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# Norwegian interbank market's response to changes in liquidity policy

Q. Farooq Akram and Jon H. Findreng\*

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## Abstract

We investigate pricing and activity in the Norwegian unsecured overnight interbank market in response to a shift in the central bank's liquidity policy. In October 2011, to encourage interbank trading, banks were allotted quotas for their overnight deposits with remuneration at the key policy rate while that on overnight deposits beyond allotted quotas was set one percentage point lower. In addition, a target range for banks' total overnight deposits was introduced and supported by open market operations to counteract not only temporary liquidity shortfalls, but also surpluses. We document substantially higher interbank trading, lower interbank interest rates relative to the policy rate as well as lower interest rate volatility following the policy shift. Notably, while overnight interbank interest rates were generally above the key policy rate before the policy shift, they have been close to but generally below the key policy rate afterwards.

**Keywords:** *Overnight interbank market, liquidity policy, regime-switching models.*

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

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\*This working 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 are thankful to colleagues for useful comments, especially Bjørn Bakke, Eric F. Schaanning, Tom Bernhardsen, Sigbjørn A. Berg, Mats Fevolden, Olav Syrstad and Kjetil H. Watne. Many thanks to Eyo Herstad for able research assistance. Correspondence: farooq.akram@norges-bank.no.

# 1 Introduction

We investigate pricing and activity in the Norwegian overnight interbank market in response to a more restrictive liquidity policy primarily intended to encourage interbank trading. 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. \(2015\)](#). The turnover in the Norwegian interbank market also declined substantially and remained relatively low for an extended period; see e.g. [Norges Bank \(2009, pp. 72–76\)](#) and [Akram and Christophersen \(2013\)](#). The fall in interbank activity was accompanied by a relatively large increase in banks' trading with Norges Bank, the central bank, through participation in its ordinary and extraordinary liquidity auctions.

To encourage interbank trading, 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, banks' overnight deposits have been remunerated at the key policy rate up to allotted quotas, while excess deposits have been remunerated at the reserve rate, set one percentage point below the key policy rate. A target range for banks' total overnight deposits, i.e. total liquidity, was also introduced and short term liquidity auctions have been undertaken to keep it within the range. In particular, short-term deposit auctions have been used quite actively to counteract temporary liquidity surpluses; such deposits had not been auctioned for more than eight years prior to October 2011.

The total value of allotted deposit-quotas across banks has been above the target level of total liquidity. Thus, it has been feasible for banks to fully deposit their liquidity at the key policy rate through trading actively in the interbank market. The cost of depositing excess liquidity at the reserve rate has been expected to encourage interbank trading and reduce banks' reliance on the central bank for managing and meeting their liquidity needs. Moreover, the avoidance of large liquidity surpluses through deposit auctions have been expected to induce interbank trading by maintaining trading needs. Previously, while overall liquidity shortages

were counteracted through fixed-term loan auctions, overall liquidity surpluses were accepted, reducing banks' demand for liquidity; see [Norges Bank \(2012\)](#) for details.

Our investigation focuses on unsecured overnight interbank trading, which may account for around 3/4 of total overnight trading and about 90% of all unsecured trading in the Norwegian money market; see [Norges Bank \(2013, 2014b, 2015\)](#) for evidence based on money market surveys.<sup>1</sup> Our measures of interbank trading include the number and volume of loans and the number of interbank market participants. Regarding pricing, we focus on whether and how the policy change has affected the interbank rates relative to the key policy rate, their volatility over time and dispersion across banks. A 'deeper' interbank market with more trading among a larger number of participants may contribute to lower interest rate volatility and smaller dispersion of interest rates across banks. A related question is to what extent the key policy rate, i.e. the overnight interest rate for within-quota deposits, has prevailed in the interbank market. When banks have opportunities to hold liquidity in the central bank at two and quite often three different rates: the policy rate, the reserve rate and the fixed-term deposit auction rate, the typical level and volatility of interbank rates may shift relative to the period when only the policy rate was available.

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 is not publicly available, we employ a Furfine-based procedure to infer overnight interest rates from the real-time gross settlement (RTGS) system of Norges Bank; see [Furfine \(1999, 2001\)](#). By a careful examination of the flows of funds between banks, fairly precise information can be obtained about amounts borrowed and overnight interest rates paid by banks; see e.g. [Kovner and Skeie \(2013\)](#) and [Akram and Christophersen \(2014\)](#) for some recent evidence. We additionally refine the Furfine-procedure by assuming that interbank participants quote and agree on overnight rates with values that do not differ from each other by more than 1/10 of a basis point, at most; cf. [Demiralp,](#)

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<sup>1</sup>Such shares are relatively lower in e.g. the UK and euro area; see e.g. [Bank of England \(2016\)](#) and [ECB \(2015\)](#).

Preslopsky, and Whitesell (2006) and Vaughan and Finch (2017). This assumption is supported by our queries to several Norwegian interbank market participants. We complement our analysis of the obtained time series of interbank trading and interest rate variables with Markov regime-switching models in which dates of possible regime shifts are not imposed; see Hamilton (1989).

To summarise our main findings, we document a substantial increase in interbank activity as measured by daily turnover, the numbers of loans and interbank market participants immediately or shortly after the policy shift. The level and the volatility of overnight interest rates (relative to the key policy rate) as well as their variance across banks decline after the policy shift. Notably, the average spread is 5.3 basis points before the policy shift and  $-2.6$  basis points afterwards which is close to the average spread of fixed-term deposits' interest rates and clearly higher than the reserve rate. Notably, most of the interest rates (96% ) since the policy shift are observed below the key policy rate.

Policies aimed at improving the functioning of interbank markets after the financial crisis have been the focus of much academic and policy debate since the financial crisis; see e.g. Allen et al. (2009), Affinito (2013), Brunetti et al. (2011), Acharya et al. (2012) and Gale and Yorulmazer (2013). Our results may therefore be of general interest. In particular, they 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 surplus of total liquidity to obtain interbank interest rates close to the overnight deposit rate. In the new system, which may be referred to as a corridor 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 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 beyond-quota surplus liquidity with the central bank. Moreover, the central bank aims to keep total liquidity within a

corridor, centered around a level of total liquidity considered sufficient for smooth interbank transactions in general.<sup>2</sup>

The paper is organised as follows. Section 2 briefly describes the objectives and instruments of Norges Bank's liquidity policy and the policy changes in October 2011. Section 3 presents the data and the Furfine-based method employed for identifying overnight interbank loans and associated overnight rates. Section 4 analyses overnight lending and corresponding interest rates identified over the sample period. We focus on detecting possible shifts in their behaviour before and after the policy change. To this end, in Section 5 we also use threshold models including Markov switching models. Section 6 presents the conclusions. Some evidence on the reliability of the Furfine-based algorithm is presented in the appendix.

## 2 Liquidity policy - objectives and instruments

A well-functioning interbank market is important for banks' payment and credit intermediation, and trading for investment and risk management. It is also important for the effectiveness of the monetary policy transmission mechanism and achieving monetary policy objectives. Moreover, an active interbank market may promote financial stability through peer monitoring; see e.g. [Rochet and Tirole \(1996\)](#) and [Furfine \(2001\)](#). Interest rates paid by a bank could indicate its default risk, especially when interbank lending is unsecured; see e.g. [Vaughan and Finch \(2017\)](#).

Activity and pricing in an interbank market depend to a large extent on the role and behaviour of the central bank; see e.g. [Prati et al. \(2003\)](#) and [Bartolini and Prati \(2006\)](#). Central banks influence interbank markets through their policy rates and by regulating the liquidity stance in money markets; see e.g. [Stigum and Crescenzi \(2007\)](#). They also influence interbank markets by altering the design and terms of their liquidity auctions and the remuneration of banks' deposits at central banks. Central banks' liquidity policies generally encourage interbank activity, not least to

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<sup>2</sup>For details, see e.g. [Bernhardsen and Kloster \(2010\)](#) and [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/](http://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/)

limit banks' reliance on central banks for meeting their liquidity needs. Liquidity provision to banks exposes central banks to credit risk, which if materialized can reduce their equity and possibly independence vis a vis fiscal policy authorities.

In the following, we describe Norges Bank's liquidity policy objectives and its main instruments. Norges Bank's liquidity policy has three main objectives; see e.g. [Norges Bank \(2014a, 2016\)](#). First, banks must have adequate liquidity to meet their short-term needs stemming from day to day activities.<sup>3</sup> Second, the key 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 the central bank.

The interest rate on banks' (regular) overnight deposits at Norges Bank is the key policy rate; see [Norges Bank \(2016, pp. 19–20\)](#). All banks established in Norway including branches and subsidiaries of foreign banks may have deposit accounts with Norges Bank.<sup>4</sup> Transactions between banks due to e.g. interbank loans and transfers between customers of different banks may be settled by debiting these deposit accounts. To ensure that banks can honour their debts in payment settlements, they need to have access to Norges Bank's standing liquidity facilities. Intraday borrowing from Norges Bank is interest-free while overnight borrowing commands interest rate of one percentage point above the overnight deposit rate.

Norges Bank conducts open market operations through competitive multi-price fixed-term loans and deposits auctions. The maturities of such loans and deposits, hereafter referred to as F-loans and F-deposits, respectively, range from overnight to usually a week and one month at most; extraordinary fixed-term loans auctioned at the height of the financial crisis in 2008 are exceptions; see e.g. [Bernhardsen et al. \(2009\)](#). Auctions are usually announced in the morning or a day ahead when actual or predicted total liquidity, i.e. banks' total overnight deposits, deviates from Norges Bank's operational target for total liquidity.

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<sup>3</sup>Norges Bank does not impose any reserve requirements on banks.

<sup>4</sup>See <https://lovdata.no/dokument/SF/forskrift/2009-02-25-240>, for more information on foreign banks' access to Norges Bank's standing facilities.

