

Essays on the Interbank Market

DISSERTATION
of the University of St.Gallen,
School of Management,
Economics, Law, Social Sciences,
International Affairs and Computer Science,
to obtain the title of
Doctor of Philosophy in Finance

submitted by

Jon Håkon Findreng

from

Norway

Approved on the application of

Prof. Dr. Martin Brown

and

Prof. Kasper Roszbach, PhD

Dissertation no. 5276

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The University of St.Gallen, School of Management, Economics, Law, Social Sciences, International Affairs and Computer Science, hereby consents to the printing of the present dissertation, without hereby expressing any opinion on the views herein expressed.

St.Gallen, October 24, 2022

The President:

Prof. Dr. Bernhard Ehrenzeller

To Sara, family and friends

Summary

My sincere gratitude goes to my supervisor Prof. Dr. Martin Brown at the University of St. Gallen and Farooq Q. Akram, PhD, who has co-authored two of the papers in this dissertation and was the research director at Norges Bank during my time there.

Bilateral payment flows between banks may provide private information about a borrowing bank's liquidity position. "*Peer Monitoring vs. Search Costs in the Interbank Market*", analyses whether private information on the bilateral payment flow of central bank reserves foster peer monitoring or whether the information is used to reduce search costs in the unsecured interbank market. In the former, banks with outflows of liquidity are penalized by their counterparties, while in the latter, these banks benefit through reduced search costs to find a liquidity provider. Using transaction level data from Norges Bank, I find results suggestive of banks using private information from payment flows to reduce search costs and not for peer monitoring.

In October 2011, to encourage interbank trading, Norges Bank set quotas for banks' overnight reserves with remuneration at the policy rate, while remuneration on excess reserves was set one percentage point lower. In addition, total liquidity in the system was substantially reduced and targeted within a narrow range. In "*Norwegian interbank market's response to changes in liquidity policy*", we document a significant increase in interbank activity and a fall in interest rates following the policy shift. In another policy paper, "*The central bank as the central counterparty*", we analyse Norges Bank's response to the Covid-19 pandemic. Long-term loan auctions and daily deposit auctions were offered simultaneously enabling banks to costlessly hoard large quantities of reserves and deposit them safely overnight. We find that these market interventions had a deteriorating effect on traded volumes in the unsecured overnight interbank market. However, the interventions had a dampening effect on the banks' holdings of excess reserves such that reserves were distributed more evenly across banks.

Zusammenfassung

Mein aufrichtiger Dank gilt Prof. Dr. Martin Brown, meinem Doktorvater an der Universität St. Gallen, sowie Farooq Q. Akram, Ph.D, dem ehemaligen Forschungsdirektor der Norwegischen Zentralbank Norges Bank und Koautoren zweier Aufsätze in meiner Dissertation.

Bilaterale Zahlungsströme zwischen Banken können private Informationen über die Liquiditätslage kreditnehmender Banken liefern. In der Studie *"Peer Monitoring vs. Search Costs in the Interbank Market"* untersuche ich, ob private Informationen über bilaterale Zahlungsströme der Zentralbankreserven sogenanntes Peer Monitoring bedingen oder zur Senkung der Suchkosten auf dem unbesicherten Interbankenmarkt verwendet werden. Im ersten Fall werden Banken mit Liquiditätsabflüssen von ihren Geschäftspartnern abgestraft, während sie im zweiten Fall von geringeren Suchkosten bei der Suche nach einem Liquiditätsanbieter profitieren. Unter Zuhilfenahme transaktionaler Daten der Norges Bank stelle ich fest, dass Banken private Informationen aus Zahlungsströmen für die Senkung von Suchkosten nutzen, nicht aber für die Überwachung ihrer Geschäftspartner.

Zur Förderung des Interbankenhandels hat Norges Bank im Oktober 2011 Quoten für die Tagesgeldreserven der Banken mit einem Zinssatz in Höhe des Leitzinses festgelegt, wohin-gegen die Zinsen für Überschussreserven um einen Prozentpunkt niedriger angesetzt wurden. Darüber hinaus wurde die Gesamtliquidität im System erheblich reduziert und bestimmt, dass diese nunmehr einer engen Schwankungsbreite unterliegen solle. In unserer Studie *"Norwegian interbank market's response to changes in liquidity policy"* dokumentieren wir als Reaktion auf die geänderte Liquiditätspolitik der Zentralbank einen signifikanten Anstieg der Aktivität im Interbankenmarkt und einen Rückgang der Zinssätze. In einem weiteren Policy Paper mit dem Titel *"The central bank as the central counterparty"* analysieren wir die Reaktion der Norwegischen Zentralbank auf die COVID-19-Pandemie. Das simultane Angebot von langfristigen Kreditauktionen und täglichen Einlagenauktionen erlaubte es den Banken in der Pandemie, Reserven in grossem Ausmass kostenfrei zu horten und diese über Nacht sicher zu deponieren. In unserer Studie beobachten wir, dass sich die genannten Markteingriffe verschlechternd auf die Grösse des Handelsvolumens auf dem unbesicherten Interbankenmarkt ausgewirkt haben. Zugleich hatten die Interventionen aber eine dämpfende Wirkung auf die Überschussreserven der Banken, wodurch diese gleichmässiger unter den Banken verteilt wurden.

Peer Monitoring vs. Search Costs in the Interbank Market: Evidence from Payment Flow Data in Norway*

Jon H. Findreng[†]

Abstract

Bilateral payment flows between banks may provide private information about a borrowing bank's liquidity position. This paper analyses whether private information on the bilateral payment flow of central bank reserves foster peer monitoring or whether the information is used to reduce search costs in the unsecured interbank market. In the former, banks with outflows of liquidity are penalized by their counterparties, while in the latter, these banks benefit through reduced search costs to find a liquidity provider. I use data from Norges Bank's real time gross settlement system over the period 2012 to 2015 to identify unsecured overnight interbank loans and payment flows. The results suggest that banks are using private information from payment flows to reduce search costs and not for peer monitoring. This has important implications for regulators' assessment of the pros and cons of a centralized versus a decentralized interbank market.

Keywords: *Peer monitoring, search cost, unsecured overnight interbank market, interest rates, central bank liquidity policy and OTC markets*

JEL Codes: G21, E42, E43, E58

*This paper should not be reported as representing the views of Norges Bank. The views expressed are those of the author and do not necessarily reflect those of Norges Bank. I am grateful for comments and suggestions from Prof. Dr. Martin Brown, Prof. Dr. Falko Fecht, Prof. Dr. Angelo Ranaldo, Kasper Roszback, Research Director at Norges Bank, and Mats B. Fevolden.

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1 Introduction

A decentralized interbank market, where trading of central bank reserves is over the counter and unsecured, creates incentives for banks to monitor their peers. Overnight unsecured funding requires the lender to make daily decisions about whether it will roll over funding or stop lending. If the lender decides to stop lending, the bank with liquidity needs may run into liquidity problems. The right to stop lending, if one becomes suspicious about the borrower's risk, makes it in the interest of the lender to monitor the borrower. In turn, the value of the lender's option can benefit the borrower through reduced funding cost. This argumentation follows Calomiris and Kahn (1991) and Diamond and Rajan (2001), who analyze the role of demandable debts in banks. A decentralized interbank market with peer monitoring among banks is in accordance with the third pillar in the Basel II recommendations aiming at encouraging market discipline (BIS (2005)).

Effective peer monitoring may have positive implications for the stability of the financial system and the overall economy. See for example Freixas and Holthausen (2005), Furfine (2001), Rochet and Tirole (1996) and Flannery (1996). However, there are also costs associated with decentralized markets. Rochet and Tirole (1996) argue that the incentives for peer monitoring are weak due to short maturities, market interventions by the central bank, moral hazard and asymmetric information. Further, Rochet and Tirole (1996) and Flannery (1996) point out that a decentralized interbank market increases systematic risk and imposes some welfare loss due to asymmetric information. They argue that if information banks can obtain about other banks can also be obtained and utilized by regulatory authorities, then there is no particular reason to encourage decentralization of the interbank market.

Alternatively, interbank trading could be organized through a central clearing house where the borrowers post collateral and are anonymous. See Holmstrom (2015) for a discussion on how opacity in money markets can increase liquidity. More generally,

a set-up with electronic auctions can result in better prices and more liquidity (see for example Hendershott and Madhavan (2015)).

Information sources for peer monitoring can be everything of interest about the counterparty, such as rumours or public and private information. One potential source of peer monitoring is payment flow data. This paper examines whether lenders in the unsecured overnight interbank market use bilateral payment flows to assess borrowers' liquidity risk. The idea of using transaction data for monitoring is not new. Black (1975) argues that if a borrower has all their transactions through one single bank, the bank has full control over the borrower's financial situation. Similarly, Fama (1985) argues that transaction history provides useful information for monitoring borrowers and especially borrowers with repeated short-term loans. Mester et al. (2007) find evidence that transaction data can help the lender monitor the value of collateral that a commercial borrower has posted for an operating loan by using monthly and annual transaction data for small business borrowers. In the case of interbank trading, one could argue that the payment flow of reserves reveals information about banks' liquidity positions. One aspect of liquidity risk is whether banks have the ability to meet an immediate request for payment (Ruozi and Ferrari (2013)). The first hypothesis I propose is that a potential lender is reluctant to lend to a bank that has revealed a negative signal about its liquidity position through its payment flow.

An alternative use of payment flow data is to reduce search costs to find a counterparty. Search cost are likely a relevant factor in a decentralized interbank market. In an over-the-counter market, prices are set through a bilateral bargaining process that reflects the participants' alternatives to immediate trade, including search costs (Duffie et al. (2005)). In an interbank market where reserves are continuously reshuffled through the system, a bank with negative liquidity is incentivized to search for a lender, and a bank with too much liquidity will be incentivized to

search for borrower.¹ It is obvious that if one bank transfers a large amount of reserves to another bank, the two banks are likely to have opposite liquidity needs following the transaction. The two banks can then agree on an offsetting interbank trade with limited search costs. Thus, I propose a second and competing hypothesis that a net flow of funds from one bank to another increases the likelihood of an interbank loan taking place within that banking relationship in the opposite direction.

I test the two competing hypotheses on transaction data from the real time gross settlement system in Norway over the period 2012-2015. As transaction level data on interbank lending is not publicly available, an algorithm proposed by Furfine (1999) and modified by Akram and Findreng (2017, 2021) is used to identify unsecured overnight interbank loans. My dataset includes gross bilateral lending between 272 bank pairs. I analyze how the bilateral payment flow affects participation in the unsecured overnight interbank market. I control for liquidity positions at both banks at the time of trade and relationship- and time fixed effects.

The results suggest that banks use the bilateral payment flow to reduce search costs to find a counterparty with an opposite liquidity need. That is, if bank i transfers reserves to bank j , the probability that a loan follows from bank j to bank i increases after controlling for the actual liquidity positions at the time of trade. In Section 6, I extend the analysis to look at pricing of loans and find that the bilateral payment flow does not affect pricing. This verifies that the payment flow is used to reduce search costs as opposed to a situation where the borrower with an outflow of reserves is trapped within the relationship and is forced to borrow at unfavourable terms. This could occur if all other banks are reluctant to lend because of asymmetric information.

The paper contributes to the literature on determinants for lending terms in the interbank market. See for example Furfine (2001) and Afonso et al. (2011), who

¹How strong incentives banks have for trading reserves depends on the liquidity management system in place at the relevant central bank.

find evidence that counterparty risk, measured through bank characteristics such as type of bank, performance ratios, and credit default swap prices, affects volume and price, indicating that some kind of peer monitoring exists. However, this information is typically not updated frequently and may lose its relevance when counterparties in the unsecured overnight interbank market are evaluated on an ongoing basis. Ashcraft and Duffie (2007) show that the liquidity position relative to the banks' normal liquidity position is an important factor in matching lenders and borrowers.

The paper also contributes to the literature on the role of relationships in money markets. See for example Cocco et al. (2009) and Bräuning and Fecht (2012), who find that banking relationships matter for accessibility and pricing in the interbank market. Controlling for risk factors, borrowing banks typically borrow at better terms within a banking relationship. However, this is reversed if the private information known to the lending bank is negative. As an example, Bräuning and Fecht (2012) find that relationship lenders to some extent anticipated the financial crisis by increasing rates in the preceding period.

I contribute to this existing literature by analysing how private information from bilateral payment flows is used within banking relationships. There are indications from the literature that private information plays a role in the interbank market. Afonso et al. (2011) find that larger banks with easy access to interbank borrowing found that access to the interbank market was more limited during the Lehman crisis. However, the banks with less access before Lehman were able to increase borrowings. A similar finding was made by Furfine (2002), who finds that during the autumn of 1998, when Russia defaulted on its sovereign bonds and the hedge fund Long-Term Capital Management nearly collapsed, the spread between active and less active institutions declined.

My findings are relevant to the debate on whether central bank liquidity policy

should incentivize interbank trading², or, in the more extreme, whether there should be a decentralized interbank market at all. The results point in the direction that decisions about interbank trading are motivated by reducing search costs and that banks are not using bilateral payment flow to assess counterparty risk. In isolation, these results favour a centralized system for trading interbank reserves.

2 Institutional Background

Banks established in Norway, including branches and subsidiaries of foreign banks, may have a deposit account with Norges Bank. When a client of one bank transfers funds to a client in another bank, the amount is debited and credited in the banks' respective accounts with Norges Bank. These transactions go through, and are recorded, in the real time gross settlement (RTGS) system.³ In 2017, 130 banks, three central counterparties and the government held an account with Norges Bank. The daily average gross volume of settlements in the RTGS system was NOK 236 bn with five banks settling about 90% of this.⁴ Smaller banks often use correspondent banks to settle transactions and hold an account with Norges Bank for contingency purposes. Most payment transactions are netted at fixed times through clearing institutions, such as small retail transactions through NICS, foreign exchange through CLS, while securities are netted through VPS. However, in terms of volume, these transactions amounted to only about NOK 38 bn each day. The largest share of the volume (NOK 197 bn) is settled gross in real time throughout the opening hours between 05:30 and 16:35. These transactions are often large and time-critical, and comprise the most relevant data for the analysis in this paper. Transactions relating to banks' liquidity management are settled gross and include unsecured interbank trading. Other large transactions, such as those on behalf of large corporate clients⁵,

²See for example Akram and Findreng (2021) who provide empirical evidence that interbank activity increased significantly when a penalty for holding excess reserves above some individual quota was imposed by the Norwegian central bank.

³Bay Fevolden and Smith (2019) offers a detailed analysis of RTGS transactions in Norway.

⁴One day of settlements corresponded to about 8.5% of Norway's mainland gross domestic product the same year. See Statistics Norway - <https://www.ssb.no/en>

⁵These clients may also include other banks, such as foreign banks without access to Norges Bank or smaller banks using a larger bank as a correspondent bank.

are important drivers of bilateral payment flows, which is the main explanatory variable in the analysis below.

The total amount of reserves varies due to transactions over the government's account in Norges Bank and fluctuations in circulating notes and coins. Norges Bank aims to keep total reserves at a stable targeted level of NOK 35 ± 5 bn by using loan and deposit auctions with short maturities.⁶ By again using the 2017 numbers from Bay Fevolden and Smith (2019), this would indicate that each unit of reserves changed hands almost seven times per day ($\frac{236}{35}$).

Norges Bank offers unlimited interest-free intraday borrowing of reserves against collateral. If the intraday loan is not paid back by the end of the day, the loan is converted into an overnight loan with an interest rate 100 basis points above the key policy rate. Banks can deposit unlimited reserves with Norges Bank overnight. The deposits are remunerated at the key policy rate up to a predefined quota. Reserves in excess of this quota are remunerated at the reserve rate, which is equal to 100 basis points below the key policy rate.⁷

The banks are divided into three quota groups based on the banks' total assets, where the quota within each group is the same with the exception of some settlement banks, which have supplemented quotas.⁸ The total amount of quotas is set at NOK 45 bn, suggesting that if Norges Bank is successful in keeping total reserves at NOK 35 bn, each bank should on average have close to 78 % of their quota filled up.⁹

The high turnover of reserves, combined with the penalty for having a shortage or a surplus of reserves overnight, incentivize the banks to trade reserves with each other.

⁶For more details on Norges Bank's market operations, see <https://www.norges-bank.no/en/topics/liquidity-and-markets/Market-operations/>

⁷Norges Bank has no reserve requirement.

⁸See the following link for an example of how the quotas were set in 2017 <https://www.norges-bank.no/en/news-events/news-publications/Circulars/2017/1-quotas-in-the-system-for-the-management-of-bank-reserves/>

⁹<https://www.norges-bank.no/en/topics/liquidity-and-markets/The-liquidity-management-system/The-management-of-bank-reserves-The-system-in-Norway/>

Banks with a shortage of reserves can borrow from banks with a surplus of reserves. Similarly, banks with reserves in excess of their quotas can place their funds with banks with spare capacity in their quotas. Liquidity statistics from Norges Bank confirm that banks mostly avoid using the overnight standing facilities.¹⁰ Over the period 2012-2015 (the data set used in this paper), total liquidity averaged NOK 33.1 bn and about NOK 1 bn of this liquidity was deposited at the reserve rate, 100 basis points below the key policy rate. Overnight borrowings from the central bank occurred on 50 days, with an average of NOK 176 million on those days at the overnight borrowing rate, 100 basis points above the key policy rate. Akram and Findreng (2021) analyze the Norwegian unsecured overnight interbank market and find that unsecured overnight interbank trading increased with the implementation of quotas and reduction in Norges Bank’s target for total reserves in 2011. They also find that, while the overnight unsecured interest rate was normally above the key policy rate in the old system, where the banks could deposit unlimited reserves remunerated at the key policy rate, it is now usually a few basis points below the key policy rate. That is, the standing facilities in place from 2011 provide incentives for both borrowing and lending in the unsecured overnight interbank market.

There are multiple ways banks can trade reserves. See for example Di Filippo et al. (2021), who analyze how banks choose between secured and unsecured trading in the euro interbank market. Table 1 displays the results from a money market survey by Norges Bank in 2015.¹¹ The survey reveals aggregated information on borrowing and lending volumes for eleven anonymous banks in April 2015. These eleven banks are among the largest and most active banks in the Norwegian market, but as the survey does not contain the entire market, these banks reported higher borrowing than lending, indicating that the sub-sample is a net borrower. The daily volumes of borrowing and lending are about NOK 88 bn and NOK 86 bn across all maturities and types of trade. The banks report trading in the categories FX Swaps,

¹⁰Aggregate liquidity statistics are published by Norges Bank - <https://www.norges-bank.no/en/topics/Statistics/Bank-liquidity/>

¹¹See Norges Bank (2015)

Table 1: *Trading of reserves in April 2015 - Norges Bank survey*

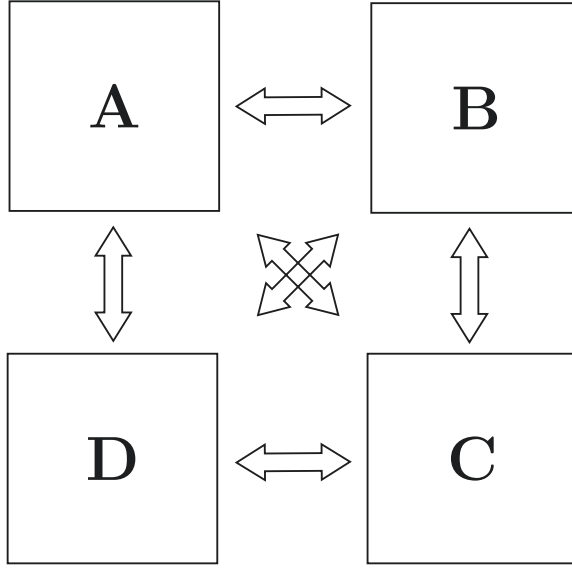
	Unsecured	Repo	FX Swaps	SUM (bn)
Borrowing	32 %	1 %	66 %	88.3
Overnight	72 %	0 %	28 %	34.2
Tomorrow-Next (T/N)	8 %	0 %	92 %	12.3
T/N-1 week	30 %	3 %	67 %	8.6
1 week - 1 month	4 %	7 %	89 %	9.1
1 month - 3 months	1 %	1 %	98 %	14.4
3 months - 6 months	1 %	0 %	99 %	7.7
6 months - 12 months	0 %	0 %	100 %	1.9
Lending	21 %	2 %	76 %	85.8
Overnight	65 %	0 %	35 %	26.4
Tomorrow-Next (T/N)	2 %	0 %	98 %	19.4
T/N-1 week	4 %	4 %	91 %	14.0
1 week - 1 month	0 %	12 %	88 %	11.2
1 month - 3 months	1 %	0 %	99 %	9.1
3 months - 6 months	0 %	1 %	99 %	4.4
6 months - 12 months	0 %	0 %	100 %	1.3

Note: Figures in this table are based on Table 1 in Norges Bank's money market survey 2015 (Norges Bank (2015)). Eleven banks report their lending and borrowing of central bank reserves for April 2015. All figures are aggregated daily averages. Columns 2 - 4 are the corresponding percentages of the total sum in column 5.

Repurchase Agreements and Unsecured. While FX swaps is the main channel for trading reserves with 66 % of borrowing and 76 % of lending in total, the unsecured market is the primary way of trading reserves overnight with 72 % of the overnight market. Repurchase agreements represents a negligible part of total trading and seem to be mostly used for maturities between a few days and a month.

Given the importance of unsecured interbank loans in the money market with the shortest maturities, it seems reasonable to use this market to analyze how payment flows affect banks' trading decisions when adjusting their daily liquidity positions. The very simplistic example illustrated in Figure 1 with four banks sending and receiving reserves may not be unrealistic in the Norwegian case as the number of active participants is rather limited. Theoretically, one can know about each bank's liquidity position by knowing all their transactions of reserves. Naturally, the banks only know about the transactions where they are themselves involved. Even though an outflow of reserves from for example bank A to bank B in isolation means that bank A will have lower liquidity, it is unclear to bank B whether bank A has a

Figure 1: *Illustration of bilateral flow of reserves between banks*



positive net payment flow with other banks or whether it for example has a positive payment flow with the government (which increases the total amount of reserves).

In the core analysis of this paper, I follow 17 banks over the period 2012-2015 (details on data selection are given in Section 4). Table 2 displays the distribution of gross and net liquidity at closing time for these banks. Gross liquidity is the banks' final holdings at end of day after trading reserves. Looking at gross liquidity, the 17 banks deposited reserves worth about 71% of their quota. Furthermore, they borrowed overnight from Norges Bank 0.25% of the times and deposited excess reserves 13% of the times.¹² The second row displays net liquidity at day-end, which is the banks' liquidity before unsecured overnight trading. We can see that before unsecured overnight trading, the banks had negative liquidity positions 18 % of the times and excess reserves almost 50 % of the times. The median time for when a loan was transferred was 58 minutes before closing time.¹³ This observation confirms that the banks are using unsecured overnight loans to adjust their liquidity holdings before closing time.

¹²See Figure A1 in Appendix C in the appendix for the full distribution of gross liquidity.

¹³As this is an OTC market based on bilateral agreements over the phone or chat system, the exact time for when the banks agree on the trade is unknown.

Table 2: *Liquidity to quota at end-day*

	Mean	St. Dev.	$X < 0$	$0 < X < 1$	$X > 1$
Gross Liquidity to Quota	0.709	0.378	0.25 %	86.83 %	12.92 %
Net Liquidity to Quota	0.782	1.113	17.89 %	33.20 %	48.91 %

Note: The table shows the average liquidity to quota ratio at closing time for a selection of 17 banks and 999 trading days over the period 2012-2015, resulting in 19 983 observations. The banks have individual quotas.

3 Identifying unsecured overnight interbank loans

In earlier papers, Akram and Findreng (2017, 2021) develop an algorithm to identify unsecured overnight interbank loans using data from the RTGS system. The algorithm is based on the work of Furfine (1999, 2000, 2001, 2002), but modified to increase accuracy and fit Norwegian data. The main goal is to distinguish interbank loan transactions from all other transaction in the RTGS system. The original procedure by Furfine (1999) classifies a pair of transactions between two banks on consecutive business days as an overnight loan if the amount transferred on day (V_t) is a plausible value and the amount returned on the subsequent day (V_{t+1}) equals the transferred amount plus an amount that may be considered a reasonable interest rate. This implied interest rate needs to be within a predefined bandwidth and the loan size is typically restricted to a round value.

In the analysis in this paper, I use a sub-sample of the data analysed in Akram and Findreng (2021) and follow their choice of restricting V_t to a round value in NOK millions and a bandwidth equal to the key policy rate ± 70 basis points. A drawback of using this algorithm is that it tends to wrongly identify a rather large number of transactions as overnight loans. A possible solution with an obvious drawback is to tighten the bandwidth for what one may consider a reasonable interest rate. In more recent versions of the algorithm, it is also considered that overnight interest rates are quoted in annual terms with a limited number of decimals. For example, if the market convention is to quote interest rates with two decimals, one could annualize the implied interest rate and round it to the nearest third decimal

and require this to be zero or nine (see for example Demiralp et al. (2006) and Frutos et al. (2016)). Akram and Findreng (2017, 2021) took this approach one step further by calculating the highest rounding error that may occur for each loan. The smallest monetary unit in Norway is $\frac{1}{100}$ NOK, implying that the return value may be off by 0.005 NOK. Allowing for three decimals in the quoted annualized interest rates, they impose the following maximum error condition:

$$\frac{|(ii_t \times 100000) - \text{round}(ii_t \times 100000)|}{100000} \leq \left(\frac{0.005}{V_t}\right) \times \frac{365}{\text{days}}. \quad (1)$$

where ii_t is the implied interest rate and days is the number of calendar days between the two consecutive business days. In Akram et al. (2019), a reliability assessment of the same algorithm is performed. In short, they collect real data on interbank loans for one month through a survey and are able to correctly identify the 223 loans reported by the banks. In the analysis in this paper, the algorithm identifies 14 684 overnight interbank loans out of 1 408 813 potential transactions in the RTGS system over the period 2012-2015.

4 Data and Methodology

The data set consists of bilateral payment flows taken directly from RTGS data and unsecured overnight trading estimated using RTGS data. The data is set up as a panel with daily observations for each directional banking relationship over the period 2012-2015. That is, each pair of banks consists of two directional banking relationships, as both banks can act as the lender and both banks can act as the borrower. Net flow of funds is then calculated as the net flow between the two banks excluding unsecured overnight interbank loans. I require each bank to have been involved in at least one unsecured overnight interbank loan (either as a lender or a borrower) over the period. As a second requirement, to avoid banks that have an account solely for contingency purposes, I limit the sample to banks that have a minimum of three general transactions in total with other banks on average per day

(any transaction above NOK 100 or about EUR 10 counts).¹⁴ After data cleaning, I am left with 17 banks over 999 business days.¹⁵

4.1 Unsecured Overnight Loans and Banking Relationships

Table 3 displays the number of days with unsecured overnight lending within each directional banking relationship over the period 2012-2015. For anonymity purposes, the actual numbers are replaced by a shading system. Light grey, grey and black indicate whether lending within the directional banking relationship occurred seldom, quite often or frequently. A substantial part of the “seldom” observations represent no activity at all. Looking at for example bank C and D, C borrowed quite often from D, and D has frequently borrowed from C. On more than half of the days, there was no lending in either direction within the pair of banks.¹⁶ There are two main takeaways from Table 3. Firstly, there are strong banking relationships in the unsecured overnight market. Secondly, some banks tend to act mostly either as a lender or as a borrower. Take for example bank B, which has frequently borrowed from nine different lenders. Bank B is not a frequent lender to any other bank.

Table 4 shows the payment flow for the same directional banking relationships over the period 2012-2015. The cell values represent the number of days the net payment flow from the sender bank to the receiver bank was more than NOK 5 million. Also in this table, the numbers are categorized in a shading system for anonymity purposes. Looking again at bank C and D, we can see that both banks were frequent senders of a net flow of more than NOK 5 million to each other. This indicates that there are few days where there was a net flow of less than NOK 5 million in either direction. The table shows that the strong banking relationship is also present in the payment flow (bank A is again a strong example). For some pairs, the relationship

¹⁴Any transaction to or from any other bank within the sample counts. Transactions with the government, central counterparties or with Norges Bank, such as daily interest income, do not count.

¹⁵See Appendix A in the appendix for a sensitivity analysis on sample selection criteria.

¹⁶There are a few occasions where the two banks within a pair borrow from each other on the same day. These observations are netted such that only one of the banks can be classified as the lender (borrower).

Table 3: *Days with Overnight Interbank Loans by Directional Banking Relationship*

	Lender																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Borrower	A																
	B																
	C																
	D																
	E																
	F																
	G																
	H																
	I																
	J																
	K																
	L																
	M																
	N																
	O																
	P																
	Q																

Note: Banks A and B constitute two banking relationships. One where bank A is the potential lender and bank B is the potential borrower, and another where the two banks have reverse roles. There are 999 trading dates and 17 banks that are deemed active in the interbank market and Real Time Gross Settlement System over the period 2012-2015. Light grey, grey and black indicate 0 to 5, 6 to 75 and more than 75 unsecured overnight interbank loans.

is skewed. Bank B, for example, was a frequent sender of more than NOK 5 million to bank O, while the reverse seldom happened. The table design is such that when the same cell in Table 3 and Table 4 are compared, the cell in Table 4 indicates how frequently there is a net flow from the potential borrower to the potential lender in Table 3. A strong link between these two numbers indicates that when funds is flowing in one direction, unsecured interbank loans are made in the opposite direction. The correlation coefficient between Table 3 and Table 4 is 0.46, showing that the relationship in unsecured lending is correlated with the number of incidents where the net flow of funds is more than NOK 5 million and in the opposite direction.

There are 14 directional relationships that are deemed completely inactive in this analysis as there are no transactions above NOK 100 and no interbank lending over the period. This leaves 257 752 observations for the regressions as opposed to the possible 271 728 observations ($17 \times 16 \times 999$).

Table 4: Days with Min. 5 million in net Transactions by Directional Banking Relationship

	Receiver																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Sender	A																
	B																
	C																
	D																
	E																
	F																
	G																
	H																
	I																
	J																
	K																
	L																
	M																
	N																
	O																
	P																
	Q																

Note: Banks A and B constitute two banking relationships. One where bank A is the potential sender of minimum NOK 5 million (excluding unsecured overnight interbank loans) and bank B is the potential receiver, and another where the two banks have reverse roles. There are 999 trading dates and 17 banks that are deemed active in the interbank market and Real Time Gross Settlement System over the period 2012-2015. Light grey, grey and black indicate 0 to 45, 46 to 250 and more than 250 qualifying transactions.

4.2 Unsecured Overnight Loans and Bilateral Payment Flows

The left-hand side of Table 5 shows how often an overnight interbank loan occurs for different levels of payment flows within the directional banking relationships. There are 8 406 cases in the sample where the potential borrower, within the directional banking relationship, transfers more than 0.3 of its quota to the potential lender (excluding unsecured overnight loans). In 15.1% of these cases, an unsecured overnight loan follows in the opposite direction. While this number is rather large and in favour of the hypothesis that banks use the payment flow to find a counterparty, this may well be an effect due to the direct effects on the two banks' liquidity positions.¹⁷

¹⁷Table A4 in Appendix D provides statistics on how often interbank lending occurs by different liquidity statuses within the directional banking relationships.

Table 5: *Overnight Interbank Loans by Net Flow of Central Bank Reserves*

	Net Flow to Quota			Net Flow Others to Quota		
	Loans	Cases	%	Loans	Cases	%
$X < -0.3$	1 272	8 406	15.1	3 866	54 574	7.1
$-0.3 \leq X < 0$	3 782	48 405	7.8	2 649	69 014	3.8
$X = 0$	2 918	144 120	2.0	47	1 894	2.5
$0 < X \leq 0.3$	3 248	47 848	6.8	2 352	73 712	3.2
$0.3 < X$	854	8 963	9.5	3 160	58 548	5.4

Note: Under Net Flow to Quota, X represents the net flow of central bank reserves (excluding unsecured overnight loans) from the potential lender to the potential borrower relative to the potential borrower’s liquidity ratio in Norges Bank. A negative value indicates that the potential borrower is the net sender of central bank reserves. Under Net Flow Others to Quota, X represents the net flow of central bank reserves from all other remaining banks, in the RTGS system, to the potential borrower in relations to its quota. There are 999 trading days and 17 banks resulting in 257 742 observations over the period 2012-2015.

