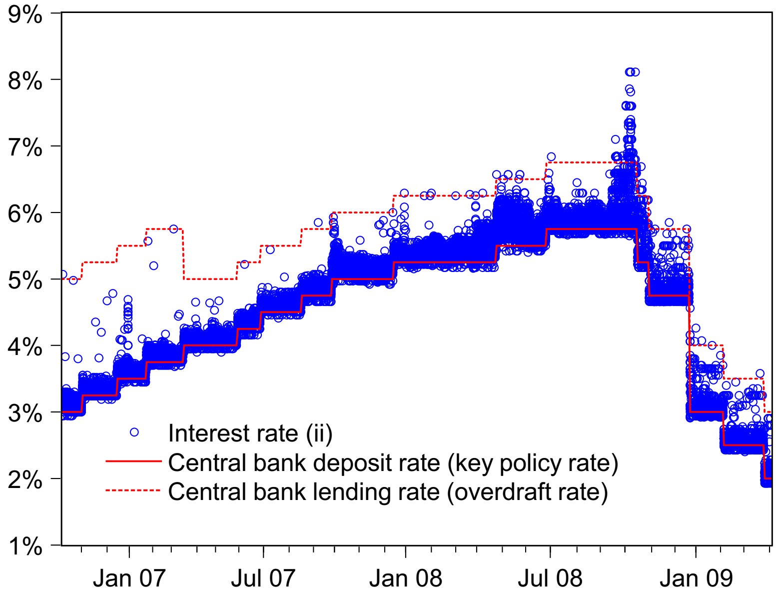


Figure 4: *Interest rates (in per cent per annum) on identified loans and central bank deposit and lending rates.*

Figure 4 displays interest rates associated with all of the identified overnight loans over the sample period. A dot depicts an overnight interest rate while the solid and dashed lines represent the central bank overnight deposit and lending interest rates, respectively. As seen, the central bank interest rates have been changed on several occasions over the sample period.

It is seen that almost all of the (derived) overnight interest rates are within the central bank interest rate corridor, despite allowance for a wider interest rate corridor. Moreover, most of the overnight interest rates are closer to the central bank deposit rate than to its lending rate. The average of (loan-value weighted) interest rates for the whole sample was just 15 basis points above the deposit rate. These observations are consistent with Norges Bank's liquidity management policy, which aims to keep interbank interest rates close to its deposit rate.

There are, however, a non-negligible number of interest rates outside the central bank interest rate corridor, mostly below the deposit rate. Interest rates below the deposit rate seem to occur mainly after the liquidity injections provided by the central bank in response to actual and pre-

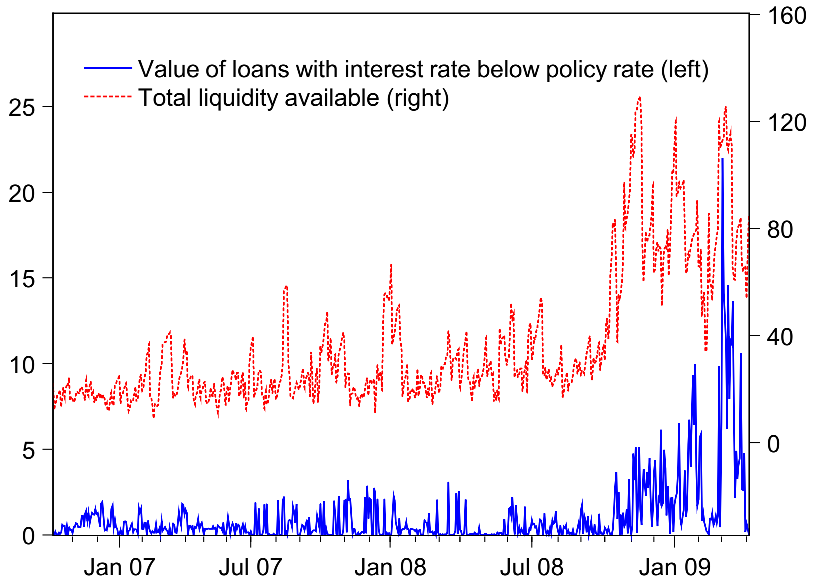


Figure 5: *Values of loans per day (in* NOK *billion) with interest rates below the central bank deposit rate (left-hand axis) and total liquidity (in* NOK *billion) as the sum of all bank deposits with Norges Bank.*

sumed liquidity shortages during the financial crisis. Figure 5 shows that values of loans at interest rates below the key policy rate increase substantially after the start of liquidity support measures by Norges Bank to raise the total liquidity available to banks. The extraordinary liquidity supply measures were effective from 1. October 2008 and continued during the rest of the sample period, and beyond; see Figure 5.

Observations of interest rates below the central bank deposit rate are consistent with the interpretation that they are associated with foreign banks depositing excess NOK liquidity with Norwegian banks. The latter can deposit excess liquidity with Norges Bank at its deposit rate and may therefore accept excess liquidity from foreign banks at a relatively lower rate, as a charge for immediacy. One would expect overnight lending below the key policy rate to occur more often when there is ample liquidity in the market and Norwegian banks have sufficient liquidity weakening their incentives to take on more liquidity. This is supported by Figure 5.

