Repo market frictions and intermediation in electronic bond markets

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Abstract

This paper studies the links between the repo market and cash market in government bonds. Higher convenience yield on government securities contributes to higher repo specialness, which increases the cost of borrowing bonds in the repo market. Dealer-specific repo quantities and trades in the two tiers of Norwegian government bond market show that passive sales in the limit order book are important drivers of repos, and that repo volume is negatively related to repo specialness. Bond market liquidity deteriorates with higher convenience yield and repo specialness, and improves with higher repo volumes. The results suggest that liquidity providers in electronic bond markets face an additional risk increasing in the level of repo specialness.

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1 Introduction

Treasuries are characterized by low default risk, high liquidity, and little disagreement about their value (Gorton, 2017). These features provide them with an important role in financial markets, especially during crises. Krishnamurthy and Vissing-Jorgensen (2012) document how the safety and liquidity of Treasuries contribute to a yield lower than the "true" riskless rate. They refer to this yield difference as the Treasury convenience yield and show that it increases with a reduction in Treasury supply. He et al. (2022) show that the convenience yield changes with changes in the demand for Treasuries. They document that the convenience yield increases with excess demand, as during the 2007/09 financial crisis, and decreases with excess supply, as during the 2020 Covid-19 crisis. Their model, where dealers intermediate bonds and provide financing to their customers in the repo market, also show that changes in the convenience yield are related to frictions in the repo market. Gottardi et al. (2019) and Infante (2020) propose models of the repo market when the collateral securities are scarce. Infante (2020) employs the Treasury convenience yield as a measure of safe asset scarcity and his model predicts that the demand for repos falls when the convenience yield increases. The model of Gottardi et al. (2019), on the other hand, predicts the opposite because repos provide insurance against price further price increases. How the convenience yield affects intermediaries' repo activity and repo market frictions has been little studied empirically due to a lack of data.[1] This paper seeks to fill this gap by investigating the links across the cash- and repo markets created by primary dealers.

To investigate potential links the paper seeks to answer the following questions. What are the drivers of primary dealers' activity in the repo market? Is the convenience yield related to repo specialness? Are repo volumes and repo market frictions related to primary dealers' liquidity provision? Are there differences across the transparent electronic limit order book (LOB) and the opaque over-the-counter (OTC) market? Answers to these questions are important for several reasons. First, a push from regulators to move bond trading from OTC markets on to LOBs makes it important to understand whether the role of the repo

[1] He et al. (2022) employ aggregate data and do not specify market structure and liquidity measures.

market differs in the two trading environments. Differences in market transparency and the way trades are agreed to potentially increase the need for a well-functioning repo market for liquidity providers in the LOB. Regulators should thus consider the availability of a repo market as they encourage traders in less liquid bonds to move on to electronic exchanges. Second, a better understanding of how the conditions in the cash market and the repo market are related can be useful for regulators and policy makers in responding to future economic shocks.

To answer these questions the paper employs a unique data set from the Norwegian government bond market. The data set contains the complete transactions history of four primary dealers in government bonds in the two-tier secondary cash market, the repo market, and the primary market for the period 2002 - 2015.[2] It includes the order book history and trades in the interdealer LOB, trades in the customer OTC market, auction bids in the primary market and trades in the repo market, all with dealer identifications. The only private repo market in government bonds in Norway is a bilateral OTC market. The data set enables the paper to apply a more granular approach than previous studies to explore the links between the secondary cash market, the primary cash market and the repo market.

Potential drivers of repo activity are related to the demand for bonds in the cash market, either to finance long positions or to facilitate short positions. As transactions-based measures of bond demand, the paper employs order flows and bid-to-cover ratios based on auctions data. Order flows, the sum of signed trades, represent the total market buying pressure at the aggregate level, and net bond purchases at the dealer level. They are based on actual order signs in the LOB and on inferred order signs in the OTC market.[3] As price-based measures of bond demand the paper employs the convenience yield and average repo specialness, a measure of the bond borrowing cost in the repo market.[4] While this paper employs direct

[2] During the 2002-15 period there were no tightening of balance sheet restrictions and often an excess demand for government bonds.

[3] As OTC trades lack information on which side initiated the trades, order signs are estimated using the Lee Ready (1991) algorithm and the tick rule. Delays by dealers in entering OTC-trades in the OSE trading system, make the OTC signs less reliable than those in the LOB.

[4] The convenience yield is often used as a measure of the demand for safe assets, see e.g. Infante (2020). Repo specialness is the difference between the GC repo rate and the special repo rate and reflects the cost of borrowing bonds, see e.g. Duffie (1996).

measures of bond demand, previous studies rely on indirect measures. D'Amico et al. (2018) and Corradin and Maddaloni (2020) use the imbalance between reverse-repos and repos as an indirect measure of the demand for bonds in the cash market.[5]

To identify the drivers of repo activity the paper employs these measures of excess demand at the weekly horizon both at the aggregate level and the dealer level. The results at the aggregate level show that the convenience yield and average repo specialness are positively correlated and that the convenience yield is the main driver. This documents that bond scarcity in the cash market leads to bond scarcity in the repo market. The linear regression results based on aggregate data show that repo volumes are positively related to the order flows in the LOB and the bid-to-cover ratios, and negatively related to orthogonalized repo specialness. The first two results are consistent with Huh and Infante (2021) who study the importance of repos for intermediation in the secondary bond market, and with Jordan and Jordan (1997) who also study the importance of repos in the primary bond market. The result for repo specialness suggests that many repos are initiated to borrow bonds, and that the demand for these security-driven repos decreases as the borrowing cost increases. Interestingly, the convenience yield appear to have no effect on repo volumes. This could be the results of two opposite effects, like the ones described in Gottardi et al. (2019) and Infante (2020). Unfortunately, the data set is not suited to test this.

The results based on the individual dealer data with dealer fixed effects show a more nuanced picture. Primary dealers' order flows in the electronic LOB are separated into regular order flows, based on initiated trades, and passive order flows, based on passive trades.[6] The results show that passive order flows in the LOB are the main drivers of primary dealers repo activity.[7] Negative passive order flows are passive sales which contributes to lower inventories, and can result in unintended inventory depletions or short positions. Higher passive sales by a dealer are related to higher repo quantities for the same dealer, which also suggest that repos are mainly security-driven. The results for repo specialness confirm the findings at the

[5] In a repo the dealer receives cash and deliver securities in the first leg, while in a reverse-repo the dealer receive securities and deliver cash in the first leg.

[6] Passive net order flows are based on executed limit orders and constructed so that positive flows mean higher bond holdings for the dealer. Negative passive order flows are net passive sales.

[7] The model is tested for redundant fixed effects, which are strongly rejected.

aggregate level while the individual bid-to-cover ratios are not significant.

To uncover whether primary dealers' repo activity and repo market frictions affect their liquidity provision in the government bond market, the paper employs the dealer specific relative bid-ask spreads in the LOB and the OTC market as measures of liquidity provision. As a measure of repo market frictions the paper employs the average repo specialness for all government bonds.[8] Duffie (1996) finds that repo specialness is increasing in short positions in the cash market and concludes that "specials can occur when those owning the collateral are inhibited, whether from legal or institutional requirements or from frictional costs, from supplying collateral into repurchase agreements".[9] The results of the panel data regressions with dealer fixed effects show that bid-ask spreads in both tiers of the market decrease with higher repo volumes and increase with higher convenience yield and orthogonalized repo specialness. They also show that higher customer order flows in the OTC-market are related to higher spreads in both tiers of the market. This suggests that dealers are not able to offload all risk from customer trades in the electronic interdealer market.

The results hold when controlling for the 2007-09 financial crisis. These findings, combined with the results for primary dealers' repo activity, suggest that if dealers cannot completely offset inventory changes in the interdealer LOB when there is a buying pressure in the customer OTC market, they go to the repo market to adjust their inventory temporarily. Borrowing bonds in the repo market via reverse repos alleviates inventory depletion caused by passive net sales. Reverse repos, where dealers receive bonds in the first leg, include repos initiated by the dealer as a bond borrower (security-driven), and repos initiated by the counterparty as a cash borrower (cash-driven).[10] The results suggest that both bond scarcity in the cash market measured by the convenience yield, and bond scarcity in the repo market measured by repo specialness, incur higher intermediation costs. Dealers pass on a large fraction of this increase to their counterparties in both market segments. An increase in the convenience

[8] Average repo specialness is calculated as the difference between the repo rate when repos are "on special" as in Duffie (1996), and a measure of the triparty GC repo rate. It represents the bond borrowing cost in the repo market.

[9] Repo specialness differs from the repo spread in He et al. (2022). They define the repo spread as the repo rate at which dealers' lend cash minus the repo rate at which they borrow cash.

[10] In cash-driven repos, where the dealer is the cash lender, the dealer can re-use the bonds received as collateral.

yield by 26 basis points is related to spread increases in the LOB and the OTC market by 10 and 7 basis points, respectively, while an increase in orthogonalized repo specialness by 10 basis points is related to an increase of 9 and 6 basis points, respectively.

This paper makes two main contributions. First, it identifies a link between primary dealers' executed limit orders and their repo market activity. Previous studies do not focus on electronic bond markets or the characteristics of the market place.[11] The findings in this paper suggest that limit orders are not only exposed to inventory- and adverse selection risk, but also to the risk of how costly it is to cover "unintended" short positions by borrowing temporarily in the repo market. Repo specialness is time-varying and poses an extra risk to primary dealers in government bonds who are obliged to act as market-makers in the electronic LOB. In less liquid markets the number of limit orders tend to be small, and trading volumes often smaller than in the OTC market. This means that when a dealer off-loads risk in the LOB she will typically take out all the limit orders on one side of the book. If any of the liquidity providers need to replenish their inventory, and they have no off-setting customer trades, they will typically go to the repo market. This suggests that market-makers in electronic bond markets face an additional risk related to the level of repo specialness when bonds are scarce.

Second, the paper contributes by documenting the relation between the convenience yield and repo specialness on one hand, and bond liquidity on the other. Previous studies do not relate the convenience yield directly to trading costs, but to repo quantities (Infante, 2020) or repo market frictions (He et al., 2022). Other studies investigate the relation between the *reduced supply of bonds* induced by quantitative easing programs (QE) and repo specialness, e.g. D'Amico et al. (2018) and Corradin and Maddaloni (2020), or the relation between securities lending and market liquidity, e.g. Foley-Fisher et al. (2019). This paper documents that an *increased demand for bonds* in the cash market via the LOB is related to repo specialness and to lower bond market liquidity. It is interesting to find that an increase in a measure representing the safety and liquidity of government securities, the convenience yield, contributes to lower market liquidity directly and indirectly via higher bond borrowing costs

[11] Huh and Infante (2021) do not specify market features or trading mechanisms.

in the repo market.