Another explanation may be that banks with a strong relationship in terms of payment flow also have a strong relationship in the unsecured interbank market. The latter argument is supported by the rather high occurrence (9.5%) of unsecured interbank loans when the payment flow of the same size is in the opposite direction.

The right-hand side of Table 5 is structured in the same way as the left-hand side, but here the payment is to all other remaining banks outside the specific directional relationship. We can see that when the aggregate net payment flow to other banks is more than 0.3 of the potential borrower’s quota, an unsecured overnight loan occurs within the relationship in 7.1% of the cases. This is about half compared to when the payment flow is directly to the potential lender. This may be because the potential lender receives excess funds from the other banks as a second-round effect and therefore has a placement need.

In Section 5, I show that when controlling for liquidity positions, relationship effects and payment flow to other banks, a bank with outflows is indeed more likely to borrow from the bank with corresponding inflows.

4.3 Are Payment Flows Informative for Liquidity Positions?

So far, I have implicitly assumed that there is a one to one relationship between bilateral payment flows and the respective liquidity positions at the two banks. Meaning that if bank A sends one unit of reserves to bank B, then bank B should on average hold one additional unit of reserves in net liquidity at end of day. However, this may not be trivial as there may be mechanisms in the banking system that affect the distribution of reserves. For example, if bank A sends bank B a large amount of reserves, could that mean that bank A also sends large amounts to other banks on that day? This could for example occur if bank A has a large corporate client that settles outstanding debt to several different creditors (with accounts at different banks) on the same date. In other words, what information can the counterparty obtain from the bilateral payment flow? In this subsection I test this assumption. Consider the following regression

$$\frac{Liquidity_{i,t}}{Quota_{i,t}} = a_i + \beta \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} + \epsilon_{i,t} \quad (2)$$

where $\frac{Liquidity_{i,t}}{Quota_{i,t}}$ is bank i's net liquidity to quota at end of day and $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ is the bilateral net payment flow of reserves from bank j to bank i, also as a ratio to bank i's quota. Both these variables are excluding unsecured overnight interbank loans. a_i are bank fixed effects to allow the banks to have individual liquidity preferences over time. If $\beta > 1$, it implies that when bank i is the net sender of flows to bank j, bank i is also a net sender on average to the other banks. If $\beta = 1$, it implies that the bilateral flow between bank i and j has no affect on bank i's net flow with the other banks. If $\beta < 1$, it implies that when bank i sends funds to bank j, bank i receives reserves on average from the remaining banks. If $\beta = 0$, then the bilateral payment flow has no information regarding the counterparty's liquidity position. While one may initially expect $\beta = 1$, banks are regularly offered short-term deposit and loan auctions by the central bank. In this case, one may expect $\beta < 1$.

Table 6 displays the result of regression (2). The coefficient for $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ of 0.131

Table 6: *Liquidity and Flow of Reserves*

	$\frac{Liquidity_{i,t}}{Quota_{i,t}}$	$\frac{Liquidity_{i,t}}{Quota_{i,t}}$
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$	0.131*** (0.023)	
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} < -0.3$		0.096*** (0.011)
$-0.3 \leq \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} < 0$		0.329*** (0.053)
$0 \leq \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} < 0.3$		0.311*** (0.056)
$0.3 \leq \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$		0.152*** (0.022)
Cons.	0.769*** (0.002)	0.768*** (0.002)
Bank FE	YES	YES
Observations	257 742	257 742
No. of Banks	17	17
R-Squared	0.313	0.313
Within R-Squared	0.002	0.002

Notes: $\frac{Liquidity_{i,t}}{Quota_{i,t}}$ is bank i's net liquidity position relative to its quota in Norges Bank at the end of day t. $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ is the bilateral net flow of central bank funds from bank j to bank i. All values are net of overnight interbank loans. Robust standard errors in parentheses. Three asterisks indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.

is significant and different from zero. This implies that if bank j sends (receives) reserves equivalent to one quota through the day to bank i, bank i's liquidity position is increased (reduced) by 0.131 quota at end of day. While the results confirm that payment flows are informative for liquidity positions, the coefficient is also about 38 standard errors away from 1. This may be explained by market operations by the central bank, the sample of banks being a net receiver or net sender of payment flow to or from smaller banks outside the sample, and by transactions to and from the government's account. The coefficient may also suffer from a negative bias. Even though net liquidity is net of interbank trading, I am not able to control for other types of reserve trading. In the Norwegian case, it is not unlikely that when a bank receives (sends) a large amount of reserves, it lends (borrows) the same amount through an FX swap. If the FX swap is made with a third party, then there will be a negative bias for the coefficient for $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$.¹⁸

¹⁸If the FX swap is made within the relationship, the FX transaction will net out in

In the second column in Table 6, $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ is split into four groups based on size to allow for a non-linear relationship in the informativeness of payment flow. Net flows from bank j to bank i below -0.3 quotas, between -0.3 and 0 quotas, between 0 and 0.3 quotas and above 0.3 quotas are all significant at the 1% level. However, one unit of net flow between -0.3 and 0.3 quotas affects bank i 's liquidity position by 0.31 to 0.33 units, more than twice the affect from the first model in Table 6. The coefficient for large negative flows from bank j to bank i has a lower value of about 0.10, and the coefficient for large positive flows from bank j to bank i has a value of about 0.15. I conclude that the bilateral payment flow is informative about the counterparty's liquidity position.

5 Main Results

Table 7 displays the results of panel regression 3. The dependent variable, $Loan(j \rightarrow i)_t$, is a binary variable equal to one if there is an unsecured overnight interbank loan from bank j to bank i on day t and zero otherwise. The panel is set up such that there is one potential observation for each directional banking relationship per day. Daily fixed effects, d_t , are included to control for varying market conditions, such as market turmoil, policy meetings, calendar effects and trading activity by the central bank. Quarterly directional banking relationship fixed effects, $a_{j,i,q}$, are included to account for directional banking relationships, but also to account for quarterly updated bank characteristics, such as accounting and performance statistics from the banks' quarterly reports.

$$Loan(j \rightarrow i)_t = a_{j,i,q} + d_t + \beta_1 \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} + \beta_2 \frac{Liquidity_{i,t}}{Quota_{i,t}} + \beta_3 \frac{Liquidity_{j,t}}{Quota_{j,t}} + \epsilon_{j,i,t} \quad (3)$$

The emphasis in this analysis is on the variable $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$, which is the daily net flow of funds from the potential lender, bank j , to the potential borrower, bank

$$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}.$$

Table 7: Overnight Interbank Loans on Net Flow and Liquidity

	$Loan(j \rightarrow i)_t$	$Loan(j \rightarrow i)_t$	$Loan(j \rightarrow i)_t$
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$	-0.017*** (0.002)	-0.017*** (0.002)	0.003 (0.002)
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times B_{i,t}$			-0.032*** (0.007)
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times P_{j,t}$			-0.035*** (0.006)
$\frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}}$		0.002*** (0.001)	0.002*** (0.001)
$\frac{Liquidity_{i,t}}{Quota_{i,t}}$	-0.033*** (0.001)	-0.034*** (0.001)	-0.034*** (0.001)
$\frac{Liquidity_{j,t}}{Quota_{j,t}}$	0.041*** (0.001)	0.041*** (0.001)	0.041*** (0.001)
Cons.	0.041*** (0.001)	0.041*** (0.001)	0.041*** (0.001)
Relationship FE (quart.)	YES	YES	YES
Date FE	YES	YES	YES
Observations	257 742	257 742	257 742
No. of Banks	17	17	17
R-Squared	0.307	0.307	0.308
Within R-Squared	0.065	0.065	0.066

Note: $Loan(j \rightarrow i)_t$ is a binary variable equal to one if there is an unsecured overnight loan of central bank reserves from bank j to bank i on day t. $B_{i,t}$ is a binary variable equal to one if the potential borrower (bank i) has negative net liquidity and thus a borrowing need at day t. Similarly, $P_{j,t}$ is a binary variable equal to one if the potential lender (bank j) has more than one quota in net liquidity and thus a placement need at day t. Robust standard errors in parentheses. Three asterisks indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.

i, normalized by the potential borrower's quota. The interesting observations are when the variable takes a negative value, meaning the net payment flow of funds is from bank i to bank j. The net flow of funds excludes unsecured overnight interbank loans. If bank j is reluctant to lend to bank i (or bank i is reluctant to borrow from bank j) following a flow of funds from bank i to bank j, the coefficient is expected to be positive, indicating a form of peer monitoring. If it is more likely that bank i borrows from bank j after transferring funds to bank j, the coefficient is expected to be negative and indicate that banks are minimizing search costs. The first regression in Table 7 shows that the coefficient on $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ is -0.017 and significant at the 1% level. That is, if bank i is a net sender of an amount worth one quota to bank j, a loan is 1.7% more likely to occur in the opposite direction. I also control for the liquidity positions net of interbank loans for the potential borrower, $\frac{Liquidity_{i,t}}{Quota_{i,t}}$,

and the potential lender, $\frac{Liquidity_{j,t}}{Quota_{j,t}}$, to their respective quotas. The results confirm that a bank with more liquidity is more likely to be a lender and a bank with less liquidity is more likely to be a borrower.

Turning to the second regression in Table 7, the variable $\frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}}$ is introduced. This represents the net payment flow received by bank i from all other banks in the sample (all banks except bank j). We can see that when this variable is negative (an outflow from bank i), the probability that bank i will borrow from bank j is reduced. That is, if bank i is a net sender of one quota worth of funds to all other banks (except bank j), bank i is 0.2% less likely to borrow from bank j . This confirms the previous result indicating that the bank prefers borrowing from a bank to which it has sent reserves.

In the third regression in Table 7, $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times B_{i,t}$ and $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times P_{j,t}$ are introduced to differentiate between situations where the potential borrower has a real borrowing need and when the potential lender has a real placement need. $B_{i,t}$ and $P_{j,t}$ are binary variables equal to 1 if the potential borrower has a negative liquidity position and if the lender has a liquidity position above one quota, respectively. We can see that both these coefficients are highly significant, and with magnitudes about twice the size compared to the coefficient for $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ in the first regression specification. A transfer from bank i to bank j worth one quota is associated with a 3.2-3.5% increased likelihood of a loan in the opposite direction if one of the banks has a real need to trade. We can also see that in the remaining situations, where none of the counterparties has an outright need to trade, the coefficient is no longer significant.

The results displayed in Table 7 show that banks use payment flow to choose a trading partner. When a bank analyze the bilateral payment flow with other banks, it can use this information to make an educated guess in finding a counterparty with

the opposite liquidity need and thereby reduce search costs.¹⁹ A model specification that allows for non-linearity in net flow variables and in net liquidity variables is offered in Section B.

6 Asymmetric Information and Pricing of Loans

The results presented above suggest that banks use bilateral payment flow to reduce search costs to find a counterparty in the unsecured overnight interbank market. The probability of bank j lending to bank i is higher following an outflow of reserves from bank i to bank j (after controlling for liquidity positions and directional banking relationship effects). This implies that bank i is not punished for “revealing” a negative signal about its liquidity position, but rather rewarded by an easier matching process in the search for a liquidity provider.

However, it may be that pricing of loans is sensitive to bilateral flow of funds. The benefit of reduced search costs may be lost in unfavourable pricing. It is possible that, due to asymmetric information, a bank with a liquidity shortage that has also revealed a negative signal (bank i) has limited options other than trading with the observer of the signal (bank j). The observer can analyze the size and nature of the bilateral flow of funds and thus have an informational advantage compared to all other potential lenders. All other potential lenders, who have not observed a signal, may then be unwilling to lend. An uninformed lender, pricing loans at average risk, will only get to lend if the borrowing bank doesn’t have a better offer. This implies

¹⁹In the results displayed in Table 7, the dependent variable is a binary variable for whether a loan takes place within the directional relationship or not. However, while the banks may use net flow of funds to reduce search costs, they may at the same time reduce volumes to contain credit risk. In a similar regression, I regress $\frac{Volume(j \rightarrow i)}{Quota_{i,t}}$, which is the loan volume for those observations where there is an actual loan from bank j to bank i in relation to bank i ’s quota, on $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ and net liquidity positions for the two banks. I find that for every one quota sent from bank i to bank j , the loan from bank j to bank i increases by 0.014 quotas. The coefficient is significant at the ten percent level. When splitting $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ into groups based on size, I find that for large net flow of funds (higher than 0.5 quota), there is a stronger relationship between net flow and lending volume. For every one unit of NOK above 0.5 quota sent from bank i to bank j , the lending volume from bank j to bank i increases by 0.028 NOK. The relationship is significant at the five percent significance level. The relationship is, however, not significant for smaller payment flows.

Table 8: *Overnight Interbank Premium on Net Flow and Liquidity*

	$ii_{i,j,t}$
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$	0.574 (0.379)
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times B_{i,t}$	-0.420 (0.311)
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times P_{j,t}$	-0.130 (0.303)
$\frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}}$	0.049 (0.051)
$\frac{Liquidity_{i,t}}{Quota_{i,t}}$	-0.559*** (0.077)
$\frac{Liquidity_{j,t}}{Quota_{j,t}}$	-0.537*** (0.053)
Cons.	-1.403*** (0.123)
Relationship FE (quart.)	YES
Date FE	YES
Observations	11 922
No. of Banks	17
R-Squared	0.785
Within R-Squared	0.024

Note: $ii_{i,t}$ is the premium relative to the key policy rate paid by bank i , borrowing central bank reserves unsecured overnight from bank j , in basis points at day t . *Borr.* is a binary variable equal to one if the potential borrower (bank i) has negative net liquidity and thus a borrowing need. Similarly, *Place.* is a binary variable equal to one if the potential lender (bank j) has more than one quota in net liquidity and thus a placement need. Robust standard errors in parentheses. Three asterisks indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.

a winning curse phenomena, and the uninformed lenders may be better off staying out of the market. In other words, the informed counterparty may have some market power and charge higher interest rates. This logic is inspired by models on asymmetric information such as the model on relationship banking and asymmetric information by Sharpe (1990) and von Thadden (2004).

While a net flow of funds from bank i to bank j increases the probability of a loan from bank j to bank i regardless of whether there is a borrowing need for bank i , a placement need for bank j , or both, the effect, if any, on pricing is more complex. If the counterparty makes use of the information advantage, a signal indicating a borrowing need should translate into a higher spread, while a signal indicating a placement need should translate into a lower spread. Table 8 displays results from a

regression setup similar to the third regression in Table 7 in Section 5. The dependent variable is now the spread, $ii_{i,j,t}$, between the interest rate on a loan from bank j to bank i and Norges Bank's key policy rate at time t. The coefficients for the variables $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$, $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times B_{i,t}$, $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times P_{j,t}$ and $\frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}}$ are not significant.

The coefficients for $\frac{Liquidity_{j,t}}{Quota_{j,t}}$ and $\frac{Liquidity_{i,t}}{Quota_{i,t}}$ are still significant and with the expected negative signs. An increase in liquidity by one quota, either by bank i or bank j, reduces the spread by 0.53 - 0.60 basis points.

The results in Table 8 indicate that the bilateral payment flow is not a driver of prices for unsecured overnight interbank loans. While it could be that banks were forced to trade with informed counterparties at unfavourable prices rather than reducing search costs, these results support the conclusion above that banks use the bilateral net flow of funds to reduce search costs and are not penalized when sending negative signals.²⁰

7 Conclusion

This paper investigates whether banks use the payment flow of central bank reserves to conduct peer monitoring or rather to reduce search costs before making trading decisions in the unsecured overnight interbank market. The payment flow represents a signal about the banks' net liquidity positions (net of unsecured overnight interbank loans), and the banks use this signal to find a counterparty and thereby

²⁰A potential drawback of the statistical method presented in Table 8 is that the decision to participate in an unsecured overnight interbank loan may not be independent of the spread. Participation is likely positively correlated with the spread for the lender and negatively correlated with the spread for the borrower. Furthermore, Table 7 provides evidence that the bilateral net flow of funds from bank j to bank i reduces the probability for each of the banks of participating in a loan from bank j to bank i. Thus, the lender's decision is likely to cause a downward bias on the coefficients for the variables related to the bilateral net flow of funds. On the other hand, the borrower's decision is likely to cause an upward bias on the same coefficients. The magnitudes of these biases and whether they cancel each other out are unclear. One could address the selection bias using the Heckman approach (see Heckman (1976) and Heckman (1979)), but it would be challenging to include the relationship fixed effects necessary in this analysis (see Table 3).

reduce search costs. The analysis disentangles the signalling effect and the direct liquidity effects of the payment flow. I have also opened up for the possibility that the bilateral payment flow affects the pricing of loans and that the banks are not reducing search costs, but are rather trapped within a banking relationship and face unfavourable pricing due to asymmetric information. In Section 6, I provide results indicating that this is not the case, and the conclusion is robust to the inclusion of pricing. Furthermore, the descriptive statistics provided in Section 4 shed some light on the high prevalence of banking relationships in the interbank market. If banks are mostly interested in reducing search costs, it makes sense that they prefer trading within existing relationships.

Overall, the results indicate that banks in a decentralized interbank market use the payment flow of central bank reserves to reduce search costs, rather than to assess counterparty risk. In isolation, this is an argument to reorganize the unsecured overnight interbank market into a centralized system with collateral and anonymous participants for a more effective distribution of liquidity.

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A Robustness Sample Size

The analysis above is sensitive to the chosen sample of banks. About 130 banks had an account with Norges Bank in the sample period. Several of these banks were inactive and held an account for contingency purposes. There were 29 banks that participated at least once, either as lender, borrower or both, in an unsecured overnight interbank loan. There are large disparities within the 29 banks when it comes to both participating in the unsecured overnight interbank market and in general transaction activity on their accounts with Norges Bank. Table A1 displays some activity measures for the 29 banks. The average bank had almost 60 transactions per day on their accounts over the period 2012 - 2015, while the 10th and 25th and 50th percentile only had 0.86, 1.87 and 7.35 transactions. The 90th percentile had more than 180.²¹ There are similar skewed distributions in the daily number of unsecured overnight interbank market transactions. On average the banks participated in 0.46 loans per day. The 10th, 25th, 50th and 90th percentile lent 0.00, 0.04, 0.28 and 0.93 times per day. Similarly, the 10th, 25th, 50th and 90th percentile borrowed 0.00, 0.01, 0.10 and 1.54 times per day.

In the analysis above, all banks were required to have an average of at least three general transactions on their account per day to avoid including inactive banks. In Table A2, I mimic the third regression in Table 7 above, but with a larger sample without any lower criteria for general transactions and a smaller sample where each bank must have minimum of ten general transactions. The sample then consists of 29 and 13 in the two regressions. When allowing the sample to include more inactive banks, the coefficients for the net flow of funds variables are no longer significant.²² Among the 29 banks, there are several relationships that are automatically excluded from the regression as there are no transactions or loans over the period. If no relationships were excluded, one would expect $29 \times (29 - 1) \times 999 = 811\,188$ observations

²¹All transactions below NOK 100 (about EUR 10) are set to zero.

²²I also test the added 12 banks in isolation and obtain similar insignificant results. This confirms that this new result is due to a larger sample with inactive participations rather than opposite behaviour by the added banks.

Table A1: *Distribution Account Activity - Wide Sample*

	Mean	Percentiles				
		10	25	50	75	90
General Transactions	59.74	0.86	1.87	7.35	46.29	180.13
Borrowing Transactions	0.46	0.00	0.01	0.10	0.60	1.54
Lending Transactions	0.46	0.00	0.04	0.28	0.60	0.93

Note: General transactions are the daily average of all transactions worth at least NOK 100 (about EUR 10) registered on each bank's account with Norges Bank. Borrowing and lending transactions are the averages of how many times each bank has borrowed and lent in the unsecured overnight interbank market per day. The sample consists of the 29 banks that have at least been involved in one unsecured overnight interbank loan over the period 2012-2015.

as opposed to the 457 353 observations from the regression.²³ Similar results, both in magnitude and significance, as in Table 7, are obtained for the second regression with a smaller sample. There are also exactly as many observations in this regression as one would expect, meaning there are no inactive relationships.

By including banks that are nearly inactive, the results are no longer significant. However, the analysis is meant to measure how active banks behave in the Norwegian interbank market. The results are robust to reducing the sample size.

B Robustness Non-Linearity in Payment Flows

One could argue that the results obtained in Table 7 in Section 5 would be different if one allows for non-linearity in the variables. The second regression presented in Table 6 in Section 4.3 provides evidence that the information $\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$ reveals is depending on its size. While it is unclear to what extent the counterparty is aware of how much information payment flows provide, it is nevertheless useful to allow for non-linearity in payment flows on the probability for a loan to take place. Furthermore, while results presented above indicate that banks are using payment flow to reduce search cost, it may be that the lending bank (bank j) is more or less reluctant lending following a large payment. On one side, a large payment flow

²³Some observations are also missing due to some days with missing liquidity reports from the smaller inactive banks.

Table A2: Overnight Interbank Loans on Net Flow and Liquidity

	$Loan(j \rightarrow i)_t$	$Loan(j \rightarrow i)_t$
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,j}}$	-0.001 (0.002)	0.004* (0.002)
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times B_{i,t}$	0.007 (0.006)	-0.031*** (0.006)
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} \times P_{j,t}$	-0.000 (0.004)	-0.032*** (0.006)
$\frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}}$	0.007*** (0.001)	0.002*** (0.001)
$\frac{Liquidity_{i,t}}{Quota_{i,t}}$	-0.013*** (0.001)	-0.042*** (0.001)
$\frac{Liquidity_{j,t}}{Quota_{j,t}}$	0.011*** (0.002)	0.050*** (0.001)
Cons.	0.033*** (0.001)	0.031*** (0.001)
Relationship FE (quart.)	YES	YES
Date FE	YES	YES
Observations	457 353	155 844
No. of Banks	29	13
R-Squared	0.282	0.326
Within R-Squared	0.019	0.081

Note: $Loan(j \rightarrow i)_t$ is a binary variable equal to one if there is an unsecured overnight loan of central bank reserves from bank j to bank i on day t. $B_{i,t}$ is a binary variable equal to one if the potential borrower (bank i) has negative net liquidity and thus a borrowing need at day t. Similarly, $P_{j,t}$ is a binary variable equal to one if the potential lender (bank j) has more than one quota in net liquidity and thus a placement need at day t. Robust standard errors in parentheses. Three asterisks indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.

from bank i to bank j could be used as a strong signal reducing search costs for a counterparty. On the other side, while bank j would normally use a payment from bank i to reduce search costs, it may, for larger sums, be reluctant to lend as a large payment flow may reveal a negative signal about bank i's riskiness. From Table A3, we can see that a net flow of funds from bank j to bank i of less than -0.3 quotas (positive flows bank i to bank j) indicates an increased probability of about 2.4% for each quota sent. The relationship is significant at the one percentage significance level. This is a stronger result than provided in the first model specification in Table 7 in Section 5 of 1.7%. Furthermore, net flows of size between -0.3 and 0 quotas of the same sum would increase the probability for a loan with about 2.9%. However, only significant at the ten percent level. Positive flows (when bank j is the sender) up to 0.3 quotas similarly reduces the probability by about 3.3%, significant at the

five percent level. Large positive net flows above 0.3 quotas are associated with a 1% reduction in probability for a loan from bank j to bank i for each amount worth one quota, significant at the one percent level. Net flows to all other banks are significant for levels below -0.3 quotas and above 0.3 quotas. The net liquidity to quota variables at day-end for bank i and bank j are also grouped by size. Bank i's net liquidity to quota is significant at the one percentage level for all groups of liquidity. However, the negative relationship between liquidity and the probability of borrowing from bank j is increasing in the borrowing need for bank i. Bank j's net liquidity to quota is strong and significant when bank j has excess liquidity, and thereby a placement need. Bank j's liquidity is less important, although strongly significant for lower levels. In sum, allowing for net flow and net liquidity variables to affect the probability for a loan from bank j to bank i in a non-linear relationship does not alter the results above.²⁴

C Distribution Gross Liquidity at Close

The histogram in figure A1 displays the distribution of net liquidity at end-of-day for the 17 banks in the sample over the 999 trading days resulting in 16 983 observations. Each bar represents the percentage of total observations that are within brackets of 0.25 quotas. There are 17 extreme observations between 6.0 and 15.5 quotas not shown in the graph for readability. In 48.9 % of the cases, the banks have net liquidity worth between 0 and 1 quota, indicating that no action is required to avoid using the standing facilities with Norges Bank. 33.2 % of the observations are above one quota (15.1 % between 1 and 1.5) and 17.9 % below the quota.

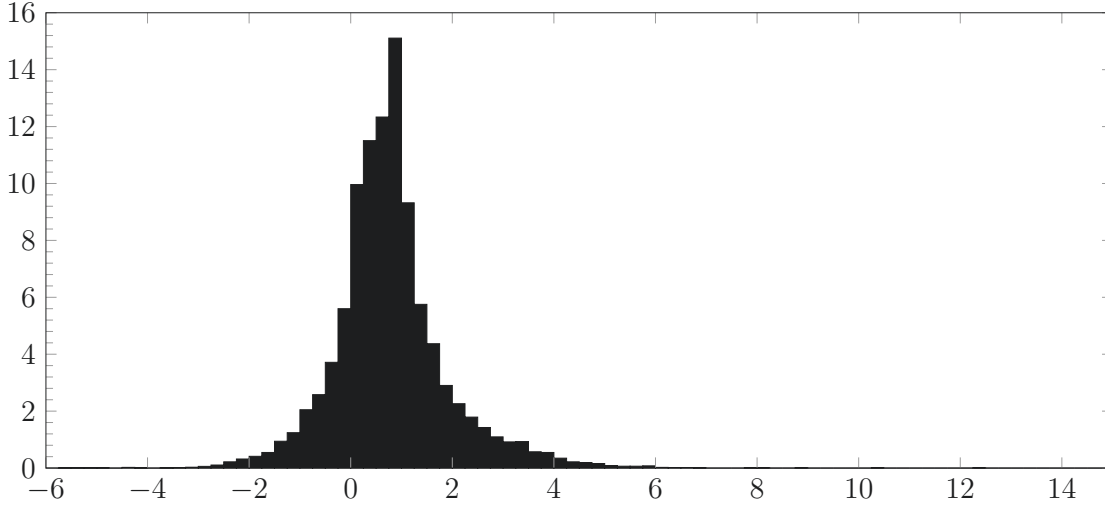
²⁴A model specification without relationship fixed effects is also tested, but due to the clear relationship between banks with high occurrence of payment flows and between banks with high occurrence of unsecured interbank loans (see Section 4.1), those results suffer from an omitted variable bias and inflate the results. Similarly, a model without testing for liquidity with the sender and with the receiver produce inflated coefficients.

Table A3: Overnight Interbank Loans on Net Flow and Liquidity

	$Loan(j \rightarrow i)_t$
$\frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} < -0.3$	-0.024*** (0.004)
$-0.3 \leq \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} < 0$	-0.029* (0.015)
$0 \leq \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}} < 0.3$	-0.033** (0.015)
$0.3 \leq \frac{Net\ Flow(j \rightarrow i)_t}{Quota_{i,t}}$	-0.010*** (0.003)
$\frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}} < -0.3$	0.002*** (0.001)
$-0.3 \leq \frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}} < 0$	-0.000 (0.006)
$0 \leq \frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}} < 0.3$	0.004 (0.005)
$0.3 \leq \frac{\sum_{k \neq j} Net\ Flow(k \rightarrow i)_t}{Quota_{i,t}}$	0.002** (0.001)
$\frac{Liquidity_{i,t}}{Quota_{i,t}} < 0$	-0.070*** (0.002)
$0 \leq \frac{Liquidity_{i,t}}{Quota_{i,t}} < 0.5$	-0.063*** (0.004)
$0.5 \leq \frac{Liquidity_{i,t}}{Quota_{i,t}} < 1.0$	-0.048*** (0.002)
$1.0 \leq \frac{Liquidity_{i,t}}{Quota_{i,t}} < 1.5$	-0.045*** (0.001)
$1.5 \leq \frac{Liquidity_{i,t}}{Quota_{i,t}}$	-0.021*** (0.001)
$\frac{Liquidity_{j,t}}{Quota_{j,t}} < 0$	0.007*** (0.001)
$0 \leq \frac{Liquidity_{j,t}}{Quota_{j,t}} < 0.5$	0.002 (0.003)
$0.5 \leq \frac{Liquidity_{j,t}}{Quota_{j,t}} < 1.0$	0.005*** (0.001)
$1.0 \leq \frac{Liquidity_{j,t}}{Quota_{j,t}} < 1.5$	0.049*** (0.001)
$1.5 \leq \frac{Liquidity_{j,t}}{Quota_{j,t}}$	0.051*** (0.001)
Cons.	0.038*** (0.002)
Relationship FE (quart.)	YES
Date FE	YES
Observations	257 742
No. of Banks	17
R-Squared	0.321
Within R-Squared	0.084

Notes: $Loan(j \rightarrow i)_t$ is a binary variable equal to one if there is an unsecured overnight loan of central bank reserves from bank j to bank i on day t . Robust standard errors in parentheses. Three asterisks indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.

Figure A1: *Distribution of net Liquidity to Quota at End of Day*



Note: There are 17 banks and 999 trading days over the period 2012-2015 resulting in 16 983 observations. Each bar is 0.25 quota wide and the y axis is the total percentage of observations that falls within this quota interval.

D Unsecured Overnight Loans and Liquidity Positions

Table A4: *Overnight Interbank Loans by Liquidity Status*

Potential Borrower	Potential Lender					Total
	$X < 0$	$0 \leq X < 0.5$	$0.5 \leq X < 1$	$1 \leq X < 1.5$	$1.5 \leq X$	
$X < 0$	4.4	4.3	5.1	21.4	44.6	14.8
$0 \leq X < 0.5$	0.8	0.6	0.9	7.6	18.5	4.8
$0.5 \leq X < 1$	0.5	0.4	0.5	4.0	9.2	2.5
$1 \leq X < 1.5$	0.2	0.2	0.4	1.6	2.4	0.9
$1.5 \leq X$	0.1	0.2	0.2	2.0	2.1	0.8
Total	1.1	1.1	1.3	7.2	15.9	

Note: All numbers are percentages and represent how often overnight interbank loans occur grouped by different liquidity combinations between the potential lender and borrower. Potential lenders in first row and potential borrowers in first column. X represents total net reserves excluding overnight interbank loans as a ratio to the bank's liquidity quota at Norges Bank. One pair of banks constitutes two directional banking relationships where each bank takes the role as either the borrower or the lender. There are 17 individual banks and 999 trading days resulting in 257 742 observations over the period 2012-2015 after excluding 14 directional relationships without any activity in the period.

Norwegian interbank market's response to changes in liquidity policy

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Abstract

We investigate activity and pricing in the Norwegian unsecured overnight interbank market in response to a change in the central bank's liquidity policy. In October 2011, to encourage interbank trading, banks were allotted quotas for their overnight reserves with remuneration at the policy rate, while that on overnight reserves beyond allotted quotas was set one percentage point lower. In addition, total liquidity in the system was substantially reduced and targeted within a narrow range. We document a significant increase in interbank activity and a fall in interest rates relative to the policy rate following the policy shift. Banks are found to distribute total liquidity more actively as borrowers and lenders. In particular, banks generally borrow from their peers at lower interest rates than before the policy shift.