## 2.1 Shifts in liquidity policy

Until 3 October 2011, banks' overnight deposits at Norges Bank were remunerated fully and equally at the key policy rate; see e.g. [Norges Bank \(2012, 2016\)](#). The key 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 interest rates.<sup>5</sup>

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. Since then, banks can only get their overnight deposits remunerated at the key policy rate up to allotted limits, while excess deposits are remunerated at the reserve rate, set one percentage point below the key policy rate. Banks have been grouped, reflecting their gross payment transactions, and allotted deposit limits accordingly.

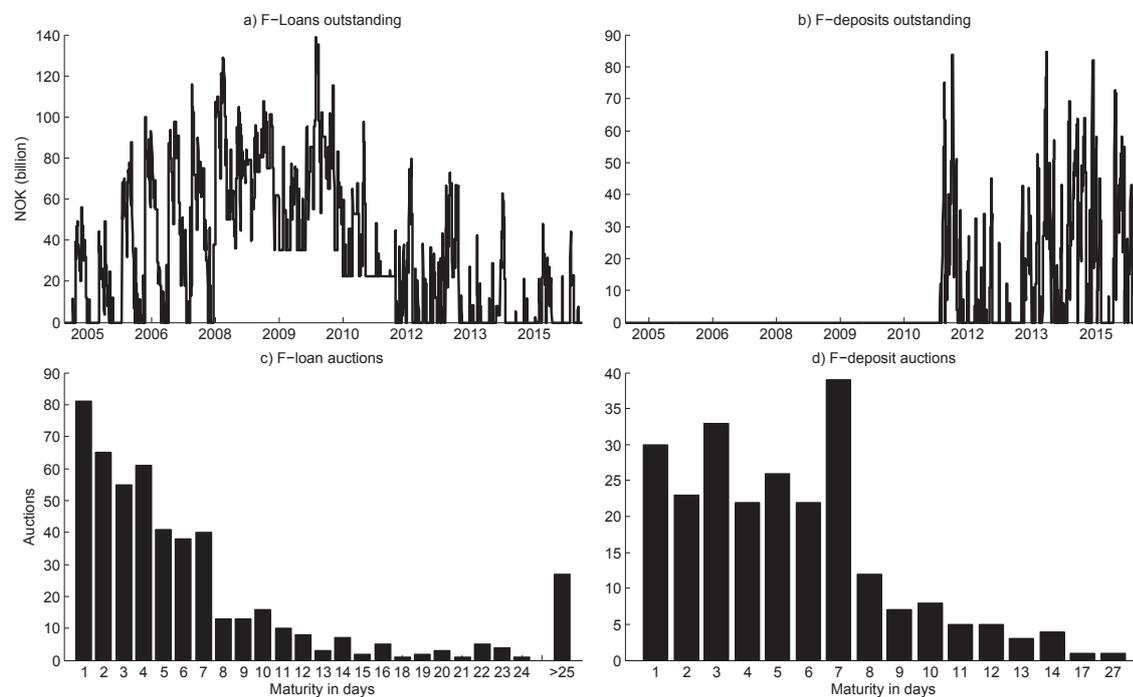
Importantly, the sum of allotted deposit limits that are remunerable at the key policy rate has been set at a higher level (NOK 45 bn) than the operational target for total liquidity, NOK 35 +/- 5 bn. This has allowed banks to deposit all of their liquidity at least at the key policy rate through trading actively in the interbank market. Passive banks with liquidity above their allotted limits have faced remuneration of their excess liquidity at the reserve rate. Thus, not only banks expecting liquidity shortage by the end of a day have incentives to search and borrow from other banks, but also banks with liquidity above their quotas have incentives to lend actively in the interbank market.

To keep total liquidity within the target range, NOK 35 +/-5 bn, Norges Bank has conducted open market operations through both F-loans and F-deposits. Without such operations, transfers between banks' and the government's account with Norges Bank would have led to relatively large fluctuations in total liquidity. For example,

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<sup>5</sup>Occasionally, 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, as a charge for immediacy. 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 \(2009\)](#).

payments of taxes reduce liquidity available to banks while the payments of pensions, salaries to public employees, social security and unemployment benefits as well as government’s purchases of goods and services increase liquidity.



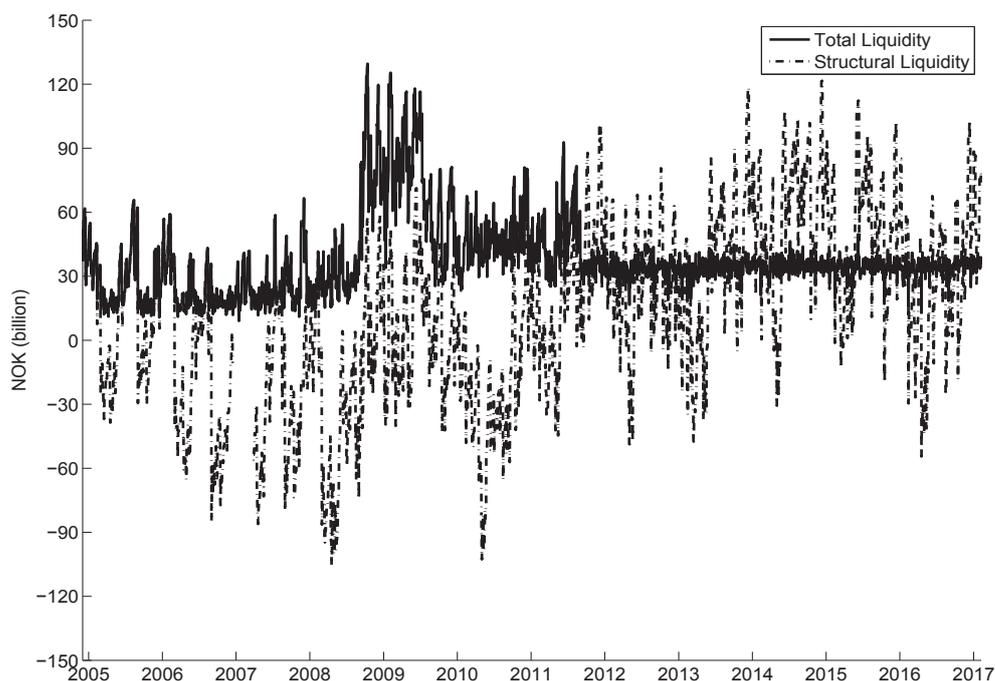
**Figure 1:** Total outstanding a) F-loans, b) F-deposits and the number of auctions across maturities (c and d) over the period 2 January 2005 to 7 January 2016. Figure a) also includes one F-loan with a floating rate NIBOR 6 month + 20 basis points), maturity 13. February 2009 to 13 February 2012, and value NOK 22 625 mill.

F-deposit auctions, which had not been held since 20 March 2003, have been an important feature of the new liquidity regime; see [Norges Bank \(2014a\)](#) for details. They have helped avoid increases in total liquidity beyond the target range (NOK 40 bn) and particularly kept it below the sum of allotted deposit limits remunerable at the key policy rate (NOK 45 bn). Thus, incentives for interbank trading have been maintained.<sup>6</sup>

Figures 1.a–b display auctioned values of F-loans and F-deposits over the period 2 January 2005 to 7 January 2016. F-loans were relatively large during the period 2008–2010 coinciding with the financial crisis but have been relatively smaller since

<sup>6</sup>Loan and deposit transactions with the central bank may occasionally be an alternative to interbank trading, however. A reduction in the supply of F-loans may encourage interbank activity while a supply of F-deposits may have the opposite effect. This could be the case on auction days if F-loans and F-deposits have overnight maturity. [Norges Bank \(2014a, p. 18\)](#) suggests some decline in interbank activity on such days, but it has been relatively small.

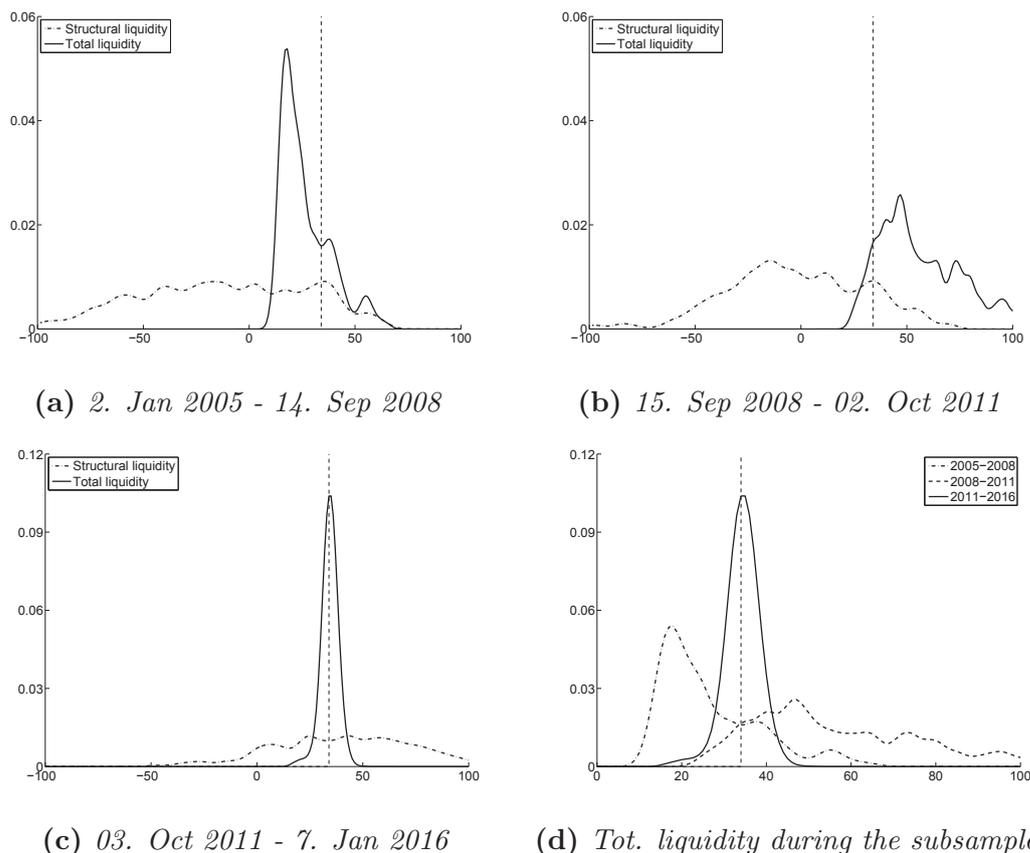
2011. While no F-deposit was auctioned (from 20 March 2003) until 3 October 2011, they have been offered quite frequently since then, that is, about weekly (4.6 times per month) on average. Figures 1.c-d show that the maturities of F-loans and F-deposits auctioned over the whole sample period has been mostly within the 1–7 days range. The average maturities of F-loans and F-deposits are 5 days since the policy shift. The average spread between the weighted average interest rate in deposit auctions and the policy rate has been  $-2.2$  basis points.