The rest of the paper is organized as follows. Section 2 presents related literature. Section 3 discusses the Norwegian government bond market and repo market frictions. Section 4 discusses the theoretical motivation and Section 5 presents the data. Section 6 presents the empirical framework and the results. Section 7 discusses the results while Section 8 concludes.

2 Related literature

This paper is related to the literature on repo markets, safe assets, and bond market liquidity. The literature on repo markets focus on the role of repos in providing funding and the role of repos in providing the collateral securities. Brunnermeier and Pedersen (2009), Gorton and Metrick (2012), Krishnamurthy et al. (2014) and Copeland et al. (2014) study how financial institutions rely on repos for short term funding and discuss the effect of higher hair-cuts during crises. The role of repos for bond borrowing was first addressed by Duffie (1996) and Jordan and Jordan (1997). They relate the borrowing demand for securities in the repo market to short positions in the cash market. Graveline and McBrady (2011) and Corradin and Maddaloni (2020) focus on the demand for securities in repo markets for hedging purposes and due to quantitative easing (QE), respectively. Fuhrer et al. (2016), Infante and Saravay (2021) and Jank et al. (2021), focus on collateral re-use when central bank asset purchases reduce the supply of collateral securities. This paper adds to the literature by showing how dealers use repos to access securities, via re-use of collateral or security-driven repos, when there is a buying pressure in the electronic cash market.

The literature on safe assets emphasizes the importance of these securities in times of uncertainty and crises. Cipriani et al. (2018) and Aggarwal et al. (2020) study periods of safe asset scarcity and the importance of safe assets as collateral in secured transactions, while Caballero et al. (2017) and He et al. (2019) focus on safe assets as a store of value. Krishnamurthy and Vissing-Jorgensen (2012) document how the characteristics of safe assets contribute to a lower yield on government securities than comparable securities without these

safe asset properties.[12] Klingler and Sundaresan (2022) study diminishing convenience yields on Treasuries after the financial crisis and find that falling excess demand in the primary market and new balance sheet constraints are the main drivers. He et al. (2022) propose a model with repo market frictions and find that these can explain changes in the Treasury convenience yield. This paper adds to the literature by documenting how the convenience yield is related to repo specialness and liquidity provision in electronic bond markets.

Brunnermeier and Pedersen (2009) find that when traders rely on repos to fund their trading activity, higher repo haircuts during crises contribute to lower market liquidity. Huh and Infante (2021) study the role of repos in bond market intermediation and find that higher repo specialness contribute to lower bond market liquidity. D'Amico et al. (2018), Foley-Fisher et al. (2019), and Corradin and Maddaloni (2020) document that bond market liquidity is related to repo rates, securities lending, and repo specialness, respectively. D'Amico et al. (2018) study QE by the Federal Reserve and find that bond purchasing programs lead to higher repo specialness. Corradin and Maddaloni (2020) and Arrata et al. (2020) study QE and find that ECB bond purchases reduce liquidity in Italian government bonds and decrease repo rates, respectively. Foley-Fisher et al. (2019) find that securities lending is positively related to market liquidity in corporate bonds. This paper adds to the literature by documenting how repo quantities and repo market frictions are related to intermediaries' liquidity provision.

3 The Norwegian market and repo market frictions

The Norwegian government bond market is relatively small due to Norway's favorable fiscal position. It is organized like major government bond markets and the market mechanisms are similar, see Valseth (2013). The cash market has a two-tier structure consisting of a dealer-to-customer OTC market and an interdealer electronic LOB.[13] New government debt is issued

[12] They find that the U.S. government has saved about 0.25 percent of GDP per year because of this characteristic of U.S. Treasuries over the period 1926 to 2008. They conclude that Treasury yields are too low to be an appropriate benchmark for "riskless" interest rates.

[13] Dealers report OTC-trades manually into the trading system within five minutes after execution. From 2005 most interdealer trades have been executed in the LOB. This is similar to major government bond markets,

regularly in the primary market to secure the government's cash holdings and to fund public lending programs for housing, higher education, innovation etc. The main intermediaries in Norwegian government bonds are the four primary dealers who have exclusive rights to participate in the primary market, obligations to post firm bid and ask orders in the LOB, and access to a limited securities lending facility.[14] See Appendix 1 for a further description of the specifics of the Norwegian primary dealer system.

There is one private repo market in Norwegian government bonds. This is a bilateral OTC-market where dealers trade directly with their customers and with each other. Repos that are part of the monetary policy implementation or the central bank security lending facility are not included. The private repo market facilitates both cash-driven repos and security-driven repos. In a cash-driven repo the cash lender receives the agreed security as collateral and has the possibility to re-use it. As described in Bowman et al. (2017) repo participants must agree on the specific securities used as collateral even if the cash lender is indifferent to the securities allocated to the trade. In a security-driven repo the security borrower requires a specific bond and the securities lender receives cash as collateral and has the possibility to reinvest/redeposit it, often to a higher rate.

To separate the two types of repos, and to facilitate the calculation of repo specialness, the paper employs a proxy for the GC repo rate as there is no triparty general collateral (GC) repo market in Norway. The proxy is the central bank deposit rate, which is also the policy rate, and represents the lower bound of a GC repo rate.[15] Duffie (1996) states that the GC repo rate and the (targeted) policy rate are normally close to each other. In Norway, the primary dealers' collateralized financing rate in the central bank is normally slightly higher than the deposit rate. This paper defines security-driven repos as repos with a repo rate at or below the deposit rate, and the remaining repos as cash-driven repos. In order to lend cash in the repo market primary dealers will typically require a repo rate higher than the alternative

e.g. Bessembinder et al. (2020) report that about 70 percent of interdealer trading in U.S. Treasuries occurs on electronic IDB platforms (such as BrokerTec).

[14] Many countries have a securities lending facility for Primary Dealers in government bonds including the US, UK, and the Euro area.

[15] There is no short term market rates available for the whole period. Primary dealers in Norwegian government bonds are banks with access to central bank financing and deposits. They also obtain financing by issuing covered bonds and senior bonds, and via FX-swaps.

of depositing the cash with the central bank.[16] In order to lend securities in the repo market the primary dealer will typically require a repo rate slightly below the central bank deposit rate in order to make a profit when reinvesting the cash collateral.

Repo market frictions can arise when government bonds are scarce and owners are less likely to "lend" them in the repo market at the "normal" repo rate. Security-driven repos that have a repo rate below the GC repo rate can according to Duffie (1996) "come about from the inability, opportunity cost, or transactions cost of supplying the instrument as collateral by certain of its owners." To be willing to lend their bonds in the repo market bond holders will typically require a premium and the repo rate will be pushed down. This means that average repo specialness, the difference between the GC repo rate and the weighted average repo rate on security-driven repos, will be positive when bonds are scarce.[17]

4 Theoretical background and predictions

The empirical analysis is based on the predictions of several theory papers. To investigate the relation between the convenience yield and repo specialness the paper builds on the mechanisms in Duffie (1996), Infante (2020), and He et al. (2022).[18] The convenience yield and the average repo specialness reflect excess demand for bonds, or bond scarcity, in the cash - and repo markets, respectively. Duffie (1996) finds that repo specialness is increasing in the demand for short bond positions in the cash market. Infante (2020) finds that increasing convenience yield is related to lower demand for cash-driven repos, and thus to a decreasing supply of securities for re-use by the cash lenders. He et al. (2022) find that changes in the convenience yield is related to periods with either high excess demand for bonds (positive convenience yields) or periods with high excess supply (negative convenience yields). They

[16] All overnight deposits were remunerated at the monetary policy rate until October 2011. From then amounts above a generous quota for each bank are remunerated at a rate below the monetary policy rate (100 bps lower).

[17] Repo rates on security-driven repos with a repo rate equal to the central bank deposit rate, which are part of the gentlemans agreement among some dealers, are not included in the calculations.

[18] He et al (2022) find that primary dealers in 2007-09 were on "the net lending side in the (GFC) repo market." Calculations of repo specialness and the repo-spread as defined in He et al. (2022) show that the two measures are highly correlated (44% during the 2002-2015 period).

find that the convenience yield is positively related to the repo spread, defined as the spread between the repo rate in the GC repo market, where dealers fund themselves, and the repo rate in the bilateral, special issue repo market, where they lend funds to their customers. Based on the predictions from these models the paper expects to find a positive correlation between the two measures of bond scarcity.

To identify drivers of dealer's repo activity the paper builds on the mechanisms in Huh and Infante (2021) where dealers can intermediate bonds without deviating from their optimal portfolio. The mechanisms in this paper differ by taking into account that the bond cash market consists of two segments, the customer OTC market and the interdealer electronic limit order book. Dealers can off-load risk incurred in the OTC market by trading anonymously in the limit order book. Lyons (2001) describes this activity as "hot potato" trading. Figure 1 shows an example of how primary dealers can create a link between the cash market segments and the repo market by off-loading inventory risk from OTC trades in the LOB, and how LOB participants in turn can off-load risk temporarily in the repo market.

Figure 1 illustrates a situation with excess demand for bonds. Dealer 1 sells a specific bond with a face value of 100 mill. NOK to a customer in the OTC market. Dealer 1 has no opposite customer trades in this case, which typically can happen in times with excess bond demand, and she goes to the interdealer LOB to partly replenish her inventory. She does this by simultaneously hitting all the sell limit orders in the LOB. In this case there are three sell limit orders in this bond, all submitted by other primary dealers. The trade size in each limit order is 25 million NOK, the minimum order size. The three passive sellers have different short term inventory capacity, and two of them go to the repo market to borrow bonds (lend cash) to make sure they can deliver the bonds to Dealer 1 on time. The possibility to borrow bonds in the repo market gives Dealer 3 and Dealer 4 time to search for customers willing to sell bonds and negotiate the terms in the OTC market, which typically requires more time in less liquid markets. Based on the predictions in Huh and Infante (2021) the paper expects to find a significant relation between signed dealer order flows and repo volumes.