Keywords: *Overnight interbank market, interest rates, central bank liquidity policy.*

JEL Codes: *G21, E43, E58.*

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1 Introduction

Interbank market activity declined in numerous countries before and particularly after the default of Lehman Brothers in mid-September 2008; see e.g. Afonso et al. (2011), Acharya and Merrouche (2013), and Heider et al. (2015). This has been a policy concern for central banks as a well-functioning interbank market is important for banks' payment services, credit supply and trading for investment and risk management. It is also necessary for the effectiveness of the monetary policy transmission mechanism and achieving policy objectives. Strategies aimed at improving the functioning of interbank markets have therefore been the focus of much academic and policy debate since the financial crisis; see e.g. Allen et al. (2009), Brunetti et al. (2011), Acharya et al. (2012), Gale and Yorulmazer (2013), Bindseil (2016) and Hamilton (2019).

We investigate the response of the Norwegian interbank market to a more restrictive liquidity policy adopted by Norges Bank, the central bank of Norway, in October 2011. Activity in the Norwegian interbank market declined substantially and remained relatively low for an extended period after the financial crisis (2008–2009); see e.g. Norges Bank (2009, pp. 72–76) and Akram and Christophersen (2013). The fall in interbank activity was accompanied by an increase in banks' trading with Norges Bank. To encourage interbank trading and discourage rather excessive liquidity deposits, Norges Bank replaced its scheme of remunerating banks' overnight deposits uniformly with a two-rate regressive scheme on 3 October 2011; see Norges Bank (2012, pp. 149–150). Accordingly, overnight deposits have earned the policy rate up to allotted quotas, while excess deposits have earned the 'reserve rate', set one percentage point below the policy rate. In addition, a target range for banks' total overnight deposits, i.e. total liquidity, was announced and maintained through market liquidity operations. This implied a substantial reduction of total liquidity relative to its level before the policy change. Ample amount of total liquidity was considered a disincentive to interbank trading.

Our investigation focuses on unsecured overnight interbank trading and interest rates before and after the policy change.¹ Among key questions are whether interbank trading has increased in response to the policy shift and how interbank borrowing and lending respond to changes in overall and individual liquidity positions, in particular whether banks to a larger extent cover liquidity shortfalls by borrowing from their peers after the policy shift. Our measures of interbank trading include the number of interbank market participants and the number and volume of loans. We focus on these measures both at the aggregate level and at the individual bank level to shed light on the interbank borrowing and lending of banks with different characteristics, including their liquidity holdings and credit limits at the central bank.

Regarding interest rates, we focus on whether and how much the policy change has affected interbank rates relative to the policy rate. While one would expect overnight interest rates to decline after the introduction of the reserve rate, a priori, it was difficult to say by how much they would be affected overall and for different borrowers and lenders. Moreover, while more trading among a larger number of participants may contribute to reduce interest rate volatility and the dispersion of interest rates across banks, it need not be the case if newcomers, say small and medium-sized participants, borrow or lend at less favourable rates than initial participants, mostly relatively large banks.

The investigation is based on a data set of banks active in the Norwegian interbank market over the period 17 April 2009 to 7 January 2016. As data on actual interbank loans and interest rates faced by individual banks are not publicly available, we employ a Furfine-based procedure to infer overnight loans and associated interest rates from the real-time gross settlement (RTGS) system of Norges Bank;

¹Unsecured overnight interbank trading accounts for around 3/4 of total overnight trading and about 90 percent of all unsecured trading in the Norwegian money market; see Norges Bank (2013, 2015) for evidence based on money market surveys.

see Furfine (1999, 2001). The procedure has been adapted to the specifics of the RTGS system. A recent evaluation by Akram et al. (2019) supports the high reliability of the employed procedure in identifying overnight loans and interest rates.

To summarise our main findings, we document a substantial increase in overnight interbank activity as measured by the number of active participants and the number and volume of loans after the policy shift. The spread between overnight interest rates and the policy rate becomes narrower after the policy shift and the dispersion of interest rates across loans (and banks) decline. Notably, while interest rate spreads are mostly positive before the policy shift, they are mostly negative afterwards. Moreover, we find that while an increase in total liquidity contributed to reducing interbank activity before the policy shift, it tends to increase interbank activity after the policy shift. An increase in banks' own liquidity relative to their quotas induces them to lend more and borrow less than earlier. Both lending and borrowing interest rates are found to decline with an increase in quota usage, possibly because banks may want to lend more and borrow (receive) less to avoid liquidity above their quotas. The evidence also suggests that banks to a larger extent meet their liquidity needs by borrowing from other banks and at lower interest rates than before the policy shift.

Our results shed light on the merits of a 'floor system' in terms of interbank activity and interest rates in comparison with those of a system that has features of a 'corridor system'. In a floor system, such as the one in place until October 2011, banks receive interest on all deposits with the central bank at the overnight deposit rate while the central bank also ensures a surplus of total liquidity to obtain interbank interest rates close to the overnight deposit rate.² In the new system, the central bank still aims to obtain interbank interest rates close to its overnight deposit rate, but it now constitutes the mid-rate between the central bank's overnight

²For details, www.norges-bank.no/en/Liquidity-and-markets/The-liquidity-management-system/The-management-of-bank-reserves-The-system-in-Norway/Background-system-managing-bank-reserves/

lending rate, which banks pay if they have to meet their short-term liquidity need, and the reserve rate, which banks receive if they have to deposit above-quota surplus liquidity with the central bank.³ More broadly, this paper contributes to the money market literature by offering insight on the roles of banks of different sizes in the overnight market for funds and as a case study where minor changes in the terms of reserves at the central bank can have significant effects on market functioning; cf. Furfine (1999) and Hancock and Wilcox (1996).

The paper proceeds as follows. Section 2 briefly presents the objectives and instruments of Norges Bank’s liquidity policy and the policy change. Section 3 outlines our Furfine-based procedure for identifying overnight interbank loans and associated interest rates. Section 4 describes overnight interbank activity and interest rates before and after the policy shift. Section 5 employs econometric models based on time series data as well as panel data to investigate the possible effects of the policy shift on interbank activity and interest rates, overall and at the individual bank level. The models take into account market liquidity conditions and a large set of banks’ characteristics. Section 6 concludes. The appendix presents our data set.

2 Liquidity policy - objectives and instruments

One may say that Norges Bank’s liquidity policy has three main objectives; see e.g. Norges Bank (2014, 2020). First, banks must have adequate liquidity to meet their short-term needs stemming from day-to-day activities. Second, the policy rate should prevail in the money market. And third, banks should predominantly meet their liquidity needs by trading with each other rather than with Norges Bank.⁴

All banks established in Norway, including branches and subsidiaries of foreign

³In some countries, including New Zealand, a ‘corridor’ has been defined without any mid-rate but with depositing and lending facilities bounding the range of overnight interest rates.

⁴<https://www.norges-bank.no/en/topics/liquidity-and-markets/The-liquidity-management-system/The-management-of-bank-reserves-The-system-in-Norway/Background-system-managing-bank-reserves/>

banks, may have deposit accounts with Norges Bank.⁵ Transactions between banks due to interbank loans and transfers between customers of different banks may be settled by debiting these deposit accounts. The interest rate on banks' overnight deposits (within quotas) at Norges Bank is the policy rate. To ensure that banks can honour their debts in payment settlements, they are granted access to Norges Bank's standing liquidity facilities. Intraday borrowing from Norges Bank is interest-free, while overnight borrowing commands an interest rate of one percentage point above the policy rate. Banks are not required to satisfy specific reserve requirements.

Until 3 October 2011, banks' overnight deposits at Norges Bank were remunerated fully and equally at the policy rate; see e.g. Norges Bank (2012, 2020). The policy rate therefore generally acted as a 'floor' for interbank overnight rates, while the overnight lending rate on overdrafts acted as a 'ceiling' on interbank overnight rates.⁶

A relatively low interbank activity in the aftermath of the financial crisis was considered mainly a consequence of ample liquidity conditions and banks' lack of incentives to avoid large individual liquidity deposits due to the remuneration policy. Thus, banks' often had no need to turn to other banks to borrow liquidity and/or had insufficient incentives to approach other banks to place liquidity in excess of their expected needs. There is no evidence to suggest that low interbank activity was due to banks' reluctance to lend to each other because of, say, credit risk. Banks were in general quite content with the existing liquidity policy, partly because they considered net gains from managing their liquidity actively to be small and expected to use liquidity deposits for partially meeting forthcoming regulatory liquidity require-

⁵See <https://lovdata.no/dokument/SF/forskrift/2019-12-18-2025>, for more information on banks' access to Norges Bank's standing facilities.

⁶Occasionally, however, overnight interbank interest rates may not be 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 resident banks at a lower interest rate than the central bank's deposit rate. Resident 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. Overnight interest rates can also exceed the central bank's lending rate since interbank loans are uncollateralised whereas loans from the central bank are collateralised, or 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).

ments; see Norges Bank (2014).⁷ Occasionally, however, they had to pay relatively high borrowing rates to meet their liquidity needs.

To encourage a higher level of interbank trading from relatively low levels following the financial crisis, Norges Bank changed its liquidity policy on 3 October 2011; see Norges Bank (2012). Since then, banks receive the policy rate on their overnight deposits only up to allotted limits (quotas), while excess deposits are remunerated at the reserve rate, set one percentage point below the policy rate.

The sum of allotted quotas has been set at a higher level (NOK 45bn) than the operational target range for total liquidity (NOK 35 +/- 5bn). This has made it possible for banks to deposit all of their liquidity at least at the policy rate through trading actively in the interbank market. Banks left with liquidity above their allotted quotas have faced remuneration of their excess liquidity at the reserve rate. Thus, not only banks expecting liquidity shortages by the end of a day have incentives to borrow from other banks, but also those with liquidity close to or above their quota limits have incentives to lend actively in the interbank market.⁸

Banks have been divided into three groups, mainly reflecting their gross payment transactions and allotted quotas accordingly.⁹ Groups 1–3 mainly corresponds to three ranges of bank assets and represent relatively large, medium and small banks; see Subsection 5.2.1 for details. Banks within a group have the same quota except settlement banks whose initial quotas are supplemented in accordance with their additional needs. While quotas have been adjusted over time, banks' group affiliation has not changed over time.

⁷All but one of the banks that responded to Norges Bank's request for feedback on the draft for the new liquidity policy objected to the policy change; see Norges Bank (2014) and <https://www.norges-bank.no/en/topics/liquidity-and-markets/The-liquidity-management-system/Norges-Banks-assessment-of-the-consultation-responses/>.

⁸One possible drawback of the new policy could be that it may have increased the overall costs of liquidity management as banks could be spending more resources to avoid liquidity in excess of their quotas; see Norges Bank (2014).

⁹See www.norges-bank.no/en/Liquidity-and-markets/The-liquidity-management-system/

Fixed-term liquidity operations by Norges Bank have kept total liquidity within the target range.¹⁰ Following the policy shift, total liquidity in the interbank system has fallen from an average of NOK 55bn to NOK 34bn. Moreover, the daily variation in total liquidity as measured by its standard deviation in the periods before and after the policy shift has fallen from NOK 20bn to NOK 4bn.

The next section outlines how we derive overnight interbank loans and associated interest rates from interbank payments data recorded in Norges Bank’s RTGS system.

3 Identifying overnight interbank loans and rates

During the sample period (17 April 2009–7 January 2016) about 130 banks, including branches and subsidiaries of foreign banks, had access to Norges Bank’s RTGS system and around 30 banks have used it on a daily basis. Most of the banks have used the system for gross settlement of large-value and time-critical payments, such as those associated with overnight interbank loans. After ignoring transactions that can be ruled out as unsecured overnight loans, we extracted a total of 1 498 907 transactions from the system covering the sample period.¹¹ The average daily value of these transactions is NOK 138bn, about USD 22bn at the average exchange rate over the period 2010 to 2015.

However, only a small share of the extracted transactions is associated with overnight interbank loans. We mainly proceed as Furfine (1999, 2001) to separate overnight loans from all of the other extracted RTGS transactions. In essence, the procedure classifies a pair of transactions between two banks on consecutive business days as

¹⁰Deposit auctions, which had not been held since 20 March 2003, have been an important feature of the new liquidity regime; see Norges Bank (2014) for details. They have helped avoid increases in total liquidity beyond the target range and particularly kept it below the sum of allotted deposit limits remunerable at the policy rate (NOK 45bn).

¹¹Ignored observations include those related to clearings from the Norwegian Interbank Clearing System (NICS) and the Norwegian central securities depository (VPS), payments sent to and from the Continuous Linked Settlement (CLS) system and banks’ transactions with Norges Bank.

an overnight loan if the amount transferred on a day (V_t) is a round value 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 rate.¹² The transferred amount is restricted to a round value as banks generally do not borrow non-round values by market convention.

Specifically, the Furfine algorithm identifies a pair of transactions as an overnight loan if the transferred amount (V_t) is a round value in NOK millions and the implied per annum interest rate (ii):

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

is within a predefined band. The bandwidth depends on what one considers to be reasonable variation in interbank interest rates. Hence, implied interest rates can be sensitive to the assumed bandwidth.

To increase the reliability of the Furfine algorithm, we additionally require the identified interest rate per cent ($ii \times 100$) to be a plausible quoted interest rate, that is, a number with no more than three decimals. Market participants generally quote interest rates in annual terms and mostly with two decimals, but sometimes with three decimals for particularly large loan amounts. Furthermore, we take into account that Norges Bank's RTGS system operates with two decimals for NOK payments as the smallest monetary unit is 'øre', equal to 1/100 of a NOK. A repayment transaction (V_{t+1}) can therefore potentially have a rounding error up to NOK 0.005. Consequently, an identified interest rate can deviate slightly from the corresponding actual interest rate agreed between two banks. An identified rate per cent is therefore treated as a valid observation if it does not disagree with its rounded value, down to three decimals, by more than the maximum of the potential rounding error

¹²It 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 of Norges Bank.

in the repayment transaction. That is:

$$\frac{|(ii_t \times 100000) - \text{round}(ii_t \times 100000)|}{100000} \leq \left(\frac{0.005}{V_t}\right) \times 365. \quad (2)$$

Including this strict form of a maximum rounding error condition reduces over identification of interbank loans, which is often a concern when applying a Furfine-based procedure.

The analysis presented is based on a bandwidth of $i_{cb} \pm 70$ basis points where i_{cb} denotes the policy rate. The chosen bandwidth is symmetric around the policy rate to allow interbank rates to be both below and above the policy rate after the policy shift. As shown in Subsection 4.2, we have found very few implied interest rates close to the bandwidth boundaries. In particular, none of the implied interest rates were found to exceed the overdraft rate (= policy rate + 100 basis points) when the bandwidth was relaxed to allow for that.¹³

Our analysis shows that the sets of identified loans and interest rates are quite invariant to changes in the bandwidth when the decimal restriction and rounding error conditions are imposed; see Akram and Findreng (2017). Akram et al. (2019) also document the high reliability of the employed algorithm using survey data. They were able to correctly identify each of the overnight interbank loans transacted and the corresponding interest rates during the survey month.

¹³The bandwidth choice rules out zero interbank rates as the policy rate is 0.75 percent in the last period of our sample. Identification of overnight interbank loans by using the algorithm presented may deteriorate if sent and returned amounts are equal, which would be the case if the bandwidth allows for interbank overnight loans at zero interest rate. If the interest rate band has a relatively high upper limit, an algorithm can wrongly classify repayment of a loan with a longer maturity than overnight as a repayment of an overnight loan. However, this is highly unlikely with the incorporation of the above mentioned decimal restriction. Unsecured interbank loans in NOK of longer maturities than overnight are in any event negligible according to money market surveys; see e.g. Norges Bank (2013).

4 Market participation, activity and interest rates

Using the adapted Furfine algorithm we identify 20 672 (unsecured) overnight loans and corresponding interest rates over the whole sample period. The identified loans are associated with 2.76 percent of the transactions extracted from the RTGS system and are between 30 banks, which are about 1/4 of the banks with access to the RTGS system.

The next subsection (4.1) describes interbank activity, particularly the number of interbank participants and their composition, before and after the policy shift. It is shown that interbank participants have remained mostly the same after the policy shift, with only a few newcomers. However, they participate more frequently, and borrow and lend more after the policy shift. Subsection 4.2 describes overnight interest rates before and after the policy shift. We observe that a relatively large number of the spreads between interbank rates and the policy rate are negative and narrower after the policy shift.

4.1 Overnight interbank market activity

Figure 1 shows upward shifts in the daily number of market participants, the volume and the number of overnight loans immediately after the policy shift on 3 October 2011. There is a relatively large variation in these activity measures over business days. Their average values are however significantly higher after the policy shift at the one percent level of significance.

Table 1 presents details of banks' participation and loans. The sample of identified overnight interbank loans suggests 27 different participants in the overnight interbank market before the policy shift and 30 afterwards; see panel I. Among the 27 participants before the policy shift, 23 banks were borrowers while 26 banks were lenders; not all banks acted as both borrowers and lenders.

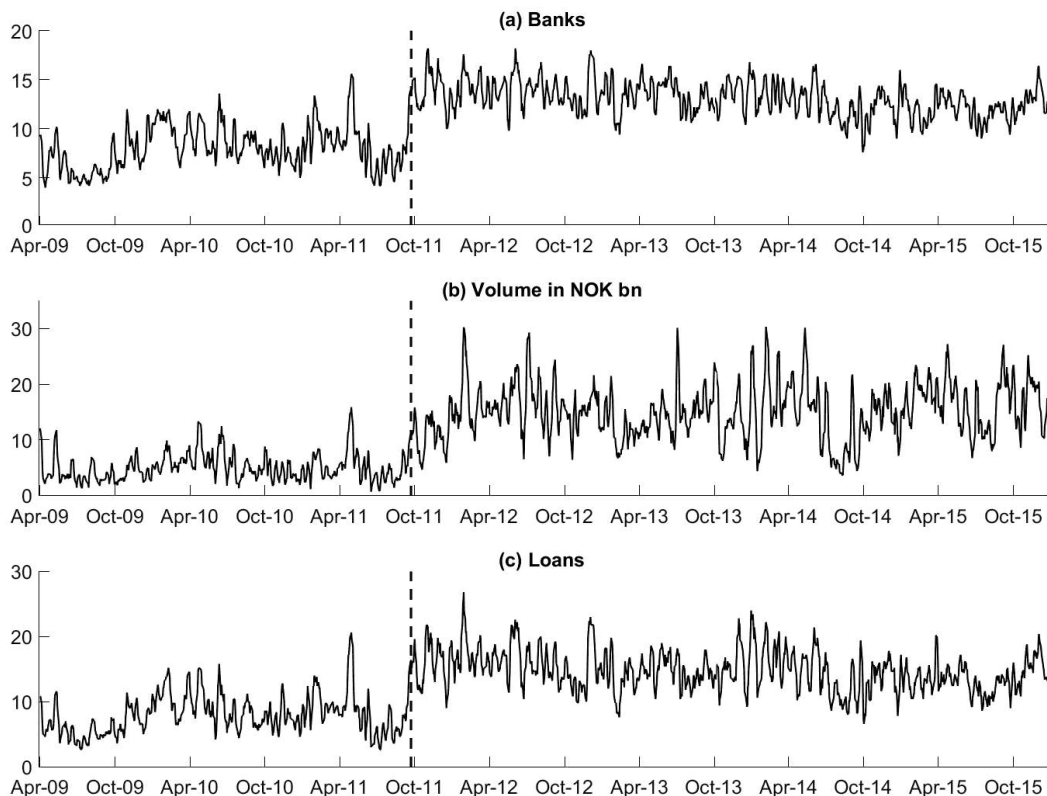


Figure 1: Five-days moving averages of (a) the number of unique participants in a day, (b) daily volume, i.e. total value of overnight loans in a day in NOK bn and (c) the number of overnight loans over the sample period 17 April 2009 to 7 January 2016. The dashed vertical lines mark 3 October 2011.

We identify three additional borrowers and two additional lenders in the sample for the period after the policy shift. The new borrowers are medium-sized banks in (quota) Group 2 while the new lenders are relatively small banks in Group 3. Borrowers as well as lenders remain otherwise the same in the two subsamples covering the periods before and after the policy shift.

Panel I of the table shows that all 6 members of Group 1 have participated in the interbank market before and after the policy shift. The number of participants belonging to Groups 2 and 3 increase marginally after the policy shift, from 16 and 5 to 17 and 7, respectively. The number of participants in Groups 2 and 3 therefore remain low relative to their total number, around 100.

Table 1: *Interbank market participation before and after the policy shift*

I. Participants, per samples						
	Before			After		
	Total	Borrowers	Lenders	Total	Borrowers	Lenders
Banks	27	23	26	30	26	28
Group 1	6	6	6	6	6	6
Group 2	16	14	16	17	17	16
Group 3	5	3	4	7	3	6

II. Participants, per day						
	Before			After		
	Total	Borrowers	Lenders	Total	Borrowers	Lenders
Banks	8.01	4.87	4.77	13.09	6.97	8.08
Group 1	4.24	2.95	2.86	5.38	3.91	3.07
Group 2	3.59	1.79	1.88	7.48	2.99	4.84
Group 3	0.18	0.13	0.04	0.23	0.07	0.17

III. Loans, per day				
	Before		After	
	Borrowers	Lenders	Borrowers	Lenders
Loans	7.91	7.91	14.71	14.71
Group 1	5.43	5.78	10.50	7.90
Group 2	2.35	2.09	4.13	6.63
Group 3	0.14	0.05	0.08	0.18

IV. Loan volume, per day				
	Before		After	
	Borrowers	Lenders	Borrowers	Lenders
Volume	4 937	4 937	15 024	15 024
Group 1	4 083	4 103	13 776	12 803
Group 2	831	822	1 227	2 197
Group 3	23	11	21	24

Notes: Summary statistics of overnight interbank activity measures over the samples 17 April 2009–2 October 2011 and 3 October 2011–7 January 2016, covering the periods before and after the policy shift, respectively. Panel I reports the number of unique banks participating in the interbank market as borrowers and/or lenders, overall and by quota group; a number reported below ‘Total’ refers to a ‘union’ of banks participating as borrowers or lenders. Panel II reports average numbers of unique participants per day before and after the policy shift. Panels III and IV present the average number of interbank loans per day and the average value of total interbank loans in (NOK) millions per day, respectively. In Panels II–IV, the differences between almost all of the mean values for periods before and after the policy shift are statistically significant at 1 or 5 percent level of significance. The exception is the difference between the mean values for borrowing volume per day for Group 3 which are roughly the same.

While the interbank participants have remained about the same after the policy shift, they have become more active in general. Panel II of the table shows that the average number of banks participating in the interbank market increases from about 8 to 13 per day after the policy shift. This increase is statistically significant at the one percent level of significance.

Banks in Groups 1 and 2 increase their participation both as borrowers and lenders. Banks in Group 3 continue to participate occasionally as their borrowing and lending per day remain negligible before and after the policy shift. Their lending rises

while their borrowing falls.

Banks' participation as lenders increases somewhat more than as borrowers. Overall, the average number of lenders increases from 4.77 to 8.08 per day while that of borrowers increases from 4.87 to 6.97 per day. In particular, banks in Group 2 participate more often as lenders after the policy shift. Their average number as lenders increases from 1.88 to 4.84 per day. The average number of Group 1 lenders increases from 2.86 to 3.07, remaining around 1/2 of the 6 banks in the group.

Panels III and IV focus on the daily number and volume of loans averaged over the periods before and after the policy shift. We note that both the number and volume of loans increase substantially after the policy shift, consistent with the higher participation of banks in the interbank market. Overall, the average number of loans increases from 7.91 to 14.71 while the average of total daily volume increases from about NOK 4.9bn to about NOK 15bn. These shifts in the means are statistically significant at the one percent level of significance.

Panel IV of the table points to the dominant role played by Group 1 banks in the interbank market. They account for 4.1bn out of 4.9bn, or about 83 percent, of the average daily loan volume as borrower as well as lenders before the policy shift. After the policy shift, their shares as borrowers and lenders increase to 92 and 85 percent, respectively. Even though Group 2 banks' borrowing and lending increase substantially after the policy shift, it constitutes a smaller share of the overall loan volume after the policy shift.

Panels III and IV indicate that each bank group borrows and lends about the same amounts before the policy shift. After the policy shift, Group 2 banks substantially increase their lending to Group 1 banks. This is reflected in Group 1 banks' higher borrowing relative to their lending and Group 2 banks' higher lending relative to their borrowing.

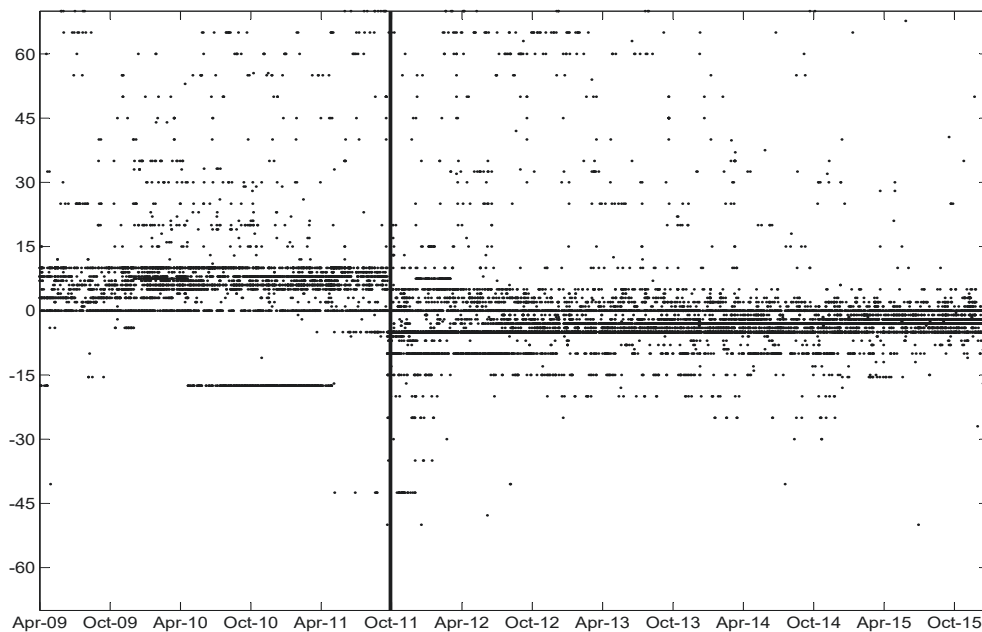


Figure 2: *Interbank interest rates associated with 20 672 overnight loans identified by the algorithm implemented. The interest rates are expressed as ‘spreads’ relative to the policy rate over the sample period: 17 April 2009–7 January 2016. The vertical line marks 3 October 2011.*

As the quota groups mainly reflect the banks’ gross payment transactions, banks within a group may be of different characteristics including liquidity and credit risk. In Section 5 we take into account banks’ individual characteristics when investigating their activity and pricing in the interbank market.

4.2 Overnight interbank interest rates

Figure 2 shows interest rate spreads associated with all of the identified individual loans (20 672) over the sample period. We observe that most interest rate spreads are clustered around zero, though asymmetrically. Before and after the policy shift date, 85.43 and 96.53 percent of the observations, respectively, are within a 30 basis point range (± 15 basis points). The dispersion of positive spreads, i.e. interest rates above the policy rate, seems to be larger than negative spreads.

Figure 2 suggests a fall in most interest rate spreads from 3 October 2011 onwards.

We note, however, only a few spreads close to the assumed lower band of the interest rate spread: -70 basis points. This finding suggests that interbank loans are mostly transacted at overnight rates far above the reserve rate, which corresponds to an interest rate spread of -100 basis points.

Negative interest rate spreads, i.e. interest rates below the policy rate, especially before the policy shift, could reflect overnight loans between interbank participants on behalf of non-resident banks or other institutions that are barred from placing liquidity at Norges Bank. Resident banks may accept liquidity from e.g. foreign non-resident banks at a lower rate than the policy rate. After the policy shift, also resident banks with excess liquidity may be willing to place liquidity at interest rates below the policy rate to avoid its remuneration at the reserve rate; see Subsection 5.2.2. This is consistent with the increase in the number of negative spreads observed after the policy shift in Figure 2.

We summarise the behaviour of (implied) interest rates over time using a measure of market-wide overnight interest rate, that is, a loan-weighted average interest rate. It is calculated by weighting each of the interest rates in accordance with the value of the corresponding loan relative to the total value of all loans on a given day.

Figure 3 plots the calculated market-wide overnight interest rate as deviations from the policy rate in basis points, hereafter referred to as ‘spread’. It shows that most of the spread values dropped from positive levels to negative levels after 3 October 2011. More precisely, 96.77 percent of the spread values were positive before the policy shift, while about the same share (94.87 percent) has been negative afterwards. The average of daily spread values declined 9.4 basis points after the policy shift, from 6.80 basis points to -2.60 basis points; see Table 2. The spread also became less variable, as its standard deviation declined from 4.81 to 2.95 basis points.

Table 2 also presents summary statistics of loan-weighted averages of borrowing and

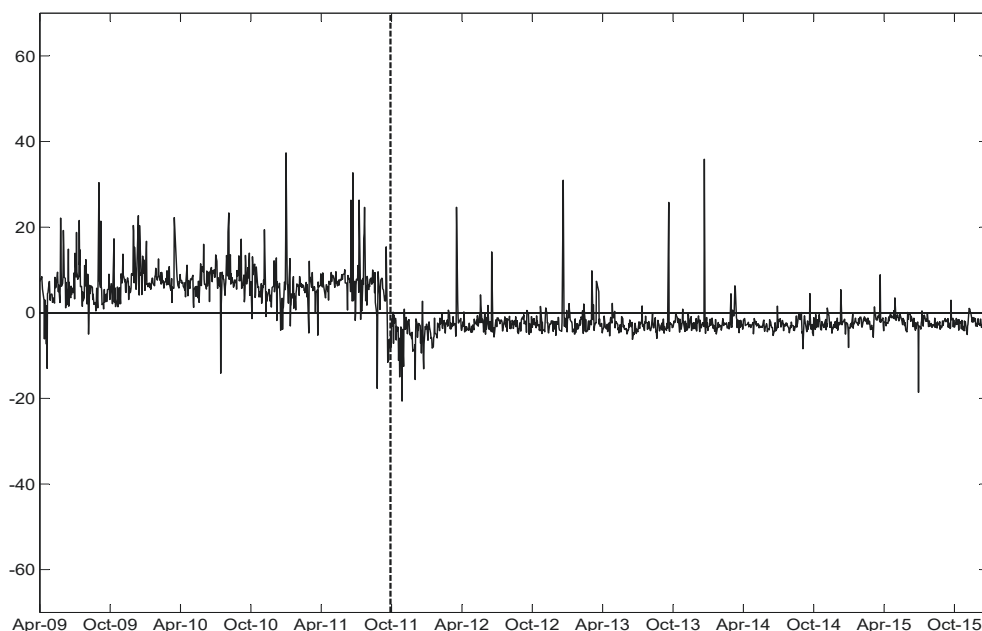


Figure 3: *The spread between derived values of the loan-weighted average interest rate and the policy rate in basis points. The sample consists of daily observations over the sample period 17 April 2009–7 January 2016. The dashed vertical line marks 3 October 2011. The relatively large spikes in the spread values occur on end-of-month days.*

lending interest rates relative to the policy rate for each quota group. The averages of both borrowing and lending interest rate spreads decline after the policy shift for the three groups, especially for Groups 2 and 3. We also note that while banks in Groups 2 and 3 borrow at higher rates on average than charging for lending, the converse is the case for banks in Group 1. This could reflect a higher bargaining power of Group 1 banks relative to banks in Groups 2 and 3.

5 Policy shift and interbank activity and interest rates

As shown above, the liquidity policy shift has largely coincided with a rise in overnight interbank lending and borrowing and a fall in interest rate spreads. Beside the remuneration of banks' liquidity above allotted quotas at a 'penalty rate', a substantial reduction and limits on total liquidity, i.e. total reserves in the system, are key elements of the policy shift.

