Repo market frictions and intermediation in electronic bond markets

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Abstract

This paper studies the drivers of primary dealers' repo activity and the effect of repo market frictions on bond market liquidity. It separates the two tiers of the bond market, the electronic limit order book (LOB) and the over-the-counter (OTC) market. The results, based on dealer-specific repo quantities and cash market trades in Norwegian government bonds, show that the passive order flow in the LOB is an important driver of repo activity. Liquidity in both tiers deteriorate with higher repo specialness, which represents the cost of "borrowing" bonds. This suggests that primary dealers enter the repo market to borrow bonds when their inventories are depleted via executed ask limit orders. Intermediaries in electronic bond markets thus face an additional risk related to the level of repo specialness.

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1 Introduction

Repo markets are often referred to as the "plumbing" of the financial system. They provide funding or securities against collateral. Intermediaries rely on repo markets for both. He et al. (2022) find that primary dealers in Treasuries borrow funds in the triparty repo market and lend funds (borrow bonds) in the GFC repo market. An important difference between the two repo markets is the eligible collateral, which is confined to Treasury securities in the GFC market.[1] Government securities are among the most liquid securities in the world, but even these securities can experience periods of deteriorating liquidity. This happened both during the 2008-09 financial crisis and the Covid-19 crisis. He et al. (2022) explain the 2020 liquidity dry-up with a combination of repo market frictions and balance sheet restrictions which increased intermediation costs in Treasury markets. Their model shows that both excess supply of government bonds in the cash market, as in 2020, and excess demand, as in 2008/09, can trigger repo market frictions. How repos and repo market frictions are linked to primary dealers' liquidity provision has been little studied so far due to a lack of dealer level data.[2] Also, the drivers of primary dealers' activity in the repo market for government securities has been little studied due to limited data availability on dealers' repo quantities. This paper aims to fill these gaps by studying the relation between dealers' repo quantities, repo market frictions and their liquidity provision in both tiers of the government bond market.

The purpose of this paper is thus two-fold. First, to uncover the drivers of primary dealers' repo activity in the repo market in government bonds. Second, to explore how repo quantities and repo market frictions influence bond market liquidity. Primary dealers intermediate government bonds in the electronic limit order book (LOB) and the over-the-counter (OTC) market. A push from regulators to move trading from opaque OTC markets on to lit LOBs makes it especially important to understand the link between the repo market and the LOB. Also, a better understanding of the relation between the conditions in the bond market and the conditions in the repo market is useful for regulators and policy makers in their response

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

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

to future economic shocks.

To study these topics the paper employs a unique data set from the Norwegian government bond market. The data set contains the primary dealers' complete repo transactions, displaying repo quantities, repo rates, and dealer identifications for the period 2002 - 2015. In addition, the data set includes all cash market trades in the OTC market and the LOB with the complete order book history in the LOB. All auction results for each dealer are also included. This enables the paper to delve deeper into the links between the repo- and cash markets than previous studies, which use indirect and aggregate data. D'Amico et al. (2018) and Corradin and Maddaloni (2020) rely on indirect measures by using the imbalance between reverse-repos and repos to proxy for the shorting demand for bonds in the cash market.[3] This paper takes a different approach by using transactions data from the repo market *and* the cash bond market. This facilitates the calculation of order flows as measures of excess demand for bonds in the two tiers of the cash market. Order flows are based on actual order signs in the LOB and on inferred order signs in the OTC-market. The auctions data facilitate the calculation of bid-to-cover ratios which represent the excess demand/shorting demand in the primary bond market.

To identify potential drivers of repo activity the paper employs these measures of demand at the weekly horizon, first at the aggregate level and then at the individual dealer level. The results based on aggregate data show that repo volumes are positively related to the excess demand for bonds in the LOB. Interestingly, there is no such relation in the OTC-market. Higher bid-to-cover ratios in auctions are related to higher repo volumes, which is consistent with findings in previous studies, e.g. Jordan and Jordan (1997). At the individual dealer level, order flows in the electronic LOB are separated into regular order flows, based on initiated trades, and passive order flows, based on passive trades.[4] The results from panel data regressions with dealer fixed effects show that passive order flows in the LOB are the main drivers of primary dealers repo activity.[5] Negative passive order flows can result in unintended

[3]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.

[4]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.

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

short positions. Higher passive sales by a dealer are related to higher repo quantities for the same dealer.

To uncover whether primary dealers' repo activity and repo market frictions affect their liquidity provision in the government bond market, the paper investigates whether dealers' repo volumes and repo market frictions are related to current and future liquidity provision. As a measure of repo market frictions the paper employs the average repo specialness for all government bonds.[6] Duffie (1996) describes how repo specialness occurs when the repo rate falls below the risk free rate. He finds 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". The measure of repo market frictions in this paper differs from the repo spread in He et al. (2022) as there is only one repo market in Norwegian government bonds.[7] As a measure of primary dealers' liquidity provision the paper employs the relative bid-ask spreads based on individual dealers' transactions in the LOB and the OTC-market.