Observations of interest rates above the central bank lending rate are consistent with the interpretation that banks in need of liquidity may prefer to borrow from their peers than from the central bank. This is to avoid sending signals of being unable to obtain (unsecured) overnight funds in the market. We observe 90 loans with an interest rate higher than the interest rate on the overdraft facility. Most of these observations refer to the period between 15 September 2008 and the end of the year 2008. A close look at the data set reveals, however, that banks lending at interest rates above the central bank lending rates also obtain loans at relatively lower interest rates during the same period. Hence, interest rates above the central bank lending rate should be interpreted with care, as they need not indicate persistently high credit risk premiums associated

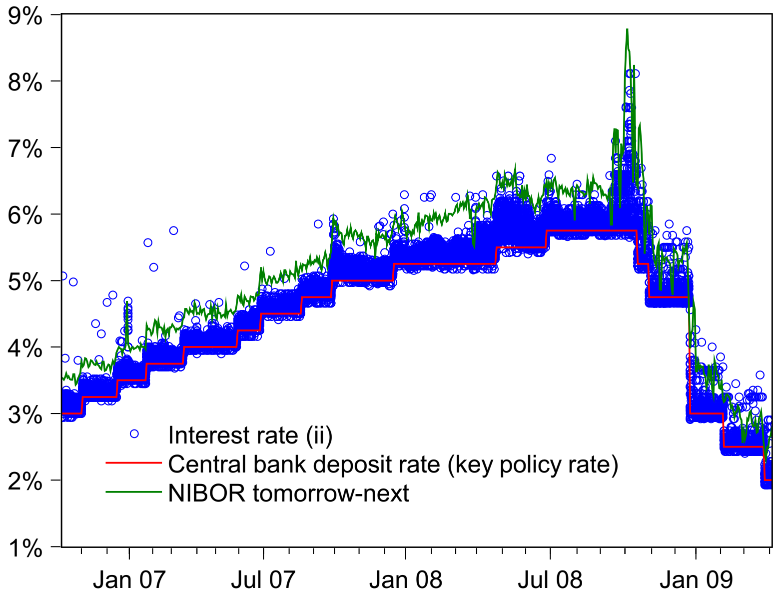


Figure 6: *Interest rates on identified loans and* NIBOR *tomorrow next (t/n) over the sample period; per cent per annum.*

with lending to the corresponding banks. The average of (loan-value weighted) interest rates during the midst of the financial crisis (15 September to 15 October) was 37 basis points above the central bank deposit rate.

The NIBOR also exceeded the central bank lending rate during this period; see Figure 6. The figure shows that although overnight interest rates were closer to the NIBOR during the crisis than before, they did not exceed NIBOR in this period. Therefore, there does not seem to be any evidence of underreporting borrowing costs by banks in the NIBOR panel, as has been suggested for the case of LIBOR; cf. McAndrews et al. (2008). The relatively large increase in NIBOR during September-October 2008 seems to mainly reflect unusual values of the NOK-USD swap rate and the US short term lending rates.

There is a relatively large variation in overnight interest rates across different loans and banks within any given day, especially during the height of the financial crisis; see Figure 7. The figure shows the standard deviation of (derived) overnight interest rates on each day of the sample period. Values of the daily standard deviation of overnight interest rates are in the range 3 to about 70 basis points. The difference in interest rates across loans is mostly below 10-15 basis points. Particularly large differences in interest rates across banks as reflected in the standard deviation series refer to the spring and the autumn of 2008, which may mainly be related to the bail-out of Bear Sterns in mid-March 2008 and the defaults of a number of financial institutions in the autumn of 2008. It should be mentioned that the daily values of the standard deviation are based on a varying number of loans and may therefore not be equally representative over time; see Figure 2. In particular,

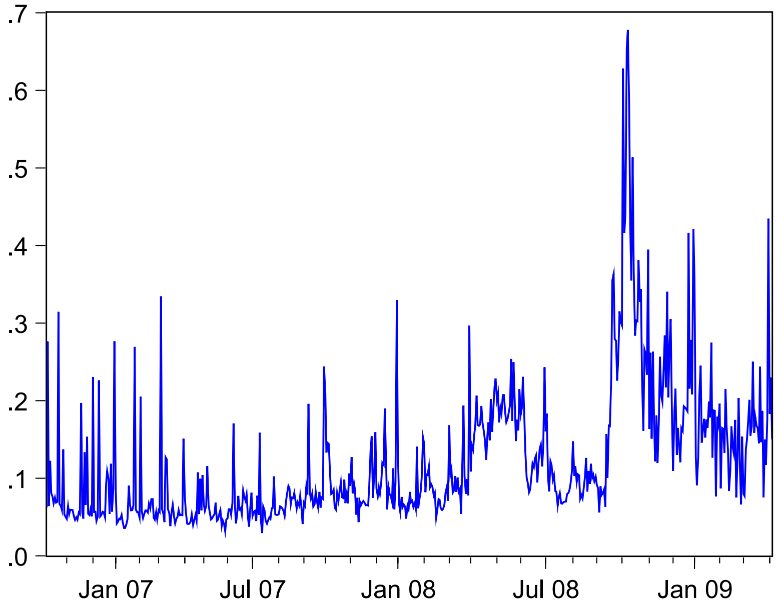


Figure 7: *Dispersion in interest rates (per cent per annum) across banks on each day of the sample period. The dispersion on a day is measured by the standard deviation of daily interest rates across banks.*

during periods of little activity in the interbank market leading to few loans, such as the last days of a year, interest rates on particular loans may influence values of the standard deviations, showing up as spikes in its series.