Table 2: *Interest rates spreads overall and by quota group, before and after policy shift*

	Before					After				
	mean	Stdev	25th	50th	75th	mean	Stdev	25th	50th	75th
Spread	6.80	4.81	4.75	6.57	8.16	-2.60	2.95	-3.62	-2.67	-1.76
<i>Group 1</i>										
borr. spread	3.78	9.32	0.00	5.00	7.05	-3.78	5.15	-5.00	-4.00	-2.12
lend. spread	7.53	13.61	3.98	6.13	8.58	0.21	11.05	-3.84	-2.00	0.00
<i>Group 2</i>										
borr. spread	13.81	15.80	8.00	10.00	10.00	0.60	12.30	-4.56	-2.00	0.00
lend. spread	6.39	5.43	0.00	9.00	10.00	-4.44	4.82	-5.00	-5.00	-3.00
<i>Group 3</i>										
borr. spread	9.90	5.18	8.00	10.00	10.00	-1.54	4.42	-5.00	-0.00	2.00
lend. spread	9.19	7.01	8.00	10.00	10.00	-5.62	3.82	-5.00	-5.00	-5.00

Note: Summary statistics of interest rate spreads over the samples 17 April 2009–2 October 2011 and 3 October 2011–7 January 2016, covering the periods before and after the policy shift, respectively. Here, ‘Spread’ is the loan-value weighted average of all overnight interest rates less the policy rate. We also present summary statistics of spreads based on interest rates on amounts borrowed and lent by each quota group. These are referred to as ‘borr. spread’ and ‘lend. spread’, respectively. The differences between the means before and after the policy shift are statistically significant at the one percent level of significance.

In this section, we first focus on overall interbank activity and interest rates over time and investigate whether their responses to changes in total liquidity have shifted. We thereafter present a panel data analysis to shed light on how the policy shift may have affected banks’ individual participation in the interbank market, borrowing, lending and corresponding interest rates. The analysis focuses on relationships between banks’ characteristics, especially liquidity positions, and their interbank activity and interest rates.

5.1 Market liquidity conditions, interbank activity and interest rates

In the following, we investigate the effects of the policy shift on interbank activity measures and interest rates while controlling for the possible influence of a number of variables representing market conditions. We are particularly interested in the effects of changes in total liquidity after the policy shift.

We estimate equations such as:

$$y_t = \mu_y + \delta_y \times ps_t + (\Gamma_{1,y} + \Gamma_{2,y} \times ps_t)X_t + \varepsilon_{y,t}. \quad (3)$$

Here, y represents the log of total daily number of banks participating as borrowers and/or lenders, the log of total daily number of loans, the log of total daily loan volume, the difference between the market-wide overnight rate and the policy rate (spread) and finally, the daily standard deviation of interest rates across loans. X denotes a vector of variables that may affect the interbank activity measures and interest rates. The policy shift is represented by ps , which is a binary variable equal to zero until 3 October 2011 and one afterwards.¹⁴ Greek letters represent parameters and a stochastic error term (ε_y). The individual parameters are assumed to be constant while the error term is assumed to have a zero mean and a constant variance.

The vector of explanatory variables (X) includes relative changes in banks' total (overnight) liquidity at the central bank. Banks' response to changes in total liquidity may have changed in the new regime. Before the policy change, an increase in total liquidity reduced banks' need for interbank borrowing without inducing them to lend more. After the policy shift, when banks are remunerated relatively less for liquidity above their quotas, an increase in total liquidity encourages them to lend more and, in particular, off-load any liquidity in excess of their quotas. They may even lend at interest rates that are below the policy rate to banks in need of liquidity, or to banks that are unlikely to fill their quotas by the end of day. The latter banks gain by accepting liquidity (borrowing) at rates lower than the policy rate and depositing it at the central bank at the policy rate.

Vector X also includes the log of the daily turnover, i.e. the value of total daily

¹⁴We have also employed Markov switching models to undertake the investigation while remaining silent about whether or not a policy shift has taken place, its timing and permanence; see e.g. Hamilton (1989). The results presented are robust to such change in the model specification.

transactions (excluding overnight loans) between banks in the RTGS system. Higher payment activity raises transaction as well as precautionary demands for liquidity as each bank's liquidity position can become more uncertain on days with a high turnover in the payment system. An increase in payment activity may therefore be associated with more interbank trading and higher interest rates; see e.g. Acharya and Merrouche (2013) and Furfine (2000).

In vector X , we also include a dummy variable to control for the possible influence of petroleum tax due dates on overall liquidity demand and its availability; there are six such due dates per year in Norway, which is a major petroleum producer. Payments of relatively large amounts of petroleum tax to the government's account remove equally large amounts of liquidity from banks' accounts at Norges Bank, reducing total liquidity. Relatively large turnover in the payment system on these days tends to put upward pressure on interbank loans and interest rates, possibly due to precautionary liquidity demand stemming from uncertainty about end-of-day positions. To reduce such pressure, Norges Bank offers additional liquidity to banks on and/or around petroleum tax due dates.

We also take into account possible end-of-month effects on interbank activity and interest rates through another dummy variable in vector X ; cf. Figure 3. Banks report various balance sheet and liquidity indicators monthly to regulatory authorities for regulatory purposes including the determination of capital requirements and deposit insurance premia. To minimise such regulatory charges, banks may reduce their unsecured lending at the end-dates of months. Calendar effects on overnight interest rates have been reported in previous studies including Fecht et al. (2007) and Akram and Christophersen (2017).

Furthermore, we take into account potential spillovers from liquidity conditions in international money markets. NIBOR, the main reference rate for the Norwegian interbank market, is derived from international interest rates such as the LIBOR

Table 3: *Interbank activity and interest rates at market level*

	banks	loans	volume	spread	stdv
μ_y	2.020 [‡] (0.015)	1.944 [‡] (0.021)	8.217 [‡] (0.035)	6.702 [‡] (0.199)	9.475 [‡] (0.291)
$\delta_y \times ps$	0.538 [‡] (0.016)	0.698 [‡] (0.023)	1.288 [‡] (0.038)	-9.389 [‡] (0.213)	-4.064 [‡] (0.327)
$\Delta \text{Tot. liq}$	-0.361 [‡] (0.073)	-0.560 [‡] (0.095)	-1.074 [‡] (0.156)	-1.509 [†] (0.892)	0.375 (1.446)
$\Delta \text{Tot. liq} \times ps$	0.566 [‡] (0.089)	0.904 [‡] (0.126)	1.489 [‡] (0.195)	-0.896 (1.074)	-1.458 (1.878)
$\Delta \text{Payments}$	0.057 [‡] (0.021)	0.099 [‡] (0.032)	0.164 [‡] (0.051)	-0.185 (0.304)	-0.258 (0.445)
Tax date	0.026 (0.036)	0.061 (0.051)	0.077 (0.074)	0.528 (0.357)	-1.258 (0.770)
ΔECB	-0.117 (0.123)	-0.172 (0.176)	-0.207 [†] (0.103)	-2.169 (1.329)	2.112 (1.805)
End-month	-0.154 [‡] (0.040)	-0.201 [‡] (0.063)	-0.464 [‡] (0.038)	1.961 [†] (0.958)	2.285 [†] (0.916)

Note: ‘banks’, ‘loans’ and ‘volume’ are the log of number of the daily number of participating banks, the log of total daily number of loans and the log of total daily loan volume, respectively. ‘spread’ is the difference between the market-wide overnight rate and the policy rate. ‘stdv’ is the unweighted standard deviation of interest rates across loans. ‘ps’ is a binary variable equal to zero until 3 October 2011 and one afterwards representing the policy shift. ‘ $\Delta \text{Tot. liq}$ ’ is the first difference of the log of banks’ total (overnight) liquidity at Norges Bank in NOK millions. ‘ $\Delta \text{Payments}$ ’ is the first difference of the log of all transactions between banks with access to Norges Bank, net of interbank loans in millions. We use the first differences because ADF-tests suggest ‘Tot. liq’ and ‘Payments’ are integrated of order one. ‘ ΔECB ’ is a dummy variable for days when the ECB has changed its policy rates. ‘Tax date’ is a dummy variable for petroleum tax due dates while ‘End-month’ is a dummy variable for end-of-month days. The sample period is 17 April 2009–7 January 2016 and contains 1691 days with interbank activity. Robust standard errors are in parentheses. The superscripts ‘[‡]’ and ‘[†]’ indicate that the associated p -values are less than one and five percent, respectively.

rate and foreign exchange swap rates using covered interest rate parity expressions. International money and foreign exchange markets can therefore influence interbank trading and pricing in the Norwegian interbank market through their possible effects on NIBOR. To control for such influence, vector X includes a dummy variable that equals one on dates when the ECB changes its policy rates and remains zero otherwise.

Table 3 presents estimation results for each of the above defined y variables. There are positive and statistically significant shifts in estimated intercept terms in equations for the three measures of interbank activity. These suggest upward level shifts in the number of interbank participants, the number of loans and their volume; cf.

Figure 1 and Table 1. In the equations for the interest rate spread and the standard deviation, which indicates how much participating banks' interest rate quotes differ from each other on a daily basis, partial effects of the policy change reflected in the intercept shifts are estimated to be reductions of 9.39 basis points and 4.06 basis points, respectively. These reductions are also statistically significant (at the one percent level of significance).

Coefficient estimates associated with the explanatory variables have expected signs and are mostly statistically significant at the standard levels of significance. Except for changes in total liquidity, however, there did not seem to be statistically significant shifts in the estimated coefficients of other explanatory variables. Their terms were therefore left out before estimating the equations presented for the sake of parsimony.

The coefficient estimates associated with changes in total liquidity suggest that an increase in total liquidity reduced the number of market participants, the number of loans and their volume before the policy shift. After the policy shift, however, an increase in total liquidity is associated with an increase in these interbank activity measures. The net effect of changes in total liquidity on the three activity measures are positive and statistically significant.

As one may expect, an increase in total liquidity tends to lower interbank interest rates. This effect seems to be stronger in the period after the policy shift, but the latter effect is statistically insignificant. Changes in total liquidity and the other explanatory variables except one do not have statistically significant effects on the standard deviation of interest rates across loans. The exception is the dummy variable for end-of-month days, which suggests an increase in the dispersion across interest rates at the end of months.

An increase in overall payment transactions excluding overnight loans is associ-

ated with higher interbank activity. Coefficient estimates associated with payments in the equations for banks, loans and their volume are positive and statistically significant. An increase in payments do not, however, lead to higher interbank interest rates.

Interbank activity seems to decline on days when the ECB changes its policy rates. While the total value of loans declines significantly, reductions in the number of loans and interbank participants are not statistically significant. The effects on interest rates are also statistically insignificant.

While interbank activity and interest rates are found to remain unaffected by due dates for petroleum tax, interbank activity as well as interest rates change significantly on end-of-month days. Interbank activity as measured by the three variables declines significantly while interbank interest rates increase significantly on end-of-month days. This suggest that banks may be more reluctant to lend on days for which they report key numbers to regulatory authorities.

5.2 Interbank activity and pricing at bank level

In the following, we investigate relationships between banks' individual characteristics and their participation in interbank lending and borrowing, amounts lent and borrowed and associated interest rates. In addition to banks' key characteristics including individual liquidity positions relative to their quotas, we take into account the effects of overall money market conditions discussed above. Previous studies close to our analysis of the role of bank characteristics and market conditions include Cocco et al. (2009) and Fecht et al. (2011).

We next describe the characteristics of interbank participants and our data on banks' liquidity positions late afternoon, before most of the daily interbank borrowing and lending take place. Among banks' individual characteristics, their liquidity positions are found to be the key driver behind changes in their interbank activity and pric-

ing after the policy shift. The contributions of banks' other characteristics remain largely the same as before the policy shift.

5.2.1 Banks' characteristics and liquidity positions

Information about banks' characteristics is mostly based on monthly and quarterly balance sheet data supplemented with information from banks' published reports. Norges Bank has also provided us with confidential daily data on banks' credit limits and overnight liquidity positions at Norges Bank late afternoon. The appendix provides precise definitions and details about the data. Next, we present and discuss the data in accordance with banks' quota-group affiliations to maintain its confidentiality.

Table 4 summarises the characteristics of the interbank participants in the three quota groups. The summary statistics point to large variations in banks' characteristics within and across the three groups. We note that all but one member of Group 1 are branches or subsidiaries of foreign banks. Market participants in Groups 2 and 3 are mostly Norwegian banks, 21 out of 24 ($= 17 + 7$) banks. Banks in Group 2 and Group 3, in particular, are mostly relatively smaller than Group 1 banks in terms of total assets; see the 75th percentiles for total assets. The relatively high mean values of their total assets are due to the 1–2 foreign banks in Groups 2 and 3.

Banks in Groups 2 and 3 are mostly medium- and small-sized saving banks, respectively, with relatively large equity ratios and deposits-to-assets ratios. These banks predominantly engage in lending to households and non-financial corporations as indicated by their relatively large (average) shares of loans to assets, around 2/3. For all three bank groups, the non-performing loans' shares are mostly 1–2 percent, while return on assets is around 1/2 percent.

Table 4 also reports banks' credit limits at Norges Bank which are also informa-

Table 4: *Characteristics of overnight interbank market participants*

	mean	Stdev	25th perc.	50th perc.	75th perc.
<i>Group 1</i>					
Participants	6				
Foreign banks	5				
Total assets	2 749 827	1 374 392	1 717 116	2 189 151	3 656 673
Equity ratio %	4.68	0.88	4.08	4.38	5.16
Deposits to assets %	30.98	5.77	27.75	30.18	33.51
Loans to assets %	54.51	9.60	49.71	50.43	65.48
Return on assets %	0.48	0.18	0.46	0.51	0.55
NPL %	2.03	1.77	1.39	1.48	1.80
Credit limit	25 326	25 723	7 718	13 138	49 561
Quota	5 245	511	5 035	5 035	5 041
<i>Group 2</i>					
Participants	17				
Foreign banks	2				
Total assets	1 816 308	4 880 099	32 366	42 336	102 394
Equity ratio %	7.15	1.57	6.71	7.18	8.08
Deposits to assets %	53.57	12.41	46.54	54.87	60.09
Loans to assets %	65.20	15.38	59.86	70.60	76.78
Return on assets %	0.66	0.31	0.45	0.63	0.98
NPL %	1.65	1.31	0.84	1.27	2.09
Credit limit	3 414	3 032	1 399	2 138	3 689
Quota	605	147	569	569	569
<i>Group 3</i>					
Participants	7				
Foreign banks	1				
Total assets	2 632 604	6 408 723	13 726	16 486	26 711
Equity ratio %	8.29	0.57	8.03	8.28	8.70
Deposits to assets %	63.81	11.78	51.46	65.64	75.14
Loans to assets %	68.89	19.24	68.91	73.47	82.07
Return on assets %	0.58	0.24	0.41	0.55	0.84
NPL %	2.29	0.89	1.61	2.06	2.73
Credit limit	622	516	165	577	943
Quota	54	0	54	54	54

Note: The summary statistics are based on data for 28–30 banks over the sample period 17 April 2009–7 January 2016. They are presented by quota groups. All of the banks have been involved in at least one interbank loan over the sample period. Total assets, credit limits at Norges Bank and quotas are reported in NOK millions. Figures for credit limits and quotas are based on data for 30 banks, while the remaining figures are based on data for 28 banks, due to the lack of monthly or quarterly data for two banks in Groups 2 and 3.

tive about their (prime) assets apart from their loan portfolios. Banks' credit limits reflect the values of securities they have collateralised at Norges Bank. A comparison of the credit limits and quota sizes suggests that banks can obtain substantially more liquidity from Norges Bank than they can deposit with it, at the policy rate.¹⁵

Banks' quotas for overnight deposits at Norges Bank that are remunerated at the

¹⁵We are not able to take into account banks' ratings because they are not available for most of the banks. The ratings available for the major banks from the international rating agencies suggest that they are highly rated and there are at most small differences between them (during the sample period).

policy rate are intended to limit the banks' placement of liquidity at the central bank. For banks in Groups 1 and 2, the average quotas are about 1/5 of their average credit limits. For banks in Group 3, the average quotas are less than 1/10 of their credit limits.

In order to take into account possible effects of market participants' liquidity on their interbank behaviour and interest rates, we use information about each bank's liquidity position at 15:30. Unsecured overnight interbank activity is mostly initiated after the results from Norges Bank's liquidity operations have been announced and implemented, usually after 15:15.¹⁶

Figure 4 shows the intraday patterns of transactions associated with the identified overnight loans. The first leg of the overnight transactions are mostly conducted after 15:30, while close to all repayments are made within the first hour of the opening of the RTGS system at 5:30; around 52 percent of the repayments are made within the first two minutes of its opening.

Table 5 summarises banks' liquidity positions at 15:30 before and after the policy shift. We note that all three groups have reduced their average liquidity positions, in line with the reduction in total liquidity. Most notable is the drop by more than 50 percent for banks in Groups 2 and 3 from NOK 904m to NOK 435m and from NOK 322m to NOK 106m, respectively. Before the policy change, banks in all three groups 1, 2 and 3 had negative liquidity at Norges Bank (at 15:30) on average in 16.4 percent, 5.6 percent and 1.3 percent of the days over the sample period. After the policy shift, the shares of days with negative liquidity rise on average to 21.9 percent, 7.0 percent and 3.4 percent, respectively.

Banks in Groups 1 and 2 have average liquidity within their respective quotas. Their liquidity over quota ratios are on average 0.76 and 0.71. For Group 3 banks,

¹⁶Banks' interbank activity and participation in the liquidity operations are not motivated by official reserve requirements as they do not apply in Norway; cf. Fecht et al. (2011).

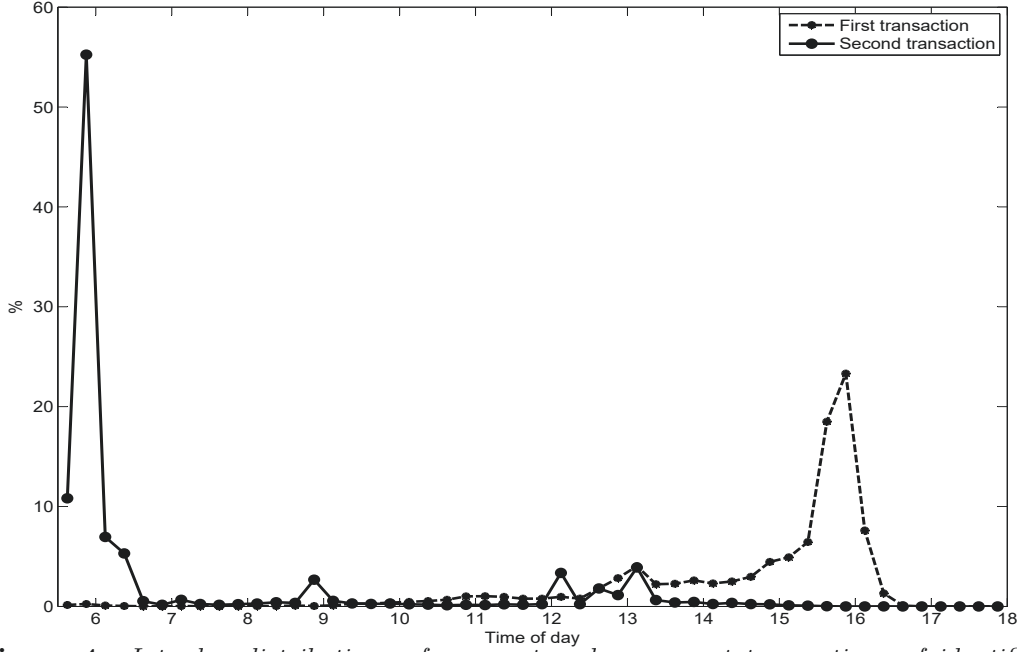


Figure 4: *Intraday distributions of payment and repayment transactions of identified overnight loans in percentage of corresponding total loan transactions. The horizontal axis depicts every 15 minutes from 5:30 to 18:00. The usual opening hours of the RTGS system are 5:30–16:35. The distributions are based on identified transactions for 30 banks over the full sample period.*

the average liquidity at 15:30 is about twice their quota. This is consistent with relatively small gains from an active liquidity management for small banks; cf. Fecht et al. (2011) and Norges Bank (2014).

To investigate whether liquidity above or below a bank’s quota affects its inter-bank activity and interest rates, we construct ‘quota usage’ as a logistic function of each bank’s available liquidity at 15:30 relative to its quota. This transformation lets ‘quota usage’ convey similar meaning in the period before and after the policy shift.¹⁷ We specify it as:

$$quota\ usage = \frac{1}{1 + e^{-(\frac{Liquidity}{Quota} - 1)}} \times ps, \quad (4)$$

¹⁷It is not obvious how to represent *quota usage* before quotas were introduced. Effectively, ‘quotas’ were infinitely large before 3 October 2011. Hence, simply using the ratio $\frac{Liquidity}{Quota}$ would make it close to zero irrespective of a bank’s liquidity position before the policy shift. This would be confusing as a ratio close to zero would indicate a small liquidity amount relative to a (limited) quota after the policy shift.

Table 5: *Banks' overnight liquidity positions by quota group before and after 3 Oct. 2011*

	Before					After				
	mean	Stdev	25th	50th	75th	mean	Stdev	25th	50th	75th
<i>Group 1:</i>										
Liq 15:30	5 166	4 099	3 248	4 258	5 849	3 912	4 289	2 900	3 143	3 377
Liq < 0, % days	16.43	9.25	8.25	17.90	20.39	21.92	22.65	0.37	19.78	31.44
Liq over quota						0.76	0.86	0.50	0.60	0.67
Quota usage						0.44	0.16	0.39	0.40	0.42
<i>Group 2:</i>										
Liq 15:30	904	516	527	816	1 254	435	215	306	438	482
Liq < 0, % days	5.59	8.97	0.34	2.23	5.83	6.97	7.65	1.36	5.04	8.02
Liq over quota						0.71	0.27	0.54	0.77	0.85
Quota usage						0.43	0.06	0.39	0.45	0.46
<i>Group 3:</i>										
Liq 15:30	322	156	277	380	405	106	80	58	63	123
Liq < 0, % days	1.33	2.52	0.16	0.16	0.49	3.41	4.37	0.09	1.96	7.73
Liq over quota						1.99	1.56	1.07	1.17	2.30
Quota usage						0.57	0.12	0.50	0.51	0.61

Note: The summary statistics are based on data for 30 banks over the sample period 17 April 2009–7 January 2016. They are presented by quota groups. All of the banks have been involved in at least one interbank loan over the sample period. ‘Liq 15:30’ denotes banks’ (overnight) liquidity position at Norges Bank at 15:30. ‘Liq <0’ is the average number of days the bank has had a negative liquidity position at Norges Bank at 15:30. ‘Liq over quota’ is the liquidity position at 15:30 divided by the sample average of quota (‘Liq over quota’). ‘Quota usage’ denotes values from the logistic function specified in Equation (4), where values above (below) 0.5 indicate liquidity positions above (below) quotas. Means before and after for the different variables are significantly different from each other at the one percent level of significance.

where ps is one from 3 October 2011 when quotas are introduced and zero before that. The values of ‘quota usage’ are bounded by zero and one, where zero indicates the possibility to deposit a large amount of liquidity at the central bank. A value of 0.5 implies that a bank’s liquidity equals its quota, whereas values above 0.5 indicate that the bank holds liquidity in excess of its quota and has a placement need; see Figure 5 in the appendix. Values of ‘quota usage’ are on average 0.44, 0.43 and 0.57 for banks in Groups 1, 2 and 3, respectively; see Table 5.

In sum, our analysis of banks’ daily liquidity positions at 15:30, before interbank activity usually takes place, suggest that they have declined substantially after the policy shift. Second, banks experience negative liquidity positions more often than before the policy shift. And third, many banks’ liquidity positions are usually just within or above their quotas. It follows that banks need to borrow and lend more often than before the policy shift to meet their liquidity needs or to avoid the remuneration of excess liquidity at the reserve rate. The next subsection investigates

possible contributions of these changes in banks' liquidity positions and those of banks' other characteristics to their interbank activity and pricing.

5.2.2 Estimation results on panel data

Table 6 presents models with estimated effects of various bank characteristics and market conditions on banks' interbank loans and interest rate spreads, i.e. interest rates expressed as deviations from the policy rate. There are separate models for borrowing, lending and corresponding spreads. The models specified as Equation (3) are estimated on a balanced panel data set consisting of information for banks that have borrowed or lent in the interbank market at least once during the sample period of 1691 business days; see Appendix for details. Given that our observations of banks' interbank loans and spreads are conditional on banks' participation in the interbank market, we use the Heckman approach to control for banks' decision to participate in the interbank market as borrowers or lenders; cf. Heckman (1976, 1979).

The dependent variables are volume and volume-weighted interest rate spreads for each bank's borrowing and lending. We are particularly interested in banks' response to their own and overall liquidity conditions before and after the policy shift. In the table, variable names with first letters in uppercase refer to common variables reflecting market conditions while the remaining variables refer to banks' individual characteristics.

The left part of Table 6 shows our main estimation results, which are adjusted for the banks' participation decision. The right section of the table presents results for the 'selection models', which characterise banks' participation in lending and borrowing as well as their setting of corresponding interest rates. Decisions to participate in borrowing and lending are not separate from decisions to set corresponding interest rates. Estimated coefficients in the selection models for loan volumes and interest rates are therefore close to each other for borrowers and lenders. Estimated 'rho'

Table 6: Banks' overnight interbank borrowing, lending and interest rates

	Borrower		Lender		Selection Models			
	volume	spread	volume	spread	Borrower volume	Borrower spread	Lender volume	Lender spread
const	1.795 [‡] (0.314)	-1.586 (2.480)	0.224 (0.370)	-1.482 (2.172)	-7.332 [‡] (0.209)	-7.55 [‡] (0.222)	-8.895 [‡] (0.200)	-8.934 [‡] (0.201)
$\hat{\delta}_y \times ps$	2.940 [‡] (0.079)	0.095 (0.773)	-1.192 [‡] (0.060)	-4.925 [‡] (0.352)	2.169 [‡] (0.057)	1.952 [‡] (0.061)	-0.976 [‡] (0.037)	-0.969 [‡] (0.037)
Δ Tot. liq	-0.428 [‡] (0.152)	-1.182 (0.803)	-0.558 [‡] (0.132)	-2.728 [‡] (0.828)	-0.141 (0.101)	-0.139 (0.099)	-0.462 [‡] (0.079)	-0.455 [‡] (0.078)
Δ Tot. liq $\times ps$	0.862 [‡] (0.183)	0.305 (0.927)	0.709 [‡] (0.161)	1.039 (0.965)	0.468 [‡] (0.130)	0.381 [‡] (0.125)	0.720 [‡] (0.107)	0.700 [‡] (0.106)
quota usage	-4.025 [‡] (0.166)	-14.752 [‡] (1.312)	3.396 [‡] (0.088)	-5.416 [‡] (0.479)	-3.198 [‡] (0.040)	-2.854 [‡] (0.039)	2.969 [‡] (0.037)	2.932 [‡] (0.036)
liq < 0	1.73 [‡] (0.052)	8.254 [‡] (0.627)	-0.97 [‡] (0.105)	-2.696 [‡] (1.048)	2.537 [‡] (0.083)	2.309 [‡] (0.077)	-0.489 [‡] (0.067)	-0.492 [‡] (0.067)
liq < 0 $\times ps$	-1.487 [‡] (0.068)	-6.201 [‡] (0.575)	1.011 [‡] (0.131)	3.917 [‡] (1.196)	-1.562 [‡] (0.113)	-1.552 [‡] (0.120)	0.130 [*] (0.065)	0.129 [*] (0.065)
corresp	0.537 [‡] (0.053)	-2.628 [‡] (0.239)	0.818 [‡] (0.058)	-1.537 [‡] (0.282)	-0.007 (0.493)	-0.012 (0.499)	0.766 [‡] (0.427)	0.732 [‡] (0.423)
foreign	18.195 [‡] (0.665)	17.166 [‡] (5.306)	10.643 [‡] (0.787)	41.928 [‡] (5.022)	17.111 [‡] (0.069)	17.094 [‡] (0.082)	3.277 [‡] (0.052)	3.498 [‡] (0.052)
tot. ass	0.380 [‡] (0.020)	0.622 [‡] (0.172)	0.489 [‡] (0.021)	0.802 [‡] (0.121)	0.688 [‡] (0.015)	0.713 [‡] (0.018)	0.608 [‡] (0.013)	0.613 [‡] (0.013)
tot. ass $\times$ for	-1.295 [‡] (0.047)	-1.408 [‡] (0.388)	-0.803 [‡] (0.053)	-3.048 [‡] (0.334)	-1.331 [‡] (0.035)	-1.336 [‡] (0.036)	-0.325 [‡] (0.030)	-0.341 [‡] (0.029)
roa	-0.001 (0.009)	-0.033 (0.057)	-0.007 (0.008)	0.020 (0.032)	0.013 (0.009)	0.016 [*] (0.009)	0.019 [†] (0.008)	0.019 [†] (0.008)
npl	-0.013 (0.008)	0.071 (0.046)	-0.181 [‡] (0.013)	0.495 [‡] (0.084)	0.029 [‡] (0.008)	0.027 [‡] (0.008)	-0.143 [‡] (0.007)	-0.14 [‡] (0.007)
equity_r	-0.116 [‡] (0.014)	-0.205 [‡] (0.062)	-0.216 [‡] (0.008)	-0.583 [‡] (0.042)	-0.087 [‡] (0.008)	-0.083 [‡] (0.008)	0.002 (0.005)	0.003 (0.005)
depos_r	-0.025 [‡] (0.002)	-0.002 (0.010)	-0.005 [‡] (0.001)	-0.068 [‡] (0.007)	-0.010 [‡] (0.001)	-0.008 [‡] (0.001)	0.009 [‡] (0.001)	0.009 [‡] (0.001)
loans_r	-0.006 [‡] (0.001)	-0.074 [‡] (0.006)	0.015 [‡] (0.002)	0.063 [‡] (0.009)	-0.015 [‡] (0.001)	-0.016 [‡] (0.001)	0.007 [‡] (0.001)	0.007 [‡] (0.001)
creditlim_r	0.018 [‡] (0.006)	-1.105 [‡] (.038)	.012 [†] (.005)	-.011 (.019)	0.032 [‡] (.004)	.030 [‡] (.004)	.050 [‡] (0.003)	.050 [‡] (0.003)
creditlim_r $\times$ for	0.745 [‡] (.067)	.026 [‡] (.488)	-.020 (.064)	.935 [†] (.402)	1.376 [‡] (0.058)	1.262 [‡] (.059)	.102 [†] (.050)	.120 [†] (.049)
Δ Payments	0.186 [‡] (0.038)	0.080 (0.199)	0.179 [‡] (0.037)	0.071 (0.198)	0.059 [†] (0.030)	0.051 [*] (0.029)	0.117 [‡] (0.025)	0.116 [‡] (0.025)
Tax date	0.01 (0.094)	1.01 [†] (0.474)	0.002 (0.076)	0.36 (0.391)	-0.083 (0.065)	-0.063 (0.064)	-0.01 (0.055)	-0.007 (0.055)
Δ ECB	0.034 (0.158)	-1.467 [*] (0.883)	-0.354 [†] (0.143)	-2.211 [†] (1.099)	0.069 (0.110)	0.113 (0.108)	-0.192 [†] (0.096)	-0.196 [†] (0.096)
End-month	-0.198 [‡] (0.063)	2.340 [‡] (0.515)	-0.283 [‡] (0.060)	2.635 [‡] (0.606)	-0.133 [‡] (0.044)	-0.011 (0.051)	-0.217 [‡] (0.040)	-0.214 [‡] (0.040)
Cens obs.					28 538	28 538	31 702	31 702
Uncens obs.					10 039	10 039	10 951	10 951
prob > chi2					0.000	0.000	0.000	0.001
rho					.515 [‡] (.015)	.699 [‡] (.051)	.369 [‡] (.018)	.042 [‡] (.013)
sigma					1.230 (.012)	6.514 (.251)	1.200 (.011)	6.439 (.153)
lambda					.633 (.022)	4.555 (.485)	.443 (.023)	.273 (.081)

Note: Panel data regressions for 25 borrowers and 27 lenders over the full sample period; see Appendix. Standard errors clustered by date and bank are in parentheses. [‡]: $p < 0.01$; [†]: $p < 0.05$; ^{*}: $p < 0.10$.

parameters are statistically significant for each of the selection models supporting the adjustment for possible participation bias; see Heckman (1979).