**Figure 2:** *Total and structural liquidity (dashed) from 2 Jan 2005 to 7 Jan 2016.*

Figure 2 displays daily time series of total liquidity and structural liquidity, which is defined as total liquidity adjusted for F-loans and F-deposits. We observe large fluctuations in structural liquidity primarily owing to transfers of liquidity to and from the government’s account at Norges Bank. Until the policy shift in October 2011, total liquidity exceeds or equals structural liquidity because negative liquidity shocks have been counteracted through F-loans while positive liquidity shocks have been accommodated, as F-deposits have not been used making total liquidity increase with structural liquidity. Since the policy shift, total liquidity has been largely disconnected from structural liquidity as both positive and negative

liquidity shocks have been counteracted through F-deposits and F-loans, respectively. Total liquidity has therefore been relatively stable and mostly fluctuated within the target range. The relatively large increases and high level of total liquidity from October 2008 to October 2011 are also due to the extraordinary liquidity supply during the financial crisis through F-loans of relatively long maturities ranging from 92 to 731 days and foreign exchange swaps.



**Figure 3:** Probability density functions of total and structural liquidity in NOK bn using data from three subsamples. Dashed vertical line indicates NOK 35 bn, the operational target for total liquidity after the policy shift.

Figures 3.a–d display probability density functions of total and structural liquidity series before and after the liquidity policy shift. We note that while the ranges and shapes of structural liquidity distributions have been comparable over the subsamples, both the ranges and the shapes of total liquidity have changed substantially over time reflecting the prevailing liquidity policy and the use of F-loans and F-deposits. Notably, Figures 3.a and 3.b reflect the ‘floor system’ in which total liquidity is bounded downward, while Figure 3.c reflects a ‘corridor system’ in which

total liquidity is bounded both downward and upward and is apparently symmetric around its target level NOK 35 bn.

To summarise, we have documented changes in the distribution of total liquidity consistent with the shift in liquidity policy. Notably, it has largely varied symmetrically within a relatively smaller range than in the periods before the liquidity policy shift; see Figure 3.d. To this end, both F-loans and F-deposits have been used actively to counteract negative and positive aggregate liquidity shocks, respectively.

To investigate the response of interbank activity and pricing to the liquidity policy shift, we need data on overnight interbank loans and associated interest rates. The next section explains how we derive such data from our sample of interbank payments data recorded in Norges Bank’s real-time gross settlement system (RTGS). Interbank payments data available to us are from 17 April 2009 – 7 January 2016, which restricts us from analysing interbank activity and pricing in the earlier periods.

### 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 30–40 banks have used it on a daily basis. Most of the banks use the system for gross settlement of large-value and time-critical payments, such as those associated with overnight interbank loans. After ignoring transactions that can be ruled out as unsecured overnight loans, we extracted a total of 1 674 664 transactions from the system covering the sample period.<sup>7</sup> The average daily value of these transactions is NOK 153.6 bn, about USD 24.4 bn 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 lending. We mainly proceed as [Furfine \(1999, 2001\)](#) to separate overnight loans from all of the other extracted RTGS transactions. In essence, the

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<sup>7</sup>Ignored 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.

procedure classifies a pair of transactions between two banks on consecutive business days as an overnight loan if the amount transferred on a day ( $V_t$ ) is a round 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 rates.<sup>8</sup> It is common to restrict the transferred amount to a round value as banks 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 value ( $V_t$ ) is a round value in NOK millions and the implied interest rate ( $ii$ ), defined as:

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

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 become sensitive to the assumed bandwidth.

To increase the reliability of the Furfine-algorithm, we additionally require the implied interest rate in % ( $ii \times 100$ ) to be a plausible quoted interest rate, that is a number with no more than three decimals. Market participants seem to generally quote interest rates in annual terms and mostly with two decimals, i.e. in basis points, but sometimes with three decimals for particularly large loan amounts.<sup>9</sup> The decimal restriction may also help avoid matching  $V_t$  with repayment of a loan with longer maturity. If the interest rate band imposed has an upper limit higher than e.g. twice the central bank's overnight rate, an algorithm without the decimal restriction can wrongly classify repayment of a loan with two days maturity as a repayment

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<sup>8</sup>It is not possible to extract information from the RTGS system indicating whether a loan has been initiated by a borrower or a lender. Nor does the system contain information on whether transacting banks are borrowing or lending themselves or just transacting on behalf of other banks or institutions that do not have direct access to the deposit and lending facilities of Norges Bank.

<sup>9</sup>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 implied interest rate can deviate slightly from the corresponding actual interest rate if agreed with three decimals between two banks. An implied rate in % ( $ii \times 100$ ) is therefore treated as a valid interest rate if it does not disagree with its rounded value, down to three decimals, by more than the maximum of the potential rounding error in the repayment transaction. That is:

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

of an overnight loan. Unsecured interbank loans in NOK of longer maturities than overnight are anyway negligible according to money market surveys; see e.g. [Norges Bank \(2013\)](#).

The analysis presented in this paper is based on a bandwidth of  $i_{cb} \pm 70$  basis points where  $i_{cb}$  denotes the key policy rate. The chosen band is symmetric around the key policy rate to allow interbank rates to be both below and above the key policy rate after the policy shift. The width is chosen to avoid including zero interest rate as the key policy rate is 0.75% in the last period of our sample. Identification of overnight interbank loans may deteriorate if sent and returned amounts may be equal, which would be the case if the bandwidth allows for interbank overnight loans at zero interest rate.

Appendix B evaluates the properties of the employed algorithm. It is shown that the sets of identified loans and interest rates are fairly invariant to changes in the bandwidth.<sup>10</sup>

## 4 Interbank overnight interest rates and activity

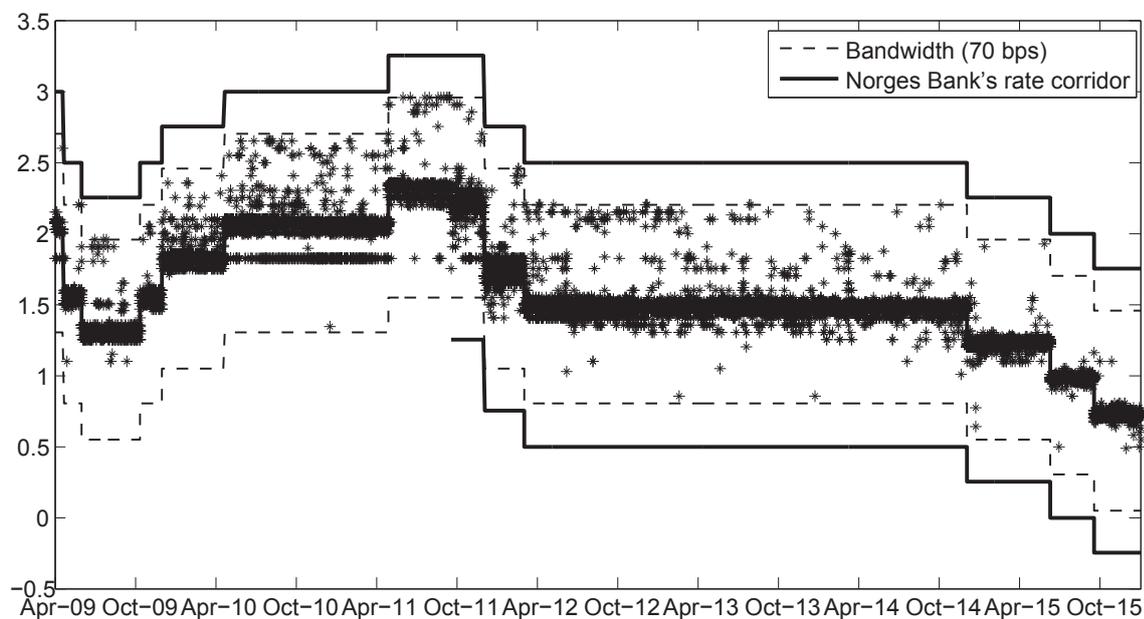
The following subsection presents (implied) interest rates for the individual overnight loans over the whole sample period as well as the constructed market-wide measure of overnight interbank rates, NONIA. The second subsection presents and discusses the time series behaviour of various implied measures of overnight interbank activity such as daily turnover, number of loans and number of market participants. A more rigorous investigation of possible shifts in market-wide overnight interest rates and various interbank activity measures using regime-switching models is provided in [Section 5](#).

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<sup>10</sup>By choosing a floating bandwidth where the implied interest rate needs to be between  $\max\{i_{cb} + 110 \text{ bps}, i_{cb} \times 1.934\}$  and  $\min\{i_{cb} - 110 \text{ bps}, 5 \text{ bps}\}$ , the number of identified loans is increased by 0.67%.