Panel data regressions with dealer fixed effects show that bid-ask spreads in both tiers of the bond market decrease with higher repo volumes and increase with higher repo specialness. Also, higher repo specialness and lower repo volumes predict higher spreads in the following week. These results, combined with the results that passive sales are important drivers of repo quantities, suggest that dealers often enter into repos to access/borrow bonds. Borrowing bonds in the repo market via reverse repos alleviates inventory depletion caused by passive net sales. It also facilitates higher trading volumes when there is a buying pressure in the cash market. However, higher repo specialness means higher bond borrowing costs which contribute to higher intermediation costs.

The results suggest that dealers pass on the higher intermediation costs due to repo market frictions to their counterparties in both tiers in the market. The increase in spreads provided by primary dealers reflect an excess demand for government bonds, especially via net passive

[6] Average repo specialness is caluculated 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.

[7] They define the repo spread as the repo rate at which dealers' lend cash minus the repo rate at which they borrow cash.

sales in the LOB. The buying pressure seen in the interdealer LOB can reflect a buying pressure in the dealer-to customer OTC-market. According to Lyons (2001) the theory of hot potato trading says that dealers off-load their risk from customer trades in the interdealer market. Excess demand for bonds in both tiers of the market combined with repo market frictions can thus explain the increase in spreads in the LOB and the OTC-market. As a robustness check the paper includes a dummy for the 2008-09 financial crisis when there was a scarcity of safe securities and an especially high demand for government bonds. The results including the crisis dummy confirm the previous results indicating they are not only due to the financial crisis.

This paper makes two main contributions to the literature on repo markets in government bonds. 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. Huh and Infante (2021) do not specify market features and trading mechanisms and Foley-Fisher et al (2019) study OTC-markets in corporate bonds. The findings in this paper suggest that limit orders are not only exposed to adverse selection risk and inventory 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 changes substantially over time and poses a risk to primary dealers who are obliged to act as market-makers in the electronic LOB. While trades in the OTC-market are negotiated and conditioned on dealer inventory, passive trades in the LOB are dependent on submitted limit orders which can be stale, especially in less liquid markets. The results suggest that primary dealers as market-makers in electronic bond markets face an additional risk related to the level of repo specialness when government bonds are in high demand.

Second, the paper contributes by documenting that both repo market frictions and repo quantities are directly related to primary dealers' liquidity provision in the cash market. Previous papers study how central bank quantitative easing programs (QE) are related to repo specialness. D'Amico et al. (2018) study FED QE and find that FED bond purchases lead to a scarcity of Treasury bonds and increases repo specialness. Corradin and Maddaloni

(2020) study ECB QE and find that ECB bond purchases decrease market liquidity in Italian government bonds. This paper finds that an increased demand for bonds, rather than a reduced supply, is related to higher repo specialness and lower bond market liquidity. Foley-Fisher et al. (2019) find that securities lending is positively related to market liquidity in corporate bonds. This paper finds that higher bilateral repo volumes, which can facilitate both re-use of collateral and bond borrowing/securities lending, are related to higher bond market liquidity.

The paper also contributes to the literature by documenting the predictive power of repo market frictions on bond market liquidity. The relation between repo specialness and bond market liquidity documented in this paper complements previous findings on the relation between repo specialness and bond prices. D'Amico and Pancost (2022) document a special collateral risk premium explaining about 80% of the on-the-run premium in Treasury securities. This paper shows that average repo specialness in government bonds predicts both bond prices *and* bond market liquidity.

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. Previous literature on repo markets mainly focus on the role of repos in providing funding during crises. 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 repo markets in lending/borrowing securities 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. The literature on collateral re-use including Fuhrer et al. (2016), Infante and Saravay (2021) and Jank et al. (2021), focus on the reduced supply of safe collateral securities due to central bank asset purchases. This paper adds to the literature by documenting that primary dealers use reverse repos in the bilateral repo market to access securities for market making purposes. These reverse repos include repos initiated by customers for funding purposes (cash-driven repos) and repos initiated by dealers to borrow bonds (security-driven repos).

Gorton (2017) defines safe assets as securities with low default risk, high liquidity, and little disagreement about their value. 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, and show that when Treasuries are relatively scarce this difference, the convenience yield, increases.[8] 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. This paper adds to the literature by documenting the important role of the repo market for the liquidity of government bonds.