For brevity, we only present results for equations where we allow for a shift in intercepts and coefficients associated with relative changes in total liquidity ($\Delta \text{Tot. liq}$) and banks' individual liquidity positions represented by the variables 'quota usage' and possibly negative liquidity position late afternoon ($\text{liq} < 0$). Possible effects of other bank characteristics described in Table 4 and market conditions are assumed to be invariant to the policy shift. This is supported by preliminary analysis and the evidence regarding market conditions presented in Subsection 5.1.

There are two key findings regarding banks' response to the policy shift. First, increases in total liquidity are associated with higher interbank participation and trading after the policy shift. The table shows that an increase in total liquidity contributes to increasing banks' borrowing as well as lending after the policy shift. This contrasts with the period before the policy shift when an increase in total liquidity contributed to lowering interbank borrowing and lending. The response of interest rates, which tend to decline when there is an increase in total liquidity, remains almost the same after the policy shift; changes in the estimates of the associated coefficients are not statistically significant.

The second key finding is that the introduction of quotas reduces the extent of 'liquidity hoarding'. The results suggest that 'quota usage' contributes to reducing banks' borrowing and increasing their lending. Banks may borrow (accept liquidity) and/or lend at lower rates when their quota usage rises, *ceteris paribus*. Moreover, banks tend to borrow smaller amounts than before the policy shift when their liquidity deposits become negative. They also do not reduce their lending when their deposits become negative, which was the case before the policy shift. They may, however, lend at a somewhat higher rate than before the policy shift, but pay significantly lower borrowing rates than before the policy shift. The corresponding

coefficient estimates change from -2.70 to 1.22 ($= -2.70 + 3.92$) in the case of lending rates and from 8.25 to 2.05 ($= 8.25 - 6.20$) in the case of borrowing rates.

The above findings suggest that banks in need of liquidity may be able to meet their borrowing needs more easily and at less expensive rates than before the policy shift. Banks have also expressed that they are able to borrow from each other without bidding up interest rates as much as before the policy shift; see Norges Bank (2014). This is consistent with the reduction in the variability of interest rates across loans and at the aggregated level noted in Subsection 4.2.

The estimated effects of other bank characteristics and market conditions on both banks' borrowing and lending are qualitatively similar and they have been found to be largely the same before and after the policy shift. In summary, large banks in terms of assets, especially five banks that often act as correspondent banks for non-resident banks, borrow and lend more than other banks. Their lending and borrowing rates are also relatively lower. While an increase in total assets is associated with higher interbank participation as a lender and borrower, correspondent banking itself makes a bank's participation as a lender more likely, but not as a borrower. Higher assets of domestic banks go together with higher lending rates as well as higher borrowing rates, *ceteris paribus*.

The dummy variable 'foreign', which indicates that a bank is a foreign branch or subsidiary, could suggest that foreign banks borrow and lend relatively larger volumes than comparable domestic banks. Foreign banks are, however, substantially larger than domestic banks, and their size is not reflected in their interbank lending and borrowing. There is a negative relationship between their total assets and interbank activity. Despite the positive coefficient estimate associated with 'foreign' dummy variable, foreign banks are associated with low interbank activity when their total assets are taken into account. Among the foreign banks, however, small foreign banks could be more active than larger ones. Foreign banks are associated

with higher borrowing and lending interest rates while an increase in their assets go together with lower lending and borrowing rates. Return on assets does not have significant effects on interbank loans and interest rates, for foreign or domestic banks.

An increase in the share of non-performing loans may contribute to reducing a bank's lending and increasing its lending rates. Banks with high shares of non-performing loans may become more reluctant to part with their liquidity to avoid facing possibly adverse borrowing conditions in the unsecured interbank market. An increase in the share of non-performing loans contribute to a statistically significant reduction in a bank's participation as a lender. Such an increase seems to reduce banks' borrowing volumes and increase their borrowing rates, but the coefficient estimates are not statistically significant. A higher share of non-performing loans increases banks' participation in the interbank market as borrowers though.

Higher shares of equity, deposits and loans relative to total assets go together with lower interbank activity. Banks with such characteristics are mostly small- and medium-sized banks. High credit limits, reflecting high shares of assets pledged as collateral at the central bank, however, are associated with a higher interbank activity for both domestic banks and foreign branches and subsidiaries. A higher share of pledged assets may itself reduce borrowing rates, but do not have significant effects on lending rates. The results suggest an advantage to particularly solvent borrowers in the unsecured overnight market.

The effects of overall market conditions are comparable to those observed in the aggregate models in Subsection 5.1. An increase in overall payments (interbank transactions excluding interbank loans) go together with higher interbank borrowing and lending. Borrowing and lending rates increase, but not significantly. Petroleum tax due dates and dates for the ECB's policy meetings are not associated with a statistically significant increase in interbank borrowing and lending. Both borrowing and lending rates have, however, declined on the ECB's policy change dates. This

may reflect that the ECB has mostly reduced interest rates on these dates over the sample period. Finally, the results suggest that interbank activity tends to fall while both borrowing and lending rates rise at the end of months.

6 Conclusion

We have investigated the effects of the shift in Norges Bank's liquidity policy on activity and interest rates in the Norwegian unsecured overnight interbank market. The liquidity policy shift has been characterised as a shift from a 'floor' to a 'corridor' system and was primarily aimed at increasing interbank market activity. The former system was assumed to discourage interbank activity due to the availability of ample liquidity and the remuneration of banks' whole individual liquidity positions at the policy rate. The policy shift has implied a sizable reduction in total liquidity and the remuneration of banks' individual liquidity holdings beyond allotted quotas at a lower rate than the policy rate.

We find that the policy shift has been followed by a significant increase in overnight interbank activity as measured by the daily number of market participants and the number of overnight loans and their volume. We also find evidence of a relatively smaller dispersion in interest rates across individual loans, and narrower and mostly negative interbank interest rate spreads relative to the policy rate following the policy shift.

Banks have been found to play a more active role in the distribution of total liquidity in the system as borrowers and lenders. This contrasts with earlier when an increase in total liquidity contributed to reducing interbank activity. The evidence suggests that banks tend to avoid 'liquidity hoarding' after the policy shift. An increase in banks' own liquidity relative to their quotas contributes to higher lending, but lower borrowing. Both lending and borrowing interest rates decline with an increase in quota usage; banks may want to reduce the likelihood of liquidity above their quotas

as it is remunerated at a lower rate than the policy rate. Banks are also found to borrow less than earlier and at lower interest rates when they experience liquidity shortfalls. Banks therefore seem able to meet their liquidity needs more easily and at lower interest rates than before the policy shift.

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A Data sources, sample and variable definitions

A.1 Data sources and sample

While the data for the left-hand side variables in the models are at daily frequency, the time series of variables related to banks' characteristics on the right-hand sides are a mix of daily, monthly and quarterly data. The details are as follows.

Overnight interbank activity and interest rates: Our main data source is Norges Bank. Overnight interbank activity measures and interest rates are based on data for all transactions recorded in the bank's RTGS system over the period 17 April 2009–7 January 2016; see Section 3 for details.

Banks' characteristics and liquidity positions: We also had access to data on banks' credit limits at Norges Bank and their liquidity positions late afternoon (15:30), shortly after the results of liquidity auctions are announced and liquidity operations implemented. Banks' liquidity positions together with publicly available information about banks' quotas have been used to define 'quota usage' as a function of each bank's liquidity position relative to its quota, displayed in Figure 5; see also Subsection 5.2.1.

Moreover, we have been able to use banks' monthly balance sheet data as reported to the supervisory authorities and Norges Bank. These monthly data series include several balance sheet figures and the bottom line earnings figures, which are used in the calculation of banks' return on assets (roa).

However, we have had to supplement the monthly balance sheet data with quarterly balance sheet data from Norges Bank, Bloomberg and from small banks' quarterly or biannual reports. For some non-listed small banks, however, quarterly or biannual reports were not available. There is one such bank in Group 2 and one in Group 3 in our data set. Due to missing information about their characteristics, they have

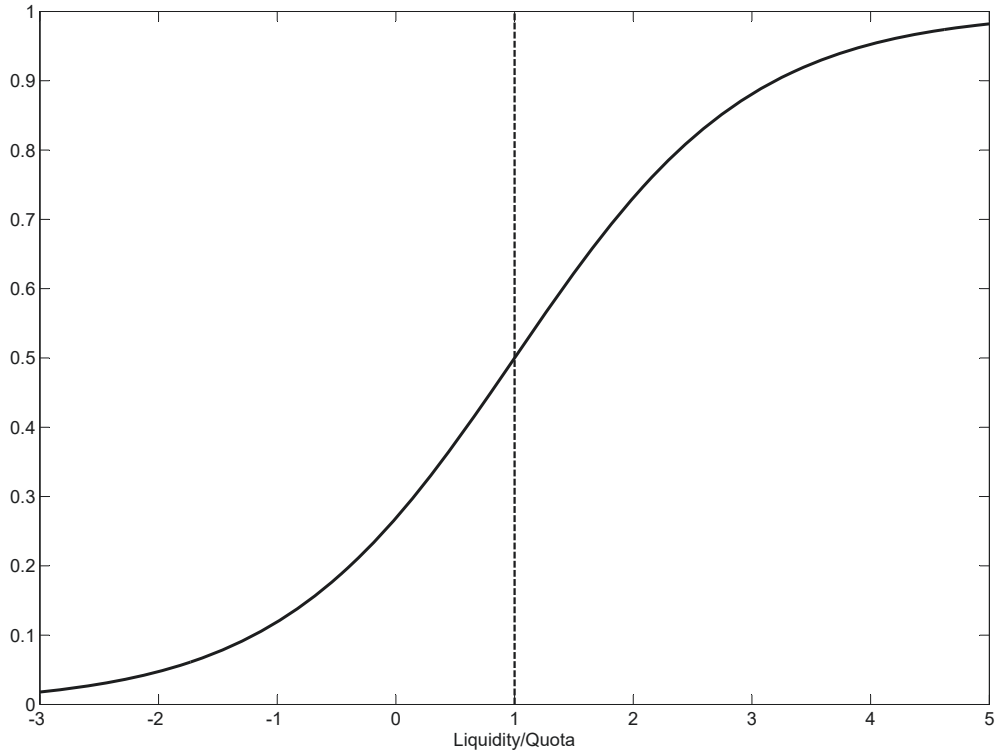


Figure 5: Values of ‘quota usage’ defined by function $\frac{1}{1+\exp(-1(\frac{Liquidity}{Quota}-1))}$ for different levels of $\frac{Liquidity}{Quota}$. The dashed vertical lines indicates when a bank’s overnight liquidity equals its quota.

been left out from the panel data analysis in Subsection 5.2.

For foreign banks, we use data from Bloomberg and their own quarterly reports. One of the foreign banks has been left out from the analysis of banks’ borrowing and associated interest rates due to its particularly high borrowing interest rates, which skewed the results.

Data sample: There are 30 unique banks and 1691 days with interbank trading in our data sample. Table 1 presents an overview of borrowers and lenders, reporting up to 26 borrowers and 28 lenders over the sample period. After merging the identified interbank transactions with balance sheet data and liquidity positions for each bank we were left with complete data sets for 25 borrowers and 27 lenders.

The panel data analysis is based on data for banks that have participated in the interbank market at least once over the whole sample period of about seven years. Arguably, one should consider the whole sample of all banks that had the possibility to be active in the interbank market, regardless of whether they have participated or not. The main reason for limiting the analysis to more or less active participants is the lack of readily available complete balance sheet data for the other banks. The latter banks are relatively small banks who conduct their interbank transactions including interbank loans through commercial settlement banks.

A.2 Variable definitions

Variable names with first letters in uppercase refer to market-wide common variables. The other variable names refer to bank-specific characteristics.

- ☐ quota usage: A logistic function of a bank's liquidity position at 15:30 relative to its quota; see Appendix A.1 for details.
- ☐ $liq < 0$: A 0–1 variable, which equals 1 if a bank's liquidity position at Norges Bank is negative at 15:30.
- ☐ $\Delta Tot. liq$: Banks' total liquidity (reserves) at Norges Bank at 15:30.
- ☐ corresp: A 0–1 variable, which equals 1 if the bank is active in borrowing or lending on behalf of non-resident foreign banks. We assign this variable to the top five banks that account for more than 90 % of such volume over the sample period. This information is based on an application of a version of the Furfine algorithm that incorporates 360-day convention for interest rate quotes in line with the market convention for such loans.
- ☐ foreign: A 0–1 variable, which equals 1 if the (resident) bank is not Norwegian.
- ☐ tot. ass: A bank's total assets in NOK billions, in logs.
- ☐ tot. ass $\times$ for: A foreign bank's total assets in NOK billions, in logs.
- ☐ roa: Return on assets, in percent.

- ☐ `npl`: Ratio of non-performing loans in percent, as reported in quarterly balance sheet data of banks.
- ☐ `equity_r`: Equity ratio, in percent.
- ☐ `depos_r`: Deposits-to-assets ratio, in percent.
- ☐ `loans_r`: Loans to assets are a bank's loans to households and non-financial firms relative to its total assets, in percent.
- ☐ `creditlim_r`: A bank's daily credit limit at Norges Bank as a share of its total assets, in percent.
- ☐ `creditlim_r×for`: A foreign bank's daily credit limit at Norges Bank as a share of its total assets, in percent.
- ☐ `ΔPayments`: Daily relative changes in payments, which refer to the log of all daily transactions between banks with access to Norges Bank, net of interbank loans. The variable is in first difference as the log of payments has a unit root.
- ☐ `Tax dates`: A 0–1 variable, which equals 1 on due days for petroleum tax.
- ☐ `ΔECB`: A 0–1 variable, which equals 1 if the ECB has made a change to its policy rates.
- ☐ `End-month`: A 0–1 variable, which equals 1 at the last business day of a month.

The central bank as the central counterparty

Q. Farooq Akram, Jon H. Findreng and Lyndsie Smith*

Abstract

In response to the Covid-19 pandemic, Norges Bank simultaneously offered long-term loan auctions and daily short-term deposit auctions enabling banks to costlessly hoard large quantities of reserves and deposit them safely overnight. We analyse how the unsecured overnight interbank market for trading reserves and the distribution of reserves across banks were affected by this market intervention. We document an adverse effect on traded volumes in the unsecured overnight interbank market as the central bank became the main intermediary. While increased uncertainty in financial markets increase banks' holdings of excess reserves, the market interventions ensured that reserves were distributed more evenly across banks.

Keywords: *Distribution of Central Bank Reserves, Market Interventions, Interbank Market, the Covid-19 Pandemic*

JEL Codes: G21, E42, E47, E58

*This paper should not be reported as representing the views of Norges Bank. The views expressed are those of the authors and do not necessarily reflect those of Norges Bank. We have received useful comments from Prof. Dr. Martin Brown, Prof. Dr. Angelo Ranaldo, Prof. Dr. Matthias Weber, Per Marius Pettersen and participants at the University of St. Gallen brown bag seminar.

1 Introduction

Central banks are typically thought to play an important role as lender of last resort in time of aggregate liquidity shocks or lack of trust between banks (see for example Freixas et al. (2000)). But what are the consequences if the central bank rather becomes the intermediary in the money market? This happened in the Norwegian interbank market when the central bank responded to the Covid-19 pandemic by offering overlapping long-term loan auctions and short-term deposit auctions.

A well functioning interbank market allows for distribution of central bank reserves between banks securing efficient intermediation to households and corporations and implementation of monetary policy (see for example Allen et al. (2009); Acharya et al. (2012)). The interbank market may also ensure peer monitoring between banks (see for example Rochet and Tirole (1996); Freixas and Holthausen (2005)).

The liquidity policy of Norges Bank has three main objectives centring around a well functioning interbank market (see Norges Bank (2014b, 2020)). First, banks must have adequate liquidity to meet their short-term needs stemming from day-to-day activities. Second, the policy rate should prevail in the money market. And third, banks should predominantly meet their liquidity needs by trading with each other rather than with Norges Bank.

If the central bank becomes the central counterparty for trading central bank reserves, it may ensure that banks have adequate liquidity to meet their short-term needs stemming from day-to-day activities and possibly ensure that the key policy rate prevails in the money market during times of financial uncertainty. However, a direct consequence may be that the interbank market becomes inactive and fails to convey important information about money market conditions to the general audience. Another consequence may be that incentives for performing peer monitoring in the interbank market are weakened if banks expect the central bank to intervene

whenever financial uncertainty increases (see for example Rochet and Tirole (1996)).

Covid-19 was declared a pandemic on 11th March 2020. The VIX-index, an indicator for implied volatility on derivatives linked to the S&P 500, rose drastically and peaking above 80 on 19th March, levels not seen since 2008.¹ Norwegian markets were hit hard as a parallel supply shock led to plummeting oil prices through February and March. The main reference index on the Oslo Stock Exchange fell more than 30% from 20th February to 23rd March. Over the same period, the USD appreciated about 25% towards the Norwegian krone.²

In the Norwegian interbank market, banks increased their holdings of excess reserves, which are reserves deposited with the central bank at the reserve rate 100 basis points below the key policy rate, indicating that banks were willing to be remunerated less in exchange for holding more liquidity. Banks can deposit reserves at the key policy rate up to individual quotas, designed such that no bank should need to hold excess reserves if they rather trade central bank reserves with each other. Higher holdings of excess reserves is indicating higher unevenness in the distribution of liquidity between banks.³

Norges Bank responded to Covid-19 by providing "two-sided" market operations. Prior to the pandemic, Norges bank used what is referred to as F-auctions to steer the levels of liquidity. When liquidity is scarce, a F-loan auction is offered, and when there is surplus liquidity, a F-deposit auction is offered. In the pandemic, Norges Bank changed its role from controlling total liquidity levels to also become a dominant intermediary in the interbank market by offering long-term loan auctions and daily repetitive short-term deposit auctions. Following the introduction of market interventions, excess reserves were reduced, but at the same time trading activity in

¹The average in February 2020 was 18.6.

²See Alstadheim et al. (2021) for an overview over causes and consequences of the turbulence in Norwegian markets in March 2020.

³While these reserves are not necessarily excess from the banks', nor the central bank's perspective, they are, in this paper, called excess reserves as they represent the total amount of reserves held across individual banks in excess of the banks' quota limits.

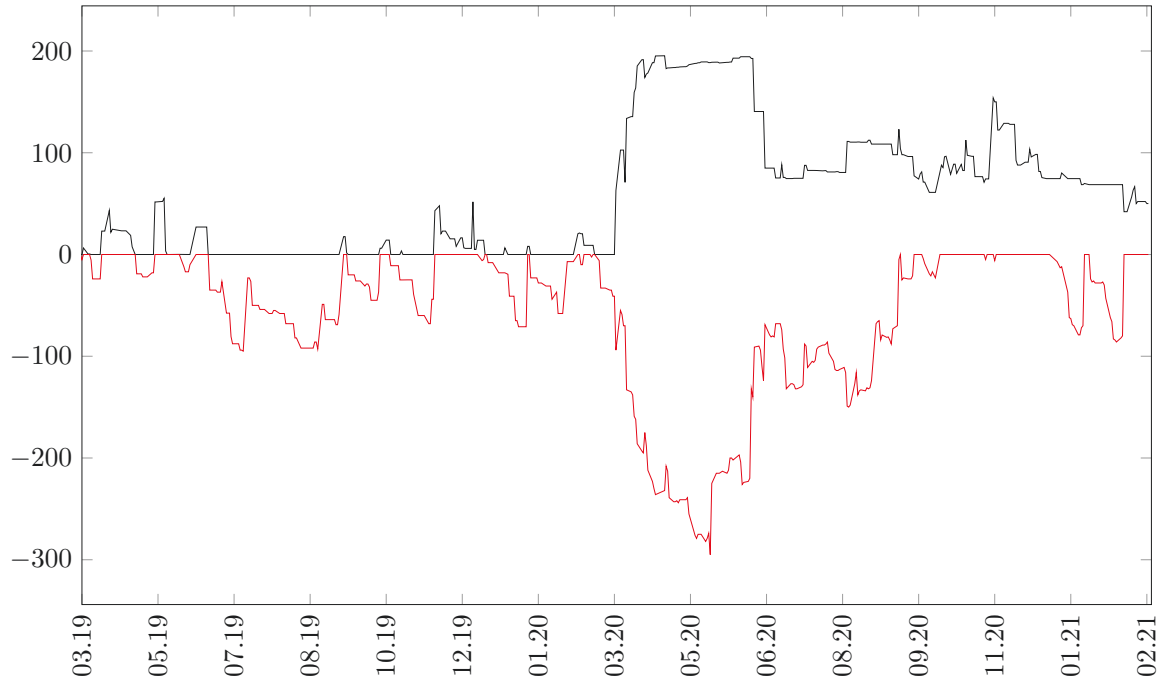


Figure 1: The positive black graph shows the outstanding stock of F-loans and the negative red graph shows the outstanding stock of F-deposits in NOK billions. All business days from 28th March 2019 to 26th February 2021. 13th March 2020 is the first day with large offsetting auctions of NOK 63 bn. From here, there are offsetting outstanding auctions every day until 15th September 2020 and periodically afterwards.

the interbank market declined. No volume was reported in the unsecured overnight interbank market for 23 consecutive business days starting on 8th May 2020. Figure 1 graphs the outstanding stock of F-loans and F-deposits over the period 28th March 2019 to 26th February 2021. While there has normally been no offsetting auctions, there were NOK 195 bn in offsetting auctions at the end of March 2020, or about 5.5 times the operational target for liquidity.

We analyse how Norges Bank's two-sided market interventions affected trading in the interbank market using daily data from the unsecured overnight interbank market over the period 28th March 2019 to 26th February 2021. Our findings suggest that when Norges Bank introduced market interventions, trading activity in the interbank market declined. We also find that after the implementation of market interventions, trading activity increased with increased financial uncertainty measured by the VIX-index. Trading activity did not respond to financial uncertainty in the period before market interventions. We also analyse how the distribution of liq-

uidity between banks was affected by market interventions. As the total amount of central bank reserves in the Norwegian system is fixed around an operational target, an increase in banks' holding of excess reserves directly implies more unevenly distributed central bank reserves. We find that, while increased uncertainty in financial markets increased the unevenness in the banks' holdings of central bank reserves, the market interventions reduced the banks' holding of excess reserves. That is, when Norges Bank introduced overlapping long-term loan auctions and short-term deposit auctions, it took the role as the intermediary at the expenses of the interbank market. However, central bank reserves became more evenly distributed across banks.

As an extension, we analyse whether pricing in the unsecured overnight interbank market is affected by uncertainty in financial markets and market interventions. The reduction in interbank trading following market intervention could be a result of true prices for borrowing reserves were exceeding the price of Norges Bank's standing facility for overnight loans. We do not find evidence that uncertainty or increased market interventions affect pricing in the unsecured overnight interbank market.

While offering perhaps the first empirical analysis of the Norwegian unsecured overnight interbank market during the Covid-19 pandemic, this paper also contributes to the literature on banks' behavior in interbank markets during high uncertainty and market stress, and on the possible relationships between central banks' liquidity policies and interbank trading and the distribution of central bank reserves across banks. Inter alios, Afonso et al. (2011) and Acharya and Merrouche (2013) investigate possible liquidity hoarding in the US federal funds market and the UK interbank market, respectively, during periods of market stress. While the latter study documents extensive liquidity hoarding by market participants as a precautionary measure in response to anticipated liquidity stress, the former study points to credit rationing as the main cause of an increase in banks' liquidity reserves; cf. Ashcraft et al. (2011). A paper closer to ours is Fuhrer (2018), which studies the Swiss

overnight repomarket over a sample period that includes the period with stress in financial markets following the Lehman Brothers default in mid-September 2008 and the period around mid-January 2015 when the Swiss National Bank (SNB) abandoned the exchange rate peg to the euro following a strong appreciation pressure on the Swiss Franc. The SNB’s liquidity management system had several resemblances to Norges Bank’s liquidity management system during the latter period. Consistent with our findings, Fuhrer (2018) finds that an increase in general market uncertainty tends to accompany an increase in interbank turnover while a provision of generous liquidity support may go together with a decline in interbank turnover. Brunetti et al. (2011) studying the euro interbank market reaches similar conclusions for the case with long-term refinancing operations while the converse may be the case for short-term refinancing operations, which are the ECB’s main refinancing operations.

2 Liquidity in the Norwegian banking system

Norges Bank’s system for managing central bank reserves aims at keeping total liquidity, or the quantity of available central bank reserves, fixed within the banking system.⁴ The operating target is to keep total reserves at NOK 35 +/- 5 bn. Norges Bank make liquidity projections and use market operations to adjust the level of total liquidity.⁵ The primary instrument to adjust liquidity in the banking system

⁴<https://www.norges-bank.no/en/topics/liquidity-and-markets/The-liquidity-management-system/>

⁵The primary source for fluctuating total liquidity in the banking system comes from transactions between the public and the Norwegian government. The Norwegian government has its account with Norges Bank and each transaction where the government is a counterparty affects total liquidity in the interbank market. Such transactions may for example relate to tax collection, transfers of public welfare benefits, issuance of government debt and the government purchasing FX for transferring to the Government Pension Fund of Norway. At year end 2020, the fund had asset under management worth NOK 10 914 bn in foreign currency. In comparison, the Norwegian GDP was NOK 3 557 bn in the same year. Special petroleum taxes and dividends from direct government ownership in exploration and production companies are paid to the government in NOK. These funds are later used to purchase FX and eventually transferred to the fund. On the other hand, the government can use up to 3% of the value of the fund each year to cover expenses on the government budget. If this value exceeds petroleum taxes and dividends, the government will sell FX and buy NOK. This has been the case over the entire period 1st January 2017 - 26th February 2021. See <https://www.norges-bank.no/en/topics/liquidity-and-markets/Foreign-exchange-purchases-for-GPFG/> for more details. Another source of variation in total liquidity is outstanding notes and coins. However, this source of variation is close to negligible. Cash usage is limited in the Norwegian economy, and the average daily change in outstanding notes and coins over the period 1st January 2017 - 26th February 2021 is about NOK 10 million.

is F-auctions, which are auctions that can take the form of both loan and deposit auctions. These auctions are used when projections indicate that central bank reserves will deviate from its target. If Norges Bank wishes to increase the quantity of reserves in the banking system, a F-loan is issued. If Norges Bank rather wishes to reduce the quantity of reserves, a F-deposit is issued. The maturity for F-auctions is set by Norges Bank and the interest rate is determined by an American auction (multi price auctions). For F-loans, the interest rate must be minimum the key policy rate, while for F-deposits, the interest rate cannot exceed the key policy rate. F-loans and F-deposits can have both floating and fixed interest rates.⁶ During the time period from 28th March 2019 to 26th February 2021, used in this analysis, the interest rate on F-deposits, which seldom have maturities longer than one to four days (see Figure 4d), was on average 0.82 basis points below the Key Policy and 42 basis points lower than the NOWA rate⁷. For F-loans the average price was 1.45 basis points above the key policy rate for maturities from 1 day to 1 month and 12.92 basis points above for maturities from 3 months to 12 months. Auctions are normally held less than two hours before the banking closes at 16:35, and banks can redistribute liquidity through trading of reserves after the outcome of the auctions are known (usually at 15:15).^{8,9} All banks with an account at Norges Bank can participate in the auctions.¹⁰

Every time there is a payment from a client of one bank to a client with another bank, reserves are credited and debited on the banks respective accounts with Norges Bank. When the banking system closes, deposits placed with Norges Bank are re-

Looking at 2020 in isolation, the average was about NOK 2 million (See <https://www.norges-bank.no/en/topics/Statistics/Bank-liquidity/>.)

⁶See <https://www.norges-bank.no/en/topics/liquidity-and-markets/Market-operations/>

⁷Excluding quarter ends where the NOWA rate averages 56 points above the key policy rate

⁸See Akram and Findreng (2021).

⁹In special cases, Norges Bank may offer fine tuning operations. These auctions function like normal auctions, but are held right before close and after the banks have traded reserves with each other. While auction data is publicly available, we cannot extract whether the auction is a fine tuning operation. However, over the period from the implementation of the new system in October 2011 to June 2014, there was only one fine tuning (F-deposit) auction after a large public entity made NOK 12 bn in payments one day earlier than what had been communicated to Norges Bank (see Norges Bank (2014a)).

¹⁰See <https://www.norges-bank.no/en/topics/liquidity-and-markets/Market-operations/>

munerated at either the key policy rate or at the reserve rate 100 basis points below. Banks have been allotted individual quotas for how much they can deposit at the key policy rate. The banks are primarily divided into three different groups, where the members of each group have equal quotas. There are, however, a few exceptions for banks deemed settlement banks which have additional capacity on their quotas. The six largest banks have about eight times larger quotas than the 15 mid-sized banks and the mid-sized banks have about eight times larger quotas than the smaller banks.¹¹ The quotas sum up to NOK 45 bn, well above the operational target for total reserves at NOK 35 +/- 5 bn, meaning that no bank should need to deposit reserves at the reserve rate if they rather borrow and lend reserves between each other.¹² When a bank has a shortage of reserves it can adjust by borrowing in the interbank market, do an FX swap, do a repurchase agreement (repo) or by selling financial assets.¹³ Similarly, if a bank has excess reserves, it can make the opposite actions to avoid the alternative reserve rate.

The system described was implemented by Norges Bank in 2011 to increase activity in the interbank market. Prior to the policy shift, Norges Bank had a classical floor system, where all deposits were remunerated at key policy rate.^{14,15} Norges Bank could alternatively have implemented a pure corridor system, where total central bank reserves is zero, to further incentivize interbank trading. However, as the government holds its account with Norges Bank, liquidity management of total central

¹¹The number of small banks was 101 in October 2020. See <https://www.norges-bank.no/en/news-events/news-publications/Circulars/2020/4quotas-in-the-system-for-the-management-of-bank-reserves/>.

¹²At this point, we would like to point out the difference between total liquidity at close and total intraday liquidity. Throughout the opening hours of the banking system, the banks have unlimited access borrowing reserves from Norges Bank against collateral. Furthermore, total liquidity may very well be affected by large transactions with the government early in the day and not adjusted by F-auctions before later in the day. The intraday liquidity is therefore a result of total liquidity in the banking system at any given time together with the banks' access to eligible collateral. The liquidity referred to throughout this paper, is the sum of all deposits (at the key policy rate and at the reserve rate) at close.

¹³Selling financial assets has a positive impact on the bank's liquidity as long as the buyer does not hold her account with the same bank. However, most financial assets have settlement dates one to three days after the trade. See Nyborg and Östberg (2014) who empirically find a link between the interbank market and the stock market.

¹⁴See Akram and Findreng (2021) who analyse the policy shift and find that activity increased significantly and interest rates fell and became more stable.

¹⁵There are no reserve requirements.

bank reserves is subject to forecasting errors. The chosen system is a compromise between increasing incentive for interbank trading and leaving some room for imprecise liquidity projections.¹⁶

Figure 2a displays total liquidity in the banking system over the period 28th March 2019 to 26th February 2021. It is evident that Norges Bank has kept liquidity stable within the operational target with mean of NOK 34.7 bn and standard deviation of NOK 2.5 bn. This indicates that liquidity projections have been sufficiently accurate, enabling Norges Bank to offer suitable quantities of liquidity injections and withdrawals through F-auctions. Total liquidity has been less than NOK 30 bn on 23 occasions with NOK 19 bn as the lowest on 11th December 2019. On 20 of these 23 occasions, Norges Bank has offered F-loans. In 19 of these auctions, the banks were allotted 100% of their bids. The reason banks did not bid more, despite total liquidity being low, is likely because the liquidity was evenly distributed. Thus, the banks had no reason to bid for reserves just to deposit them overnight at the key policy rate (Norges Bank (2014a)).¹⁷ Total liquidity has also been above the operational target on six occasions. On one occasion, it was slightly above NOK 45 bn, indicating that the banks in sum were not able to place all deposits at the key policy rate. Among these six occasions, Norges Bank offered F-deposits in five of them with full allotment. Figure 1 in Section 1 graphs outstanding F-loans and F-deposits, showing how much liquidity Norges Bank has injected into or withdrawn from the banking system over the period.