To study whether repo volumes and repo market frictions are related to primary dealers'

liquidity provision the paper builds on the mechanisms in Brunnermeier and Pedersen (2009), Huh and Infante (2021), and He et al. (2022). Brunnermeier and Pedersen (2009) provide a model to study cash-constrained traders who rely on repos to fund their trading activity. The model predicts that dealer funding restrictions, e.g. higher repo rates and hair-cuts, have a negative effect on market liquidity. Huh and Infante (2021) provide a model with a triparty GC repo market, where dealers fund themselves, and a bilateral (specific issue) repo market, where dealers provide funding or securities to their customers. The model predicts that higher repo specialness in the specific issue repo market is related to higher bid-ask spreads. He et al. (2022) provide a model of bond intermediation with two repo markets as in Huh and Infante (2021) and find that repo market frictions (higher repo spread), are related to market illiquidity. Based on the predictions in these models the paper expects that dealer funding restrictions, repo market frictions, and dealer intermediation costs, are negatively related to market liquidity.

Finally, to study whether there are differences across the transparent, electronic LOB and the opaque, bilateral OTC market, the paper builds on the literature on financial market structure, e.g. Foucault et al. (2013) for asset markets in general and Bessembinder et al.(2020) for fixed income markets. In an electronic LOB with mandatory liquidity provision, featuring buy- and sell limit orders with minimum size and maximum spread, one-sided markets can induce substantial inventory imbalances for the liquidity providers. To resolve this temporarily, liquidity providers can enter into repos. In OTC markets the dealer negotiates with her counterparties and can to a larger extent condition her quotes/orders on inventory imbalances. Based on differences in liquidity provision in the two tiers of the bond market, the paper expects to find that repo market activity has a greater impact on the LOB.

5 Data

The data set from the Norwegian government bond market is well suited to study the links created by primary dealers across the repo- and cash markets in government bonds. It comprises all trades in government bonds reported to the Oslo Stock Exchange including the

complete trading history of four primary dealers' in the repo - and cash markets from June 2002 to December 2015. The transactions by the four dealers constitute 80-100 percent of total trading volumes over the period.[19] This period contains several episodes of excess demand for government bonds, including the years 2007-09 in the pre-Covid framework in He et al. (2022). There were no substantial changes in the balance sheet requirements for primary dealers during this period.

All transaction level data are first aggregated to daily and then to weekly variables, both at the dealer level and the aggregate market level. Repo variables include all private repos between two dealers or between a dealer and her customer. They are calculated by adding up the volumes (the face value of the bonds) in all repo trades. There are no hair-cuts nor restrictions on re-use of collateral bonds in the Norwegian market, which makes repo volumes consistent over time. Repo trading volume is the sum of all repos entered into that week.[20] Figure 2 shows the weekly trading volume (four week moving average) in the private, bilateral repo market and the cash market for Norwegian government bonds from May 2002 to December 2015.

Repo rates and repo specialness are volume weighted and based on all private repos.[21] Repo specialness is calculated as the difference between the risk free rate (GC repo rate), measured by the central bank overnight deposit rate, and the average repo rate on security-driven repos. The convenience yield on Norwegian government securities is calculated as the difference between the short term risk free rate and the interest rate on 3-month government bills.[22] Figure 3 displays the average repo rate in the bilateral repo market in Norwegian government bonds and the central bank overnight deposit rate from 2002 to 2015. The figure reflects the downward trend in interest rates over the period and shows that the repo rate has been slightly lower than the risk free rate for extended periods. This suggests that many

[19] The transactions are extracted from the trading system Saxess from May 2002 to April 2010, TradElect from April 2010 to November 2012, and Millennium from November 2012 to December 2015.

[20] The maturity of the repo contract is not available in the period preceeding December 2012. For the period 2013 to 2015 the average maturity was 4 days for cash-driven repos and 6 days for security-driven repos.

[21] A few repos, especially early in the period, do not have information about the repo rate and are left out in the calculations.

[22] Similar to the convenience yield employed in Infante (2020).

repos are security-driven. Figure 4 displays average repo specialness and the convenience yield on Norwegian government bonds. Both repo specialness and the convenience yield were elevated during the period of rapidly falling interest rates in 2002-03, the 2007-09 financial crisis, and the European debt crisis. These periods were characterized by an excess demand for government bonds. While repo specialness in the private, bilateral repo market was on average 14 basis points over the whole 2002 - 2015 period, the convenience yield was close to zero.[23]

Order flow variables are constructed by adding signed trades over a day. Buyer-initiated trades have a positive sign and seller-initiated trades have a negative sign. Order signs, with the identity of the initiator and the passive trader, are included for electronic trades, and inferred based on the mid prices in the LOB for OTC trades.[24] At the dealer level the paper differentiates between active- and passive order flows in the LOB. Passive order flows are based on a dealers' passive trades in the electronic limit order book (LOB). Sales, executed ask limit orders, have a negative sign, and buys, executed bid limit orders, have a positive sign. A positive number for the net passive order flow thus reflects positive net purchases by the dealer. This separation is not possible in the OTC market as the data lacks customer identities. In the OTC cash market data, the primary dealer appears as both the buyer and seller. The paper assumes, in line with the market microstructure literature, that customer trades are initiated by the customers.

Excess demand in the primary market is measured by the bid-to-cover ratios in bond auctions, both at the individual dealer level and at the aggregate level.[25] The bid-ask spread in the LOB is the best bid and best ask prices right before a trade by the dealers. The bid-ask spread in the OTC cash market is the absolute difference between dealer $i's$ trade price and the mid-quote in the LOB right before a trade, multiplied by two. Figure 5 depicts the relative effective spreads in the LOB and OTC market quoted by the four primary dealers.

[23] Including interdealer repos with zero borrowing cost in the period 2002-2012, the average cost of borrowing bonds (repo specialness) was 9 basis points.

[24] Inferred order signs, based on mid-quotes in the LOB right before the OTC trade, are calculated by using the Lee and Ready algorithm combinded with the tick rule. This means that the OTC order flow is less reliable than the LOB order flow.

[25] These variables are based on government bond auctions data kindly provided by the central bank.

Table 1 presents the descriptive statistics for the variables included in the analysis. The first seven rows contain panel data for the four primary dealers including repo volumes, order flows, bid-to-cover ratios, and bid-ask spreads. The first row shows that repo volumes vary a lot over time with a standard deviation more than twice the size of the median value. All panel variables are stationary according to the Levin, Lin & Chu test and the Im, Pesaran and Shin test. The last nine rows contain aggregate market data including total repo volume, average repo specialness for Norwegian government bonds, the convenience yield, order flows and relative spreads in both tiers of the bond market, and total bid-to-cover ratios in all bond auctions. All aggregate variables are stationary according to the Augmented Dickey-Fuller test.

6 Empirical framework and results

6.1 Repo specialness and the convenience yield

What is the relation between the convenience yield, a measure of the demand for safe bonds in the cash market, and average repo specialness, a measure of the excess demand and the borrowing cost for bonds in the repo market? The paper seeks to answer this question by employing a VAR model including the convenience yield, repo specialness and repo volume as endogenous variables. Figure 6 displays the accumulated impulse response functions for the variables based on a standard VAR with 2 lags. They reveal that repo specialness increases significantly with a one standard deviation innovations in the convenience yield, while there is no such effect on the convenience yield with one standard deviation innovations in repo specialness. This one-way positive relation suggests that the increase in repo specialness is driven by the increase in the convenience yield, and not vice versa. Based on this finding the paper orthogonalizes the repo specialness variable with respect to the convenience yield in the further analysis. Figure 6 also shows that repo specialness decreases significantly with a one standard deviation innovations in the repo volume, and that repo volume also decreases with a one standard deviation innovations in repo specialness, indicating a two way, negative

relation.

6.2 Drivers of repo activity

To uncover the drivers of primary dealers' repo activity the paper investigates potential drivers at the aggregate market level and at the individual dealer levels. The aggregate model includes three measures of transactions-based demand for bonds as explanatory variables. From the secondary market are the net order flows in the interdealer electronic market (LOB) and in the dealer-to-customer OTC market.[26] From the primary market are the bid-to-cover ratio in the 137 bond auctions over the years 2002 -2015. In addition the two price based measures, the convenience yield and repo specialness are included. The aggregate model is specified in Equation (1),

$$repo_t = \beta_0 + \beta_1 OF_t^{LOB} + \beta_2 OF_t^{OTC} + \beta_3 cv_t + \beta_4 sp_t + \beta_5 BTC_{t-1} + \varepsilon_t, \tag{1}$$

where $repo_t$ is the total repo trading volume in billion NOK in the private, bilateral repo market in week t. OF_t^{LOB} and OF_t^{OTC} are the order flows in the LOB and the OTC market, respectively. cv_t is the average convenience yield and sp_t is the average orthogonalized repo specialness in week t. BTC_{t-1} is the bid-to-cover ratio in week $t-1$.[27]

The results are presented in Table 2. They show that the buying pressure in the electronic limit order book, measured by the order flow OF_t^{LOB}, repo specialness sp_t, and the excess demand in the primary market, measured by bid-to-cover BTC_{t-1}, are significantly related to the private repo volume. An increase in the LOB order flow by 257 million NOK face value is related to an increase of 3.6 million NOK in repo volume, while an increase in average repo specialness by 10.9 basis points is related to a decrease of 11.2 billion NOK the repo volume. An increase in the BTC ratio by 79 % in the previous week is related to an increase the repo volume by 787 million NOK in this week. An increase in the excess demand in the OTC market and the convenience yield, do not appear to have any significant effects on the repo

[26] The paper employs order flow variables calculated as net volume in mill. NOK face value.

[27] The bid-to-cover ratio is lagged one week in order to ensure that the total effect on repos of end-of-week auctions are accounted for.

volume.[28]

The model at the dealer level includes an additional measure for excess bond demand, the passive order flow. The passive order flow is negative if the dealer's executed limit orders sum up to a net sale of bonds.[29] The panel data model with dealer fixed effects is specified in Equation (2),

$$repo_{i,t} = \beta_0 + \beta_1 OF_{i,t}^{LOB} + \beta_2 POF_{i,t}^{LOB} + \beta_3 OF_{i,t}^{OTC} + \beta_4 cv_t + \beta_5 sp_t + \beta_6 BTC_{i,t-1} + \alpha_i + \varepsilon_{i,t} \quad (2)$$

where $repo_{i,t}$ is the total repo trading volume in the private, bilateral repo market by dealer i in week t. $OF_{i,t}^{LOB}$ and $POF_{i,t}^{LOB}$ are the (active) order flow and passive order flow by dealer i in the LOB, respectively. OF_t^{OTC} is the order flow of dealer i in the OTC market. cv_t and sp_t are the average convenience yield and repo specialness in week t and $BTC_{i,t-1}$ is the bid-to-cover ratio by dealer i in week $t-1$. α_i and $\varepsilon_{i,t}$ are the dealer fixed effects and error terms, respectively.[30] The regression coefficients are corrected using the White two-way cluster, which adjust for both cross-sectional correlation and serial correlation in the data covering the four primary dealers over the period 2002 to 2015.