Until recently the effect of repo market frictions on bond market liquidity has been little discussed. 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. D'Amico et al. (2018), Foley-Fisher et al. (2019), and Corradin and Maddaloni (2020) document how bond market liquidity is related to repo rates, securities lending, and repo specialness, respectively. Arrata et al. (2020) document the effect of Euro area QE on repo rates. He et al. (2022) propose a model with repo market frictions which increase primary

[8] 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.

dealers' intermediation costs to explain changes in the Treasury convenience yield. This paper adds to the literature by studying the role of intermediaries' and how repo market frictions are related to their liquidity provision in both tiers of the cash market, particularly in the electronic interdealer market. These questions are relevant for financial regulators as bond trading merges from opaque OTC-markets to lit electronic markets.

3 The Norwegian market and repo market frictions

The Norwegian government bond market is relatively small due to Norway's favorable fiscal position. However, 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.[9] New government debt is issued regularly in the primary market to finance public lending programs for housing, higher education, innovation etc. The main intermediaries in Norwegian government bonds (NGBs) 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.[10]

There is only one private repo market in NGBs. It is an OTC-market where dealers trade directly with each other and with their customers. Repos that are part of the monetary policy implementation or the central bank security lending facility are not included. The bilateral 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

[9] OTC trades are agreed on over the phone, via chat etc. Dealers report OTC-trades manually into the trading system within five minutes after execution. From 2005 nearly all interdealer trades have been executed in the LOB which implies that the OTC-market is synonymous with the customer market.

[10] In a number of countries the Central Bank (Government Debt Office) administers a securities lending facility for Primary Dealers in government bonds. E.g. the Federal Reserve Bank of New York administers a securities lending program in Treasuries and Norges Bank a securities lending facility in Norwegian government bonds.

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 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 and represents the lower bound of a GC rate.[11] Duffie (1996) states that the GC repo rate and the (targeted) policy rate are normally close to each other. [12]Security-driven repos are defined as repos with a repo rate at or below this rate, the remaining repos are defined as cash-driven repos.[13] In order to lend cash in the repo market primary dealers will typically require a repo rate higher than the alternative of depositing the cash with the central bank.[14] 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.[15]

He et al. (2022) measure repo market frictions as the difference between the repo rate at which dealers lend cash (the GFC repo rate) and the repo rate at which they borrow cash (the triparty GC repo rate). The measure of repo market frictions in this paper, repo specialness, differs as there is only one repo market (and repo rate) including Norwegian government bonds as collateral. Repo specialness is calculated as the average repo rate on security-driven

[11]The central bank deposit rate is the best measure of a short term market rate as there are no other short term market rates available for the whole period. The primary dealers in Norwegian government bonds are large banks with access to central bank funding and central bank deposits. They also obtain funding in domestic and international financial markets, long term funding by issuing covered bonds and senior bonds, and short term funding by doing FX-swaps.

[12]The primary dealers' collateralized funding rate in the central bank is normally slightly higher than the deposit rate.

[13]Duffie (1996) says that for special (security-driven) repos "we can take the upper bound on repo rates to be the general collateral rate which is typically at or near the market clearing fed funds rate for uncollateralized borrowing."

[14]Overnight deposits were remunerated at the monetary policy rate in full until October 2011. From then on the banks are alotted (generous) quotas in NOK for which they receive a deposit rate equal to the monetary policy rate. Amounts above these quotas are remunerated at a rate below the monetary policy rate (100 bps lower). The short term funding rate (F-loans) is normally a few basis points above the central bank deposit rate.

[15]However, some of the primary dealers had a gentleman's agreement to lend bonds to each other at the same terms as they could borrow from the central bank, i.e. at the central bank deposit rate. The central bank security lending facility offered primary dealers to borrow bonds within a certain limit from the central bank at a repo rate equal to the monetary policy rate/central bank deposit rate. A share of the interdealer security-driven repos thus have a repo rate equal to the deposit rate. From October 2011 the repo rate was adjusted to the deposit rate minus five basis points.

repos minus the proxy for a triparty GC repo rate in Norway.[16] When government bonds are scarce, owners are less likely to "lend" them in the repo market at the "normal" repo rate. This creates frictions in the repo market and as a result the repo rate will be pushed down and repo specialness increases. 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."

4 Theoretical motivation

The extensive use of repos for funding and collateral transformation has given rise to a growing theoretical literature on repo markets. Brunnermeier and Pedersen (2009) provide a model to study cash-constrained traders who rely on repos to fund their trading activity. Their 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) and He et al. (2022) propose models of dealer intermediation including a repo market. Both models differentiate between the triparty GC repo market and repo markets with specific collateral/collateral categories. Huh and Infante (2021) study how dealers use repos to facilitate customer levered long - and short positions. They find that higher repo specialness in the specific collateral repo market, where dealers access bonds, is related to lower market liquidity. He et al. (2022) study periods with high excess demand or high excess supply of bonds in the cash market for Treasuries. They find that the difference between the repo rate in the GFC repo market in Treasury collateral, where dealers mainly access bonds, and the repo rate in the triparty GC repo market, where dealers obtain funding, is related to lower Treasury market liquidity. This is the case when the difference is highly positive, as in 2020, or highly negative, as in 2007-09. The predictions from these models constitute the theoretical basis for this paper.