Figure 2b displays the total daily stock of excess reserves deposited by the banks at the reserve rate. As indicated by figure 2a, the banks should not need to hold excess reserves, but the banks did deposit NOK 806 million¹⁸ at the reserve rate on average over the period 28th March 2019 to 26th February 2021. This corresponds

¹⁶See <https://www.norges-bank.no/en/topics/liquidity-and-markets/The-liquidity-management-system/The-management-of-bank-reserves-The-system-in-Norway/Background-system-managing-bank-reserves/>

¹⁷Another possible explanation is that the banks did not have sufficient collateral to bid for F-loans.

¹⁸About EUR 80 million.

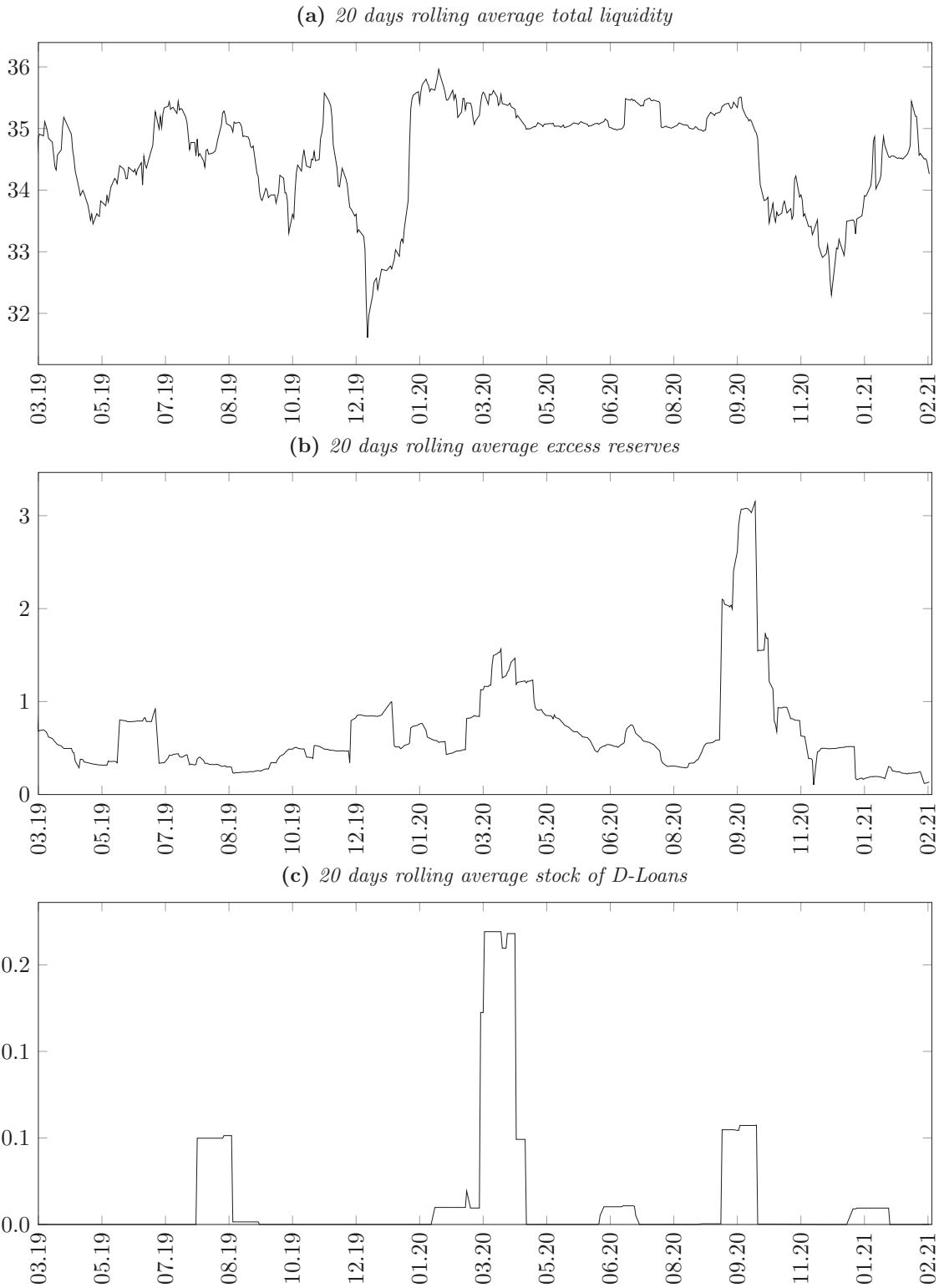


Figure 2: 20 days rolling average of the stock of a) total liquidity, which is the sum of all deposits placed with Norges Bank overnight, b) deposits at Reserve Rate, which is the sum of all reserves deposited with the central bank at the reserve rate 100 basis points below the key policy rate and c) D-Loans, which are the total of reserves banks borrowed overnight from Norges Bank at 100 basis points above the key policy rate. All numbers in NOK bn. Daily observations over all business days from March 28st 2019 to February 26th 2021 corresponding to 350 business days before and after Norges Bank introduced offsetting auctions. All observations on quarter ends are ignored.

to about 2.3% of Norges Bank's operational target for liquidity. Banks hold low levels of excess reserves, but pay a high price on some days when reserves are unevenly distributed. We can see that the 20 days rolling average increased in March 2020 before declining in April through August before peaking to its highest level in September. Comparing this with Figure 1, we can see that Norges Bank offered large volumes in offsetting auctions in the period from mid March to mid September. The average amount of deposits banks placed at the reserve rate in the second half of September, on those days when there were no offsetting auctions, was about NOK 9.5bn.

On the other side of the coin, uneven distribution of reserves also means that some banks end up with low levels of deposits. A D-loan occurs if a bank is not able to cover its negative position with Norges Bank before the banking system closes. The negative position is transferred into a D-loan, which is an overnight loan from the central bank priced 100 basis points above the key policy rate. The loan is against the same collateral the bank posted to make use of Norges Bank's intraday overdraft facility. Using D-loans may be associated with a stigma cost. Armantier et al. (2015) analyse the magnitude of the stigma effect during the subprime crisis and find that banks were willing to pay a premium of roughly 44 basis points compared to using the federal reserve discount window. The stigma increased with higher uncertainty, and the premium after the default of Lehman Brothers increased to 126 basis points. Figure 2c graphs the daily stock of D-loans over the period 28th March 2019. One or more banks used the D-loan facility on 15 occasions. The average amount borrowed across banks on those days were NOK 444 million and the maximum was NOK 2 259 million at 10th March 2020. We can see that there are no occurrences of D-loans during most of the time period. However, there is a distinct spike in March 2020.

2.1 The Norwegian interbank market

The largest share of overnight trading is in the unsecured market for central bank reserves. However, FX-swaps is the largest market across all maturities and is primarily traded in maturities from tomorrow/next to three months.¹⁹ A small share of the market is in repos, and for this type of trade, mostly with maturity of one month (Norges Bank (2019)). In general, information from these markets is limited, but the NOWA panel, a group of the most active banks in the unsecured overnight interbank market, report daily volumes and interest rates for overnight trading. The reports are aggregated and made available to the general public.

Analysing activity in the unsecured overnight interbank market is by no means a comprehensive approach for investigating how the banks responded to Covid-19 and Norges Bank's market interventions, as it is unlikely that the share of liquidity trades that happens unsecured and overnight is stable. Piquard and Salakhova (2019) analyse the choice between the unsecured and the repo market in the euro interbank market. They create a model where the friction in the unsecured market is counterparty risk and the friction in the repo market is the opportunity cost to pledge collateral. They find empirically that banks may be active in both markets even when their collateral constraint is not binding. Di Filippo et al. (2021) also analyse the two markets in the euro interbank market jointly. They find that borrowers with low credit quality reduce unsecured borrowings, but increase secured borrowings. The total supply from the lending bank is not changed, only switched to more reliance on the secured market.

Figure 3a shows the 20 days rolling average of daily volumes in the unsecured overnight interbank market reported by the NOWA panel banks.²⁰ The daily volume was relatively stable before and into the first period of the Covid-19 pandemic

¹⁹See Molland (2014) for more details on how Norwegian banks use FX-swaps as a funding source.

²⁰The NOWA panel is a group of the most active banks in the Norwegian Unsecured Overnight Interbank Market. See Finance Norway's webpage for more information: <https://www.finansnorge.no/en/interest-rates/nowa—the-norwegian-overnight-weighted-average/>

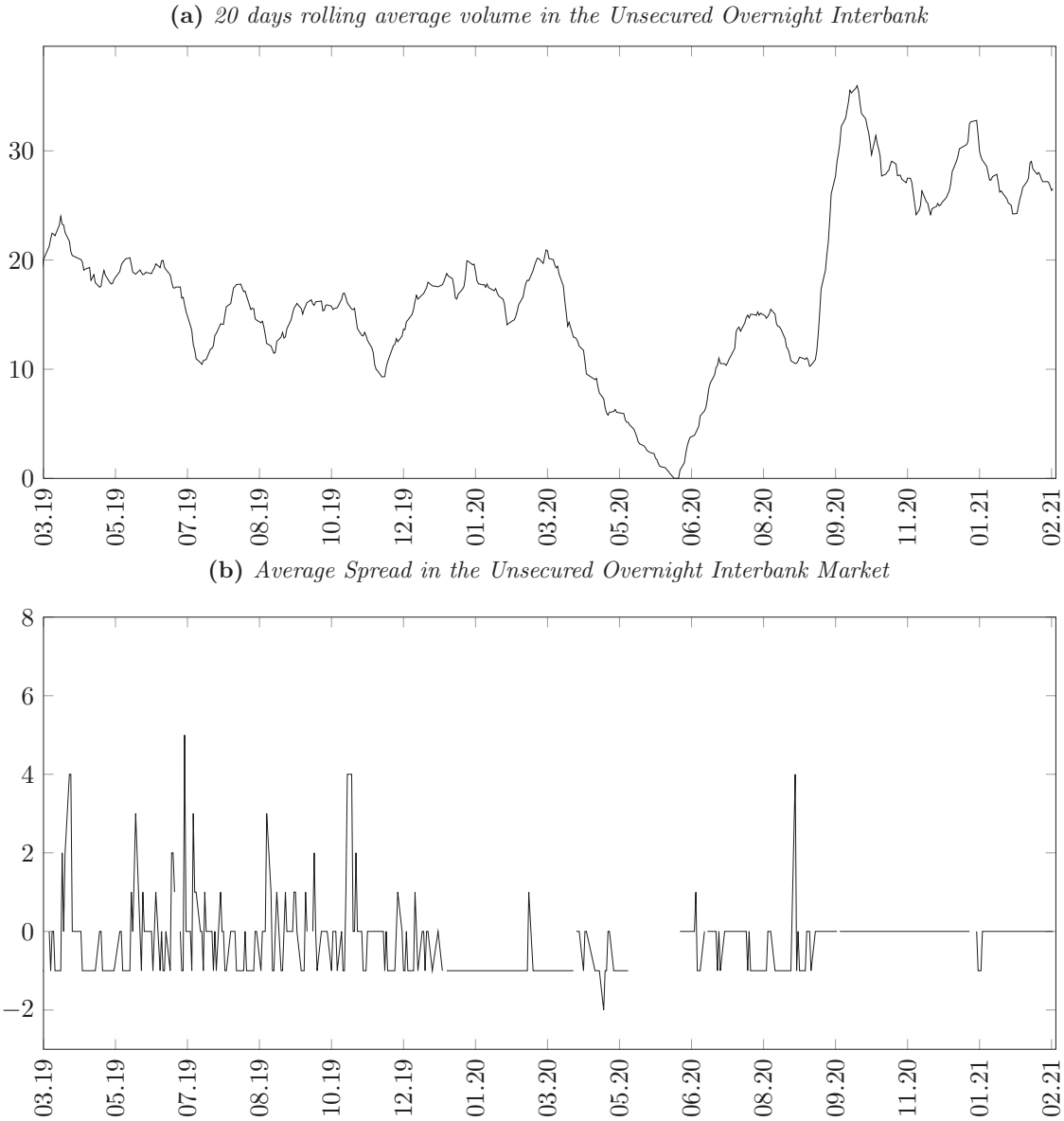


Figure 3: a) 20 days rolling average of daily trading volume in the unsecured overnight interbank market in NOK billions. b) Spread is the volume weighted interest rate on unsecured overnight interbank lending less the key policy rate in basis points. Volumes and interest rates are reported by the NOWA panel banks. Daily observations for all business days from 28th March 2019 to 26th February 2021 excluding quarter ends. Days where there are no trading activity and the interest rate is estimated are removed.

of about NOK 16 bn in trading. However, in the six months period of continuous offsetting auctions, starting on March 13th, the average was NOK 8.7 bn. This includes 23 consecutive days without any reported volumes. In the period after, the volumes increased on days without offsetting auctions. When it comes to pricing in the unsecured interbank market, Figure 3b shows that the spread to the key policy

rate is rather stable throughout the entire period.

Figures 2a to 2c, 3a and 3b are displayed excluding observations falling on quarter ends. At quarter ends, the averages for total liquidity, excess reserves, D-loans, NOWA volumes and spread are NOK 40.5 bn, NOK 10.5 bn, NOK 70.7 bn, NOK 1.0 bn and 56 basis points. Particularly excess reserves and spreads are significantly higher on quarter ends. Volumes of unsecured overnight interbank trading is on the other side significantly lower. The pattern may be related to some banks hoarding liquidity at important reporting days (window dressing) like in Bindseil et al. (2003) and Munyan (2017).

Around the same period as the Covid-19 pandemic started to create turmoil in Norwegian financial markets, Norges bank increased its daily purchase of NOK. The background for these purchases was to transfer FX from the Government Pension Fund Global to cover expenses on the national budget in NOK. While these purchases are motivated by government expenses, and not to stimulate the banking system, the effect is similar to F-deposits. Banks trading FX could sell NOK to the central bank in exchange for foreign currency and thereby reduce their liquidity holdings in the Norwegian banking system. Figure A1b in Appendix A displays the daily purchase of NOK by Norges Bank over the period 28th March 2019 to 26th February 2021. Comparing values before and after the introduction of offsetting auctions on 13th March 2020, the daily purchase of NOK increased from NOK 577 million to NOK 1 614 million per day.

3 Norges Bank’s response to Covid-19

In response to the pandemic, Norges Bank increased the frequency of F-auctions and changed the maturity composition. Figures 4a and 4b display the daily flow of allotted F-loans and F-deposits irrespective of maturity. We compare the period of 350 calendar days before the introduction of offsetting auctions on March 13th 2020

with the following 350 calendar days. The increase in frequency is particularly visible for allotted F-deposits where the graph becomes continuous over the period 13th March 2020 to 15th September 2020. Norges Bank offered roughly one F-deposit auction on average for every four days before 13th March 2020, compared to about two auctions for every three days after. Also the amount allotted in the F-deposits increased. On some days banks deposited up to NOK 300 bn through F-deposits, while the highest values were close to NOK 100 bn before offsetting auctions. The increase in frequency is also visible for F-loans. Norges Bank increased its offering of F-loans from about once every tenth day to once every third day.

Figures 4c and 4d display the composition of maturities across all F-auctions before and after 13th March 2020 over the period 28th March 2019 to 26th February 2021. There were 42 and 121 F-loans before and after 13th March. The dominant maturity in both periods is one business day with 15 and 38 such auctions. However, in the period after 13th March, Norges Bank offered several F-loans with long maturities. There were 19, 7 and 10 auctions with maturities of three months, six months and one year counting for 35.8% of the total volume allotted. In the period before, there were no F-loan auctions with maturity longer than one month. There were 68 and 172 deposit auctions before and after 13th March 2020. The maturities have been mostly one to a few business days before. However, after 13th March 2020, all F-deposits have a maturity of one business day. In the period before, 21.8% of the allotted volume in F-deposits came through auctions with one day maturity.

Norges Bank's response to the Covid-19 pandemic took the form of overlapping F-loans and F-deposits. While it is quite normal that the central bank needs to increase or decrease liquidity in the banking system, and may occasionally end up doing small offsetting auctions due to for example imprecise liquidity projections, Norges Bank offered a large amount of offsetting auction during the Covid-19 pandemic. Figure 1 graphs the outstanding amount of F-loans and F-deposits over the period 1st January 2017 to 26th February 2021. While there has normally been

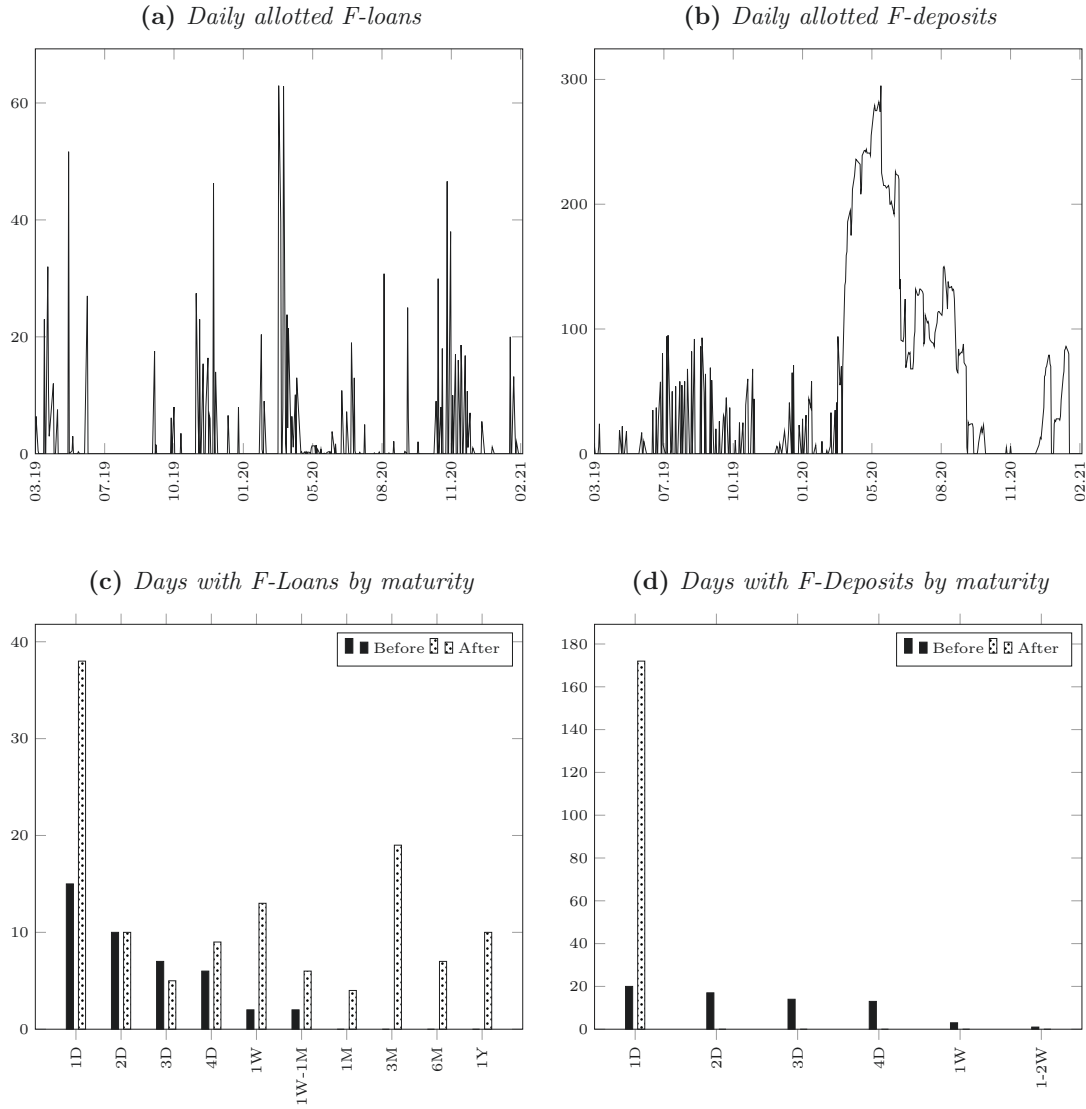


Figure 4: a) Flow of daily allotted F-loans across all maturities in NOK bn. b) Flow of daily allotted F-deposits over all maturities in NOK bn. c) Number of days with F-loan auctions by maturity. d) Number of days with F-deposit auctions by maturity. Before and after in c) and d) refer to before and after March 13th 2020, when Norges Bank introduced large volumes of offsetting auctions. Daily observations for all business days from March 28th 2019 to February 26th 2021.

no offsetting auctions, there were NOK 195 bn in offsetting auctions at the end of March 2020, or about 5.5 times the operational target for liquidity. There were offsetting auctions every day in the period from 13th March to 16th September in 2020 with NOK 125 bn on average, and periodically afterwards. The situation has similarities to the liquidity system in place prior to the policy change in 2011, where total liquidity was fluctuating and at a significant higher value. The banks could

then deposit unlimited reserves overnight with the central bank and still be remunerated the key policy rate.

It is evident that Norges Bank responded to the Covid-19 pandemic by offering overlapping auctions in both directions from March 13th 2020. In sum, one can say that Norges Bank responded to Covid-19 by offering long term F-loans followed by daily short term F-deposits. The banks were therefore offered the opportunity to pile up large amounts of liquidity and place it through F-deposits overnight on a daily base.

4 Simulation of banks' response to offsetting auctions

In this section, we analyse how trading volumes in the unsecured interbank market, banks' holdings of excess reserves and D-loans are affected when the central bank offers offsetting auctions. While we test the Norwegian market's response empirically in Section 5, we use this section to show how payment activity and the size of the offsetting auctions plays a crucial role for the outcome. We do not have data on payment activity in Section 5, but show in this section that the amount of D-loans are reduced with offsetting auctions on days where payment activity is low, while it is increased on days where payment activity is high. Furthermore, we show that the response to offsetting auctions is not linear to the auction size, which has important implications for the chosen empirical model in Section 5.

To formalize the discussion, we run rule based simulations. The simulations have similarities to simulations found in the literature on the risk of contagion in the interbank market. See for example Furfine (2003) and Amundsen and Arnt (2005). In both papers, they start with real world data on banks' outstanding lending of central bank reserves in the interbank market before imposing a liquidity event and mapping out the liquidity effect one round at the time for different levels of recovery

rates.

We simulate the response within the following framework. Before the Real Time Gross Settlement systems opens, banks bid for reserves in a F-loan auction. When the RTGS system opens, each bank makes a random payment to all other banks of varying size on behalf of its clients. After the payments, a F-deposit auction is offered to bring liquidity back down to its liquidity target. After the results of the F-deposit auction is known, the banks trade reserves in the unsecured overnight interbank market. When the RTGS system closes, banks may have a shortage of reserves, reserves within their quotas or excess reserves above their quotas.

A bank receiving extra reserves before the RTGS system opens is more likely to have a balance above zero throughout the day and avoid a borrowing need. However, if the bank does have a borrowing need, it may find it more difficult to find a natural lender in the interbank market. Depending on the distribution of reserves across the other banks, the banks with excess reserves may already have placed their holdings through the F-deposit auction. That is, if the payment activity is high, banks may be more likely to have a shortage of reserves with offsetting auctions. If payment activity is low and the banks keep their positions above zero, the likelihood of a shortage is less with offsetting auctions.

Similarly, a bank receiving extra reserves before the RTGS system opens is more likely to have reserves in excess of its quota throughout the day. Even though the F-deposit auction is of similar size to the initial F-loan action, the bank may not receive full allocation on its bid. In that case, the bank has to go to the interbank market to find a counterparty with a borrowing need to trade reserves. However, if liquidity is distributed such that one or a few banks are the only ones bidding in the F-deposit auctions, the allotment rate can be 100%, meaning that the banks are able to place more liquidity through the deposit auction than received in the F-loan auction making the banks better off compared to a situation without offsetting auctions.

The amount traded in the interbank market is also affected by offsetting auctions. On one side, it is clear that, intraday, there is more liquidity in the banking system that needs to be redistributed and may in itself point to higher levels of interbank trading. On the other side, the banks may be successful meeting their liquidity needs through auctions meaning that the central bank is the main intermediary.

From the discussion above, it is clear that it is not straight forward how offsetting auctions affects trading volumes in the interbank market, excess reserves and D-loans. Its affect is dependent on volatility in interbank payments, the size of offsetting auctions and whether we are looking at a single bank or at all banks collectively.

4.1 Rule based simulation

There are four banks. The operational target for liquidity is set to eight units, and at the beginning of the period, $t = 0$, total liquidity is in line with the target and each bank has two units of reserves. Each bank has a quota of three units. Before the RTGS system opens, an F-loan auction of 24 units is offered. Each bank either participates or pass in the auction. Each participating bank receives 24 units divided by the number of bidding banks. If one or more banks bid, total liquidity increases to 32 units, or four times the operational target for liquidity. This is similar to what we observed in the period March-September 2020.

When the RTGS system opens, all banks transfer an amount to each one of the other banks drawn from a normal distribution where all negative numbers are reset to zero.²¹ There are in total twelve transactions, as each bank transfers one amount to each of the other three banks between $t = 0$ and $t = 1$. We set the mean for each transaction to 4.67 in line with Fevolden and Smith (2018) who show a similar relationship between total liquidity and total payment activity in the Norwegian RTGS

²¹Similar to a rectified Gaussian distribution.

system. The standard deviation in the distribution is varying in the simulation.

Following the payments, the central bank offers an F-deposit auction in equal size to the allotted amount in the F-loan auction to bring total liquidity back down to its target at $t = 1$. All banks with excess reserves bid their entire holding to maximize their allocation rate.²² Any bank is entitled to bid in the F-deposit auction regardless of whether it participated in the F-loan auction or not. The allocation in the F-deposit auction is equal for all bidders and set to $\min(1, \frac{\text{Total offering}}{\text{Total bid}})$. After the F-deposit auction, the banks go to the unsecured interbank market to trade reserves if they have excess or a shortage of reserves. We limit the banks to trade only if they have a real need to trade. That is, a bank with excess reserves will only lend out what it has in excess of its quota, and a bank with a shortage will only borrow the necessary amount to settle its debt with the central bank. Akram and Findreng (2021) and Findreng (2021) find that banks are most likely to participate in unsecured interbank lending when they have a real need for trading. Furthermore, it is a likely assumption that when there is market turmoil, if banks trade at all, they only trade if they have a need and not for market making purposes. The market then settles such that all banks with a need receive the same trading result. That is, all banks are able to trade $\min(\frac{\text{Total placement need}}{\text{Total borrowing need}}, \frac{\text{Total borrowing need}}{\text{Total placement need}})$ multiplied with their trading need. The interbank system closes at $t = 2$. We then sum up total demand for D-loans, excess reserves and total volumes traded in the interbank market. We calculate the outcomes for each standard deviation from 0.01 to 6.01 with increments of 0.02 and reiterate the process one million times for each standard deviation and calculate the means.^{23,24}

²²See B for a more detailed discussion on why banks bid their entire holdings of reserves in the F-deposit auction.

²³The logic behind the simulation and the results are discussed with practitioners.

²⁴The maximum amount of D-loans can be calculated by $(n - 1) \times (q - \frac{T}{n}) - \frac{T}{n}$, where n is the number of banks, q is the banks' individual quota and T is the total target for liquidity. Similarly, if $(n - 1) \times (q - \frac{T}{n}) > \frac{T}{n}$, does not hold, there will not be any D-loans in the simulation. In other words, a D-loans may only occur when the banks average quota, q , is sufficiently large relative to the banks' average holdings of central bank reserves, $\frac{T}{n}$. In practise, this happens when the distribution of central bank reserves is such that one or a few banks have a shortage of reserves and the remaining banks have filled up their quotas. The maximum amount of reserves that may be placed at the reserve rate in the simulation is $T - q$. We have chosen four banks, which is the minimum number of banks allowing us to work with whole units for the quotas and the total

4.2 Simulation results

Figures 5a to 5c compare when all banks participate in offsetting auctions versus when no banks are participating and display the aggregate results for all banks. Looking at Figure 5a, we can see that the amount banks have to borrow in D-loans for low levels of payment activity is lower when they participate in the F-loan auction. However, there are more D-loans when volatility in payments is high. If liquidity is distributed such that, at $t = 1$, there is one bank with a shortage, one bank with excess reserves and the remaining banks are within their quotas, the bank with excess reserves will receive full allocation on its bid in the F-deposit. The bank bidding in the F-deposit increased its position with six units through the F-loan auction, and is able to place up until 24 units in the F-deposit auction. This is clearly a disadvantage for the bank with a shortage of reserves, as the bidder in the F-deposit auction would have been a natural counterparty in the unsecured interbank market.²⁵ The likeliness of such an outcome in the distribution of reserves across banks after payments is increasing with the volatility in payments.

Figure 5b displays the total sum of excess reserves. By this measure, it is clear that the four banks are always better off participating in offsetting auctions. This is because the total offer in the F-deposit auction is higher than each bank has received in the F-loan auction. The banks with excess reserves therefore takes advantage of a

target for central bank reserves, due to computer processing power. In the Norwegian case, there is a double digit number of active banks. To approach the real world, making an increase in n , there will be more D-loans on average as there will be more banks where liquidity can be stored in the space between $\frac{T}{n}$ and q , reducing the overall placement need (this is also true if we increase T proportionally with n). All graphs in Figures 5a to 5c and 6a to 6c would shift upwards if we increase n , but the response to increased uncertainty in payments and increased offsetting auctions would show a similar picture. Similarly, it would not make a difference to the result if we let banks have varying quotas.

²⁵One may compare when the banks have the following liquidity distributions after payments, but before the F-deposits, -1/3/3/27 with offsetting auctions versus -7/-3/-3/21 if nobody participates in the F-loan auction. With auctions, the bank with excess liquidity bids 27 and is allocated 24 resulting in liquidity of three (quota of three). It then has zero to lend and the borrowing bank needs one. If there were no banks participating, the bank with excess liquidity would be willing to lend out 18, and the three banks with a shortage would have a borrowing need of 13. From this example, it is also clear that offsetting auctions affect trading volumes in the interbank market.