The results are presented in Table 3. Interestingly, they show that a primary dealer's passive order flow has significant explanatory power for her repo volume, while the "active" order flow has not. The result shows that a fall in the passive order flow, i.e. a higher net volume of executed sell limit orders, is related to a higher repo volume. An increase in weekly net passive sales by 121 million NOK is related to an increase in weekly repo volume by 2.2 million NOK. A negative passive order flow can occur when another dealer takes out all the sell limit orders in the LOB. The passive dealers can in this way enter into unintended short positions as all dealers are required to post firm buy- and sell limit orders at a maximum

[28] OTC order flow is less reliable than the LOB order flow as the signs must be inferred. If volatility is high and trades are reported later than required (within five minutes of the execution of the trade) the Lee Ready algorithm can infer the wrong sign. However, when OTC order flow is replaced with OTC trading volume in the model displayed in Equation (1) we find a significant positive relation between repo volume and OTC trading volume.

[29] Passive order flows are passive purchases minus passive sales by a dealer.

[30] The models are tested for redundant fixed effects, which are strongly rejected.

spread. If the "hit" dealers need to rebuild their inventory quickly to be able to deliver the sold bonds, they can go to the bilateral repo market and access bonds via reverse repos. The table also shows that primary dealers' repo volumes are negatively related to repo specialness. This result suggests that primary dealers reduce the amount of security-driven repos when the borrowing cost increases.

6.3 Repos and bond market liquidity

To uncover whether primary dealers' repo activity and repo market frictions affect their liquidity provision the paper investigates whether the spreads provided by primary dealers are related to their repo volumes and average repo specialness. The spreads in the electronic limit order book (LOB) and in the over-the-counter (OTC) market are investigated separately. The panel data model with dealer fixed effects applied to investigate the effects on current liquidity provision is presented in the following equation,

$$Spread_{i,t}^{m} = \beta_0 + \beta_1 OF_{i,t}^{LOB} + \beta_2 POF_{i,t}^{LOB} + \beta_3 OF_{i,t}^{OTC} + \beta_4 repo_{i,t} + \beta_5 cv_t + \beta_6 sp_t + \alpha_i + \varepsilon_{i,t}, \quad (3)$$

where $Spread_{i,t}^{m}$ is the average relative quoted spread in the LOB or average relative effective spread in the OTC market, $m = LOB, OTC$, for dealer i in week t. $OF_{i,t}^{LOB}$ and $POF_{i,t}^{LOB}$ are the (active and passive) order flows of dealer i in the electronic market, and $OF_{i,t}^{OTC}$ is the order flow in the OTC market (seen from the customer perspective). $repo_{i,t}$ is the total private bilateral repo volume by dealer i in week t. cv_t is the average convenience yield and sp_t is the average orthogonalized repo specialness for all bonds in week t. α_i and $\varepsilon_{i,t}$ are the dealer fixed effects and error terms, respectively. The regression coefficients are corrected using the White two-way cluster, which adjust for both cross-sectional correlation and serial correlation in the data covering four primary dealers over the period 2002 to 2015.

The results are presented in Table 4. They show that higher repo specialness, higher convenience yield, and higher customer order flows are related to higher spreads, while higher repo volumes are related to lower spreads in both tiers of the market. An increase in the convenience yield by 26 basis points is related to an increase in the LOB spread by 10.1 basis

points and the OTC spread by 7.2 basis points.[31] As a robustness check the paper adds a dummy variable for the 2007-09 financial crisis. Including the dummy variable increases the explained variation, adjusted R^2,by 2.5 to 3 percentage points while the convenience yield and repo specialness are still significant. An increase in repo specialness by 10 basis points is related to an increase of the average relative quoted spread in the LOB by 9.2 basis points and the average relative effective spread in the OTC market by 6.3 basis points.

The results for bond market liquidity show that primary dealers increase their spreads in both tiers of the market when bonds are in high demand by their customers and scarce. A high convenience yield makes bonds expensive to buy in the cash market and high repo specialness make them expensive to borrow in the repo market. This means that dealers' intermediation costs also increase. The results document that the dealers pass on these costs to their counterparties in the cash market and that the increase in spread is slightly higher in the electronic interdealer market.

7 Discussion

This paper seeks to uncover the links between the repo market and cash market created by primary dealers. The results show that the four predictions based on previous theory papers hold. First, they show that an increase in the convenience yield leads to an increase in repo specialness. Second, they show a positive relation between bond demand (order flow) and repo volume. Third, they show that repo market frictions, measured by repo specialness, is negatively related to market liquidity. Fourth, they show that the repo market is especially important for liquidity providers in the electronic market. Together these results suggest that primary dealers to a large extent use the bilateral, private repo market in government bonds for market making purposes, especially for market making in the electronic limit order book (LOB).

In addition to confirming these predictions the results provide more detailed insights into

[31] The relative quoted spread is the quoted spread in percent of the midquote right before an electronic trade by dealer i. The relative effective spread in the OTC-market is the absolute value of the difference between the price and the midqoute (times 2) in percent of the midquote.

how primary dealers act in the repo market. Dealers typically enter into private repos to cater to their customers and borrow/lend bonds from/to each other, and not to fund themselves. Several findings support this conclusion. First, higher repo volumes are related to sell limit orders posted by dealers in the LOB. Higher passive sales (negative passive order flow) in the LOB lead to a reduction in a dealer's inventory. To cover such "unintended" short positions dealers can access bonds temporarily in the repo market. The dealer can do this in two ways, either re-use collateral via cash-driven repos or borrow bonds via security-driven repos. The significant relation between reverse repo volumes and the buying pressure in the cash market is consistent with He et al. (2022). They find that during the 2007-2009 crisis, when there was an excess demand for Treasuries, US primary dealers were net short in the cash market and on the net lending side in the repo market.

Second, higher repo specialness (a lower repo rate) is related to higher spreads. The effect of changes in the repo rate depends on whether dealers are net cash lenders or cash borrowers in repo markets. If they are net borrowers as in the Brunnermeier and Pedersen (2009) model, lower repo rates means lower financing costs. Lower financing costs are related to lower intermediation costs and contribute to lower spreads/higher liquidity. If they are net lenders, as in the GFC repo market in the He et al. (2022) model and in the special repo market in the Huh and Infante (2021) model, lower repo rates means less interest on the cash collateral, i.e. higher bond "borrowing" costs. Higher bond borrowing costs are related to higher intermediation costs and contribute to higher spreads/lower liquidity.

Third, higher convenience yield is related to higher spreads in the cash market. The convenience yield can be considered a measure of bond scarcity and reflects excess demand in the cash market. This is consistent with the findings in He et al. (2022) that periods with high excess demand for bonds have positive convenience yields and negative repo spreads. They measure the repo spread as the difference between the repo rates in the GFC market and the triparty market. As they find that dealers typically lend funds (borrow bonds) in the GFC repo market, a negative repo spread means lower repo rates in this market, i.e. higher bond borrowing costs.[32] Only if primary dealers mainly borrow bonds will this lead to higher

[32] Eligible collateral in the GFC repo market includes US Treasury bonds, notes and bills, as well as bonds

spreads.[33]

Interestingly, repo volumes appear to be unrelated to the convenience yield. When the convenience yield goes up, the alternative cost to supplying them in the repo market goes up. Safe bonds can for example be more valuable as a means to raise cash, as collateral in other markets, or to cover margins in derivatives trading. Bond holders may thus supply less bonds in the repo market. This will reduce repo volume in cash-driven repos, as in Infante (2020), and in security-driven repos. On the other hand, higher convenience yield can both increase the supply of cash-driven repos, via the mechanism in Gottardi et al. (2019), and the demand for security-driven repos. If the negative effect of the convenience yield on repos is similar in size to the positive effect of the convenience yield on on repos, the two effects will cancel each other out.

The results in this paper show that when there is an excess demand for government bonds, the bilateral repo market plays an important role for liquidity providers, especially for liquidity providers in electronic limit order books. Repo market frictions causing changes in average repo specialness contribute to changes in market liquidity via changes in the repo volume. These results complement the findings in D'Amico and Pancost (2022) who document a time-varying special collateral risk premium in Treasury prices.

The findings in this paper suggest that a higher convenience yield leads to a decrease in the supply of security-driven repos and an increase in the demand for security-driven repos, which together push up repo specialness, the bond borrowing cost. The convenience yield will typically increase in crises and times of uncertainty as a result of flight-to-safety and flight-to-quality. It is interesting to note that these flights from risky assets to government bonds sometimes are referred to as flight-to-liquidity, even if they often are related to a deterioration in market liquidity, as shown here.

with implict government guarantees. In the triparty repo market many types of securities are eligible, restricted according to a pre-defined "basket" of securities by the lender of funds.

[33] This finding is in line with several studies including Duffie (1996), but contrary to the finding in Vayanos and Weill (2008). They find that short-sellers, by reducing search frictions, increase both the asset's liquidity and repo specialness.

8 Conclusion

The purpose of this paper is to improve our understanding of the mechanisms at play in repo markets by exploring the links between the repo market and cash market in government bonds created by primary dealers. The paper employs a different approach than previous studies by using transactions data from the repo market *and* the cash bond market with dealer identities. This facilitates the calculation of dealer specific repo quantities and order flows, as measures of excess demand for bonds, in the two tiers of the cash market. The results, based on a data set from the markets in Norwegian government bonds, show that the repo market is important for market-making in the cash market, especially in the electronic limit order book (LOB).

The results show that dealers increase their repo volumes when their net passive sales in the LOB increase and decrease repo volumes when repo specialness increases. (a negative relation between repo specialness and repo volume, and a positive relation between repo volume and market liquidity dealers' liquidity provision, which suggests that intermediaries in electronic bond markets face an additional risk related to the level of repo specialness. The results suggest that primary dealers mainly access bonds in the repo market when there is an excess demand for bonds in the cash market, and especially when their net passive sales in the LOB increase. They can access bonds to limit inventory depletion either by re-using bonds received as collateral via cash-driven repos with their customers or by borrowing bonds via security-driven repos from other dealers. In this way the repo market helps dealers' balance their inventories when there is a buying pressure in the market.)