The effect of changes in repo rates depends on whether dealers are net (cash) lenders or

[16] 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.

-borrowers in repo markets. If they are net borrowers as in the Brunnermeier and Pedersen (2009) model, lower repo rates should be related to lower intermediation costs and 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 higher bond "borrowing" costs, and should be related to lower liquidity. A higher repo spread and higher repo specialness in the Norwegian repo market should according to these models be related to lower bond market liquidity.

As already mentioned the bilateral repo market in government bonds is relatively small and is not a major funding source for Norwegian banks. Rather, primary dealers mainly go to this market to serve their customers in financing long bond positions, taking short positions or accessing safe deposits. They can get access to bonds by re-using the bonds received as collateral or actively borrow bonds from their counterparties in the repo market. For Norwegian primary dealers the bilateral repo market is thus closer to the GFC repo market than the triparty GC repo market described in He et al. (2022).

5 Data

The data set from the Norwegian government bond market is well suited for an investigation of intermediaries' use of repos and the effect of repo market frictions on their liquidity provision in the cash bond market. It includes the complete trading history of four primary dealers' in the repo - and cash markets from 2002 to 2015.[17] This period have several episodes with excess demand for government bonds, including the years in the pre-Covid framework in He et al. (2022).[18]

All transaction-level data are aggregated to daily and to weekly variables, at the dealer level and the aggregate market level. Repo variables include all private repos between two

[17] The transactions by the four dealers constitute 80-100 percent of total trading volumes over the period. These 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.

[18] The sample period includes the 2008-09 financial crisis and the European debt crisis. There were no changes in the balance sheet requirements for primary dealers during this period.

dealers or between a dealer and her customer. They are calculated by adding up repo volumes (the face value of the bonds). 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 rates and repo specialness are volume weighted and based on all relevant private repos.[19] As an additional measure of excess demand for bonds the paper includes the convenience yield. 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.

Figure 1 displays the average repo rate and a measure of the short term risk free rate, 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. Figure 2 displays average repo specialness on Norwegian government bonds during the same period. It shows that repo specialness has been high on several occasions, e.g. during the 2008-09 financial crisis. Repo specialness in the private, bilateral repo market was on average 14 basis points over the period.[20]

Excess demand in the two tiers of the cash bond market is measured by order flows. The order flow variables are based on order signs, buyer-initiated or seller-initiated trades, in the LOB and inferred order signs in the OTC-market. 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 means positive net purchases by the dealer. This separation is not possible in the OTC-market as the data lacks customer identities.[21] Excess demand in the primary market is measured for individual dealers by their bid-to-cover ratios in bond auctions. The bid-ask spread in the LOB is the weekly average of the best bid and best ask right before a trade. The bid-ask spread in the OTC cash market is the weekly average of the

[19] Repo trading volume is the sum of all repos entered into that week. 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 secuirty-driven repos.

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

[21] In the OTC cash market data, the primary dealer appears as both the buyer and seller. The paper assumes that the customers are initiating these trades.

absolute difference between dealer i trade price and the mid-quote in the LOB right before a trade, multiplied by two. Figure 3 depicts the effective spreads in the OTC-market quoted by the four primary dealers.

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, dealer bid-to-cover in auctions and their 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 eight rows contain aggregate market data including total repo volume, average repo specialness for Norwegian government bonds, the convenience yield, order flows in both tiers of the bond market, relative bid-ask spreads, and total bid-to-cover ratios in bond auctions. All aggregate variables are stationary according to the Augmented Dickey-Fuller test.

6 Empirical framework and results

6.1 Drivers of repo activity

To uncover the drivers of primary dealers' repo activity the paper first investigates potential drivers at the aggregate market level and then at the individual dealer level. The aggregate model includes three measures of the demand for bonds as explanatory variables, two from the secondary market and one from the primary market. Demand in the secondary market is measured by the net order flows in the interdealer electronic market (LOB) and in the dealer-to-customer OTC-market.[22] Demand in the primary market is measured by the bid-to-cover ratio in the 137 bond auctions over the years 2002 -2015. In addition the measure of bond scarcity in the bond market, the convenience yield, is included as an explanatory variable.

[22] The paper employs order flow variables calculated as net number of trades. Employing order flow variables calculated as net trading volume give similar results.