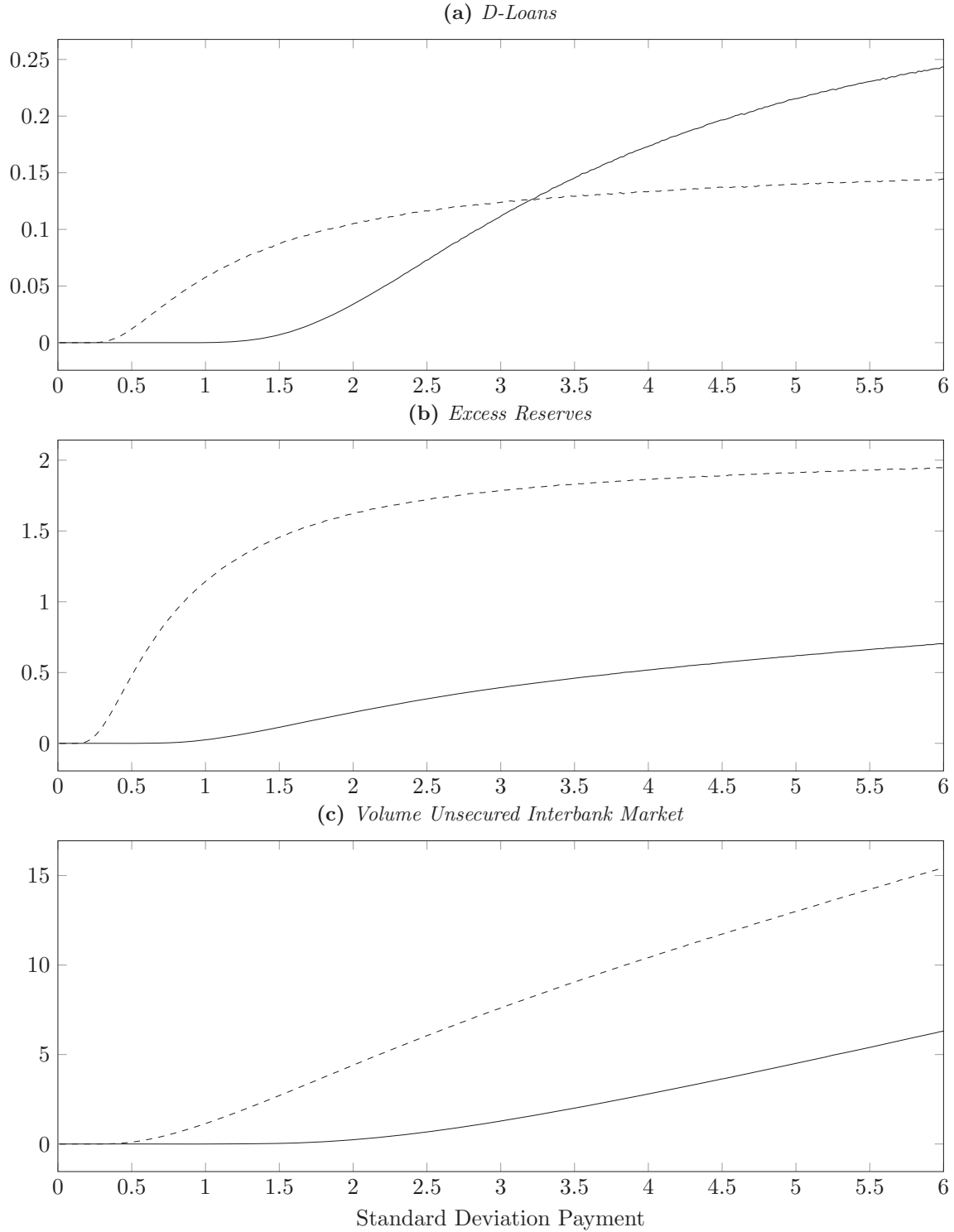


Figure 5: a) The sum of all four bank's D-deposits, b) the sum of all four bank's excess reserves and c) the total volumes traded in the unsecured interbank market between $t = 1$ and $t = 2$. The graphs compare when all four banks participate in the F-loan of 24 units (solid line) versus when no banks participate (dashed line). Each observation is the average of 1 000 000 simulations for each standard deviation level.

high allocation as the banks without excess reserves do not bid. In terms of liquidity distribution measured by excess reserves and D-loans, the banks are collectively better off participating in offsetting auctions.²⁶

Figure 5c displays the volumes of unsecured overnight interbank trading in our simulation comparing when all four banks participate in offsetting auctions versus when no banks participate. Volume is calculated as the minimum of shortage of reserves and excess reserves at $t = 1$, following the F-deposit auction. We can see that when there are offsetting auctions, interbank trading volumes are lower for all standard deviation levels except for very low levels, where there is no trading at all.

From the results in Figures 5a to 5c it is clear that banks are better off participating in offsetting auctions when they do this collectively. While the penalty for excess reserves and a shortage of reserves is symmetric, banks may weigh the penalty for taking a D-loan higher due to stigma costs as in Armantier et al. (2015), and find it attractive to participate in offsetting auctions. If all banks are worried by the stigma cost and participate, they are also better off economically.²⁷

4.3 Offsetting auctions and interbank trading

In Figures 6a to 6c, we re-run the simulation from Figures 5a to 5c, but this time we let offsetting auctions vary and keep the standard deviation in payment fixed at 2.0. The X-axis is presented as the ratio of offsetting auctions to the liquidity target (the ratio was three in the previous simulation). We can see that when the size of offsetting auctions is sufficiently large, the banks are able to solve their liquidity needs by trading with Norges Bank, and there will be no D-loans, excess reserves

²⁶When making the amount allocated in the F-loan action a function of participating banks, as opposed to a fixed amount divided on the number of participants, results are similar.

²⁷In Appendix C, we analyse a single bank's decision to participate if it is the sole participant. The results contrast the results in Figures 5a to 5c. Figures A2a to A2c show that a single bank is worse off participating in terms of excess reserves, better off in terms of D-loans and worse off when combining the two measures. The single bank is also more dependent on the interbank market when participating.

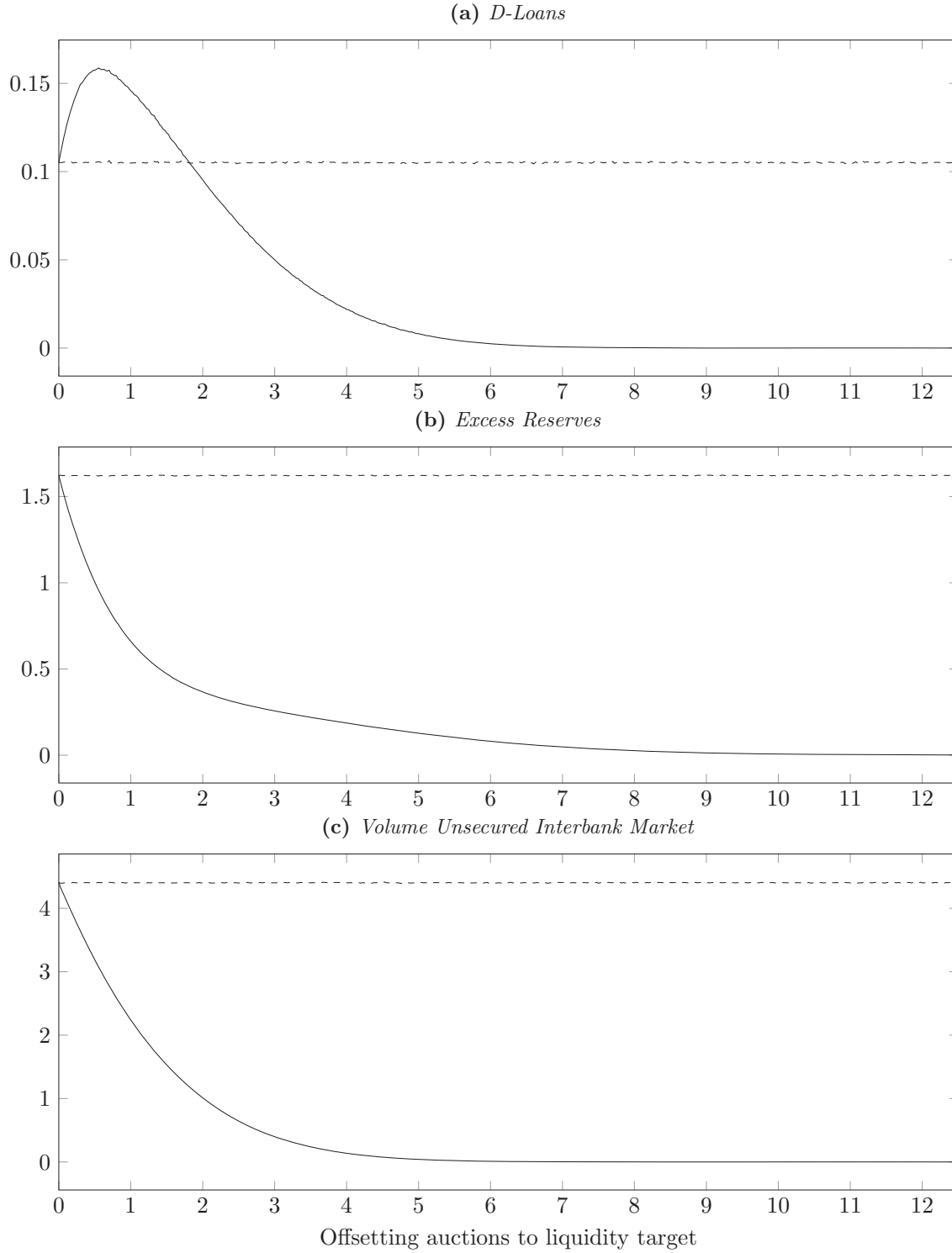


Figure 6: a) The sum of all four bank's *D*-deposits, b) the sum of all four bank's excess reserves and c) total volumes traded in the unsecured interbank market between $t = 1$ and $t = 2$. Each observation is the average of 1 000 000 simulations for each level of magnitude in offsetting auctions. The graphs compare when all four banks participate in the *F*-loan (solid line) versus when no banks participate (dashed line). The *X*-axis is presented as the magnitude of offsetting auctions to the liquidity target. Standard deviation in payments is 2.0.

or interbank trading. This is an important observation for the empirical analysis in Section 5, as the effect of offsetting auctions may not be linear. In particular, trading disappears relatively quickly already at offsetting auctions three times the reserve target. D-loans are reduced and fall to zero with high levels of offsetting auctions. However, it is actually increasing for low levels of offsetting auctions, as there is a higher probability for a corner solution with only one bidding bank in the F-deposit auctions receiving a high allocation while at the same time two out of the three other banks have reserves exactly at their quotas or close to filling it up. The forth bank will then have a shortage of reserves and is unable to find a trading partner. Excess reserves deposited at the reserve rate drops sharply for the first levels of offsetting auctions and is further steadily declining. The dashed lines in the graphs represents the outcome with no offsetting auctions for comparison. While the simulations may not mimic the Norwegian market one to one, the important outcome is that when offsetting auctions are sufficiently large, the level itself does not matter on how it affects liquidity distribution and trading of reserves. Similar results would have been achieved choosing a higher level of payment volatility, but the graphs would be pushed upwards to the right.

5 Empirical analysis

We are interested in how traded volumes in the unsecured overnight interbank market, measured by the volumes reported by the NOWA panel banks, were affected when Norges Bank introduced offsetting auctions in response to increased financial turmoil caused by the Covid-19 pandemic in March 2020. We also interested in how successful offsetting auctions were in distributing liquidity across the banks. We measure liquidity distribution by excess reserves placed at the reserve rate 100 basis points below the key policy rate and the amount banks borrowed overnight from the central bank through D-loans at 100 basis points above the key policy rate.

Data material used in the regressions is summed up in Table 1. However, leveraging

Before	Percentiles						
	Mean	S.Dev	Min	25th	50th	75th	Max
Excess Reserves	718	2 000	149	201	304	495	19 006
D-Loans	15	160	0	0	0	0	2 259
NOWA Vol.	16 108	7 847	0	10 811	16 325	20 697	37 305
Spread	0.672	12.631	-1.00	-1.00	-1.00	0.00	191.00
Offsetting Auctions	181	1 145	0	0	0	0	10 000
VIX-Index	16.38	6.34	11.55	13.18	14.77	16.94	61.46
Total Liquidity	34 678	2 719	19 025	33 405	34 773	36 092	44 456
FX-GPFG	577	143	0	500	600	700	700
After							
Excess Reserves	898	2 284	25	104	321	659	16 275
D-Loans	12	99	0	0	0	0	1 087
NOWA Vol.	17 990	13 322	0	6 790	16 477	28 025	73 940
Spread	-0.263	0.553	-2.00	-1.00	0.00	0.00	4.00
Offsetting Auctions	72 563	69 014	0	0	69 000	110 578	195 323
VIX-Index	30.08	11.06	19.97	23.42	26.94	31.68	82.69
Total Liquidity	34 691	2 366	23 275	34 601	35 000	35 373	47 903
FX-GPFG	1 651	686	0	1 600	2 000	2 100	2 500

Table 1: *Excess Reserves is the total reserves the banks placed overnight remunerated at the reserve rate 100 basis points below the key policy rate. D-loans are the total amount the banks borrowed overnight from the central bank 100 basis points above the key policy rate. NOWA vol. is the reported trading volume in the unsecured overnight interbank market by the NOWA paneel banks. Spread is the reported interest rate on unsecured overnight interbank trading less the key policy rate in basis points. Offsetting auctions are the minimum of outstanding F-loan and F-deposit auctions. VIX-Index is the implied 30 day volatility from index options on the S&P 500 downloaded from MarketWatch.com. We have used opening quotes to deal with the time difference between U.S. and Norway. Total liquidity is the sum of banks' deposits of central bank reserves at the key policy rate and at the reserve rate. FX-GPFG is the government's daily purchase of NOK for transferring from the Government Pension Fund Global to cover expenses on the national budget. During this particular period, these numbers are either zero or positive indicating that the government has not sold NOK. All numbers, except VIX-Index, are in NOK million. Daily observations for all business days from 28th March 2019 to 26th February 2021. Before and after corresponds to before March 13th 2020 and from March 13th onwards.*

on the discussion in Section 4.3 and Figures 6a to 6c, which indicates that Norges Bank's market interventions measured by offsetting auctions do not have a linear affect on interbank trading and liquidity distribution, the variable offsetting auctions is divided into brackets by size in the regressions below. Offsetting auctions is the minimum of the outstanding stock of F-loans and the outstanding stock of F-

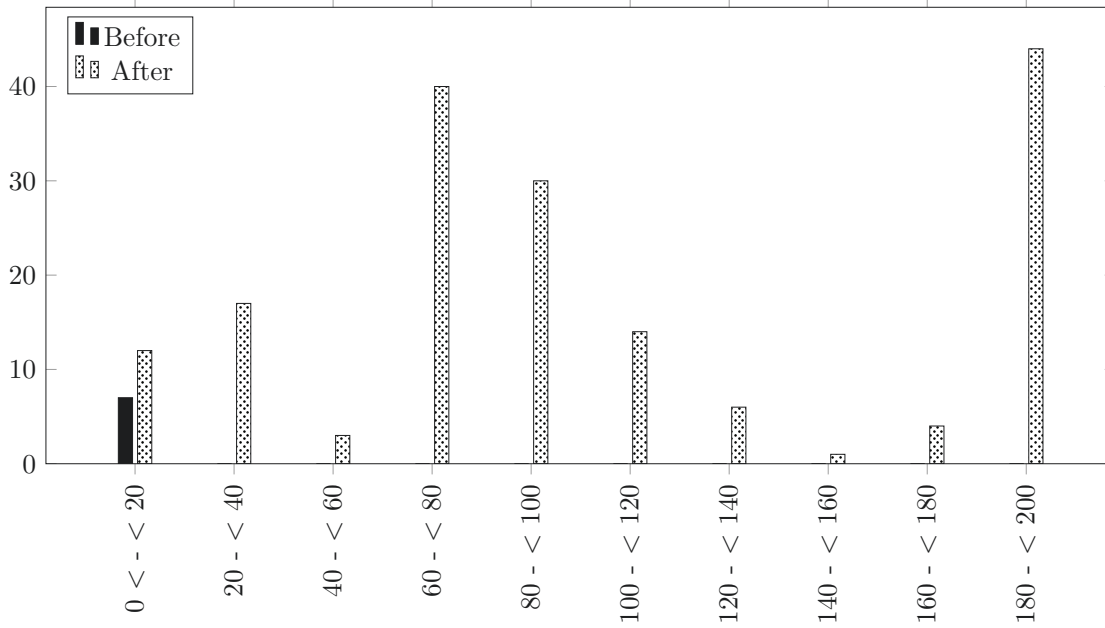


Figure 7: *Distribution of days with offsetting auctions by size. The buckets represent intervals of NOK 20 bn each. There are 231 observations of zero before and 71 after March 13th 2020. Offsetting auctions are the minimum of outstanding F-loan auctions and F-deposit auctions. Daily observations over all business days from 28th March 2019 to 26th February 2021.*

deposits. Figure 7 shows the distribution of offsetting auctions on days when this variable is positive by brackets of NOK 20 billions. We can see that there are typically four levels of offsetting auctions. The first being positive and up to NOK 20 billions. These observations occurred through the whole dataset and are likely due to imprecise liquidity projections, where Norges Bank offered small offsetting auctions to make small adjustments in liquidity (see Figure 1). The second being relatively modest offsetting auctions from 20 billions up to NOK 80 billion. The third level is from NOK 100 to 140 billions and the fourth from NOK 140 to 200 billions. In the analysis below we use binary variables for these four levels named Off. Auctions dum 1,2,3 and 4.

Table 2 displays the results of time series regressions over the period 28th March 2019 to 26th February 2021 with observations for each business day. The dependent variables in the three first regressions are the natural logarithm of total trading volume in the unsecured overnight interbank market reported by the NOWA banks,

	NOWA Volumes	Excess Reserves	D-Loans	Spread
Off. Auctions dum1	-0.248 (0.302)	0.159 (0.277)	-0.055 (0.295)	0.671 (0.569)
Off. Auctions dum2	-0.538*** (0.168)	-1.385*** (0.352)	-0.573 (0.394)	2.685 (2.859)
Off. Auctions dum3	-0.788** (0.366)	-1.704*** (0.388)	-0.658 (0.534)	5.494 (4.234)
Off. Auctions dum4	-6.277*** (0.928)	-1.629*** (0.451)	-0.374 (0.787)	4.324 (3.472)
VIX-Index	-0.090 (0.493)	1.005** (0.441)	1.443* (0.848)	-2.568 (2.424)
MI $\times$ VIX-Index	2.232* (1.185)	0.079** (0.767)	-1.147 (1.006)	8.192 (6.322)
Total Liquidity	-0.028 (0.486)	2.556*** (0.580)	0.152 (0.377)	4.476 (6.295)
MI $\times$ Total Liquidity	-0.711 (0.482)	0.148 (0.312)	0.495 (0.385)	-3.625 (2.681)
FX-GPFG	0.076 (0.071)	-0.041 (0.042)	0.002 (0.019)	0.047 (0.075)
MI $\times$ FX-GPFG	-0.059 (0.092)	-0.063 (0.071)	-0.047 (0.048)	0.058 (0.083)
End Quarter	-4.218*** (0.987)	2.207*** (0.396)	0.893 (0.804)	57.283 (38.377)
Monthly dummies	YES	YES	YES	YES
Observations	482	482	482	482
R-Squared	0.770	0.512	0.132	0.380
Adj. R-Squared	0.752	0.475	0.066	0.332

Table 2: *Excess Reserves is the total amount of reserves banks have placed at the reserve rate. D-loans is the total amount banks have borrowed overnight from the central bank at 100 basis points above the key policy rate. NOWA vol. is the reported trading volumes in the unsecured overnight interbank market reported by the NOWA panel, a group of the most active banks. Spread is the reported interest rate on unsecured overnight interbank trading less the key policy rate in basis points. Offsetting auctions are the minimum of outstanding F-loan and F-deposit auctions. Off. Auct. D1-D4 are binary variables for offsetting auctions when the amount corresponds to positive numbers up to NOK 20 bn, NOK 20 to 80 bn, NOK 80 to 140 bn and from NOK 140 to 200 bn. VIX-index is the implied 30 day volatility on the S&P 500 index at open downloaded from Bloomberg. Total liquidity is the sum of banks' placement of central bank reserves at the folio rate and at the reserve rate. FX-GPFG is the government's daily purchase of NOK for transferring from the Government Pension Fund Global to cover expenses on the national budget. During this particular period, these numbers are either zero or positive indicating that the government has not sold NOK. MI is a binary variable equal to one from 13th March 2020 and zero before. Excess reserves, D-loans, NOWA volumes, VIX-index, Total liquidity and FX-GPFG are in their natural logarithm form. Daily observations for all business days from 28th March 2019 to 26th February 2021. Robust standard errors in parentheses. Three asterisk indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.*

banks' holdings of excess reserves and total amount of D-loans in NOK. In the fourth regression, the dependent variable is the spread defined as the price of interbank lending less the key policy rate in basis points. The main control variables

are the binary variables for offsetting auctions. Another important control variable is the natural logarithm of the VIX-index, which measures implied volatility on the S&P 500 index and is included to control for general uncertainty in financial markets.²⁸ We use the opening quote to better deal with time differences between the U.S. and Norway. We further control for the natural logarithm of total liquidity and the natural logarithm of FX-GPFG, which is the government’s daily purchase of NOK for transfers from the Government Pension Fund Global to cover expenses on the government budget, and quarter ends. We include monthly dummy variables to control for varying market conditions not captured by the VIX-index. Furthermore, we also include interaction variables between the binary variable, MI, equal to one after March 13th 2020 and zero before, and the three control variables; VIX-index, Total Liquidity and FX-GPFG

In the first regression in Table 2 explaining traded volumes in the unsecured overnight interbank market, we can see that offsetting auctions reduce interbank trading once they are larger than NOK 20 billions. Offsetting auctions in the range NOK 20 to 80 bn reduce traded volumes by nearly 42%.²⁹ Offsetting auctions in the range NOK 80 to 140 bn reduce volumes of about 55% and when offsetting auctions are very high and in the range NOK 140 to 200 bn volumes nearly disappears with a reduction of 99.8%. The coefficients are significant at the one, at the five and at the one per cent significance level, respectively. Volumes respond positively to increased uncertainty in financial markets measured by the VIX-index. However, only after March 13th 2020. A doubling in the VIX-index increased volumes by more than 220%. The significance level of the coefficient is however weak at the ten per cent level. It is not straight forward what one should expect of unsecured interbank trading of reserves when volatility changes. On one side, increased volatility should reduce the lenders’ risk appetite and reduce supply. On the other side, increased volatility may

²⁸Alternatively, one could use pricing of credit default swaps on the banks to measure riskiness. However, the market for credit default swaps on Norwegian banks is limited. See also Fuhrer (2018) who uses the VIX-index as a control variable measuring global financial risk sentiment when analysing the Swiss Franc repo market over the period 2006 to 2016.

²⁹ $100 \times (e^\beta - 1)$

incentivize liquidity hoarding and increase demand. However, increased trading in the interbank market as the VIX-index increases is also reported in Fuhrer (2018). As expected, trading falls drastically (about 99.5%) on quarter ends.

One concern interpreting the first regression in Table 2 is whether the relationship between offsetting auctions and interbank trading suffers from reverse causality.³⁰ One may argue that the relationship is caused by Norges Bank offering offsetting auctions when low interbank activity is observed. While this cannot be the case intraday, as interbank trading occurs after the of the F-auctions are carried out, low activity may be autocorrelated and affect the following day's level of offsetting auctions. However, offsetting auctions consist of long-term F-loans and short-term F-deposits. The decision to offer offsetting auctions is locked in for the period equalling the maturity of the F-loans. The first day with offsetting auctions starts on 13th March 2020, when a F-loan of NOK 63 bn with maturity of 91 days was issued. Two weeks later, on 27th March, another NOK 21.5 bn was issued followed by NOK 10.8 bn on 12th June and NOK 19 bn on 26th June, all with maturity of 91 days. In addition, the offerings were made following a period with rather high interbank trading.³¹ The concern of endogeneity may therefore be somewhat relaxed as Norges Bank decided to offer offsetting auctions for a longer time period following a period of high interbank activity. However, one may argue that Norges Bank could have offered a long-term F-deposit with matching maturity to the remaining outstanding F-loans at any time during this period to effectively end the scheme immediately. The continuous decision of not offering a long-term F-deposit auction may be due to low interbank activity. Another argument is that Norges Bank foresaw a decrease in interbank activity and therefore offered offsetting, making the relationship endogenous.

³⁰The following discussion is also relevant for the relationship between offsetting auctions and interest rates in the fourth regression in Table 2, although this relationship is not significant.

³¹In the week and month before offsetting auctions, the average NOWA volumes were NOK 20.4 bn and NOK 20.7 bn, compared to the lower average of NOK 16.3 bn over the period 28th March 2019 to 12th March 2020.

The results in the first regression in Table 2 points towards the conjecture that Norges Bank, through market interventions, became the intermediary for trading reserves. We are also interested in how successful the market interventions were in distributing liquidity. Turning to the second column in Table 2, we can see that offsetting auctions reduce the banks' daily aggregated holdings of excess reserves. The coefficients for the three largest brackets of offsetting auctions are all significant at the one per cent level and ranging from -1.39 to -1.70. These levels correspond to a 75% to 81.8% reduction in excess reserves. The three levels of offsetting auctions seem to reduce reserves with roughly the same amount, suggesting that the effect is binary of nature and not dependent on the level of offsetting auctions as long as they are sufficiently large.

The coefficient for the VIX-index is significant at the five percent level and suggest that a doubling of this measure is associated with a doubling of excess reserves. The coefficient for the interaction variable between the binary variable, MI, and the VIX-index is also significant at the five per cent level, indicating that a doubling of the VIX-index after March 13th 2020 is associated with an additional 8% increase in excess reserves. The coefficient for total liquidity is significant at the one per cent level and the coefficient is 2.56.

Turning to the third regression in Table 2, where the dependent variable is D-loans, we can see that none of the offsetting auctions variables are significant, suggesting that market interventions are not successful in reducing the banks' probability for avoiding a shortage of reserves. The coefficient for the VIX-Index is significant at the ten per cent level indicating that a doubling in the index increases D-loans with about 140%. There are only 15 days in the sample when one or more banks made use of the D-loan facility. Due to the distribution of D-loans, where close to all observations are zero, we present a similar Tobit model in Table A1 in Appendix D. The results in this regression yield stronger results. The coefficient for large offsetting auctions is significant at the five per cent level and suggest that D-loans are

reduced by nearly 100%. The coefficient for the VIX-index is significant at the one per cent level suggesting that a doubling in financial uncertainty nearly increases D-loans nine times. However, due to the limited number of positive observations, the model will not converge with monthly dummies. As a substitute, we have used quarterly dummies. We have also limited the amount of control variables and therefore excluded the interaction variables.³²

A possible interpretation of the result in the first regression in Table 2 is that market interventions are seen as bad news indicating that market conditions are worse than first anticipated by the banks, like in Brunetti et al. (2011). The reduction in traded volumes in the unsecured interbank market may be caused by the true price of borrowing reserves is higher than Norges Bank standing facility for overnight loans priced 100 basis points above the key policy rate. In the fourth regression in Table 2, we do not find that market interventions affect prices in the unsecured interbank market. One may argue that these type of market interventions should reduce interest rates. However, on the other side of the coin, we do not find that increased financial uncertainty increases interest rates. One possible explanation may be that the composition of banks trading during uncertainty changes from a broad sample to a narrower sample representing banks with high creditworthiness, and thus continue to borrow at normal terms.³³ When a lender finds the potential borrower to have higher risk, the lender may rather stop lending to this particular borrower as opposed to increase prices due to adverse selection or the incentive effect as in Stiglitz and Weiss (1981).

In addition to the Tobit model in Table A1 discussed above, other robustness checks are offered in Appendix D. In Table A2, we re-run the regressions from Table 2 without interaction variables. While the results across all four regressions are broadly in

³²We also include a Tobit regression for NOWA volumes in Table A1 in Appendix D as there are 32 days in the sample without any trading in the unsecured interbank market. Also in this regression, we find similar results to the ones presented in Table 2.

³³While Table 3 indicates that it is roughly the same participants, based on quota affiliation, using the unsecured overnight interbank market in the two periods before and after March 12th 2020, we do not know whether the participants within each quota group are the same.

line with Table 2, it is only offsetting auctions above NOK 140 bn that significantly reduce NOWA volumes. This is likely due to a positive correlation between the interaction variable between the binary variable for market interventions and the VIX-index and offsetting auctions in Table 2. The interaction variable and offsetting auctions have opposite coefficients, and the effect may cancel each other out. In the first three regressions in Table A3, we re-run the regressions from Table A2, but this time without monthly dummy variables. The coefficient for offsetting auctions above NOK 140 bn explaining excess reserves is now significant with the opposite sign. The monthly dummies are included in the main regressions to control for market conditions not captured by the VIX-index. It may be that Norges Bank offered offsetting auctions when uncertainty peaked resulting in an omitted variable bias. In model four to six in Table A3 we present a simpler regression specification where we do not divide offsetting auctions into brackets based on size. The results broadly point to the same conclusion, as in Table 2, that offsetting auctions reduce NOWA volumes and the unevenness in distribution of reserves.

5.1 Composition of borrowing and lending banks

In this subsection, we analyse the composition of borrowing and lending banks in the period before and after the introduction of market interventions. The comparison uses groups of banks based on size and activity level. The results are further presented as averages over each of the two time periods for anonymity purposes. The grouping follows the banks' quota affiliation set by Norges Bank. Group 1 includes the six largest banks, group 2 include 15 mid-sized banks, while group 3 consists of the remaining smaller banks with a varying amount of members around 100.

Individual unsecured overnight interbank transactions are identified analysing all transactions between banks in Norges Bank's Real Time Gross Settlement (RTGS) system. The procedure for the identification process follows Akram and Findreng (2021) who develop an algorithm to identify unsecured overnight interbank loans in Norges Bank's RTGS system based on the original work of Furfine (1999, 2000,

		Lending Banks							
		Before				After			
		G1	G2	G3	Sum	G1	G2	G3	sum
Borrowing Banks	G1	12 913 (7 205)	1 013 (1 013)	- -	13 926	4 826 (4 346)	508 (910)	1 (10)	5 335
	G2	1 815 (1 618)	874 (580)	- -	2 689	143 (286)	328 (596)	1 (14)	473
	G3	- -	- -	- -	-	- -	- -	- -	-
	Sum	14 727	1 887	-	16 614	4 969	836	2	5 807

Table 3: Average daily volume of unsecured overnight interbank lending by group. G1, G2 and G3 refer to groups of banks following Norges Bank quota system. G1 banks are the six banks with the largest quotas, which are about eight times larger than the quotas for the 15 banks in G2, which again have about eight times larger quotas than the broader G3 group. Before and after refer to the samples 28th March 2019–12th March 2020 and 13th March 2020 – 26th February 2021. Market interventions were introduced by Norges Bank on 13th March 2020. Standard errors in parenthesis.

2001, 2002). The results of the algorithm, after the necessary anonymization, are made available to present in this paper. The details of the algorithm is described in Appendix E.

Table 3 presents the average daily volume of unsecured overnight interbank trading grouped by lending and borrowing banks, which are again aggregated into three groups based on size and activity in the Norwegian market, and by the two periods before and after the introduction of market interventions. In the period before, only the larger banks in group 1 and 2 were active. About 78% of all trading identified by the algorithm is within group 1. About 17% of the volume has one counterparty in each of the two groups and only 5% of the volume is within group 2.

In the period after market interventions, the daily average of intrabank trading drops to NOK 5.8 bn. This is lower than the NOK 18 bn reported by the NOWA panel in Table 1. Although, we do not expect the algorithm to produce exactly the same outcome as the NOWA reported volumes, the mismatch is substantial. On

May 8th 2020, Norges Bank set the key policy rate to zero. The algorithm may encounter problems identifying unsecured overnight interbank loans when the interest rate on those loans are zero. If the sent amount is the same as the returned amount the following day in the RTGS system, it is difficult to ensure that the returned amount is not the first leg in another transaction or a repayment for a loan with longer maturity (Akram and Findreng (2021)). See Appendix E.1 for a comparison between reported NOWA volumes and identified unsecured overnight interbank loans using the modified Furfine algorithm in the period before and after Norges Bank set the key policy rate to zero on May 8th 2020. This may indicate that the numbers presented in Table 3 for the second period systematically ignores a portion of the interbank loans with zero per cent interest rate. Another possible explanation may be that some banks have changed behaviour such that the algorithm is unable to identify all interbank loan transactions. Key assumptions behind the algorithm include that the lending amount needs to be a round value to the nearest NOK million with an interest rate quoted in no more than three decimals using 365 interest days. Any unsecured overnight interbank loan not compliant with these assumptions will not be identified.

However, by using the data material made available, we can see that, in the period after, 83% of the volumes are within group 1. 11% of the volumes involve one bank from group 1 and one bank from group 2. Although, the volumes identified within group 1 is a larger portion of the total compared to the period before, we now see some lending from group 3 banks to group 1 and 2 banks. Activity in the unsecured overnight interbank market seems to be centred around the largest banks in both periods, although we do not see the whole picture in the period after market interventions.