## 4.1 Identified overnight interbank rates

Figure 4 shows implied overnight rates associated with all of the identified individual loans (19 889) over the sample period. The identified loans are associated with 2.38% of the transactions extracted from the RTGS system.



**Figure 4:** *Overnight interbank interest rates associated with the 19 889 overnight loans identified by the algorithm implemented. Solid lines: Norges Bank's overdraft rate, deposit rate (key policy rate) and the reserve rate from 3 October 2011 onwards. The dashed lines indicate the bandwidth (key policy rate  $\pm 70$  basis points). Unless stated otherwise, the sample period is 17 April 2009 to 7 January 2016 here and elsewhere in the remaining paper.*

We observe that most interest rates are clustered around the key policy rate, though asymmetrically. There is a larger dispersion of interbank interest rates above the policy rate than below it. None of the implied interest rates were found to exceed the overdraft rate when the bandwidth was relaxed to allow for that. 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 any liquidity at Norges Bank. Resident banks may accept liquidity from e.g. foreign banks at a lower rate than the deposit rate, as a charge for immediacy. After the policy shift, also resident banks with excess liquidity may be willing to place liquidity at interest rates below the key policy rate.

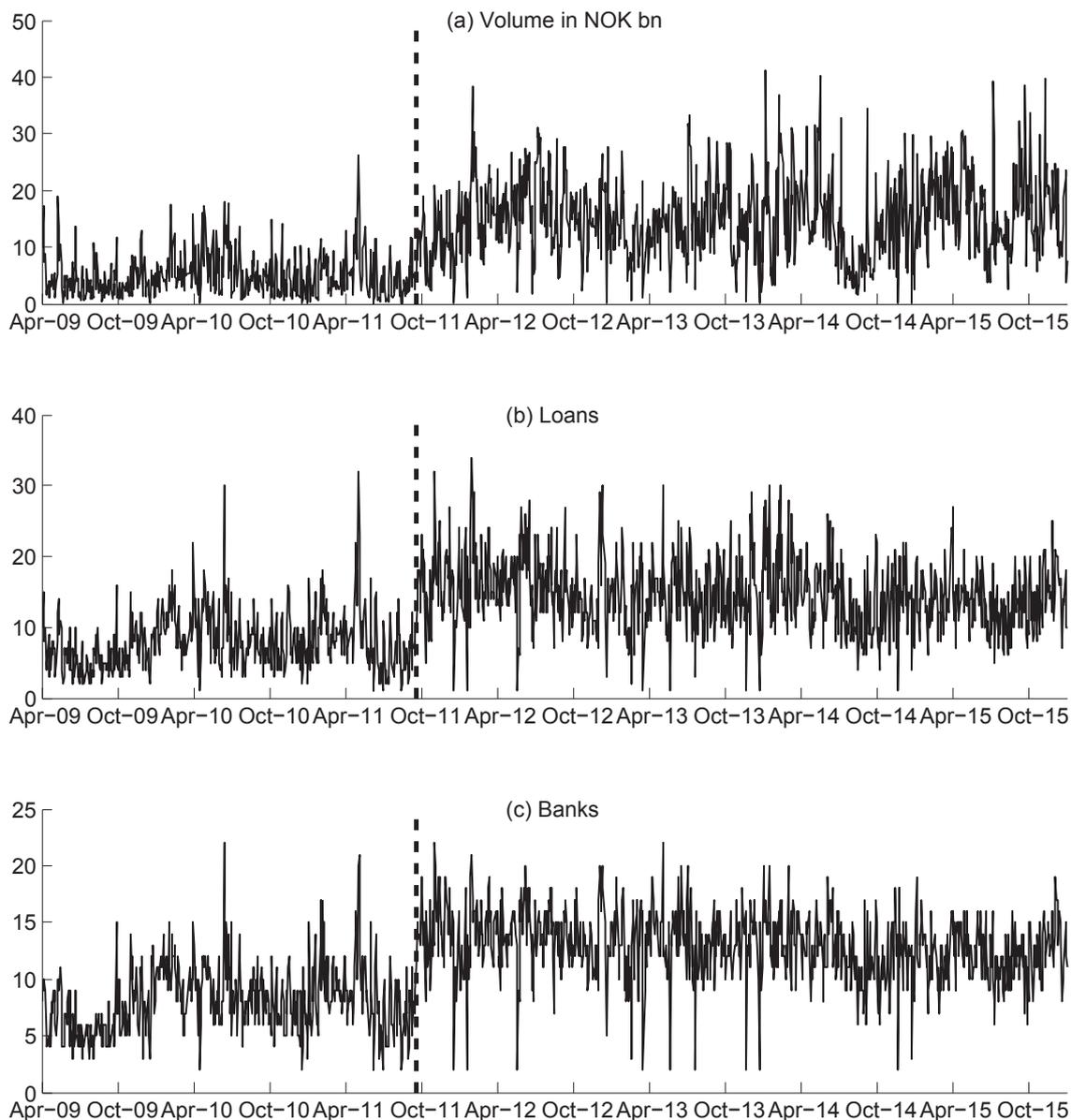
We note, however, that only a few of the interest rates are close to the reserve rate, say by being close to the assumed lower band of the interest rates: key policy rate – 70 basis points. Before and after the policy shift date, 95.8% and 98.4% of the observations, respectively are within a 30 basis points range ( $\pm 15$  basis points) from the policy rate. While Figure 4 does not give a clear impression of a systematic and significant fall in interbank interest rates relative to the key policy rate from 3 October 2011 onwards, evidence presented in Sections 4.3 and 5 suggests this to be the case.

## 4.2 Interbank activity

The sample of overnight interbank loans corresponding to the interest rates presented above suggests that 33 different banks have participated in the overnight interbank market. In total, this constitutes less than 1/4 of the banks with access to the RTGS system. These banks are large Norwegian banks and branches and subsidiaries of foreign banks. Among the 33 participants, 32 banks have acted as lenders. Of these, 29 banks have also borrowed during the sample period. In addition, one bank has solely borrowed during the sample period. Over the sample period, there have been 1 to 14 different borrowers and 1 to 19 different lenders in a day. It is not uncommon for lenders and borrowers to undertake several overnight loan deals daily. The sample average is around 1.10 loans per participating bank, though.

We observe substantial variation in the total daily volume, the daily number of overnight loans and the number of market participants in a day. Figure 5.a shows that the total daily value of all loans varies from 25 million to NOK 41.2 billion while Figure 5.b shows the number of loans per day to vary between 1 and 34. The number of market participants in a day has varied from 2 to 22 over the sample period; see Figure 5.c.

Figures 5.a–c suggest an increase in the average values of the three activity measures immediately or shortly after the policy shift. Moreover, the ranges of daily variation in volume, the number of loans and the number of participating banks have also increased. This has been due to an increase in their maximum



**Figure 5:** (a) Daily volume, *i.e.* total value of overnight loans in a day in NOK bn, (b) the number of overnight loans and (c) the number of different participants in a day over the sample period. The dashed vertical line marks 3 October 2011.

values, while their minimum values have remained unchanged. However, all of the three activity measures occasionally take on values comparable to those in the period before 3 October 2011.

### 4.3 Market-wide overnight interest rates (NONIA)

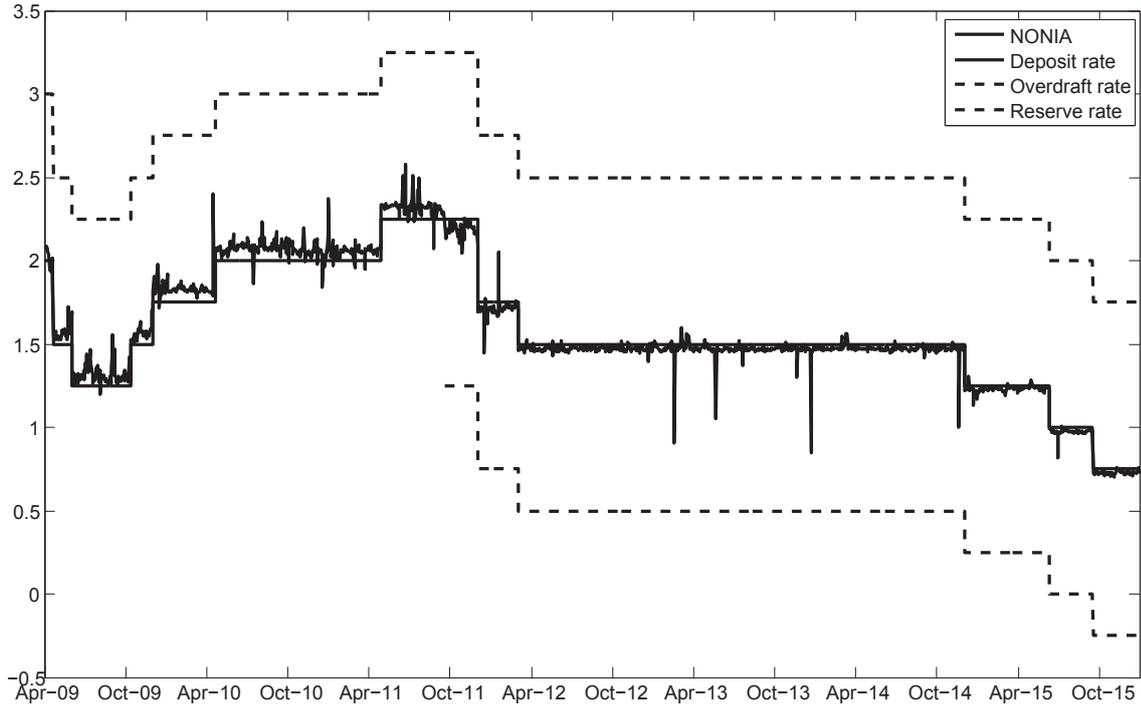
There is a relatively large variation in overnight interest rates across interbank loans as shown in e.g. Figure 4. We summarise their behaviour over time using an indica-