4 Modeling overnight interest rates

In the following, we model variation in overnight interest rates across banks and over the sample period. To explain such variation, we investigate the effects of banks' characteristics and liquidity conditions in the interbank market on overnight interest rates. We particularly investigate whether banks considered systemically important are able to borrow at lower rates than banks considered to be relatively less important.

4.1 The model and variables of interest

We employ an econometric model that is estimated using a panel data set containing the interest rates paid by different banks over the sample period. Specifically, we estimate a fixed-effect model with 25 different borrowers on the cross-sectional dimension and 609 business days on the time dimension.[10,11] We assume that there is (unobserved) individual heterogeneity across banks which is captured by allowing for different intercepts for each bank. We assume, however, that the slope

[10] Three of the banks among the 28 borrowers in our data set are excluded from the estimation due to their rare participation in the interbank market which leads to relatively few observations of their interest rates.

[11] Our main conclusions are not affected if we estimate a model with period fixed effects, as in Cocco et al. (2009); see Appendix C.

coefficients are equal across banks.[12] The data set constitutes an unbalanced panel as every bank does not participate in the market every day. The model is formulated as follows:

$$
\begin{aligned}
i^{m}_{j,t} - i^{b}_{cb,t} \quad = \quad & \alpha_j + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t \\
& + \beta_3 \times (ii^{m}_{j,t-1} - i^{b}_{cb,t-1}) + \varepsilon_{j,t}, \qquad (3)
\end{aligned}
$$

where ii^m denotes the loan-size weighted mean of implied interest rates. We use the mean of implied interest rates on a day, as a bank may have several overnight loans with different interest rates. Subscript j indexes banks while subscript t indexes days; j =1–25 and t =1–609. We model deviation of implied interest rates (in basis points) from the central bank deposit rate as the latter is contemporaneously reflected in the overnight interest rates; this is supported by preliminary analysis. Thus, one is 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 stationary over the sample period, while implied interest rates may not be stationary.

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 term $\varepsilon_{j,t}$, which represents an independent and identically distributed stochastic error term that is bank and period specific. The parameter α_j is assumed to control for time-invariant bank-specific characteristics not included in the model. The vectors $\boldsymbol{B}_{j,t}$ and $\boldsymbol{M}_t$ contain sets of bank-specific and market-specific control variables, respectively. To account for possible bank-specific dynamic adjustment as well as for possibly omitted factors, we include the lagged dependent variable.[13] Appendix A provides detailed information about the variables used in the model.

The systemic importance of a bank is represented by its size and connectedness. A bank's size may be represented by several variables representing different dimensions. To represent a bank's size, we include a bank's share of the total assets for all banks in the sample. 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 week (b_{week})) by each bank and the bank's share of the total daily borrowing (b_{daysh}). Previously, relatively large banks have been found to obtain more favorable interest rates than smaller banks; see e.g. Furfine (2001) and Cocco et al. (2009). Favourable effects of amounts borrowed have been documented by Furfine (2001), but an increase in a bank's share of the total daily borrowing has been associated with higher interest rates.

[12] A Hausman test does not support the use of the random effects model, which would allow for heterogeneity in slope coefficients across banks.

[13] We have a relatively large number of observations on the time dimension (above 600 for the most active banks). OLS estimates of the model parameters may therefore not suffer from bias affecting our conclusions; see e.g. Arellano and Bond (1991).

A bank's connectedness is calculated using the network centrality measure proposed by Bonacich (1987) and employed by a number of studies including Bech and Atalay (2008). The measure used takes into account the (overnight) borrowing and lending activity of each of the banks and its counterparts. Banks with a relatively large number of counterparts and extensive borrowing and lending, and which are counterparts to other such banks, obtain a higher centrality score. Thus, a systemically important bank would be a bank that is itself active in the interbank market and trades with other banks that also participate actively in the market. The relevant literature suggests several centrality measures; for a review, see Borgatti (2005). However, the various measures of centrality are usually highly correlated with the one used and hence do not alter our conclusions. For example, Appendix C shows that our results are robust to the centrality measure suggested by Ballester et al. (2006). The latter measure 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, the correlation between the Bonacich centrality and the centrality measures suggested by Ballester et al. (2006) is relatively high, 0.99.

To allow for different effects of domestic banks and branches of foreign banks, we let a bank's size and its centrality interact with a 0–1 dummy variable indicating a foreign branch (F). Effects associated with branches of foreign banks may differ from those of domestic banks as the former are not regulated under the same rules as domestic banks. Morever, the measures of size and centrality only takes into account assets and interbank activity of the foreign branch in Norway. Figure 3, however, suggests that there is a rather loose relationship between the interbank activity of foreign branches and their sizes. This suggests that a foreign branch's size and centrality relative to Norwegian domestic banks may not adequately represent its importance.