6 Discussions

In response to the turmoil imposed by the Covid-19 pandemic, Norges Bank offered long term F-loans and short term F-deposit auctions with overlapping maturities. We find that the scheme of offsetting auctions deteriorated traded volumes in the unsecured overnight interbank market as Norges Bank became the intermediary. Offsetting auctions in the range NOK 20 to 140 bn reduced traded volumes by 42% to 55%. However, for offsetting auctions above NOK 140 bn, the volumes disappeared completely. We also find that, when market interventions through offsetting auctions were offered, the unevenness in liquidity distribution across banks were reduced. Increased financial uncertainty measured by the VIX-index increased both the banks' holdings of excess reserves, remunerated 100 basis points below the key policy rate, and the amount banks borrowed by using Norges Bank's standing facility for overnight borrowings priced 100 basis points above the key policy rate. Offsetting auctions above NOK 20 bn reduced the banks' holding of excess reserves by 75% to 82%. We also find indications that the amount of D-loans is reduced with large levels offsetting auctions through a Tobit model, but there are only 15 days with D-loans in the sample.

We have rationalized why banks are willing to participate in offsetting auctions and through a rule based simulation suggested how trading activity in the unsecured interbank market and the liquidity distribution across banks are affected by this type of market interventions. In terms of avoiding a liquidity shortage, banks are collectively better off by offsetting auctions when uncertainty in payments is low. However, in terms of avoiding excess reserves, the banks are always better off by offsetting auctions. In total, the banks are better off. We have also looked at the banks' response to varying levels of offsetting auctions. Offsetting auctions increase D-loans for low levels, but then reduce D-loans sharply as higher levels of offsetting auctions are offered. Excess reserves and interbank trading are reduced already for low levels of offsetting auctions. When offsetting auctions are sufficiently large, there

are no D-loans, excess reserves or trading activity in the unsecured interbank market.

One can say that Norges Bank was successful in keeping the distribution of liquidity across banks stable during the turmoil caused by Covid-19. When the central bank became the central counterparty for trading central bank reserves, this may have ensured that banks had adequate liquidity to meet their short-term needs stemming from day-to-day activities, which complements one of the three main objectives in Norges Bank's liquidity policy (see Norges Bank (2014b, 2020), and possibly also the objective that the key policy rate should prevail in the money market. We do not know the consequences if Norges Bank had not intervened. In such a case, liquidity could become scares preventing banks from settling transactions and pushing short term money market interest rate away from the key policy rate. However, it came at a price of less interbank trading as Norges Bank became the central counterparty in the overnight market for redistribution of reserves. As a direct consequence of less interbank trading, the NOWA rate was set equal to the key policy rate on 23 consecutive business days in the midst of the Covid-19 turmoil in the spring of 2020. This occurs when there is insufficient trading in the unsecured overnight interbank market reported by the NOWA panel, a group of the most active banks in the Norwegian market. The NOWA rate is an important indicator for many participants in the Norwegian economy and financial markets, and there is therefore an unknown cost to the market inventions as the NOWA rate failed to convey important information about money market conditions to the general audience. Furthermore, less interbank trading contradicts the objective that banks should predominantly meet their liquidity needs by trading with each other rather than with Norges Bank. An active interbank market fosters peer monitoring, but incentives for actively performing peer monitoring may be weakened if banks expect the central bank to intervene when financial uncertainty increases.

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A Supporting graphs

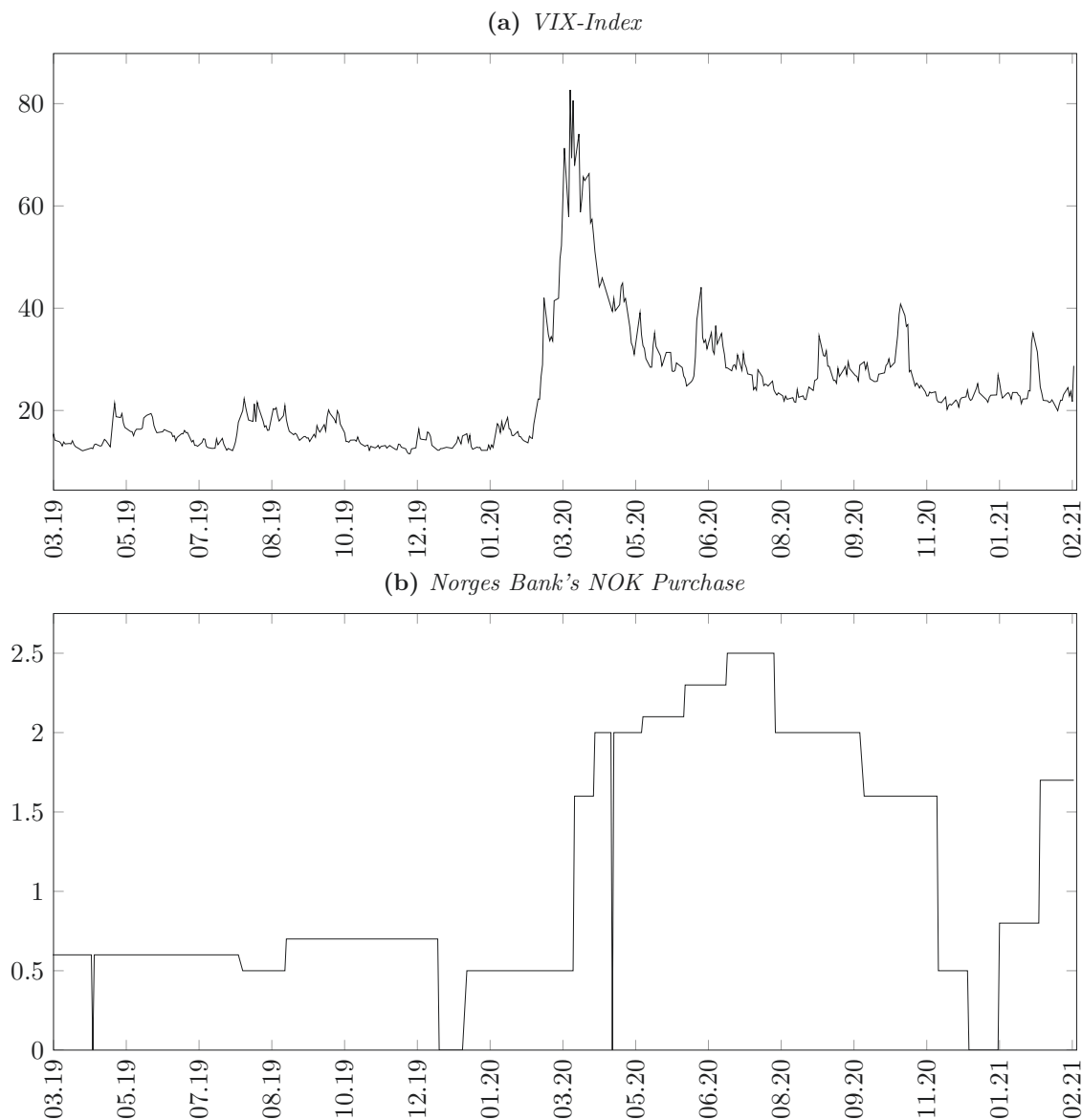


Figure A1: a) *VIX-Index* is the implied 30 day volatility on the S&P 500 index downloaded from Bloomberg. We use opening quotes to better match opening hours of Norges Bank. In cases of U.S. specific holidays, we use the close from the previous day. b) Daily purchases of NOK in billions for transferring funds from the Government Pension Fund Global to cover expenses on the national budget. Both graphs display daily observations over all business days from 28th March 2019 to 26th February 2021.

B Why banks bid excessively in deposit auctions

When there is excess total liquidity in the market, it is perhaps puzzling how Norges Bank manages to withdraw liquidity back to the target, well below the total sum of quotas. During the period when Norges Bank offered large scale F-loans with long maturity and similarly sized daily F-deposits with short maturity, the total liquidity stayed very close to the operational target (see Figure 2a). Why do banks willingly bid for allocation in F-deposits bringing total liquidity down to NOK 35 bn, when they can place a total of NOK 45 bn deposits remunerated at the key policy rate? One could argue that Norges Bank should never be able to bring liquidity below the sum of quotas through F-deposits, as these F-deposits never offer higher interest rates than regular deposits (within their quotas) overnight.

When a bank has reserves in excess of its quota, it is incentivised to bid its excess reserves if Norges Bank offers an F-deposit auction. However, the bank does not know how much it will be allocated in the auction. The allocation ratio is a function of total bids and total offer size, and the bank does not know how liquidity is distributed across the other banks, and therefore does not know how much the other banks will bid. If liquidity is unevenly distributed,³⁴ the offered amount in the F-deposit auction may not be sufficient to meet demand from all banks with excess reserves. The bank can therefore be opportunistic and bid for more than it needs in case the allocation ratio is less than one. As a consequence, all other bidding banks should do the same to avoid receiving an even lower allocation in the auction. The result is that all banks participating in the auction are incentivized to bid up to their entire holding of reserves and the likelihood for the central bank being able to bring down liquidity to target increases.³⁵

³⁴Due to for example high payment activity.

³⁵They do not bid more than their entire holding of reserves as they may receive full allotment resulting in a liquidity shortage

C A single bank's participation in offsetting auctions

Figures A2a to A2c display the results from a simulation comparing a situation where a single bank is the sole participant in the F-loan auction at $t = 0$, with a situation where no bank participates. The solid line is the result for the single bank if it bids and the dashed line is the result for the single bank if it does not bid. The X-axis on the graph represents different standard deviation in payments between the banks.

Figure A2a shows that the single bank will need less borrowings through D-loans if it participates. The difference is particularly meaningful for relatively low levels of standard deviations. When payment activity is low, the extra units of reserves added to the single bank's liquidity at $t = 0$ substantially reduces the probability for having a liquidity shortage at $t = 2$. However, when the standard deviation increases, the two lines will ultimately converge. Let's say that Bank A makes large payments to all other banks such that it has a shortage of liquidity after payments. Bank A is 24 units better off if it borrowed in the F-loan auction, but at the same time, the other banks are able to deposit an additional 24 units of reserves through the F-deposits as a consequence of Bank A's decision to borrow in the F-loan auction. While Bank A's borrowing need in the interbank market is reduced, the placement need for the remaining banks are reduced with the same magnitude. However, in terms of D-loans, a single bank will never be worse off participating in the F-loan.

Similarly to Figure A2a, Figure A2b displays how many units the single bank needs to deposit at the reserve rate at a penalty rate below the key policy rate at $t = 2$. Naturally, if the bank participates in the F-loan, receiving 24 extra units of reserves, it is more likely to have excess reserves. While the single bank can bid in the F-deposit, it may have to compete with other banks having excess reserves too, and receive a low allocation. This typically happens if the payment activity is low and liquidity is distributed such that no banks have a shortage of reserves, but more

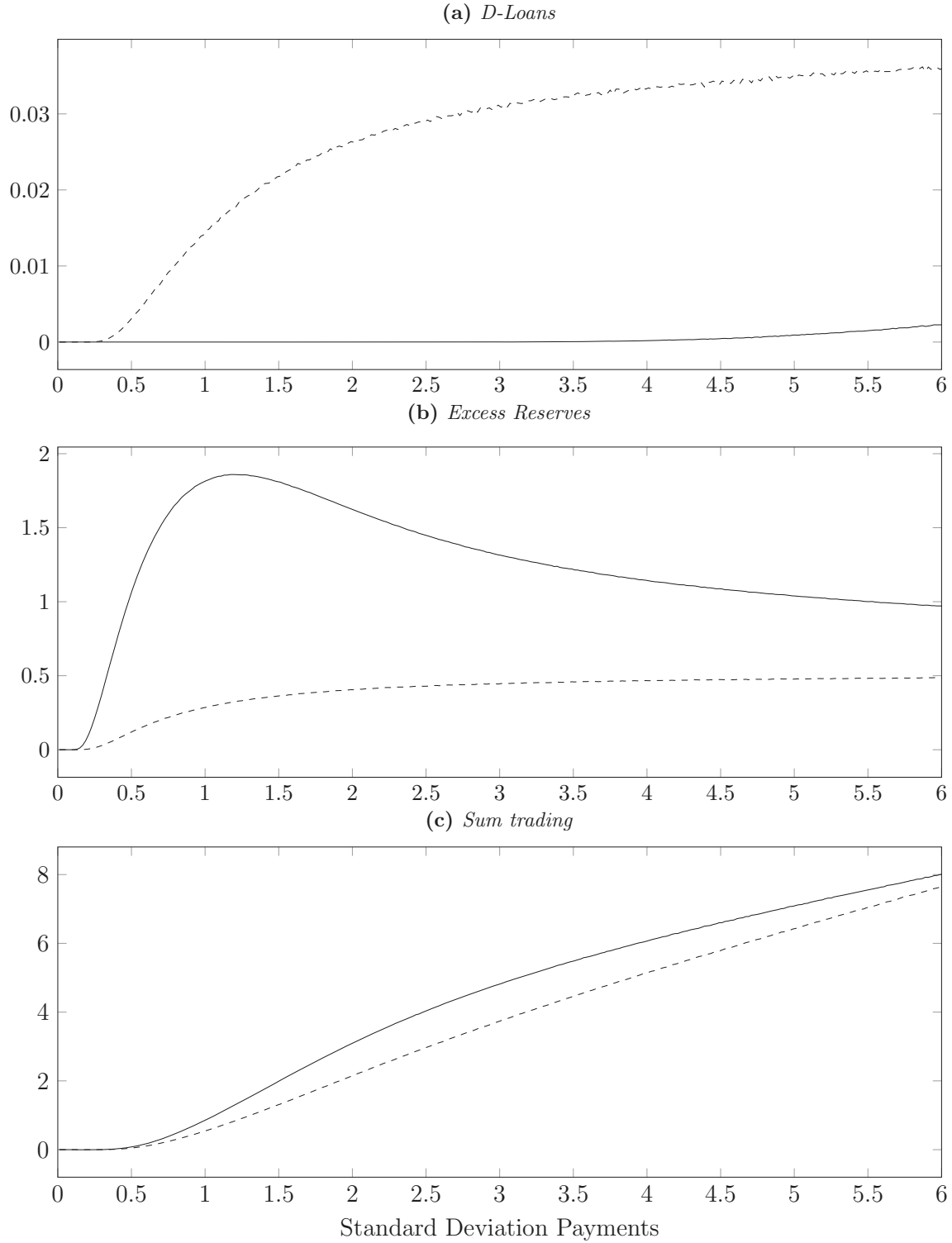


Figure A2: a) The sum of a single bank's D-deposits, b) the sum of a single bank's excess reserves and c) the total sum of a single bank's trading in the unsecured interbank market. The graphs compare when the single bank is the sole bidder for 24 units in the F-loan (solid line) versus when no banks bid (dashed line). Each observation is the average of 1 000 000 simulations for each standard deviation level.

than one bank has excess reserves. The bank is never better off participating in terms of excess reserves. The lines converge with increasing payment activity, as it is then more likely that other banks have borrowing needs resulting in more trading activity in the unsecured interbank market.

Figure A2c shows the sum of units the single bank is able to trade in the unsecured overnight interbank market. We can see that the single bank trades more if it did participate in the offsetting auction. This is because, the particular single bank is far more likely to have excess reserves and may receive a low allocation in the F-deposit auction.

In total, the single bank is worse off participating as the sole participant as the magnitude of excess reserves outweighs the magnitude of D-loans. In addition, the bank is more dependent on the interbank market to meet its liquidity needs.

D Robustness tests

Table A1 displays the result of the Tobit regressions discussed in Section 5. Table A2 displays the regression outcome for regressions similar to the main regressions in Table 2, but without interaction variables. When the interaction variables are left out of the regression, the coefficients for the binary variables for offsetting auctions for the levels of NOK 20 to 80 bn and NOK 80 to 140 bn are not significant on NOWA volumes. Table A3 provides alternative model specifications to the main regressions for traded volumes, excess reserves and D-loans. In model 1 to 3 in Table A3, we re-run the regressions from Table A2 without monthly dummies. Monthly dummies are included in the main regressions to control for market conditions not captured by the VIX-index. As the VIX-index is a measure on volatility in the U.S. stock market, it may not be directly relevant for measuring uncertainty for Norwegian banks. While the results are in general similar, there are some differences. In particular the fourth binary variable for offsetting auctions in model 2, explaining the stock of excess reserves, is significant at the five per cent level with the opposite sign compared to the second regression in Table 2. This may be due to Norges Bank offering the largest amount of offsetting auctions when uncertainty peaked and thereby causing an omitted variable bias. In model 4 to 6 in Table A2, we substitute the binary variables for offsetting auctions with the natural logarithm of offsetting auctions.³⁶ The coefficient for offsetting auctions on the traded volumes and excess reserves are negative and significant as they are in Table 2. However, the coefficient for FX-GPFG on excess reserves is now significant at the five per cent level. When the government purchases NOK, the banks trading FX have an extra venue to sell NOK and can thereby reduce excess reserves.

³⁶We only take the log of the variable when it is above zero. The variable can never be negative.

	D-Loans	NOWA Vol.
Off. auctions dum1	0.743 (3.980)	-0.213 (0.267)
Off. auctions dum2	-5.733 (4.455)	-0.242 (0.193)
Off. auctions dum3	-6.073 (4.389)	-0.435 (0.403)
Off. auctions dum4	-10.927** (5.126)	-6.341*** (1.020)
VIX-Index	8.953*** (2.923)	1.183** (0.545)
ln. Total Liquidity	9.346 (13.905)	-0.294 (0.481)
ln. FX-GPFG	-0.247 (0.640)	0.044 (0.035)
End Quarter	12.409*** (4.754)	-4.345*** (1.072)
Monthly dummies	NO	YES
Quarterly dummies	YES	NO
Observations	482	482
Pseudo R-Squared	0.148	0.318
Prob. > F	0.000	0.000

Table A1: Tobit models. *Excess Reserves* is the total amount of reserves banks have placed at the reserve rate. *D-loans* is the total amount banks have borrowed overnight from the central bank at 100 basis points above the key policy rate. *NOWA vol.* is the reported trading volumes in the unsecured overnight interbank market reported by the NOWA panel, a group of the most active banks. *Spread* is the reported interest rate on unsecured overnight interbank trading less the key policy rate. *Offsetting auctions* are the minimum of outstanding *F-loan* and *F-deposit* auctions. *Off. Auct.* *D1-D4* are binary variables for offsetting auctions when the amount corresponds to positive numbers up to NOK 20 bn, NOK 20 to 80 bn, NOK 80 to 140 bn and from NOK 140 to 200 bn. *VIX-index* is the implied 30 day volatility on the S&P 500 index at open downloaded from Bloomberg. *Total liquidity* is the sum of banks' placement of central bank reserves at the folio rate and at the reserve rate. *FX-GPFG* is the government's daily purchase of NOK for transferring from the Government Pension Fund Global to cover expenses on the national budget. During this particular period, these numbers are either zero or positive indicating that the government has not sold NOK. *Excess reserves*, *D-loans*, *NOWA volumes*, *VIX-index*, *Total liquidity* and *FX-GPFG* are in their natural logarithm form. Daily observations for all business days from 28th March 2019 to 26th February 2021. Robust standard errors in parentheses. Model for *D-loans* will not converge with monthly dummies, we are therefore using quarterly dummies. Three asterisk indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.

	NOWA Volumes	Excess Reserves	D-Loans	Spread
Off. Auctions dum1	-0.217 (0.271)	0.231 (0.282)	-0.010 (0.307)	0.349 (0.383)
Off. Auctions dum2	-0.244 (0.190)	-1.055*** (0.294)	-0.529 (0.414)	1.822 (2.226)
Off. Auctions dum3	-0.445 (0.404)	-1.280*** (0.333)	-0.590 (0.487)	4.276 (3.321)
Off. Auctions dum4	-5.971*** (0.905)	-0.996*** (0.325)	-0.463 (0.714)	1.355 (1.327)
VIX-Index	1.095** (0.539)	1.386*** (0.310)	1.046** (0.521)	-0.439 (1.080)
Total Liquidity	-0.313 (0.487)	2.445*** (0.584)	0.234 (0.430)	4.034 (6.284)
FX-GPFG	0.043 (0.036)	-0.070 (0.035)	-0.019 (0.025)	0.050 (0.058)
End Quarter	-4.204*** (1.000)	2.295*** (0.368)	0.931 (0.812)	56.630 (38.250)
Monthly dummies	YES	YES	YES	YES
Observations	482	482	482	482
R-Squared	0.764	0.501	0.124	0.376
Adj. R-Squared	0.748	0.467	0.064	0.332

Table A2: *Excess Reserves is the total amount of reserves banks have placed at the reserve rate. D-loans is the total amount banks have borrowed overnight from the central bank at 100 basis points above the key policy rate. NOWA vol. is the reported trading volumes in the unsecured overnight interbank market reported by the NOWA panel, a group of the most active banks. Spread is the reported interest rate on unsecured overnight interbank trading less the key policy rate. Offsetting auctions are the minimum of outstanding F-loan and F-deposit auctions. Off. Auct. D1-D4 are binary variables for offsetting auctions when the amount corresponds to positive numbers up to NOK 20 bn, NOK 20 to 80 bn, NOK 80 to 140 bn and from NOK 140 to 200 bn. VIX index is the implied 30 day volatility on the S&P 500 index at open downloaded from Bloomberg. Total liquidity is the sum of banks' placement of central bank reserves at the folio rate and at the reserve rate. FX-GPFG is the government's daily purchase of NOK for transferring from the Government Pension Fund Global to cover expenses on the national budget. During this particular period, these numbers are either zero or positive indicating that the government has not sold NOK. Excess reserves, D-loans, NOWA volumes, VIX-index, Total liquidity and FX-GPFG are in their natural logarithm form. Daily observations for all business days from 28th March 2019 to 26th February 2021. Robust standard errors in parentheses. Three asterisk indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.*

	NOWA Volumes	Excess Reserves	D-Loans	NOWA Volumes	Excess Reserves	D-Loans
Off. Auct. D1	-0.209 (0.268)	0.086 (0.342)	-0.076 (0.287)			
Off. Auct. D2	-0.537** (0.168)	-0.572** (0.222)	-0.310 (0.170)			
Off. Auct. D3	-1.152*** (0.246)	0.009 (0.155)	-0.215 (0.185)			
Off. Auct. D4	-5.961*** (0.612)	0.450** (0.187)	-0.434* (0.235)			
Off. Auctions				-0.087*** (0.020)	-0.050** (0.020)	-0.032 (0.030)
VIX-Index	1.397*** (0.235)	0.355* (0.184)	0.627** (0.259)	1.606** (0.641)	1.134*** (0.301)	0.956* (0.528)
Tot. Liquid.	-0.851* (0.465)	3.508*** (0.715)	0.868 (0.499)	0.354 (0.673)	2.488*** (0.578)	0.251 (0.476)
FX-GPFG	-0.059 (0.041)	-0.014 (0.035)	-0.018 (0.031)	0.003 (0.037)	-0.081** (0.036)	-0.024 (0.030)
End Quarter	-4.758*** (1.010)	2.503*** (0.433)	0.934 (0.818)	-4.578*** (1.295)	2.494*** (0.427)	1.011 (0.803)
Cons.	14.968*** (4.981)	-31.875*** (7.585)	-7.154 (5.573)			
Monthly dum.	NO	NO	NO	YES	YES	YES
Observations	482	482	482	482	482	482
R-Squared	0.555	0.248	0.070	0.663	0.477	0.120
Adj. R-Squared	0.547	0.235	0.054	0.643	0.445	0.065

Table A3: *Excess Reserves is the total amount of reserves banks have placed at the reserve rate. D-loans is the total amount banks have borrowed overnight from the central bank at 100 basis points above the key policy rate. NOWA vol. is the reported trading volumes in the unsecured overnight interbank market reported by the NOWA panel, a group of the most active banks. Spread is the reported interest rate on unsecured overnight interbank trading less the key policy rate. Offsetting auctions are the minimum of outstanding F-loan and F-deposit auctions. Off. Auct. D1-D4 are binary variables for offsetting auctions when the amount corresponds to positive numbers up to NOK 20 bn, NOK 20 to 80 bn, NOK 80 to 140 bn and from NOK 140 to 200 bn. VIX-index is the implied 30 day volatility on the S&P 500 index at open downloaded from Bloomberg. Total liquidity is the sum of banks' placement of central bank reserves at the folio rate and at the reserve rate. FX-GPFG is the government's daily purchase of NOK for transferring from the Government Pension Fund Global to cover expenses on the national budget. During this particular period, these numbers are either zero or positive indicating that the government has not sold NOK. Excess reserves, D-loans, NOWA volumes, VIX-index, Total liquidity and FX-GPFG are in their natural logarithm form. Daily observations for all business days from 28th March 2019 to 26th February 2021. Robust standard errors in parentheses. Three asterisk indicate $p < 0.01$ while two indicate $p < 0.05$ and one indicates $p < 0.10$.*

E Identifying unsecured overnight interbank loans

In an earlier paper, Akram and Findreng (2021) develop an algorithm to identify unsecured overnight interbank loans in Norges Bank’s Real Time Gross Settlement (RTGS) system based on the original work of Furfine (1999, 2000, 2001, 2002). The same algorithm is tested and verified in Akram et al. (2019), where the authors had access to real data provided by the banks through a survey and successfully identified the same loans using the algorithm. The procedure identifying unsecured overnight interbank loans is described broadly following Akram and Findreng (2021) and Findreng (2021).

All transactions settled in Norges Bank between banks goes through and is stored in the RTGS system, and only a small fraction of these transactions relate to unsecured overnight interbank loans. The algorithm searches through all transactions stored in the RTGS system for the relevant period and identifies transactions with a typical loan size. In our case, amounts that are in whole millions. Every time such an amount is identified, it is stored as V_t . The algorithm then moves on to searching through all transactions going in the opposite direction on the consecutive business day. An unsecured overnight interbank loan is identified if the algorithm identifies a repayment, V_{t+1} , equal to the original amount plus an amount that is considered a feasible interest payment. The interest rate $i_t = (\frac{V_{t+1}}{V_t} - 1) \cdot 365$, must be within a predefined bandwidth around the key policy rate, in our case ± 70 basis points. Furthermore, to be deemed feasible, the interest rate must follow market convention and be quoted with a maximum of three decimals, similar to Demiralp et al. (2006) and Frutos et al. (2016). However, the smallest monetary unit in the RTGS system is $\frac{1}{100}$ NOK, and due to rounding error, the implied interest rate will in most cases deviate from the exact quoted rate. The identified interest rate is therefore allowed to deviate somewhat from the restriction of maximum three decimals, but must comply with the following maximum error condition:

$$\frac{|(i_t \times 100000) - \text{round}(i_t \times 100000)|}{100000} \leq \left(\frac{0.005}{V_t}\right) \times \frac{365}{\text{days}}. \quad (\text{A1})$$

where *days* is the number of calendar days between the two consecutive business days.

E.1 Identifying loans in a zero interest rate environment

Comparing reported NOWA volumes with the identified volumes using the modified Furfine algorithm imposes some challenges.³⁷ On one side, the modified Furfine procedure may identify loans not included in the NOWA reporting as smaller banks do not report unsecured overnight interbank lending. On the other side, the algorithm may miss unsecured overnight interbank loans if the loans are not in a typical size (round to the nearest million) or if the interest rate is quoted in more than three decimals.

Another potential identification problem may arise if the interest rate on the unsecured interbank loan is zero per cent. If the sent amount is the same as the returned amount, one would not know whether the returned amount is the first leg in another transaction or a repayment for a loan with longer maturity. Figure A3 shows the reported NOWA volumes less the identified volumes by using the modified Furfine algorithm. The leftmost dashed line represents May 8th 2020, when Norges Bank set the key policy rate to zero. In the period before May 8th, we can see that the difference is small and mostly negative. That is, the modified Furfine procedure estimated on average unsecured overnight interbank lending of 283 million more than the reported NOWA volumes. This may represent lending between banks not part of the NOWA reporting scheme. During the first period in the zero rate environment, there were no NOWA volumes reported before June 12th 2020 (the rightmost dashed

³⁷Norges Bank has provided us with daily volumes and rates identified with the modified Furfine algorithm. We have also received data on average lending and borrowing by quota group association in the two time periods from March 28th 2019 to March 12th 2020 and March 13th 2020 to February 26th 2021 presented in Table 3. We do, however, not have the daily split between quota groups on a daily base.

graph). Hence, the trend of the algorithm identifying higher volumes continues in this short period. However, from June 12th and until the end of the period, NOWA volumes were reported daily. During this time period, the algorithm identified on average daily loans of 16 728 million less than the reported NOWA volumes. The difference is even larger on the 148 days when the reported NOWA rate is zero. On those days, the difference is NOK 20 091 million compared to NOK 2 506 million on average over those 35 days when the reported NOWA rate is not zero. This indicates that the modified Furfine algorithm underestimates reported NOWA volumes systematically when the interest rate is zero and may explain the differences between Table 1 and Table 3 in Section 5.

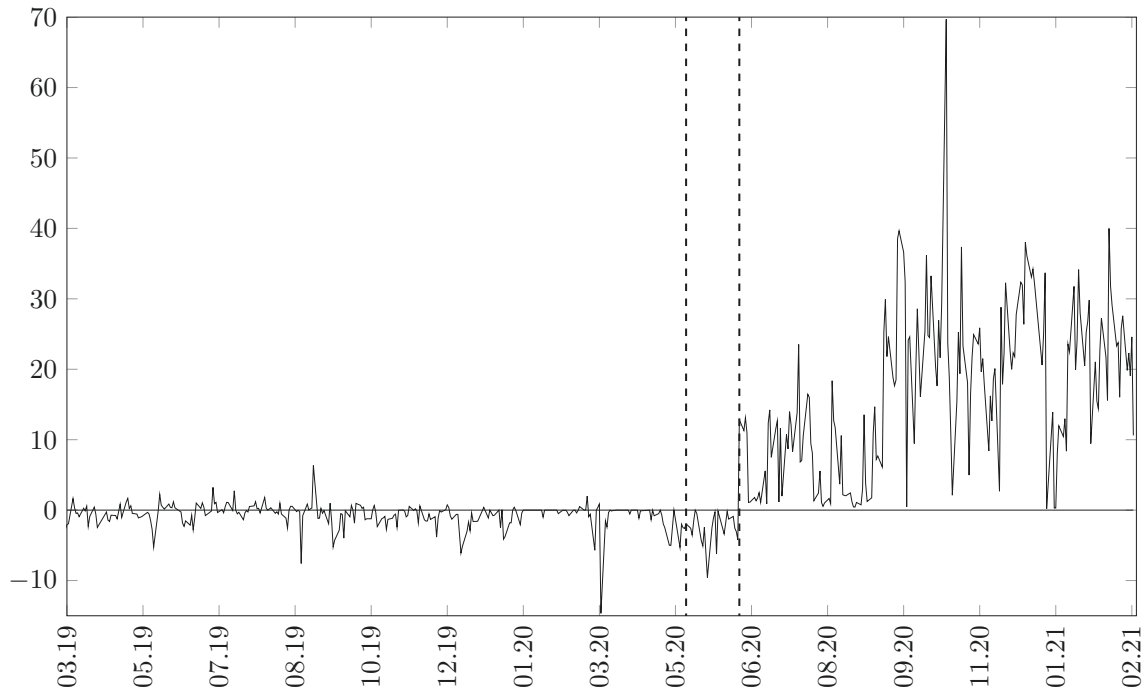


Figure A3: The graph displays the reported NOWA volumes for unsecured overnight interbank lending less the identified volumes using the modified Furfine algorithm in NOK billions. The leftmost dashed vertical line represent May 8th 2020 when the key policy rate was set to zero. The rightmost dashed vertical line represent June 12th 2020, which is the first days in the zero rate environment with reported NOWA volumes. There are reported NOWA volumes every day in the remaining period of the sample.

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PUBLICATIONS AND WORKING PAPERS

- "Peer Monitoring vs. Search Costs in the Interbank Market: Evidence from Payment Flow Data in Norway." Working paper Norges Bank May 2021.
- "Norwegian interbank market's response to changes in liquidity policy", with Farooq Q. Akram. Journal of Banking and Finance Feb. 2021.
- "Relative Purchasing Power Parity and the European Monetary Union: Evidence from East Europe." Journal of Scientific Papers - Economics and Sociology May 2014.