The aggregate model is specified in Equation (1),

$$repo_t = \beta_0 + \beta_1 OF_t^{LOB} + \beta_2 OF_t^{OTC} + \beta_3 conv_{t-1} + \beta_4 BTC_{t-1} + \varepsilon_t, \quad (1)$$

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. $conv_t$ is the average convenience yield in week t and BTC_{t-1} is the bid-to-cover ratio in week $t-1$.[23]

The results of the model are presented in Table 2. They show that the buying pressure in the electronic limit order book, measured by OF_t^{LOB}, and the excess demand in the primary market, measured by BTC_{t-1}, have significant effects on the repo volume. While an increase in the LOB order flow by 9 trades increases the repo volume that week by around 71 mill. NOK, an increase in the BTC ratio by 0.79 % increases the repo volume by around 99 mill. NOK the week after the auction. An increase in the excess demand in the OTC-market and in the scarcity of government securities, measured by the convenience yield, do not appear to have any significant effects on the total repo volume in the private repo market for government bonds.

To uncover the drivers of primary dealers' repo activity in more detail the paper investigates a new measure for the demand for bonds in the electronic limit order market experienced by individual dealers, the passive order flow. The passive order flow in the LOB consists of limit orders "hit" by other dealers. The passive order flow is negative if the dealer's executed limit orders sum up to a net sale of bonds.[24]

The panel data model with dealer fixed effects is specified in Equation (2),

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

[23] 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.

[24] Passive order flows are passive purchases minus passive sales by a dealer. Sales (ask limit orders) have a negative sign and buys (bid limit orders) a positive sign.

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.[25] $conv_t$ is the average convenience yield 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.[26] 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 of the model 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 her "active" order flow has not. The passive order flow is inversely related to repo quantities. A negative passive order flow in the LOB reflects a reduction in a dealer's inventory. The result shows that higher passive selling, i.e. a higher number of executed sell limit orders, are related to higher repo volumes. If the liquidity in the LOB is limited, a negative passive order flow can reflect a dealer's unintended short position. If the dealer needs to rebuild her inventory quickly she can go to the bilateral repo market and access bonds via reverse repos or security driven repos.

6.2 Repos and bond market liquidity

To uncover whether primary dealers' repo activity and repo market frictions affect their current and future liquidity provision in the government bond market the paper investigates whether the spreads provided by primary dealers are related to their repo volumes and average repo specialness. To uncover whether the repo activity and repo specialness have different effects in the two tiers of the bond market, the paper investigates the spread a dealer provides in the electronic limit order book (LOB) and in the over-the-counter (OTC) market separately. The panel data model with dealer fixed effects applied to investigate the effects on current

[25] In order to sign the trades in the OTC-market, where primary dealers are named as both buyer and seller of the bonds, the paper has applied the algorithm suggested by Lee and Ready (1991).

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

liquidity provision is presented in the following equation,

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

where $Spread_{i,t}^{m}$ is the relative effective spread in the LOB or OTC-market, $m = LOB, OTC$, for dealer i in week t. $OF_{i,t}^{LOB}$, $POF_{i,t}^{LOB}$ and OF_{t}^{OTC} are the order flows of dealer i in the two tiers of the bond market. $repo_{i,t}$ is the total private bilateral repo volume of dealer i in week t. sp_t is the average repo specialness for all repos 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 volumes are related to lower spreads in both tiers of the market. Repo market frictions, represented by the average repo specialness, are related to higher spreads in both tiers, indicating that dealers pass on borrowing costs in the repo market to their counterparties in the bond market. As a robustness check, to show that the results are not entirely due to the financial crisis, the paper adds a dummy variable for the 2008-09 financial crisis to the model. The results show that spreads were higher during the crisis, and that the results for dealer repo volumes and repo specialness still hold.

To investigate the effect of repo volumes and average repo specialness on future liquidity provision by primary dealers, the paper employs the following panel data model with dealer fixed effects,

$$Spread_{i,t}^{m} = \beta_1 repo_{i,t-1} + \beta_4 sp_{t-1} + \alpha_i + \varepsilon_{i,t} \quad (4)$$

where the variables are the same as in the previous model, except that repo volumes and repo specialness are lagged one period. The coefficients are corrected using White two-way cluster, adjusting for both cross-sectional correlation and serial correlation. The results are presented in Table 5. They show that repo activity has predictive power for spreads in the electronic interdealer market, but not for spreads in the OTC-market. However, repo specialness, which measures the cost of borrowing Norwegian government bonds in the repo market, has predictive power for next week's spreads in both tiers of the government bond market.

7 Discussion

The results in this paper provide new insights on how primary dealers in government bonds act in repo markets where government bonds are collateral. Based on the predictions from the models of Brunnermeier and Pedersen (2009), Huh and Infante (2021), and He et al. (2022) the results suggest that primary dealers mainly access bonds, not cash, in these repo markets. The findings that repo volumes increase with "unintended" short positions and that bond market liquidity deteriorates with higher repo specialness are consistent with the model in He et al. (2022) for the 2007-2009 crisis. They are also consistent with the model in Huh and Infante (2021) where repo specialness is negatively related to bond market liquidity. However, the results in this paper are not consistent with the model in Brunnermeier and Pedersen (2009). While the two former models focus on how costly repo market frictions are to dealers who access bonds/lend cash in the repo market, the latter focuses on how costly repo market frictions are to traders who access cash/funding in the repo market.