While investigating the possible effects on interest rates of differences in the systemic importance of banks, we control for possible effects of differences in their creditworthiness as reflected in explicit credit risk measures. Specifically, the vector $\boldsymbol{B}_{j,t}$ includes banks ratings ($ratA$) and shares of defaulted loans (dl) of the total outstanding amount of loans to the public. Defaulted loans are defined as loans that are past-due for a period exceeding 3 months. The credit rating variable ($ratA$) is a binary dummy variable which takes a value of 1 if a bank has rating A or better, and zero otherwise.[14]

Furthermore, we control for the possible effects of relationship between banks on overnight interest rates. A number of studies including Cocco et al. (2009) find that banks are able to obtain better terms on their loans if they borrow from counterparts with which they maintain a banking relationship. By maintaining relationships in the interbank market, a bank provides counterparts with (additional) information on its creditworthiness over time. Interbank relationships are often

[14]Only a few banks are rated by international rating agencies. Therefore, we have to additionally use indicative ratings published by DnB NOR to construct the binary variable $ratA$.

proxied by the number and/or values of transactions between two counterparts. We use a related measure, rel, which we define as the share of loans obtained from a bank's two biggest counterparts, i.e. the two banks with which a bank has transacted most often during the sample period.

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. Liquidity distribution among banks is measured daily by 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; a value of zero indicates an even distribution, while the value of 1 indicates complete inequality. Previously, Fecht et al. (2009) have reported that liquidity distribution affects the prices paid by banks in the primary liquidity market (central bank auctions) while Wu (2009) and McAndrews et al. (2008) find evidence of such effects in the US interbank market. A relatively unequal liquidity distribution may increase the market power of banks that have a large amount of liquidity and thereby enable them to lend at higher interest rates. On the other hand, banks with ample liquidity may reduce their lending rates to reduce excess liquidity. It is well known from the financial microstructure literature that financial agents may adjust their lending and borrowing rates to achieve a desirable level of liquidity; see e.g. Harris (2000, ch. 13). Thus, the net effect of liquidity distribution on interest rates is not obvious.

A number of studies show that an increase in payment activity is associated with higher interbank interest rate; see e.g. Acharya and Merrouche (2009) and Furfine (2000). Higher payment activity raises transaction demand for liquidity as well as precautionary demand for liquidity. This is because on days with a high turnover in the payment system each bank's liquidity position becomes more uncertain. To account for the effects of payment activity we include the log level of gross settlements in the RTGS systems (pay) in vector $\boldsymbol{M}_t$, which contains market-specific control variables.

The vector $\boldsymbol{M}_t$ also includes a set of dummy variables to control for the influence of other factors affecting liquidity, such as days when petroleum tax is due in Norway. Overall liquidity in the Norwegian money market is affected when the petroleum tax is due because of the Norwegian government's account with Norges Bank. Payments to the government remove liquidity from banks' accounts at the central bank, reducing overall liquidity. Relatively large turnover in the payment system on these days tend to put an upward pressure on interest rates, possibly due to precautionary liquidity demand stemming from uncertainty about end-of-day positions. To reduce possible interest rate effects of relatively high liquidity demand and reduction in overall liquidity, the number of due dates of petroleum taxes per year was increased from 2 to 6 in 2008; see Norges Bank (2009). By including dummies for days when the petroleum tax is due, we control for possible effects on interest rates beyond those represented by the payment activity measure, *pay*, and overall liquidity, *liq*. To reduce such pressure on interest rates, Norges Bank provides additional liquidity to banks in connection with the payment of the petroleum tax which contributes to increase overall liquidity (*liq*).

In addition, vector $\boldsymbol{M}_t$ includes dummy variables to account for possible effects of the recent financial crisis on overnight interest rates.[15] We also include changes in average credit default swap (CDS) prices for the five largest Nordic banks to control for the general increase in credit risk during the financial crisis.

Finally, we include a dummy variable to control for the possible influence of end-of-year effects on overnight interest rates; see Figure 7. Calendar effects in overnight interest rates have been reported in previous studies; see e.g. Fecht et al. (2007).

4.2 Results

Table 2 presents the estimated model (3). Our main conclusions are robust to several alternative model specifications, variable definitions and data samples; see Appendices B and C and Section 4.3.

The estimation results suggest that domestic banks that may be considered relatively large and well-connected may borrow at relatively lower overnight interest rates. We note that indicators of systemic importance, i.e. size and network centrality, have expected signs and are statistically significant at the 1% level of significance; absolute values of the corresponding t-values are above 4. The significance of the network centrality measure when controlling for measures of bank size (assets($size$), weekly borrowing and share of daily borrowing) indicates that a bank's size may not reflect all aspects of a bank's systemic importance. Accordingly, even relatively small but well connected banks may face relatively lower borrowing costs. At its face value, the corresponding coefficient estimate implies that a one-standard deviation increase in a bank's centrality would reduce the rate the bank pays by 1.5 basis points. For example, if a bank's centrality increases by 0.4, a relatively large increase observed in our data set, the interest rate would decline by about 4 basis points. Size has a comparable effect. Taken at face value, the size coefficient estimate indicates a reduction by 5 basis points following an increase in asset share from 2 to 4%; an increase observed in our data set. Although such reductions contribute only to modest savings overnight due to the short maturity of overnight loans, an average reduction of e.g. 5 basis points over time amounts to a substantial reduction in costs.

Moreover, gains from centrality are beyond those of relationships with other banks, which are explicitly taken into account as well. We note that average daily interest rates paid by a bank may decline with an increase in the share of borrowing from two largest counterparts, aligning our

[15] The relevant dummy variable takes on the value of 1 from 15 September to 15 October 2008 and zero otherwise.