When the convenience yield goes up, safe government bonds become more valuable. This will both increase the demand and decrease the supply of security-driven repos, and in turn push average repo specialness up. The results show that average repo specialness is negatively related to the repo volume, and that lower repo volume is related to a deterioration in cash market liquidity. The convenience yield will typically increase in crises and times of uncertainty as a result of flight-to-safety and flight-to-quality. The results show that these flights from risky assets to government bonds, also referred to as flight-to-liquidity, are related to a deterioration in market liquidity both directly and indirectly, as shown in this paper.

The findings in this paper have implications for regulators and policy makers in many countries who want to move bond trading from opaque OTC markets to lit electronic exchanges. Well-functioning repo markets appear to be an important prerequisite for a successful transition to electronic limit order books.

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Appendix A

The primary dealer system in Norwegian government bonds

The Norwegian central bank, which manages government debt on behalf of the Treasury, enters into agreements with primary dealers to promote orderly markets in government bonds. The agreements include obligations and benefits for the financial institutions choosing to become primary dealers. The obligations include liquidity provision in the interdealer electronic limit order book (LOB) and participation in auctions in the primary market. Primary dealers must post firm bid and ask quotes (limit orders) in the LOB with a minimum transaction volume and a maximum spread throughout the trading day.[34] These spreads and volumes have varied substantially since the inception of a LOB in 1999.[35] Table A.1 displays the requirements during the period 2002-2015. Generally the minimum amounts are lower for long bonds than short bonds and the maximum spreads are higher for long bonds than short bonds. Graph A.1 shows the actual total depth in the LOB at the bid-side and the ask-side including all benchmark bonds. The reduction in liquidity in the second part of 2011 is due to two primary dealers withdrawing, reducing the total number of primary dealers from six to four.

In return for market maker obligations, primary dealers have an exclusive right to participate in auctions/syndications. They also have access to a securities lending facility managed by the central bank at a favorable borrowing cost. Up to April 2012 the remuneration on their cash collateral was equal to the central bank deposit rate. After April 10, 2012 the remuneration was set to 5 basis points below this rate, increasing the borrowing cost from zero to 5 basis points.[36] The repo-rate on the central banks' securities lending programs varies across nations. Under the securities lending operations at the Federal Reserve bank of New York, the repo-rate is determined by competitive bidding by primary dealers. The borrowing

[34] Regular trading starts at 9 am and closes at 4 pm.

[35] Table 1A and 2A in the appendix display an overview of the requirements according to the primary dealer agreements.

[36] This is for security lending agreements with settlement at t+2 (days). For securities lending agreements with settlement at t+1, the interest rate on cash collateral is reduced from 100 to 105 basis points below the central bank deposit rate.

cost at the ECB securities lending program is set at a minimum fee of 10 basis points.[37]

Table A.2 displays the per bond total maximum available volumes available for the primary dealers. The volume available for each dealer is the total volume divided by the number of primary dealers. The amount per dealer has gradually increased from 270 million NOK in 2002 to 8 billion in each bond in 2015. The maturity of these securities-lending agreements are typically one to five days, with an overweight of one day.

There is only one repo market in Norwegian government bonds. It is a bilateral OTC market where the primary dealers are the major players. This is different from the fragmented repo markets in e.g. U.S. Treasuries and European government bonds, which consist of general collateral (GC) repo markets (triparty repo, interdealer general collateral finance (GCF) repo, and central counterparty (CCP) repo), bilateral (specific issue) repo markets, and private security lending programs. The bilateral Norwegian repo market facilitate cash-driven and security-driven repos between dealers and their customers or between two dealers.[38] The paper separates cash-driven and security-driven repos by applying the difference between the repo rate and the central bank deposit rate. Bowman et al. (2017), who study the bilateral repo market in U.S. Treasuries, use as a rule that repos collateralized by on-the-run or first-off-the-run securities are security-driven (special repos), and repos collateralized by older off-the-run securities are cash-driven (GC repos). However, they emphasize that the rule is imprecise and leads to some misspecifications. As all issues in the Norwegian government bond market can be considered on-the-run bonds, this paper assumes that the cash lender in a cash-driven repo will require a repo rate higher than her funding rate. As government bonds are relatively scarce, large banks to a large extent access funding by issuing covered bonds, entering the repo market for covered bonds, or borrowing in the central bank at a rate slightly above the central bank deposit rate. Repos with a repo rate above the central bank deposit rate are

[37] ECB's securities lending arrangements allow eligible counterparties, at any time, to borrow securities against securities as collateral at a fixed minimum fee of 10 basis points, or a fee based on prevailing market rates, whichever is the higher. The fee is the difference between the repo and reverse repo rates.

[38] Normally there are no hair-cuts (margins) in repos involving Norwegian government bonds.

thus classified as cash-driven repos and the remaining as security-driven repos.[39][40]

[39] Also, the cash lender will require a rate higher than the risk free alternative; deposit the cash in the central bank. Until the end of 2011 large banks could deposit unlimited amounts overnight in the central bank at the deposit/monetary policy rate. Since then the central bank imposed a (generous) max amount, and amounts above this are remunerated at a rate 100 bps below the official deposit rate.

[40] A few repos, especially early in the period, do not have information on the repo rate, and cannot be classified.

Table 1: Descriptive statistics

The table presents the descriptive statistics of the convenience yield, repo specialness, and panel data set for the four primary dealers for the period June 2002 to December 2015. The convenience yield is the difference between the central bank deposit rate and the three month Norwegian treasury bill rate, repo specialness is the difference between the central bank deposit rate and the average repo rate on security-driven bonds, her repo volume in mill. NOK. The first four columns of the table display variable name, total number of observations, the mean value, and standard deviation. The 5th column displays the first order autocorrelation for the variables and the last column reports unit root test values (Augmented Dickey-Fuller test stat for aggregate market data and the Levin, Lin &Chu test for the panel data). Spreads are weekly averages, while the volume data (mill. NOK) are accumulated weekly. Values in bold are significant at the 5 % level, and marked with * are significant at the 1% level.

Series	obs	mean	median	std.dev.	AR(1)	Unit root
Panel data:						
Repo vol, all private (mill.NOK)	2808	1873.1	996.3	2362.1	0.815	**−4.676***
Order flow, LOB	2836	−19.152	0	178.77	0.106	**−17.18***
Passive order flow, LOB	2836	8.553	0	121.12	0.208	**−16.80***
Order flow, OTC customer	2836	3.835	2.900	639.33	0.029	**−21.03***
OTC Bid-Ask spread, effective	2826	0.122	0.107	0.063	0.528	**−7.93***
LOB Bid-Ask spread, quoted	2833	0.214	0.190	0.088	0.742	**−7.03***
Bid-To-Cover, auctions	525	4.456	2.352	10.08	−0.000	*na*
Aggregate market data:						
Convenience yield	678	−0.0024	−0.0484	0.2629	0.891	**−3.62***
Repo specialness	674	0.142	0.122	0.109	0.429	**−8.27***
Repo specialness (⊥)	642	0	−0.025	0.102	0.370	**−8.81***
Repo volume (Mill.NOK)	710	6808.6	6148.6	4661.5	0.780	**−5.14***
Order flow, LOB	710	−20.672	0.00	257.48	0.136	**−23.19***
Order flow, OTC customer	710	22.631	−16.330	1001.51	0.069	**−16.34***
Quoted spread, LOB	710	0.2294	0.2034	0.0905	0.801	**−4.92***
Effective spread, OTC	709	0.1287	0.1163	0.0538	0.748	**−4.79***
Bid-To-Cover, auctions	137	2.55	2.41	0.79	−0.017	*na*

Table 2

The table presents the results of the following regression model

$$repo_t = \beta_1 OF_t^{LOB} + \beta_2 OF_t^{OTC} + \beta_3 conv_t + \beta_4 BTC_{t-1} + FC + \varepsilon_t$$

where $repo_t$ is the aggregate private repo volume (mill. NOK face value) in week t, OF_t^{LOB} is the aggregated order flow in the electronic interdealer market and OF_t^{OTC} the order flow in the over-the-counter (OTC) market in week t. $conv_t$ is the convenience yield of Norwegian government bonds calculated as the difference between the risk free rate and the yield on 3 month Treasury bills. BTC_{t-1} is the bid-to-cover ratio in government bond auctions in the previous week. FC is a dummy variable for the financial crisis with the value 1 from August 2007 to December 2009. The results are corrected for heteroscedasticity and autocorrelation by Newey-West std. errors. Coefficients significant at the 10% level are in bold, and coefficients significant at the 5 % level or better are marked with an asterisk. T statistics are in parenthesis.

	Private repos (aggregate) 2002 - 2015				
Order Flow, LOB	**3.1794***	**3.2586***	**2.7699***	**4.0501***	**3.6494***
	(3.89)	(3.97)	(3.53)	(4.43)	(3.80)
Order Flow, OTC	−0.0912	−0.1672	−0.1793	−0.5530	−0.5886
	(−0.55)	(−0.96)	(−1.08)	(−1.45)	(−1.44)
Convenience yield		−1414.5	−1289.3	−1837.1	−2411.6
		(−0.85)	(−0.85)	(−1.06)	(−1.36)
Specialness (⊥)			**−10534***		**−11235***
			(−3.85)		(−2.74)
Bid-To-Cover(-1)				**964.40**	**787.20**
				(1.96)	(1.70)
Adj. R^2	0.0269	0.0337	0.0769	0.0941	0.1338
Obs.	710	678	642	133	130

Table 3

The table presents the results of the following panel data regression with dealer fixed effects

$$repo_{i,t} = \beta_0 + \beta_1 OF_{i,t} + \beta_2 POF_{i,t} + \beta_3 COF_{i,t} + \beta_4 conv_t + \beta_5 BTC_{i,t-1} + \alpha_i + \varepsilon_{i,t}$$

where $repo_{i,t}$ is the private repo volume (mill. NOK face value) by dealer i in week t. $OF_{i,t}^{LOB}$ is the "active" order flow and $POF_{i,t}^{D}$ is the passive order flow in the electronic interdealer market by dealer i in week t. $OF_{i,t}^{OTC}$ is the order flow in the over-the-counter (OTC) market by dealer i in week t. Order flow is measured in mill. NOK. $conv_t$ is the convenience yield of Norwegian government bonds calculated as the difference between the risk free rate and the yield on 3 month Treasury bills. $BTC_{i,t-1}$ is the bid-to-cover ratio by dealer i in the government bond auction in week $t-1$. The coefficients are corrected by White two-way cluster std.errors and covariance. Coefficients significant at the 10% level are in bold, and coefficients significant at the 5 % level or better are marked with an asterisk. T statistics are in parentheses.