He et al. (2022) 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. This is consistent with the finding that passive order flows are related to higher repo volumes and supports the conclusion that primary dealers mainly lend cash/access bonds in the bilateral repo market to cover "unintended" short positions. A negative passive order flow depletes a dealer's inventory, and she can rebuild her inventory quickly/temporarily by turning to the repo market. The dealer can access bonds in two ways, either via cash-driven repos or via security-driven repos.

Cash-driven repos are often initiated by customers who needs funding to purchase bonds.

The dealer can re-use the bonds received as collateral in the repo.[27] If this is not possible the dealer can initiate a security-driven repo to borrow bonds from a customer or another dealer, and post cash as collateral.[28] Reusing the collateral in a cash-driven repo does not incur any extra cost for the dealer, while a security-driven repo often comes with a borrowing cost. This cost depends on the repo rate and is higher the lower it is compared to the GC repo rate.[29]

Figure 4 shows the aggregate weekly repo volume for all private repos and the aggregate repo volume for repos classified as security-driven repos. Security-driven repos are defined as repos with a repo rate at or below the GC repo rate.[30] The figure shows that a majority of the repos are classified as security-driven repos. This is consistent with the findings based on total repo volume if dealers often lend cash to their customers at a favorable/low rate and initiate security-driven repos with other dealers when they experience negative passive order flows/depletion of inventory.

The finding in this paper that bond market liquidity deteriorates with repo market frictions/higher repo specialness is consistent with the mechanisms in He et al. (2022) when the repo spread is negative. Figure 5 shows the Norwegian repo spread. He et al. (2022) define this as the spread between the repo rates at which primary dealers lend and borrow cash. As an empirical measure He et al. (2022) employ the difference between the GFC repo rate and the triparty GC repo rate. The Norwegian repo spread is calculated as the difference between the repo rate and a floor rate for dealers funding cost (the central bank deposit rate). As mentioned earlier, Norwegian primary dealers use the repo market in government bonds much in the same way as primary dealers in the US use the GFC market. Figure 5 shows that the Norwegian repo spread is negative for most of the 2002- 2015 period. He et al. (2022) find that a negative repo spread is related to an excess demand for Treasuries. A negative repo spread reflects that US primary dealers are net short in the cash market and on the net

[27] Collateral received in bilateral repos can in general be re-used. However, collateral received in repos involving a third party may have restrictions on re-use.

[28] In the literature cash-driven repos are also referred to as repos, and securities-driven repos referred to as reverse-repos or securities lending. Collateral re-use is a feature of bilateral repos that allows the cash lender, who owns the collateral securities until the repo expires, to use these securities for other purposes.

[29] This borrowing cost is the difference between the repo rate on cash-driven repos (GC repo rate) and the repo rate on security-driven repos (if the repo rate is lower than the GC repo rate it is referred to as a special repo rate).

[30] Proxied by the central bank deposit rate as no short term market rate is available for the whole period.

lending side in the repo market and dealers incur a short selling cost. The results in this paper suggest that the same dynamics apply to the Norwegian government bond market over the period 2002-2015.

Finally, the results in this paper provide new insights into the predictive power of repo specialness for the government bond market. Several papers, e.g. Duffie (1996) and D'Amico and Pancost (2022), document the relation between repo specialness or special collateral risk premium, respectively, and bond prices. This paper complements these papers by documenting the relation between repo specialness and current and future and bond market liquidity. As a robustness check, the paper investigates the relation between repo specialness and bond yields. The results show that average repo specialness has significant explanatory power for changes in 3, 5, and 10 year Norwegian government bonds yields. Also, average repo specialness predicts next week's change in 3 year bond yields, which is documented in Table 6. As the results based on data from the Norwegian government bond market show similar results on the relation between repo specialness and bond yields, it appears plausible that the mechanisms documented between repo specialness and bond market liquidity in this paper also apply to other government bonds markets.

The predictive power of repo specialness on future bond market liquidity can be related to the risk of higher intermediation costs. Higher intermediation costs can occur as a result of a high demand pressure, especially in the electronic market, combined with repo market frictions. In the electronic LOB dealers can end up with "unintended" short positions if their ask limit orders are hit more often than their bid limit orders. If they need to borrow bonds in the repo market to deliver the bonds, the level of repo specialness determines their additional intermediation costs. The finding that average repo specialness in Norwegian government bonds predicts bid-ask spreads in the following week therefore suggests that dealers are aware of the risk related to the level of repo specialness. As primary dealers trades in both market segments it appears plausible that they will increase their spreads in both the LOB and the OTC-market to compensate for this risk.

In all, the results in this paper show that well-functioning repo markets are important for liquidity provision in bond markets. The large trade sizes in bond markets compared to equity markets strengthen the need for efficient repo markets when bonds previously traded in OTC-markets will move on to electronic and lit exchanges.