Table 2: ***Main econometric analysis***

$$i^m_{j,t} - i^b_{cb,t} = \alpha_j + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \beta_3 \times (ii^m_{j,t-1} - i^b_{cb,t-1}) + \varepsilon_{j,t}$$

Variable	**Notation**	**Coefficient**	**(s.e.)**	**[t-value]**
Bank specific variables				
Size	$size$	-7.37	(1.65)	[4.48]
Centrality	$centrality$	-10.88	(2.23)	[4.89]
Size-Foreign branch	$size\times$ F	5.74	(1.21)	[4.74]
Centrality-Foreign branch	$centrality\times$ F	14.71	(2.85)	[5.15]
Borrowed amount weekly	b_{week}	-0.19	(0.36)	[0.53]
Share of daily borrowing	b_{daysh}	1.01	(0.25)	[4.00]
Defaulted loans	dl	2.66	(0.44)	[6.01]
Rating equal to or above A	$ratA$	-1.59	(0.93)	[1.70]
Relationships	rel	-0.89	(0.47)	[1.89]
Market conditions				
Liquidity	liq	-1.46	(0.39)	[3.75]
Liquidity distribution	$liqdist$	3.50	(2.47)	[1.42]
Payment system turnover	pay	3.90	(0.90)	[4.35]
Oil tax due date (old regime)	$oil1$	2.86	(2.03)	[1.41]
Oil tax due date (new regime)	$oil2$	-2.92	(5.20)	[0.56]
Financial crisis time dummy	fc	10.53	(2.09)	[5.03]
Changes in CDS prices	ΔCDS_t	0.07	(0.11)	[0.68]
Changes in CDS prices, lagged	ΔCDS_{t-1}	0.28	(0.16)	[1.76]
End-of-year time dummy	$endyear$	39.13	(10.96)	[3.57]
Lagged dependent variable	$ii^m_{j,t-1} - i^b_{cb,t-1}$	0.55	(0.05)	[10.66]

Observations	4317
Est. method: Fixed effects OLS	(N=25, T=607)

Note: Values in parentheses are robust cross-section standard errors; see White (1980). The estimator is robust to cross-equation correlation and different error variances in each cross-section. Values in square brackets are absolute values of t-values. The sample period is 9 October 2006 to 6 April 2009 implying 609 business days. The effective sample size consists of 607 business days, however, due to two lagged variables in the model. Here and elsewhere in this paper, the numerical results are obtained using EViews version 6.

results with those of e.g. Furfine (2001) and Cocco et al. (2009). Furthermore, centrality as well as measures of size seem to provide information of, or perception of, credit risk in addition to that provided by standard credit risk indicators such as credit rating and shares of defaulted loans. An increase in a bank's share of defaulted loans leads to significantly higher borrowing rates at the 5% level. A reduction in rating below grade A may have a similar effect. This effect is significant only at the 10% level, however.

However, it should be noted that branches of foreign banks gain less from their size than domestic banks in the overnight market. Moreover, they do not seem to gain from their centrality in a statistically significant way. The corresponding coefficient estimate has a positive sign, i.e. 14.71–10.88 = 3.83, though the positive sign is not robust to different model specifications (see Model I in Appendix C). A possible interpretation of differences in effects of size and centrality between domestic banks and branches of foreign banks is that market participants consider it less likely that a foreign government would bail out a bank due to its relatively high size and centrality in a market other than its home market.

The estimated model suggests that overnight interest rates also vary with market conditions. Specifically, overnight interest rates tend to decline in response to an increase in overall liquidity. There is weak evidence that concentration of liquidity also matters. Our results suggest an upward pressure on interest rates in periods with uneven liquidity distribution, consistent with the evidence in Bindseil et al. (2004), Wu (2009) and McAndrews et al. (2008). Our finding is not statistically significant, though.

An increase in payment activity is found to place upward pressure on interest rates. Once we include the measure of payment transactions (*pay*), possible effects of due dates for petroleum taxes within the previous and the current regime become insignificant. This suggests that there is no effect of due dates for petroleum taxes beyond those represented by measures of payment activity and overall liquidity.

As expected, the recent financial crisis contributed to higher interest rates. There was a substantial increase in overnight interest rates that can be related to the bank defaults in September–October 2008. We note that this increase is in addition to that suggested by the changes in average CDS prices, capturing a general increase in credit risk. We also observe a significant end-of-year effect on the interest rates. This effect could be ascribed to the particularly low turn-over in the interbank market in the final days of a year. Finally, the lagged dependent variable suggests relatively high degree of persistence in overnight interest rates.[16] Results in the next subsection suggests that this is partly owing to the persistence of high interest rates during the financial crisis.

4.3 Effects of the financial crisis

In the following, we investigate possible effects of the financial crisis on the results presented above. Table 3 shows estimation results based on a sample of pre-crisis data. While the exact date of the financial crisis can be debated, we use data prior to March 2008, i.e. several days before the bail-out of Bear Sterns.[17] The subsample contains 40% fewer observations than used above, affecting estimates of coefficients as well as their standard errors.

[16]Our main results also apply in a 'static' version of the model, i.e. a model specification without the lagged dependent variable.