All private bilateral repos 2002 -2015				
(Active) OF, LOB	0.2191	0.2087	0.1697	−0.1974
	(0.39)	(0.38)	(0.38)	(−0.59)
Passive OF, LOB	**−2.2090**	**−2.2315**	**−1.9250**	**−1.7855***
	(−2.98)	(−3.12)	(−2.93)	(−3.30)
OF, OTC	0.0197	0.0046	0.0005	0.1688
	(0.56)	(0.19)	(0.02)	(1.26)
Convenience yld		−309.75	−261.25	−746.10
		(−0.44)	(−0.39)	(−0.57)
Specialness (⊥)			**−3848.96**	−3935.36
			(−2.61)	(−2.28)
BTC, Ind (-1)				38.261
				(1.36)
Adj. R^2	0.1131	0.1113	0.1393	0.0987
Dealer fixed effects	*Y*	*Y*	*Y*	*Y*
Periods	709	678	642	130
Observations	2808	2684	2540	496

Table 4

The table presents the results of the following panel data regression with dealer fixed effects

$$Spread^m_{i,t} = \beta_0 + \beta_1 OF_{i,t} + \beta_2 POF_{i,t} + \beta_3 COF_{i,t} + \beta_4 repo_{i,t} + \beta_5 cv_t + \beta_6 sp_t + \beta_7 D^{FC}_t + \alpha_i + \varepsilon_{i,t}$$

where $Spread^m_{i,t}$ is the relative effective spread in the LOB or OTC market, $m = LOB, OTC$, for dealer i in week t. $OF^{LOB}_{i,t}$, $POF^{LOB}_{i,t}$ and OF^{OTC}_t are the order flows (trade volume, mill. NOK) of dealer i in the two tiers of the bond market where $POF^{LOB}_{i,t}$represents the passive order flow. $repo_{i,t}$ is the total private bilateral repo volume of dealer i in week t. cv_t is the convenience yield on government securities and sp_t is the average repo specialness for all bonds in the repo market based on all security-driven repos in week t. D^{FC}_t is a dummy variable for the 2008-09 financial crisis. α_i and $\varepsilon_{i,t}$ represent the dealer fixed effects and error terms, respectively. The regression coefficients are corrected using White two-way cluster, adjusting for both cross-sectional correlation and serial correlation. Coefficients significant at the 10% level are in bold, and coefficients significant at the 5 % level or better are marked with an asterisk. T statistics are in parentheses.

	Relative Bid-Ask spreads 2002 - 2015					
	LOB quoted spreads			Effective OTC spreads		
(Active) OF, LOB	$-1.94E^{-05}$ (−2.31)	$-7.97E^{-06}$ (−1.05)	$-1.15E^{-06}$ (−1.42)	$-3.47E^{-06}$ (−0.48)	$3.62E^{-06}$ (0.86)	$7.83E^{-07}$ (0.10)
Passive OF, LOB	$1.09E^{-05}$ (0.61)	$-5.57E^{-06}$ (−0.40)	$1.70E^{-06}$ (0.08)	$-1.89E^{-06}$ (−0.17)	$-1.19E^{-05}$ (−1.17)	$-6.29E^{-06}$ (−0.41)
OF, OTC	$\mathbf{5.38E^{-06}}$ (2.99)	$\mathbf{8.58E^{-06*}}$ (3.69)	$\mathbf{7.42E^{-06*}}$ (3.68)	$\mathbf{2.73E^{-06}}$ (3.09)	$\mathbf{4.87E^{-06*}}$ (4.11)	$\mathbf{3.96E^{-06*}}$ (3.85)
Repo volume	$\mathbf{-4.95E^{-06}}$ (−2.85)	$\mathbf{-4.00E^{-06}}$ (−2.81)	$\mathbf{-5.84E^{-06}}$ (−3.21)	$\mathbf{-3.47E^{-06}}$ (−2.71)	$-2.73E^{-06}$ (−2.20)	$\mathbf{-4.19E^{-06*}}$ (−3.67)
Convenience yld		**0.1005*** (4.27)	**0.0973*** (4.27)		**0.0720*** (4.97)	**0.0696*** (5.05)
Specialness (⊥)		0.0688 (2.14)	**0.0917** (3.12)		**0.0448** (2.71)	**0.0632*** (3.72)
Financial crisis			**0.0408** (2.77)			**0.0323*** (4.65)
Adj. R^2	0.0230	0.1137	0.1391	0.0342	0.1284	0.1598
Dealer fixed effects	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Periods	709	642	642	709	642	642
Observations	2806	2538	2538	2799	2532	2532

Table A.1

The table presents minimum limit order volumes (mill. NOK) and maximum bid-ask spreads (price points) for bid and ask limit orders in the LOB according to the primary dealer agreements.[41] The requirements differ according to bond maturity. Bonds are therefore divided into three maturity groups, short bonds with a remaining time to maturity from 1(2) to 4 years, medium term bonds with a remaining time to maturity between 4 and 7 years, and long bonds with a remaining time to maturity between 7 and 11 years.

Period	Min. order volume (mill. NOK)			Max. bid-ask spread (price points)		
Year	Short	Medium	Long	Short	Medium	Long
2002-05	20	15	10	20	30	40
2006	20	15	10	15	20	30
2007	35	25	20	15	20	30
2008	35	25	20	15	20	30
2009	35	25	20	30	40	60
2010	35	25	20	20	30	40
2011	45	35	25[42]	15	25	35[43]
2012	45	35	25	25	50	70
2013	50	45	40	15	35	50
2014	50	45	40	15	30	45
2015	65	55	45	5	5	5[44]

[41] Spreads are measured in price points up to and including 2014, and in yields (basis points) in 2015.

[42] From August 18, minimum volumes were reduced to 35, 30 and 20 mill. NOK for short, medium, and long bonds, respectively.

[43] From August 18, maximum spreads were increased to 30, 50 and 70 price points for short, medium, and long bonds, respectively.

[44] Spread in yield basis points for all maturities.

Table A.2

Central Bank securities lending facility available for primary dealers in government bonds. The total limit (billion NOK) in each issue is divided evenly among the primary dealers in Norwegian government bonds. The amount available under the facility varied according to the time to maturity of the bond until 2013. The table show the average amount available for three maturity groups; short bonds with a remaining time to maturity from 1(2) to 4 years, medium term bonds with a remaining time to maturity between 4 and 7 years, and long bonds with a remaining time to maturity between 7 and 11 years. The amounts shown are for each loan. The amount available for each dealer is the total amount divided by the number of primary dealers. The number of primary dealers decline from 6 to 4 over the 2002-2015 period.

	Total limit each bond (Bill. NOK)			
	Time to maturity			#
Year	Short	Medium	Long	Primary Dealers
2002	1.6	1.6	1.6	6
2003	2.5	2.0	1.6	6
2004	2.5	2.0	1.6	6
2005	2.5	2.0	1.6	6
2006	2.5	2.5	2.5	6
2007	5.0	3.7	3.7[45]	6
2008	5.0	3.7	3.7	6
2009	5.0	3.7	3.7	6
2010	6.0	5.0	4.0	6
2011	6.0	5.0	4.0	6
2012	6.0	5.0	4.0	4
2013	8.0	8.0	8.0	4
2014	8.0	8.0	8.0	4
2015	8.0	8.0	8.0	4

[45] Increased from 2.5 to 3.7 million NOK in medium and long term bonds from August, 23.

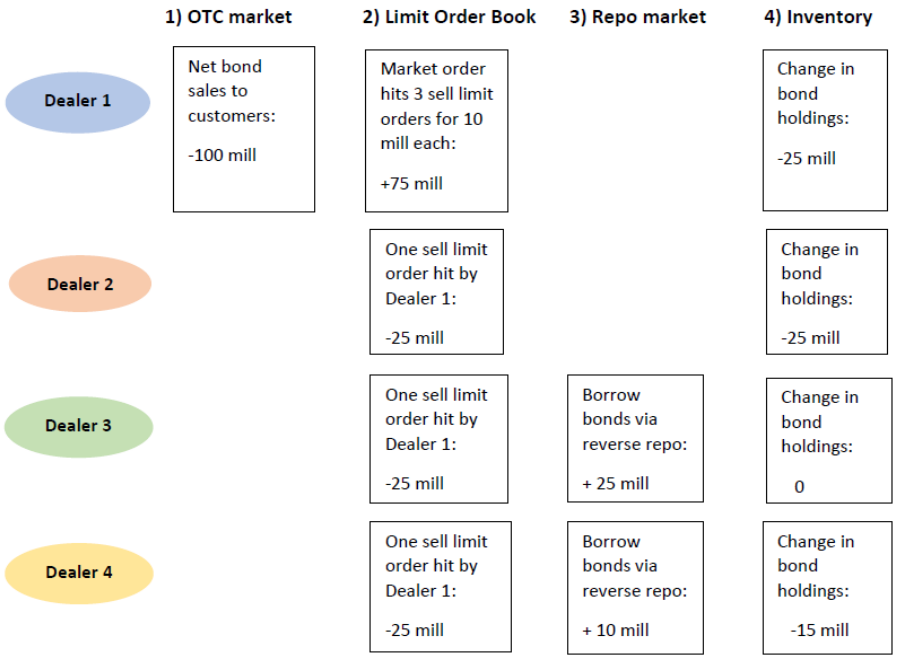

Figure 1: The graph shows how a sale of bonds by Dealer 1 in the customer OTC-market can generate trades in the interdealer electronic LOB and in the repo market. If there is an excess demand for bonds by customers, Dealer 1 may go to the interdealer market and offload risk by simultaneously hitting the sell limit orders provided by Dealers 2, 3, and 4. While Dealer 2 is well positioned , Dealers 3 and 4 go to the repo market to borrow bonds via reverse repos to make sure they can deliver the bonds to Dealer 1 on time.