tor of the market-wide actual overnight interest rates termed Norwegian OverNight Index Average (NONIA); see Akram and Christophersen (2013). It is a loan-weighted average interest rate based on implied interest rates of all identified overnight loans on a given day. Each of the interest rates is weighted in accordance with the value of the corresponding loan relative to the total value of all loans on a given day:

$$NONIA_t = \sum_{j=1}^{J_t} \omega_{j,t} i_{j,t}, \quad (3)$$

$$\omega_{j,t} = \frac{V_{j,t}}{\sum_{j^*=1}^{J_t} V_{j^*,t}}. \quad (4)$$

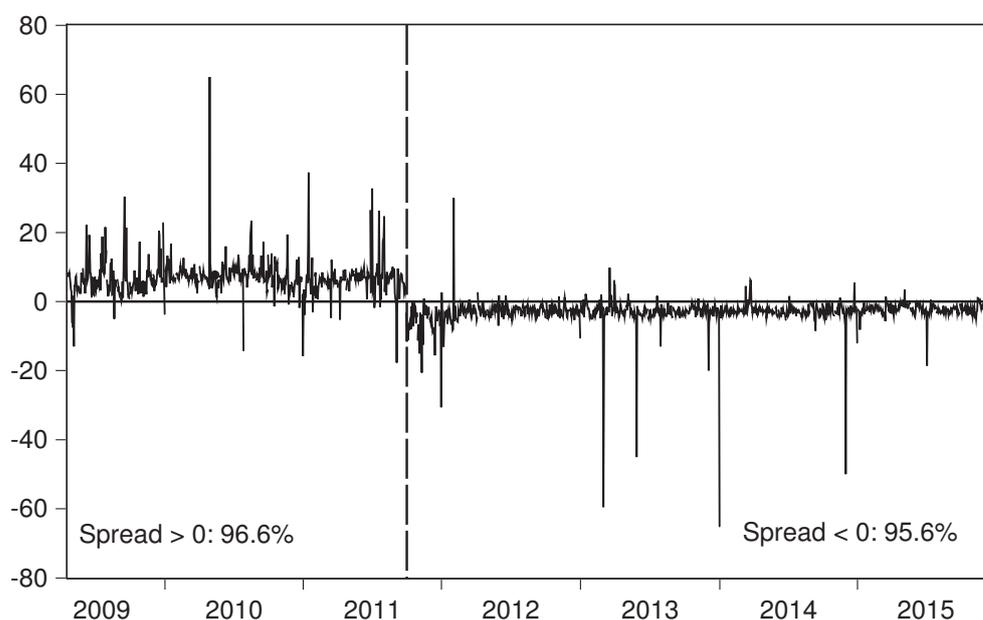
$\omega_{j,t}$  represents the weight given to interest rate  $j$  on day  $t$ ,  $V_{j,t}$  represents the value of a loan  $j$  on a day  $t$  while  $\sum_{j^*=1}^{J_t} V_{j^*,t}$  sums the values of all loans on day  $t$ ;  $J_t$  denotes the number of loans (and interest rates) on a day  $t$ .



**Figure 6:** Derived values of NONIA (thick solid line), Norges Bank's deposit rate (key policy rate, thin solid line), overdraft rate (one percentage above the deposit rate, dashed line) and the reserve rate (one percentage below the deposit rate, dash-dot line). Interest rates are in % and per annum. The sample consists of daily observations over the sample period.

Figure 6 plots NONIA together with the key policy rate (the overnight deposit

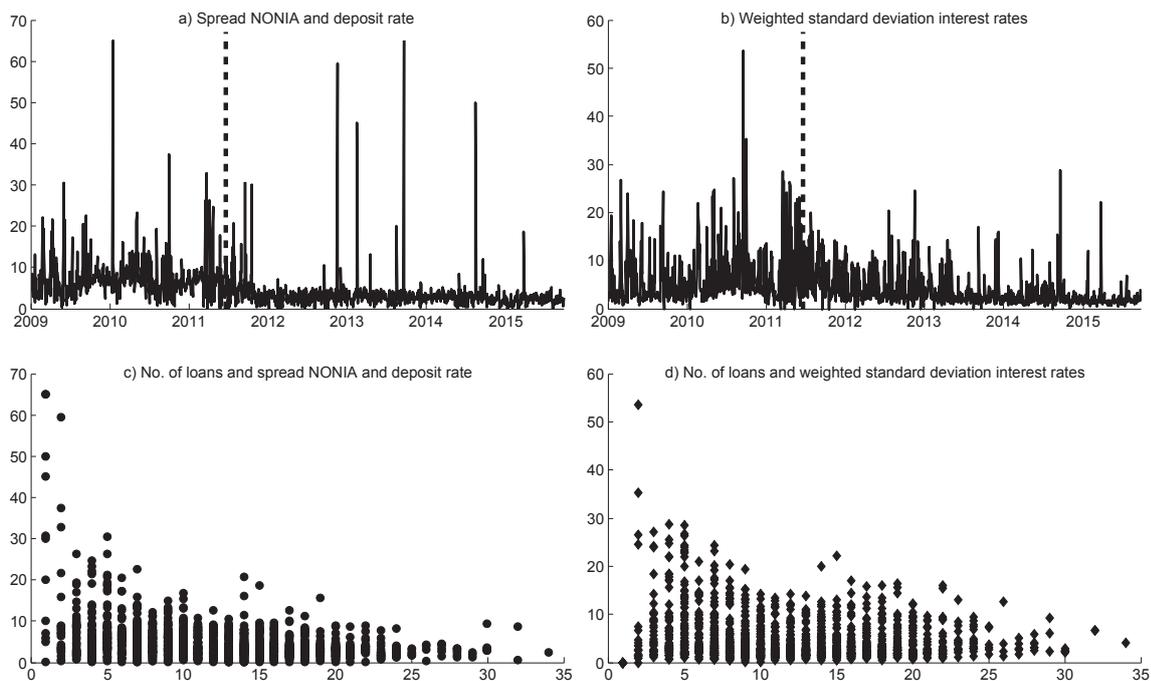
rate), the reserve rate and the (overnight) overdraft rate. It shows that NONIA dropped from levels mostly above the key policy rate to levels mostly below the key policy rate after 3 October 2011. This is evident in Figure 7, which shows that 96.63% of the derived spreads between NONIA and the key policy rate were positive before the policy shift, while about the same share (95.56%) has been negative afterwards. On average, NONIA is 6.86 basis points above the key policy rate before the policy shift and 3.03 basis points below the policy rate afterwards.



**Figure 7:** *The difference between derived values of NONIA and the key policy rate in basis points. The sample consists of daily observations over the sample period. The dashed vertical line marks 3 October 2011.*

One of the objectives of Norges Bank’s liquidity policy is to ensure that interbank interest rates are close to the key policy rate and are stable. From this perspective, market-wide overnight interest rates represented by NONIA have been closer to the policy rate after the policy shift than in earlier periods. NONIA has also been more stable over time after the policy shift than before. This is apparent in Figure 8.a, which displays the absolute spread between NONIA and the key policy rate over the sample period.

Furthermore, the dispersion of interest rates across individual overnight loans



**Figure 8:** *Absolute values of spread between NONIA and the deposit rate (key policy rate), the loan-weighted standard deviation of individual interest rates and the relationship between the number of loans (horizontal axis) and absolute values of the spread, and between the number of loans and the standard deviation. Daily observations over the sample period.*

has become relatively smaller after the policy shift. Figure 8.b displays daily values of the loan-weighted standard deviation of individual interest rates plotted in Figure 4. We note that the range of variation in the standard deviation is mostly lower and its values spike less often after the policy shift than before.

Figures 8.c and 8.d indicate that both volatility measures, the NONIA-spread and the standard deviation in Figures 8.a and 8.b, are negatively correlated with interbank activity. These cross plots suggest that particularly large values of the NONIA-spread and the standard deviation occur on days with relatively few loans.

## 5 Shifts in interbank activity and pricing

This section investigates more rigorously possible shifts in the time series properties of measures of overnight interbank activity and interest rates. We are particularly interested in testing whether their levels and/or variances have shifted following the policy shift. As a reference model, we first estimate a linear model of selected variables where only corresponding means may shift from the day when policy shift

**Table 1: Impact of policy shift on activity and interest rates**

	Volume	Loans	banks	Spread	Std. dev.
$\widehat{\mu}_y$	4.911 (0.248)[.000]	8.45 (0.196)[.000]	8.00 (0.118)[.000]	6.862 (0.191)[.000]	6.27 (0.178)[.000]
$\widehat{\delta}_y$	10.231 (0.311)[.000]	6.28 (0.246)[.000]	5.07 (0.148)[.000]	-9.845 (0.240)[.000]	-2.71 (0.224)[.000]
R-squared	0.51	0.29	0.42	0.51	0.08

Note: Estimated model (5). The  $y$  variables are: (a) volume: the total value of overnight interbank loans in NOK bn; (b) Loans: number of overnight loans per day in NOK bn; (c) Banks: the number of banks participating in the overnight market in a day; (d) Spread: difference NONIA and the key policy rate in basis points; and finally (e) std. dev.: the value-weighted standard deviation of overnight interest rates in basis points. Standard errors and p-values under the null hypothesis are placed below the coefficient estimates. These suggest statistically significant estimates at the 1% level. Estimation method is OLS while the data samples for each of the  $y$ -variables consist of 1627 observations over the sample period (17 April 2009–7 January 2016).

was implemented. Specifically, we estimate equations as:

$$y_t = \mu_y + \delta_y PS_t + \epsilon_t, \quad (5)$$

where  $y_t$  represents the total daily turnover (Volume), number of loans (Loans), number of participants either as lenders or borrowers or both (Banks), the difference between NONIA and the key policy rate (Spread) and the weighted standard deviation of individual interest rates (std. dev.); see Figures 5, 7 and 8 for their time series.  $PS$  is a binary variable equal to zero until 3 October 2011 and 1 afterwards. The Greek letters represent presumably constant parameters ( $\mu_y$  and  $\delta_y$ ) and a stochastic term ( $\epsilon$ ), which is assumed to have a zero mean and a constant variance. Under the null hypothesis of no impact of the policy shift  $\delta_y = 0$ , the mean of variable  $y$  would be constant and equal to  $\mu_y$ . If the policy shift has had an effect, the mean would shift from  $\mu_y$  to  $\mu_y + \delta_y$  from 3 October 2011 onwards.