[17]One could argue that the financial crisis started in the summer of 2007. Leaving out observations after summer 2007 would have substantially truncated our data set, however.

Table 3: ***Econometric analysis using pre-crisis data***

$$i^m_{j,t} - i^b_{cb,t} = \alpha_j + \beta_1 size_{j,t} + \beta_2 centrality_{j,t} + \boldsymbol{\varphi}'\boldsymbol{B}_{j,t} + \rho_1 liq_t + \rho_2 liqdist_t + \boldsymbol{\psi}'\boldsymbol{M}_t + \beta_3 \times (ii^m_{j,t-1} - i^b_{cb,t-1}) + \varepsilon_{j,t}$$

Variable	Notation	Coefficient	(s.e.)	[t-value]
Bank specific variables				
Size	$size$	-0.33	(1.25)	[0.26]
Centrality	$centrality$	-3.81	(1.70)	[2.24]
Size-Foreign branch	$size \times$ F	2.80	(0.96)	[2.94]
Centrality-Foreign branch	$centrality \times$ F	6.48	(2.17)	[2.98]
Borrowed amount weekly	b_{week}	0.17	(0.26)	[0.64]
Share of daily borrowing	b_{daysh}	0.41	(0.17)	[2.39]
Defaulted loans	dl	0.04	(0.54)	[0.08]
Rating equal to or above A	$ratA$	-0.45	(0.28)	[1.60]
Relationships	rel	-0.41	(0.33)	[1.23]
Market conditions				
Liquidity	liq	-0.51	(0.47)	[1.10]
Liquidity distribution	$liqdist$	2.73	(2.00)	[1.37]
Payment system turnover	pay	1.32	(0.53)	[2.49]
Oil tax due date (old regime)	$oil1$	5.47	(2.92)	[1.87]
Oil tax due date (new regime)	$oil2$			
Financial crisis time dummy	fc			
Changes in CDS prices	ΔCDS_t	0.19	(0.14)	[1.36]
Changes in CDS prices, lagged	ΔCDS_{t-1}	0.18	(0.11)	[1.61]
End-of-year time dummy	$endyear$	50.43	(10.72)	[4.70]
Lagged dependent variable	$ii^m_{j,t-1} - i^b_{cb,t-1}$	0.24	(0.07)	[3.44]
Observations	2613			
Est. method: Fixed effects OLS	(N=24, T=335)			

Note: The sample period is 9 October 2006 to 28 February 2008. Values in parentheses are robust cross-section standard errors; see White (1980). The estimator is robust to cross-equation correlation and different error variances in each cross-section. Values in square brackets are absolute values of t-values.

Still, the economic interpretation of the results is not affected. In particular, the effects of centrality on overnight interest rates remain statistically significant. Overall, the numerical values of the coefficient estimates become smaller relative to those presented in Table 2. One could argue that implicit and explicit measures of credit risk associated with banks became more important for overnight interest rates during the financial crisis than earlier. Hence, the observed reduction in values of coefficient estimates associated with size and centrality and those of explicit measures of credit risk such as credit rating and share of default loans is as expected when estimates are based on a subsample consisting of data from the pre-crisis period.

We also note that effects of overall liquidity is less important numerically in data before the crisis. The liquidity conditions were more stable in terms of overall liquidity before the financial crisis. The effects of liquidity distribution and payment activity also seem to be numerically lower before the crisis. Finally, the coefficient estimate associated with the lagged dependent variable is significantly smaller in the data before the crisis. This is consistent with the impression of relatively small degree of persistence in interest rates prior to the crisis.

5 Conclusions

We have inferred actual overnight interest rates from transactions recorded in the payment settlement system of Norges Bank. These transactions have also enabled us to shed light on activity in the Norwegian interbank market during calm and turbulent periods. There is a relatively large variation in actual overnight interest rates over time and across banks. Moreover, these interest rates are substantially below indicative ask quotes provided by major banks, especially during the current crisis.

Our econometric analysis has suggested that such variation can be partly ascribed to banks' characteristics. In particular, domestic banks that may be considered 'too big to fail' and 'too connected to fail' are able to borrow at relatively lower rates than other banks. This results emerges even when we control for variables representing interbank relationships and creditworthiness. Arguably, possible effects of size and connectedness could reflect lower credit risk owing to the perception of implicit government guarantee against default for banks considered relatively large and/or with significant financial linkages.

We have also observed that the influence on interest rates of measures of systemic importance, credit ratings and liquidity supply and demand variable have increased since the start of the financial crisis. It remains to be seen whether this continues to be the case, or whether this influence fades back to pre-crisis levels.

Our results have proved to be fairly robust to changes in the algorithm for deriving actual overnight interest rates and to alternative measures of network centrality. They are also fairly robust to different model specifications.