8 Conclusion

The purpose of this paper is to explore how intermediaries in government bonds link the repo market and cash market in government bonds. First, the paper explores the drivers of primary dealers' activity in the repo market for government bonds. Second, the paper explores the relation between average repo specialness and liquidity provision by primary dealers. The paper employs data for the period 2002 to 2015 which is characterized by a time-varying demand for bonds and no new balance sheet restrictions, as in the pre-Covid period in He et al. (2022).

The results show that passive sales in the electronic LOB are related to higher repo volumes. The results further show that average repo specialness in the repo market for government bonds is negatively related market liquidity. This means that repo market frictions, causing the repo rate to deviate substantially from the risk free rate, are negatively related to market liquidity. Repo specialness represents the borrowing cost for bonds in the repo market and tends to be higher when bonds are scarce. These findings suggest that dealers often enter into repos to access/borrow bonds for market-making purposes in the LOB, and that they pass on higher bond borrowing costs to their counterparties in both tiers of the market.

The finding that primary dealers go to the repo market to access bonds to cover "unintended" short positions in the LOB combined with the negative relation between repo specialness and dealers' liquidity provision suggests that intermediaries in electronic bond markets face an additional risk related to the level of repo specialness. The findings in this paper have implications for regulators and policy makers in many countries who want to increase transparency in bond markets by moving bond trading to electronic markets. The results suggest that well-functioning repo markets should be in place before this move takes place.

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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, the aggregate repo-share is the repo volume over the trading volume in the cash market for all government bonds, and the dealer repo-share is her repo volume over her trading volume in the cash market 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 (Four primary dealers):						
Repo vol, all private (mill.NOK)	2808	1873.1	996.3	2362.1	0.815	**−4.676***
Order flow, LOB	2836	−0.5532	0	5.969	0.084	**−15.18***
Passive order flow, LOB	2836	0.3015	0	4.151	0.203	**−15.61***
Order flow, OTC customer	2836	1.493	1.00	7.5435	0.305	**−9.75***
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:						
Repo specialness	674	0.142	0.122	0.109	0.429	**−8.27***
Repo spread	710	−0.029	−0.016	0.262	0.675	**−5.73***
Convenience yield	678	−0.0024	−0.0484	0.2629	0.891	**−3.62***
Repo vol, all private (Mill.NOK)	710	6808.6	6148.6	4661.5	0.780	**−5.14***
Order flow, LOB	710	−0.5777	0.00	9.3095	0.089	**−24.32***
Order flow, OTC customer	710	−0.1592	0.00	2.3015	0.039	**−9.29***
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

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

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. 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	**69.295*** (3.04)	**88.976*** (2.24)	**70.777*** (3.04)	**99.202*** (2.23)
Order Flow, OTC	55.737 (1.07)	−28.819 (−0.16)	−2.235 (−0.03)	−212.34 (−0.71)
BTC(-1)		**926.15*** (2.11)		**1115.6*** (2.31)
Convenience yld			−1292.9 (−0.78)	−1412.2 (−0.89)
Adj. R^2	0.0176	0.0452	0.0223	0.0498
Obs.	710	137	678	133

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 number of trades. $conv_t$ 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	7.2505 (0.34)	6.0548 (0.30)	−14.867 (−0.65)
Passive OF, LOB	**−60.044** (−3.14)	**−62.456** (−3.44)	**−61.451*** (−3.40)
OF, OTC	−9.7828 (−1.06)	−8.3966 (−0.86)	5.0520 (0.41)
Convenience yld		−302.65 (−0.44)	−559.36 (−0.43)
BTC, Ind (-1)			29.959 (1.13)
Adj. R^2	0.1116	0.1100	0.0640
Dealer fixed effects	*Y*	*Y*	*Y*
Periods	709	678	133
Observations	2808	2684	508

Table 4

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

$$Spread_{i,t}^{m} = \beta_0 + \beta_1 OF_{i,t} + \beta_2 POF_{i,t} + \beta_3 COF_{i,t} + \beta_4 repo_{i,t} + \beta_5 sp_t + \beta_6 D_t^{FC} + \alpha_i + \varepsilon_{i,t}$$