Table 1 presents the estimation results for each of the above defined  $y$  variables. The results clearly suggest the policy shift has had statistically and economically significant effects on the measures of interbank activity and pricing. The estimated coefficients imply that the average daily volume increases from about NOK 5 bn to about 15 bn (= 4.911 + 10.231), the average number of loans per day rises from 8.45 to 14.73 while the average number of participants increases from 8 to 13 per day following the policy shift. The estimated coefficients for the spread

between NONIA and the policy rate suggest that it falls from 6.86 basis points to -2.98 (= 6.862 – 9.845) basis points. Estimates in the final column imply that the daily dispersion of interest rates across the loans has also declined. Accordingly, the estimated mean of the value-weighted standard deviations of interest rates falls by 43%, from 6.27 basis points to 3.56 basis points, after the policy shift.

The linear model (5) with allowance for a permanent shift in a variable’s mean at a known date as well as a constant variance may be too restrictive, however. It cannot be precluded that the variance also shifts after the policy shift. Moreover, it need not be the case that a variable’s behaviour shifts permanently and irreversibly and that it never returns to its behaviour pre-policy shift, even occasionally. Furthermore, possible effects of the policy shift need not occur exactly on the day the policy change was implemented.

## 5.1 Markov switching models

In the following, we employ 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 \(1989\)](#). We consider the following model specification:

$$y_t = \mu_y(s_t) + \sigma_y(s_t)\varepsilon_t, \quad \varepsilon_t \sim IIDN(0, 1), \quad (6)$$

where  $\mu_y(s_t)$  represents the mean value of  $y$  while  $\sigma_y(s_t)$  represents its standard deviation. The values of both parameters depend on an unobserved state variable  $s$ . The stochastic disturbance term is  $\sigma_y(s_t)\varepsilon_t$  where  $\varepsilon_t$  is assumed to be an identically and independently distributed unobserved term with a standard normal distribution.<sup>11</sup>

We assume  $s$  takes on discrete values, 1 or 2, governed by a first-order Markov chain. Since  $s$  is unobservable, probabilistic inference about the value of  $s_t$  is based on observations of  $y$  available at time  $\tau$  ( $\geq t$ ) and the estimated value of the parameter vector  $\Theta$  containing all parameter values in the model for all states. The

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<sup>11</sup>The case of constant parameters, model (6), corresponds to  $s_t = 1, \forall t$ .

**Table 2: *Parameter estimates in the two states/regimes***

$y$	$\hat{\mu}_y(1)$	$\hat{\mu}_y(2)$	$\hat{\sigma}_y$	QLR	$\hat{\mu}_y(1)$	$\hat{\mu}_y(2)$	$\hat{\sigma}_y(1)$	$\hat{\sigma}_y(2)$	QLR
Volume	5.457 (0.234)	16.957 (0.241)	5.265 (1.020)	981.26	4.660 (0.139)	16.032 (0.243)	2.995 (1.036)	6.605 (1.024)	1324.66
Loans	7.609 (0.214)	15.385 (0.182)	4.195 (1.020)	730.03	7.217 (0.183)	15.068 (0.176)	3.136 (1.037)	4.721 (1.023)	821.67
Banks	7.405 (0.144)	13.225 (0.094)	2.555 (1.023)	967.50	7.308 (0.141)	13.117 (0.115)	2.394 (1.042)	2.691 (1.038)	971.33
Spread	7.177 (0.190)	-3.024 (0.140)	4.508 (1.017)	1165.05	5.226 (0.331)	-2.628 (0.046)	8.273 (1.028)	1.353 (1.029)	2441.20
Std. dev.	16.757 (0.542)	3.603 (0.091)	3.001 (1.021)	675.63	7.941 (0.250)	2.203 (0.041)	5.425 (1.028)	0.959 (1.036)	1895.57

Note: We estimate two versions of model (6), one with shifts in means only and one with shifts in both means and variances. The  $y$  variables are as above; see Table 1. Estimates of standard errors are placed below the parameter estimates. QLR-statistics are defined as 2 times the difference between the log-likelihood value of a given Markov switching model and that of the corresponding linear constant parameter model; see Carter and Steigerwald (2013). Estimation method is MLE while the data samples for each of the  $y$ -variables consist of 1627 observations over the sample period. The estimation has been carried out in EViews 9.5.

smoothed probability of  $s_t = j$  expresses the probability of being in state  $j$  at time  $t$ , conditional on the available full sample information;  $\tau = T$ . Smoothed probabilities can be expressed as:

$$P(s_t = j | y_1, y_2, \dots, y_T; \hat{\Theta}), \quad j = 1, 2. \quad (7)$$

Estimates of model (6) can reveal the extent of changes in the mean and/or variance of variable  $y$  over the sample period. The associated probabilities of different states can suggest when these shifts took place, whether potential shifts in the mean and/or variance coincided with the official shift in liquidity policy, and to what extent possible shifts can be considered transitory or permanent.

To summarise our findings before presenting them in detail: although there are days when overnight interest rates and different activity measures take values that were typically observed before the policy shift, we find that the level of interbank activity has been generally higher, while overall overnight interbank interest rates have been lower and more stable after the policy shift.

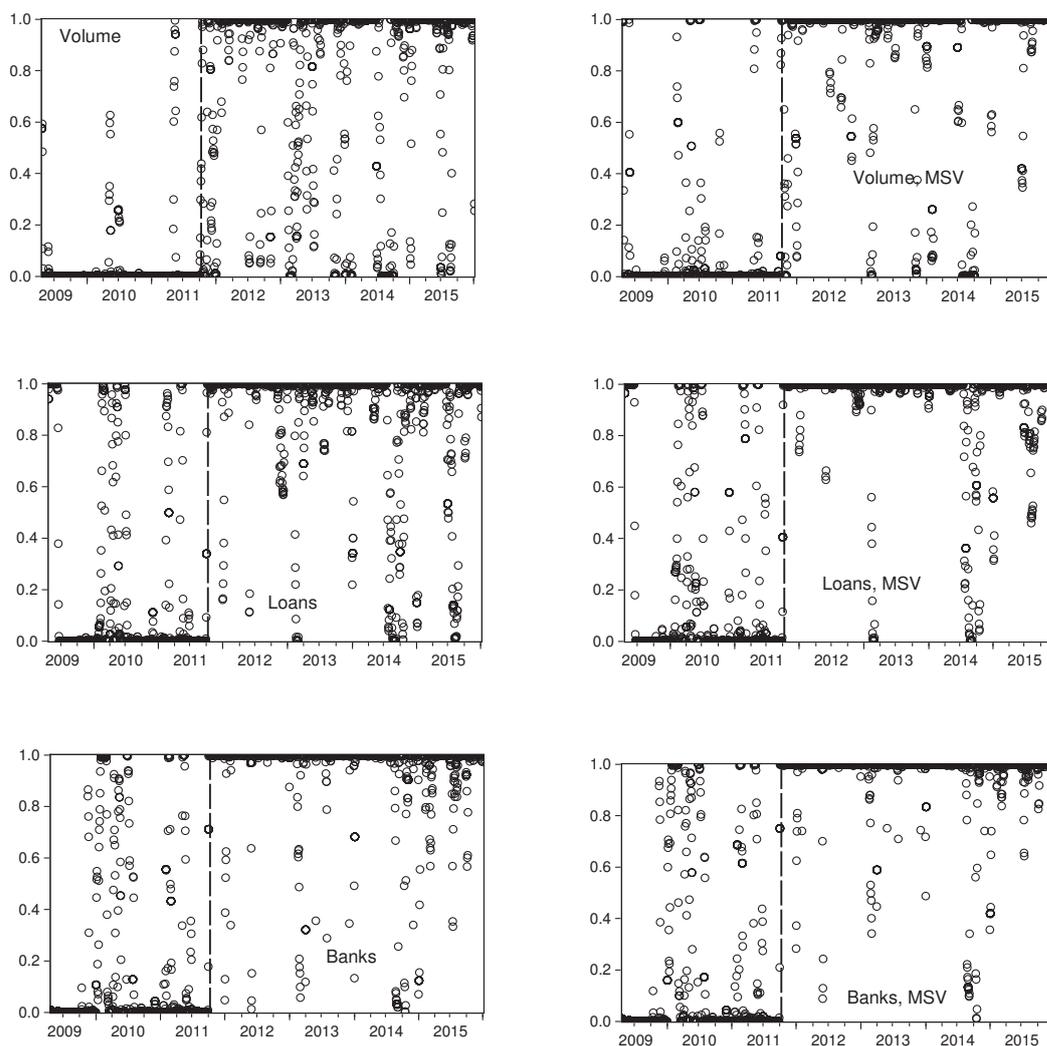
Table 2 presents estimates of means and standard deviations of different  $y$  variables under the assumption of two possible states at each point in time:  $s_t = 1, 2$ . The left-hand part of the table shows parameter estimates assuming state-invariant

variances while the means are allowed to vary across the two states. The QLR-column reports (quasi) log-likelihood ratio statistics for tests of constant parameter-models under the null-hypotheses against the alternative hypotheses of switching-mean models. The right-hand part of the table shows parameter estimates when both the means and variances of  $ys$  may vary across the two states. The right-hand QLR-column reports test statistics when constant parameter-models under the null hypotheses are tested against corresponding models with both switching means and variances under the alternative hypotheses. While relevant critical values depend on the specification of the model and parameter space, the magnitude of QLR-statistics suggest that constant parameter models would be rejected at standard levels of significance against the corresponding regime-switching models presented; see [Cho and White \(2007\)](#) and [Carter and Steigerwald \(2013\)](#) for details and indicative asymptotic critical values.