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Appendix

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

Appendix A. Data definitions

Table 4: ***Description of variables***

Variable		**Description**	**St.dev (within)**
Bank specific variables			
Size	*size*	A bank's share of all banks total assets (share)	0.13 (0.01)
Centrality	*centrality*	Measure of centrality proposed in Bonacich (1987). The centrality measure is calculated on the basis of a matrix containing the values of transactions between the banks on a given day. 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 centralities of one bank to be affected by its counterparts. Selecting other reasonable (positive) values of β does not affect our conclusions.	0.15 (0.1)
Borrowed amount weekly	b_{week}	Weekly amount borrowed by each bank (NOK bn)	1.32 (0.785)
Daily borrowing share	b_{daysh}	A bank's share of the total borrowing each day	0.13 (0.09)
Relationships	*rel*	Share of funds obtained from a bank's two biggest counterparties on each day. We define the two biggest counterparties to a bank as the two banks with which it has traded most often during the sample period.	0.39 (0.33)

Table 4: ***Description of variables (continued)***

Variable		**Description**	**St. dev (within)**
Defaulted loans	*dl*	Loans that are past-due for a period exceeding 3 months as a percentage of total outstanding amount of loans to the public (per cent)	1.26 (0.54)
Rating above A	*ratA*	Dummy indicating a rating, or an indicative rating, of A or better	0.44 (0.24)
Market conditions			
Liquidity	*liq*	Amount of NOK liquidity available to banks, i.e. the aggregate of their position towards Norges Bank at the beginning of each day (NOK bn)	25.93 (25.93)
Liquidity distribution	*liqdist*	The Gini coefficient is calculated from each banks available liquidity per day. The Gini coefficient is defined as the ratio of the areas on the Lorentz curve diagram.	0.07 (0.07)
Payment system turnover	*pay*	Gross payment systems turnover in the RTGS-system on each day, in logs. (NOK bn)	26.5 (26.5)
Oil tax regime	$oil1$, $oil1$	Dummy indicating a due date for the payment on petroleum taxes under the previous regime with two dues dates in a year (1) and the current regime with six due dates (2). The last half-yearly payment being on 1 April 2008 and the first due date in the new arrangement was 1 August 2008.	
Financial crisis time dummy	*fc*	A binary dummy variable with a value of 1 from 15 September 2008 to 15 October 2008 and 0 otherwise.	
CDS prices	CDS_t	Average credit default swap (CDS) prices for the five largest Nordic banks	49.66 (49.66)
End-of-year effect	*endyear*	Dummy indicating the end of each calendar year	

Appendix B. Robustness to data samples

One faces the risk of overestimating the number of interbank loans with a too wide predefined band for possible (derived) interest rates, but underestimating interbank loans by choosing a too small band. In the following, we show that our results are quite robust to a narrower and a wider band for possible interest rates than used in the main analysis.

The results are presented in Table 5, where the the three right-hand column present results based on possible interest rates within a relatively wide band, which allows values of ii between $i^b_{cb} - 0.2$ and $\max\{i^a_{cb} + 0.2, NIBOR\}$; i^b_{cb} and i^a_{cb} are Norges Bank's deposit and lending rates, respectively. The results in the middle column are based on possible interest rates within a relatively tighter band allowing values of ii between i^b_{cb} and $NIBOR$.

Table 5 shows that changes in the bands used to define possible overnight interest rates do not alter our conclusions. The coefficient estimates are comparable to those presented in the main analysis ; see Table 2. In particular, variables that are statistically significant in the main analysis remain in general statistically significant at the standard levels of significance. One exception is the relationship measure, which becomes insignificant at the 5% level and also changes sign under the narrow interest rate span. (The coefficient estimate associated with weekly borrowing also changes sign, but it is insignificant at the standard levels of significance, irrespective of the band width.) We also note that overall liquidity matters more when estimated on a wider interest rate span, which allows for a higher number of interest rates below the key policy rate. This coincides in time with an increase in overall liquidity since the autumn of 2008.

Table 5: ***Robustness of results to narrow and wide interest rate bands***

Variable	Notation	Narrow span Coeff.	(s.e.)	[t-val.]	Wide span Coeff.	(s.e.)	[t-val.]
Bank specific variables							
Size	$size$	-4.67	(1.46)	[3.19]	-7.61	(1.70)	[4.47]
Centrality	$centrality$	-10.02	(1.98)	[5.08]	-11.13	(2.36)	[4.71]
Foreign branch							
× Size	$size \times$ F	5.03	(1.11)	[4.54]	6.10	(1.24)	[4.91]
× Centrality	$centrality \times$ F	12.68	(2.61)	[4.87]	15.14	(2.94)	[5.16]
Borrowed amount weekly	b_{week}	0.41	(0.32)	[1.28]	-0.17	(0.36)	[0.48]
Share of daily borrowing	b_{daysh}	0.58	(0.24)	[2.40]	1.09	(0.26)	[4.16]
Defaulted loans	dl	0.91	(0.52)	[1.75]	2.74	(0.45)	[6.12]
Rating above A	$ratA$	-0.96	(0.29)	[3.28]	-1.78	(0.94)	[1.88]
Relationships	rel	0.64	(0.37)	[1.73]	-1.17	(0.48)	[2.41]
Market conditions							
Liquidity	liq	-0.86	(0.38)	[2.27]	-2.16	(0.41)	[5.32]
Liquidity distribution	$liqdist$	2.38	(2.21)	[1.08]	3.58	(2.50)	[1.43]
Payment system turnover	pay	3.29	(0.91)	[3.62]	3.75	(0.91)	[4.12]
Oil tax (old regime)	$oil1$	6.69	(3.29)	[2.03]	6.40	(4.26)	[1.50]
Oil tax (new regime)	$oil2$	3.26	(3.18)	[1.03]	-4.19	(4.93)	[0.85]
Financial crisis dummy	fc	10.72	(2.42)	[4.42]	10.75	(2.10)	[5.12]
ΔCDS	ΔCDS_t	0.03	(0.13)	[0.23]	0.11	(0.10)	[1.05]
ΔCDS, lagged	ΔCDS_{t-1}	0.25	(0.18)	[1.45]	0.27	(0.16)	[1.67]
End-of-year dummy	$endyear$	33.79	(14.60)	[2.31]	39.82	(10.64)	[3.74]
Lagged dependent variable	$ii^m_{j,t-1} - i^b_{cb,t-1}$	0.60	(0.05)	[11.35]	0.55	(0.05)	[11.29]
Observations		4062			4382		
Est.: Fixed effects OLS		(N=25, T=606)			(N=25, T=607)		