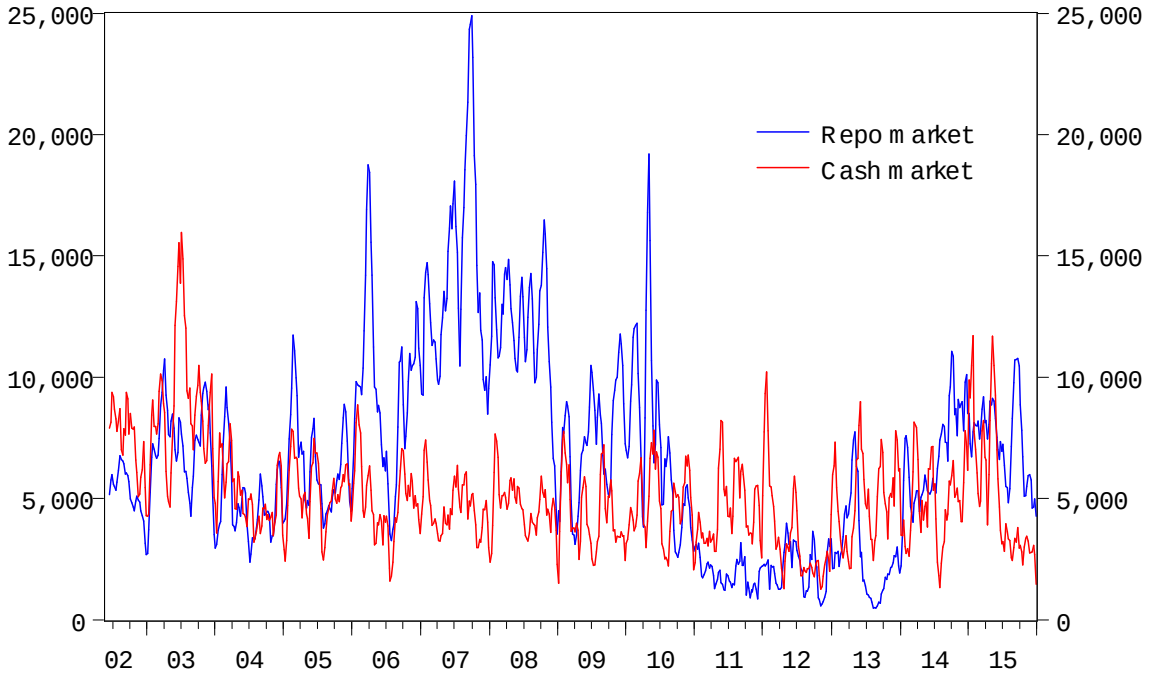

Figure 2: Weekly trading volume in the private, bilateral repo market and the cash market for Norwegian government bonds. Four week moving average. May 2002 to December 2015.

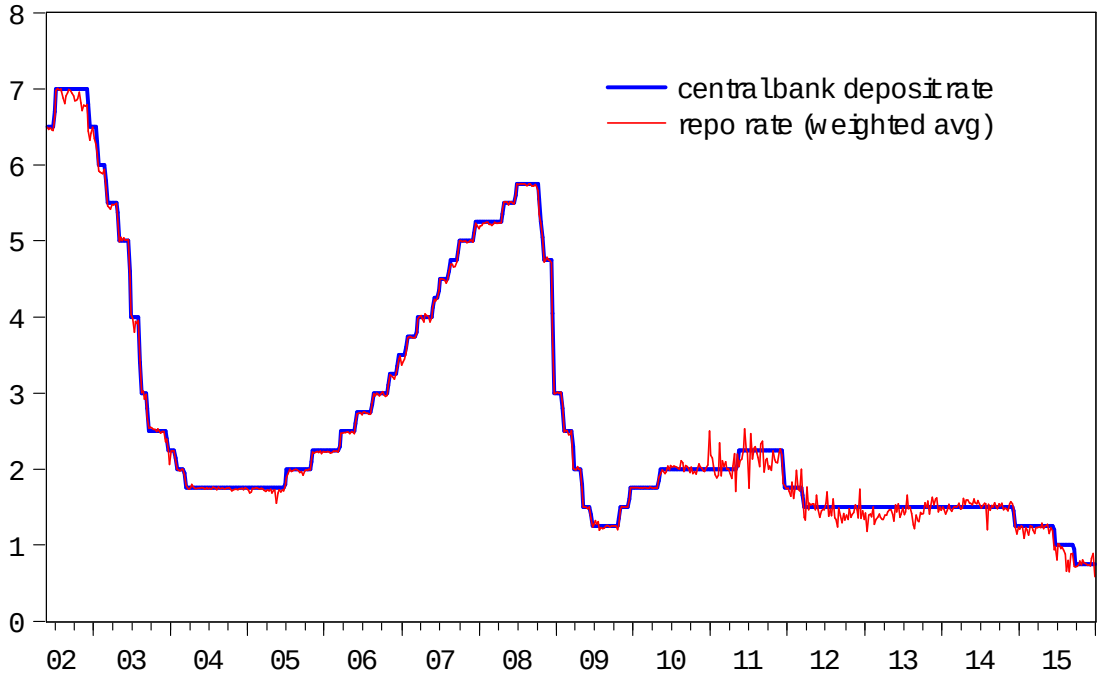

Figure 3: The repo rate in the bilateral repo market in Norwegian government bonds (weighted average of all repos) and the central bank deposit rate (the monetary policy rate). Weekly average from May 2002 to December 2015.

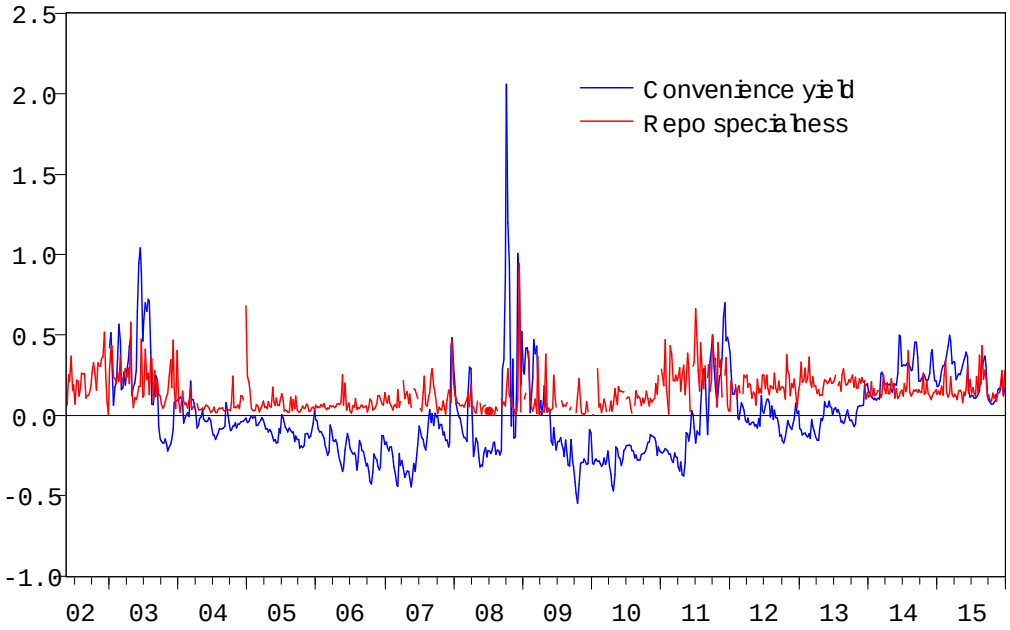

Figure 4: The convenience yield in the Norwegian government bonds and repo specialness in the bilateral repo market. The convenience yield is measured as the difference between the risk free rate (proxied by the central bank deposit rate) and the rate on Norwegian Treasury bills. Repo specialness is measured as the difference between the risk free rate/GC repo rate (proxied by the central bank deposit rate) and the repo rate on security-driven repos. Weekly averages from May 2002 to December 2015.

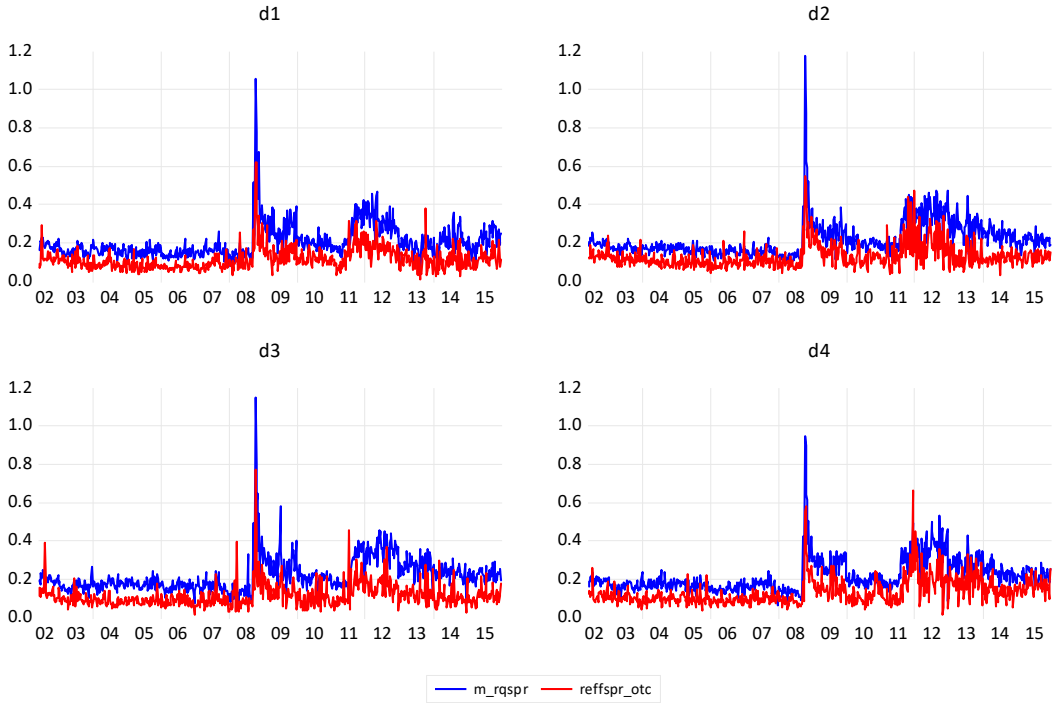

Figure 5: The figure shows the relative spreads provided by the four primary dealers in the interdealer electronic limit order book (LOB) and in the customer over-the-counter (OTC) market. The quoted spread in government bonds in the LOB is measured as the difference between the dealer's best bid and best ask right before the trade. The effective spread in government bonds in the OTC-market is measured as the absolute difference between the transaction price and the mid-quote in the LOB for the same bond issue multiplied by 2.