Table 2 shows that the two regimes are characterised by distinctively different estimates of the mean values. Observations of daily turnover (Volume) either belong to a regime with mean around NOK 5 bn or 16 bn, while those for the daily number of loans (Loans) are from a regime with about 7-8 loans or from a regime with about 15 loans on average. Observations of the number of different banks participating in the overnight interbank market (Banks) either come from an underlying distribution with about 7 participants on average or from one with about 13 participants on average. We also note that the standard deviations of the variables tend to increase together with the level of variables. Accordingly, the standard deviations of daily turnover, number of loans and number of banks are slightly higher after the policy shift while those of the spread and the dispersion in interest rates are relatively lower after the policy shift.

We have tested whether the estimated parameters in the two states are significantly different from each other using wald-tests. We found that the null hypotheses of equal mean ( $\mu_y$ ) values and equal standard deviations ( $\sigma_y$ ) in the two states are rejected at the 1% level of significance. The only exception is in the case of the standard deviation of the number of interbank participants (Banks), which is barely

rejected at the 5% level of significance; the chi-square test statistics is 3.73 while the  $p$ -value is 0.054. For all of the five  $y$ -variables, we have also estimated two state Markov switching models with constant as well as state-dependent autoregressive terms (of order one) in addition to state-dependent means and variances and found parameter estimates comparable to those reported in Table 2. For all of the latter models, null hypotheses with equal mean values and equal variances across the two states were rejected at the 1% level of significance.



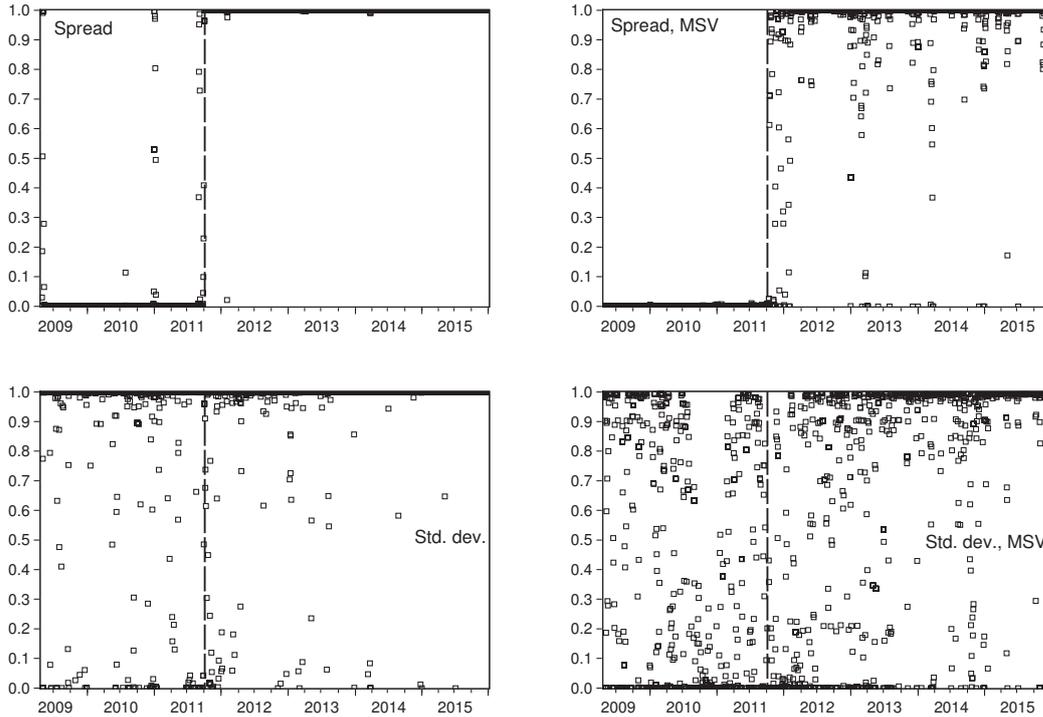
**Figure 9:** Smoothed probabilities of being in a high-turnover regime,  $s = 2$ , (top row), high number of daily loans (middle) and large number of market participants (bottom) over the sample period. Smoothed probabilities based on the model with switching means and variances are presented on the right-hand side.

Figure 9 presents smoothed probabilities of the second regime ( $s = 2$ ) on each

of the business days over the sample period for our three measures of interbank activity; the dashed vertical lines mark 3 October 2011. Smoothed probabilities based on the model with switching means and variances are on the right-hand side and are indicated by MSV. We note that most observations of daily turnover seem to be drawn from the high-mean distributions from 3 October 2011 onwards. There are just a few days when the observations could have come from the low-mean regime after this date, or from the high-mean regime before this date. Smoothed probabilities of being in the high-mean regime for the number of loans transacted and the number of different banks involved also suggest that the corresponding observations are mostly from the corresponding high-mean distributions from 3 October 2011 onwards. Prior to this, the observations are mostly from the corresponding low-mean regimes, with several exceptions though; see Figure 9, the middle and lower panels.

Regarding estimation results for the spread and the dispersion of interest rates across loans, Table 2 shows that the NONIA spread shifts between a regime where the average spread is 5.3 basis points and a regime where the average spread is  $-2.6$  basis points while the corresponding standard deviations are 8.3 and 1.4 basis points, respectively. The value-weighted standard deviations of interest rates switch between a regime where the average value is 7.9 basis points and a regime where the average is 2.2 basis points. The weighted standard deviation of interest rates across loans is also relatively less volatile in the second regime than in the first regime; the standard deviations are 5.43 and 0.96 basis points, respectively.

The smoothed probabilities for NONIA-spread in the upper panel of Figure 10 suggest that a regime shift characterised by a lower mean and lower variance occurred after 3 October 2011, and this regime has prevailed in all or a majority of the following days in the sample. Some of the observations after 3 October 2011 may have been drawn from the relatively low mean and/or higher variance regime. These observations typically occur at the end-of-months and on days when there is relatively low activity; see Figure 6. The smoothed probabilities from the model with just switching means give a less nuanced characterisation of the time series behaviour of the NONIA-spread. They suggest that its observations are exclusively



**Figure 10:** *Smoothed probabilities of being in a low interest rate regime,  $s = 2$ , (top row) and those of being in low-interest rate dispersion regime over the sample period. Smoothed probabilities based on the model with switching means and variances are presented on the right-hand side.*

from the regime with a negative average spread from 3 October 2011 onwards.

The lower panel of Figure 10 suggests that most observations of dispersion in interest rates, represented by the value-weighted standard deviation of interest rates of individual loans, from around 3 October 2011 onwards are from the regime with relatively low and stable dispersion. In the earlier period, both regimes seem to prevail quite often.

## 6 Conclusions

We have investigated the effects of the shift in Norges Bank’s liquidity policy on activity and pricing in the Norwegian overnight interbank market. The policy shift on 3 October 2011 was primarily aimed at increasing interbank market activity. It entailed quotas on banks’ overnight deposits remunerable at the key policy rate and the remuneration of deposits above-quotas at the ‘reserve rate’, set one percentage

point lower than the key policy. These changes were accompanied by a target range for total liquidity and an active use of fixed-term central bank loans as well as deposits to achieve the total liquidity target. The liquidity policy shift could be characterised as a shift from a ‘floor system’ to a ‘corridor system’.

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

Notably, our measure of market-wide overnight interbank interest rate, NONIA, falls from a model-dependent average in the range of about 5-7 basis points above the key policy rate to about 2-3 basis points below the key policy rate. While 97% of NONIA observations were above the key policy rate before the policy shift, 96% were below the key policy rate after the shift. That is, the key policy rate has in general not acted as a floor for overnight interbank interest rates after the policy shift. Yet, relatively smaller deviations of interbank rates from the key policy rate suggest that it prevails more strongly in the interbank market after the policy shift than before.

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# Appendix

We evaluate the reliability of the implemented Furfine-based approach by comparing aggregated results for a set of 11 banks with those based on their reports submitted to Norges Bank since end september 2011, as a part of the new liquidity policy. As an additional cross check, we investigate intraday seasonality in the implied overnight loans and check whether it conforms to expected behavior. In the Norwegian overnight interbank market, loans are typically transacted in the afternoon, after the outcome of liquidity auctions has been announced, while return transactions occur mostly early in the morning.

## A The Norwegian Overnight Weighted Average (NOWA)

Since 29 september 2011, a panel of 11 banks in Norway that regularly offer unsecured NOK loans in the Norwegian interbank market have reported their (unsecured) overnight loans and overnight lending rates daily to Norges Bank; see e.g. [Norges Bank \(2014a, 2016\)](#) and the website of *Finance Norway*, the organization of the financial industry in Norway. The banks' daily reports have included information about their total overnight loans and associated loan-weighted average interest rates. It is required that loans and interest rates must have been set in agreements concluded by banks, either directly or via a broker. These loans must also represent banks' own lending and not be on behalf of any financial or non-financial customer. Moreover, the loans must have been paid out on the day of the agreement with repayment the following banking day.

The Norwegian Overnight Weighted Average interest rate, NOWA, is calculated by Norges Bank every business day as an average of the (loan-weighted average) reported interest rates.<sup>12</sup> NOWA is calculated when data is available from at least three banks and their total reported loan volume is at least NOK 250 million.<sup>13</sup> NOWA

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<sup>12</sup>If a panel bank has been unable to report actual interest rates, it can occasionally be requested to submit an estimate of the interest rate at which it would be willing to issue loans. This can be the case if an insufficient number of panel banks has reported overnight trading for Norges Bank to calculate the NOWA rate.