Note: Here, model (3) is estimated by using derived interest rates (ii) from relatively narrower and wider corridors relative to that in used in the main analysis presented in Table 2. 'Narrow span' refers to results based on possible values of ii between $i^b_{cb} - 0.2$ and $\max\{i^a_{cb} + 0.2, NIBOR\}$ while 'Wide span' refers to results based on possible values of ii between i^b_{cb} and $NIBOR$. Values in parentheses are robust cross-section standard errors; see White (1980). Values in square brackets are absolute values of t-values. The sample period is 9 October 2006 to 6 April 2009 implying 609 business days. The effective sample size consists of 607 business days, however, due to two lagged variables in the model.

Appendix C. Robustness to changes in model specifications

In the following, we show the robustness of our main conclusions to an alternative model specification and to an alternative measure of centrality. The results are presented in Table 6.

Specifically, the column labeled Model I presents results based on a simple model specification with period fixed effects. Introducing period fixed effects allows us to account for changes along

Table 6: ***Robustness of results to changes in models specification***

Variable		Model I Coef.	(s.e.)	[t-value]	Model II Coef.	(s.e.)	[t-value]
Bank specific variables							
Size	$size$	-6.07	(1.83)	[3.32]	-4.04	(1.28)	[3.16]
Centrality	$centrality$	-18.77	(2.92)	[6.42]	-4.03	(0.81)	[4.99]
Foreign branch							
× Size	$size \times \mathrm{F}$	6.40	(1.45)	[4.40]	2.30	(0.60)	[3.87]
× Centrality	$centrality \times \mathrm{F}$	14.93	(3.46)	[4.31]	5.25	(1.08)	[4.86]
Borrowed amount weekly	b_{week}	-0.80	(0.41)	[1.93]	-0.19	(0.36)	[0.53]
Share of daily borrowing	b_{daysh}	1.59	(0.32)	[4.96]	1.02	(0.25)	[4.03]
Defaulted loans	dl	3.61	(0.54)	[6.64]	2.67	(0.44)	[6.02]
Rating above A	$ratA$	1.15	(1.09)	[1.05]	-1.50	(0.93)	[1.61]
Relationships	rel	-0.67	(0.51)	[1.32]	-0.94	(0.47)	[2.00]
Market conditions							
Liquidity	liq				-1.47	(0.39)	[3.76]
Liquidity distribution	$liqdist$				3.44	(2.47)	[1.39]
Payment system turnover	pay				3.91	(0.90)	[4.35]
Oil tax (old regime)	$oil1$				2.96	(2.03)	[1.46]
Oil tax (new regime)	$oil2$				-2.92	(5.20)	[0.56]
Financial crisis dummy	fc				10.50	(2.09)	[5.02]
ΔCDS	ΔCDS_t				0.07	(0.11)	[0.69]
ΔCDS, lagged	ΔCDS_{t-1}				0.28	(0.16)	[1.76]
End-of-year dummy	$endyear$				39.12	(10.96)	[3.57]
Lagged dependent variable	$ii^m_{j,t-1} - i^b_{cb,t-1}$	0.42	(0.06)	[7.54]	0.55	(0.05)	[10.67]
Observations		4333			4317		
Est.: Fixed effects OLS		(N=25, T=609)			(N=25, T=607)		

Note: Model I refers to a model with period fixed effects, while Model II refers to a model specification where we use the centrality measure suggested by Ballester et al. (2006). The model is otherwise as used in the main analysis. Values in parentheses are robust cross-section standard errors; see White (1980). Values in square brackets are absolute values of t-values. The sample period is 9 October 2006 to 6 April 2009 implying 609 business days. Model II is estimated on a sample size consisting of 607 business days due to two lagged variables in the model.

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.

The right-hand column labeled Model II presents results based on the centrality measure proposed by Ballester et al. (2006) which is also referred to as the inter-centrality measure. This measure could be better at capturing the possible spill-over effects of removing one node from a network by defining the centrality measure as the sum on one node's Bonacich centrality and its contribution to the centrality of other nodes in the network. Removing one bank from the network may have two immediate consequences. First, fewer banks would contribute to the aggregate activity level and, second, the remaining banks would adopt different actions, for instance by reacting to an unexpected lack of liquidity by lending less themselves. The inter-centrality measure may be interpreted to account for this, thus identifying the bank whose removal would lead to the overall largest decrease in activity.

In sum, despite changes in numerical values of coefficient estimates across the two different model specifications, we find statistically significant evidence of overnight interest rates being responsive to measures of the size and centrality of banks.