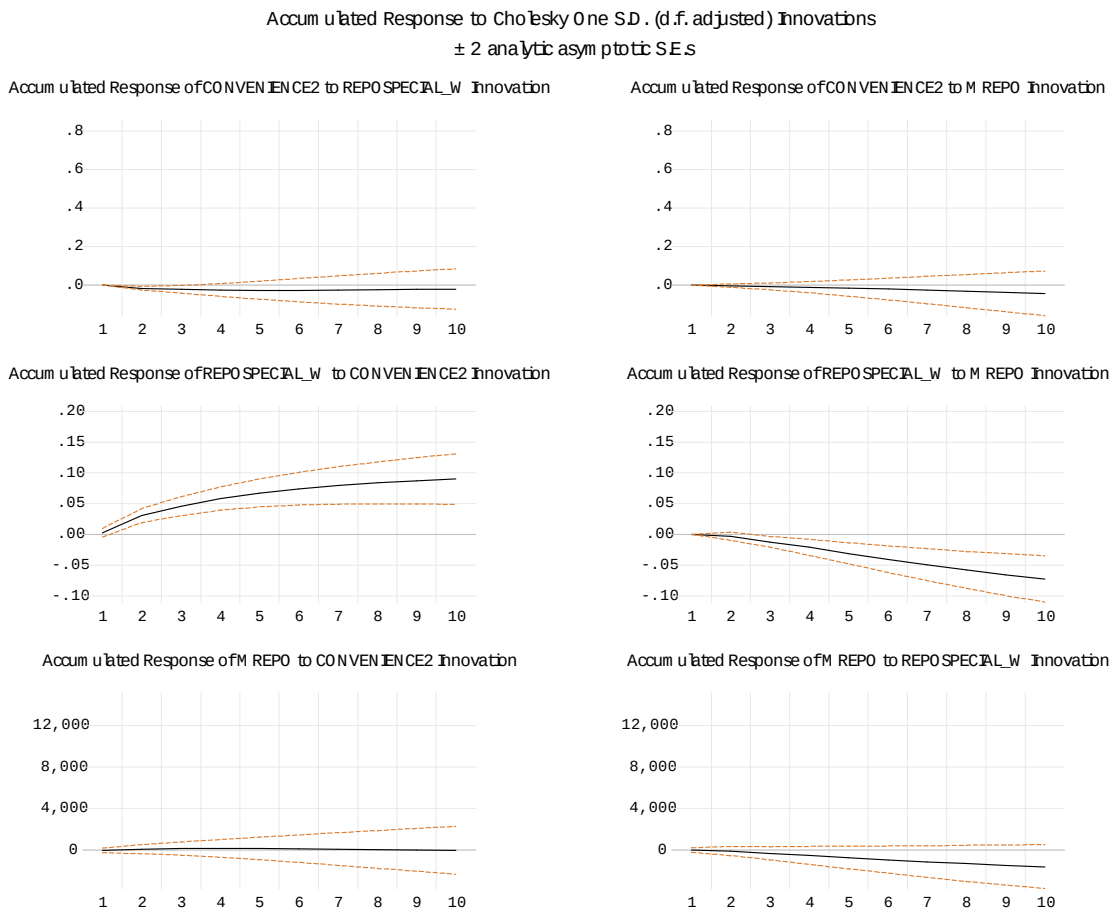

Figure 6: Impulse response functions to Cholesky one std. deviation innovations for the convenience yield, average repo specialness, and repo volume in Norwegian government bonds.

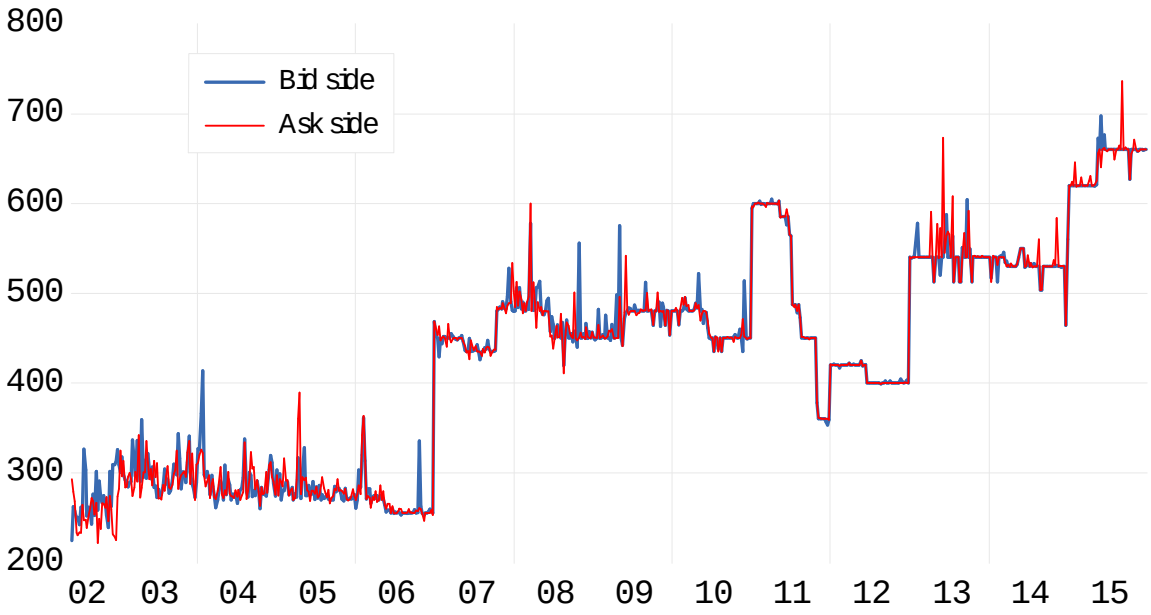

Figure 7: The graph shows the weekly average of actual total depth on each side of the limit order book for all bonds and all dealers, based on a snapshot at 3:30pm each day, and adding the order book depth for each bond.

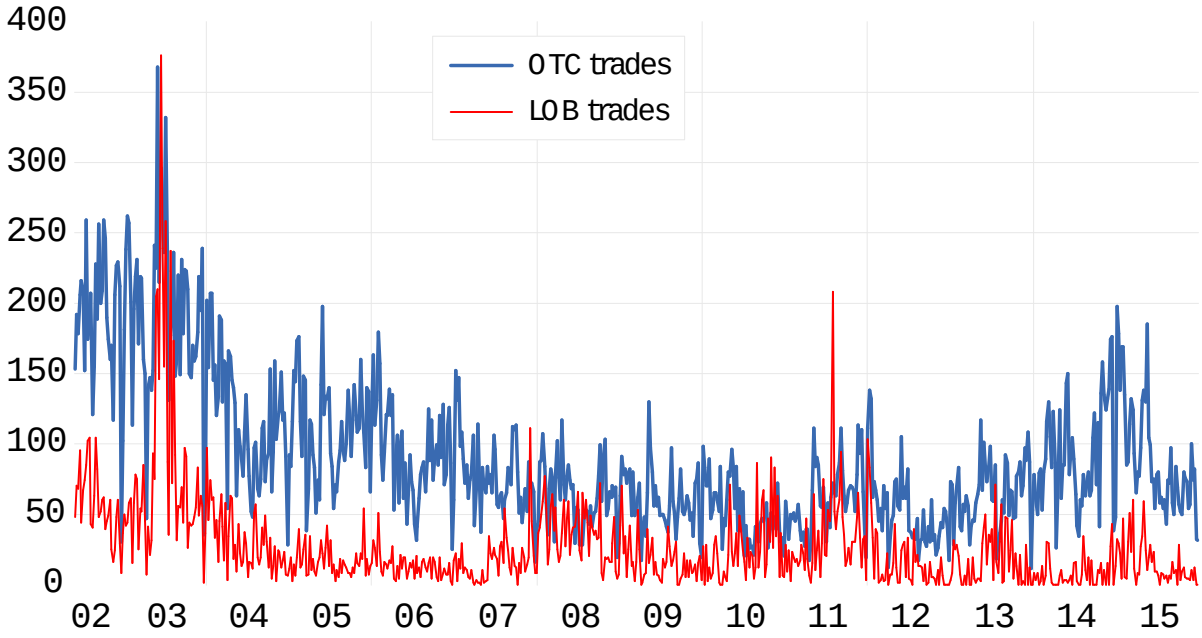

Figure 8: The graph shows the total number of executed trades in Norwegian government bonds registered at the Oslo Stock Exchange from May 2002 to December 2015. The trades are separated into OTC-market trades and the trades in the LOB.

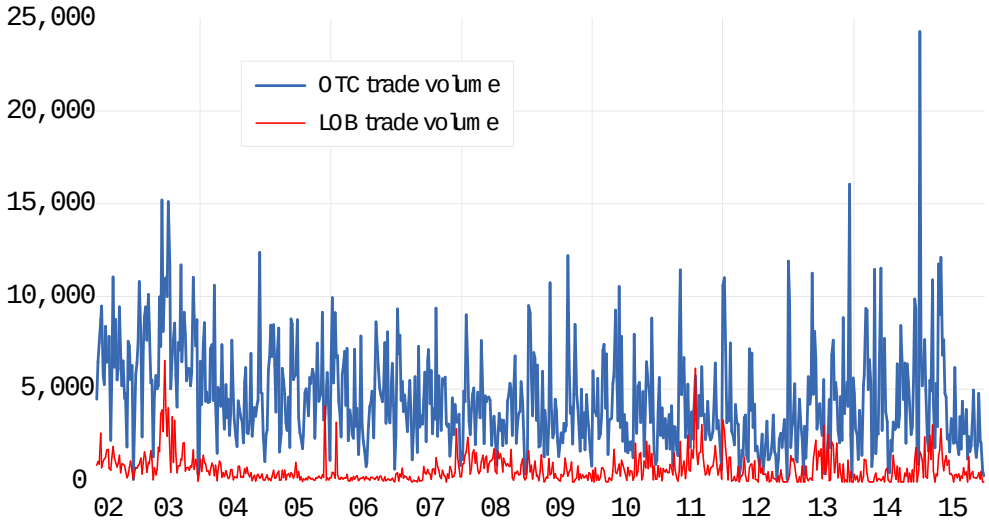

Figure 9: The graph shows the total trading volume in the OTC-market and the interdealer LOB from May 2002 to December 2015.