<sup>13</sup>Loans smaller than NOK 25 million may be excluded from the calculations. We do not know to what extent this has ever happened. There is evidence of 212 such loans among the sample of

is estimated as an unweighted average of estimated overnight interest rates if these conditions are not fulfilled. These estimates are provided by selected panel banks. This happened 24 times during our sample period. NOWA has been published daily by Norges Bank since 29 September 2011.

Specifically, daily loan volume for a bank  $j$ ,  $L_{j,t}$ , its weighted lending rate ( $r_{j,t}$ ) and the market level lending interest rates, NOWA ( $r_t$ ), may be defined as:

$$L_{j,t} = \sum_{i=0}^{I_{j,t}} l_{i,j,t} \quad (8)$$

$$r_{j,t} = \sum_{i=1}^{I_{j,t}} \frac{l_{i,j,t}}{L_{j,t}} r_{i,j,t} \quad (9)$$

$$r_t = \sum_{j=1}^{J_t^N} \frac{L_{j,t}}{L_t} r_{j,t}, \quad (10)$$

where  $L_t = \sum_{j=1}^{J_t^N} L_{j,t}$  defines the daily sum of all loans (daily turnover) and  $J_t^N \in [0, 11]$  indicates the number of overnight lenders on day  $t$  in the NOWA bank panel. Subscript  $i$  refers to an overnight loan while  $I_{j,t}$  denotes the total number of such loans by bank  $j$  on day  $t$ ;  $j = 1, 2, 3, \dots, J^N$ . Values of individual loans ( $l_{i,j,t}$ ) and associated overnight interest rates ( $r_{i,j,t}$ ) are not reported by the banks, only their total daily loan volumes ( $L_{j,t}$ ) and loan-weighted overnight interest rates ( $r_{j,t}$ ). Norges Bank uses the reported information to derive and publish NOWA ( $r_t$ ) daily.

## B Comparison of Furfine-based NOWA with official NOWA

The quoted rates and volumes from NOWA banks enable us to evaluate the reliability of our algorithm by comparing daily loan volumes ( $L_t$ ) and NOWA lending rates ( $r_t$ ) published by Norges Bank with estimates based on different versions of the algorithm ( $\widehat{L}_t$  and  $\widehat{r}_t$ ). The estimates are obtained by aggregating the algorithm-based values of individual loans and corresponding interest rates for the NOWA panel banks.

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11 463 loans identified by the algorithm where a NOWA bank is lender. Given their small share (1.85%) and lack of information about their possible exclusion, we proceed by excluding such relatively small loans.

Previously, Akram and Christophersen (2014) have found the Furfine approach to be quite reliable at the aggregate level with negligible difference between the Furfine-based NOWA rate and the official one calculated by Norges Bank.<sup>14</sup>

One source of discrepancy between Furfine-based NOWA and official NOWA is that the latter is by requirement based on banks' own lending, while such a requirement needs not be met in the former case. The Furfine-algorithm based on recorded transactions between banks does not know whether a given transaction is on own behalf of a bank or on behalf of a foreign bank or another institution without access to Norges Bank's RTGS system. We therefore expect the aggregate Furfine-based turnover to be higher than the reported aggregated turnover.

Other sources of discrepancy include violation of the assumed characteristics of overnight loans: that a transaction needs to be divisible by NOK 1000 000; that implied interest rates do not have more than 3 decimals; and that implied interest rates do not deviate implausibly much from the overnight deposit rate (the bandwidth assumption).

**Table 3: *Furfine-based values minus official values for NOWA banks***

Bandwidth	Volume (mean)	NOWA (median)	NOWA (mean)	Returned 5:45-5:47am
70	1 034	1.09	-1.79	52.69 %
50	1 018	1.10	-1.69	53.01 %
30	992	1.06	-1.56	53.86 %
Floating <sup>x</sup>	1 036	1.06	-1.52	52.34 %

Note: Results in the second and the last columns are based on the whole sample period (17 April 2009–7 January 2016). However, when comparing with official NOWA statistics in the third and fourth columns, the sample period is 3 October 2011 to 7 January 2016. <sup>x</sup>The floating rate band requires the implied interest rate to be between  $\max\{i_{cb}+110 \text{ bps}, i_{cb}\times 1.934\}$  and  $\min\{i_{cb}-110 \text{ bps}, 5 \text{ bps}\}$ . An overnight interbank loan is typically repaid at 5:45 the following day. We record transactions between between 5:45 and 5:47 and check the share of these satisfying our criteria to be considered an overnight interbank loan. The last column reports shares of transactions classified as overnight interbank loans that are returned 5:45–5:47 am under the different bandwidth assumptions.

Table 3 presents the evaluation of the implemented Furfine-based algorithm. The first column specifies the width of the interest rate band by noting symmetric deviations in basis points from the prevailing overnight deposit rate at each point in

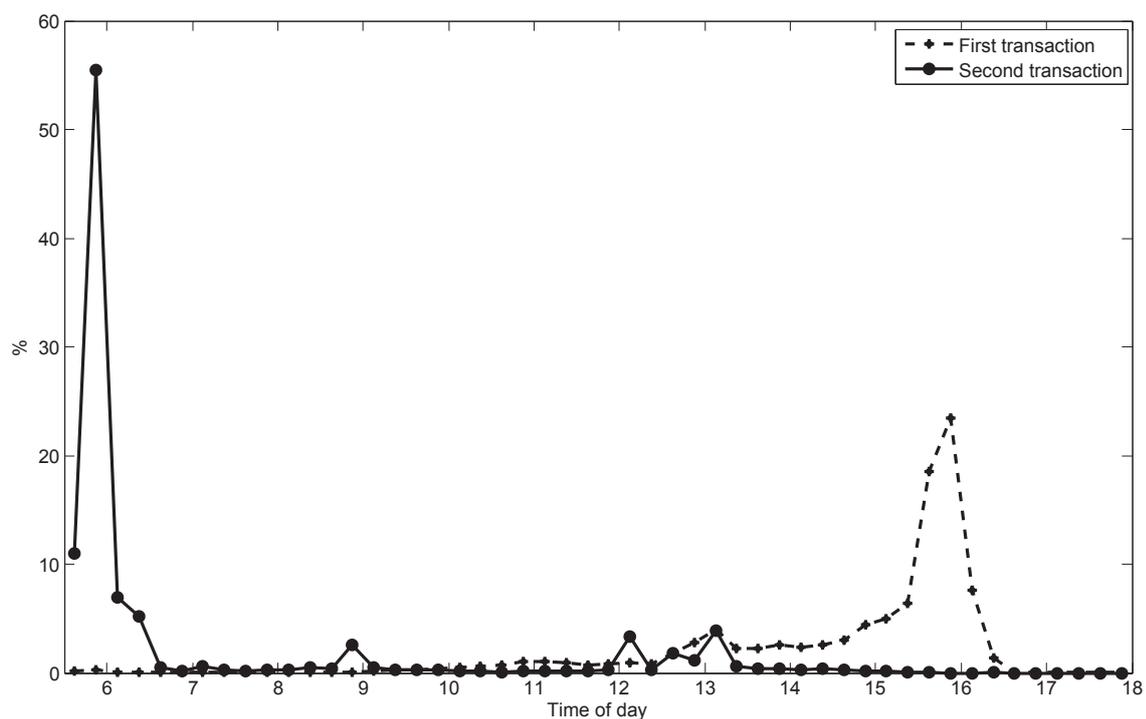
<sup>14</sup>Akram and Christophersen (2014) also offer a more rigorous evaluation of the Furfine-approach in which the NOWA banks' individual daily loan turnover and loan-weighted interest rates are compared with those based on the Furfine-approach. The Furfine-approach was shown to be quite reliable in general and especially for relatively small banks that mostly act on their own behalf.

time. The results presented in the paper are based on  $\pm 70$  basis points deviation and decimal restrictions on implied interest rate. We note, however, that the results presented do not change much with changes in the bandwidth.

The mean and median deviations between Furfine-based and official NOWA rates are -1.79 and 1.09 basis points, respectively. The mean deviation may have been influenced by some extreme observations of the official NOWA rate. There are eight days in the sample when the difference between the Furfine-based NOWA and the official NOWA is about -30 basis points, while there is just one day when the difference is 30 basis points. Unusually large official NOWA rates, or atypically small estimates of the Furfine-based NOWA account for these extreme values.

In the case of daily turnover, the mean deviation is around NOK 1 bn. As noted above, in contrast with the NOWA reports, the Furfine approach also captures loans on behalf of other banks or financial and non-financial customers. The deviations suggest that lending on behalf of other institutions constitutes around 8% of NOWA banks loans.

A final piece of evidence supporting the reliability of the implemented Furfine-based algorithm is that the intraday seasonality pattern of identified overnight loans largely conforms with the expected pattern. The last column of Table 3 shows that around 53% of return transactions occur early in the morning, that is within two minutes 5:45-5:47am. Close to all of the return transactions are completed within the first hour after the opening of the RTGS system at 5:30am; see Figure 11. The figure also shows that the first legs of the overnight transactions are conducted in the afternoon and mainly shortly after the results of liquidity auctions have been announced, usually some minutes after 15:15; on average, 59% of the implied loans are transferred from lenders between 15:15 and 16:15.



**Figure 11:** *Intraday distribution of payment and repayment transactions of overnight loans in percentage of corresponding total loan transactions. The horizontal axis depicts the time from the opening to the closure of the RTGS, 5:30 to 18:00, every 15 minutes. The intraday distributions are based on identified transactions over the full sample period 17 April 2009 to 7 January 2016.*