where $Spread_{i,t}^{m}$ is the relative effective spread in the LOB or OTC-market, $m = LOB, OTC$, for dealer i in week t. $OF_{i,t}^{LOB}$, $POF_{i,t}^{LOB}$ and OF_t^{OTC} are the order flows of dealer i in the two tiers of the bond market (number of trades). $repo_{i,t}$ is the total private bilateral repo volume of dealer i in week t. sp_t is the average repo specialness for all repos in this repo market with a repo rate below the risk free rate in week t. D_t^{FC} 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 (Individual dealers) 2002 - 2015					
	LOB quoted spreads			Effective OTC spreads		
(Active) OF, LOB	$-3.62E^{-04}$	$-2.88E^{-04}$	$-3.89E^{-04}$	$-1.14E^{-04}$	$-7.02E^{-05}$	$-1.50E^{-04}$
	(-1.14)	(-0.96)	(-1.03)	(-0.73)	(-0.53)	(-0.63)
Passive OF, LOB	$-2.75E^{-05}$	$1.50E^{-04}$	$3.75E^{-04}$	$-5.10E^{-05}$	$3.97E^{-05}$	$2.10E^{-04}$
	(-0.06)	(0.40)	(0.63)	(-0.06)	(0.13)	(0.49)
OF, OTC	$2.04E^{-04}$	$4.58E^{-05}$	$-4.00E^{-05}$	$3.97E^{-04}$	$2.38E^{-04}$	$1.71E^{-04}$
	(0.48)	(0.10)	(-0.10)	(2.17)	(1.31)	(0.96)
Repo volume	$\mathbf{-5.02E^{-06}}$	$-4.24E^{-06}$	$\mathbf{-6.39E^{-06}}$	$\mathbf{-3.43E^{-06}}$	$-2.74E^{-06}$	$\mathbf{-4.40E^{-06}}$
	(-2.89)	(-2.31)	(-2.55)	(-2.65)	(-2.06)	(-2.92)
Repo specialness		**0.0616**	**0.0710**		**0.0555***	**0.0630***
		(2.56)	(3.04)		(3.50)	(3.98)
Financial crisis dum			**0.0444**			**0.0343***
			(2.59)			(4.13)
Adj. R^2	0.0209	0.0286	0.0599	0.0357	0.0502	0.0872
Dealer fixed effects	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
Periods	709	669	669	709	669	669
Observations	2806	2647	2647	2799	2641	2641

Table 5

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

$$Spread_{i,t} = \beta_1 repo_{i,t-1} + \beta_4 sp_{t-1} + \alpha_i + \varepsilon_{i,t}$$

where $Spread_{i,t}$ is the average relative effective spread in the OTC market or the quoted spread in the LOB provided by dealer i in week t. $repo_{i,t-1}$ is the bilateral, private repo volume (1000 NOK) for dealer i in week $t-1$. sp_t average repo specialness for all government bonds in week $t-1$. 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 (Individual dealers) 2002 - 2015	
	LOB quoted spreads	Effective OTC spreads
Constant	**0.2104*** (38.65)	**0.1135*** (22.92)
Repo volume (-1)	$-\mathbf{4.27E}^{-06}$ (-2.82)	$-2.49E^{-06}$ (-2.24)
Repo specialness (-1)	**0.0517** (2.47)	**0.0587*** (3.42)
Adj. R^2	0.0255	0.0487
Dealer fixed effects	Y	Y
Periods	668	668
Observations	2642	2636

Table 6

The table presents the results of the following regression model

$$\Delta y_{m,t} = \beta_0 + \beta_1 PC1_{t-1} + \beta_2 PC2_{t-1} + \beta_3 PC3_{t-1} + \beta_4 OF^{LOB}_{t-1} + \beta_5 RS_{t-1} + \varepsilon_t$$

where $\Delta y_{m,t}$ is the yield change in 3, 5, and 10 year bonds ($m = 3y, 5y, 10y$) in week t, OF^{LOB}_{t-1} is the order flow in the electronic interdealer market, aggregated over all bonds (and dealers) in week $t-1$. RS_{t-1} is repo specialness in Norwegian government bonds calculated as the difference between the risk free rate and the average repo rate on repos with a repo rate below the risk free rate in week t-1. 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.

	Yield changes (2002-2015)					
	Δ3 year		Δ5 year		Δ10 year	
PC1(t-1)	−0.0034	**−0.0045***	−0.0027	**−0.0038**	−0.0017	−0.0024
	(−1.54)	(−2.11)	(−1.19)	(−1.73)	(−0.81)	(−1.20)
PC2(t-1)	−0.0126	−0.0239	−0.0231	−0.0295	−0.0280	−0.0271
	(−0.61)	(−1.09)	(−1.15)	(−1.50)	(−1.63)	(−1.60)
PC3(t-1)	**−0.2926***	**−0.1923**	**−0.2115**	−0.1423	**−0.3469***	**−0.3127***
	(−2.56)	(−1.68)	(−1.88)	(−1.30)	(−3.62)	(−3.34)
Order flow (t-1)	**−0.0028***	**−0.0028***	**−0.0034***	**−0.0033***	**−0.0028***	**−0.0028***
	(−7.19)	(−5.39)	(−8.46)	(−7.69)	(−7.20)	(−6.59)
Specialness (t-1)		**−0.0872***		−0.0614		0.0017
		(−2.15)		(−1.55)		(0.05)
Adj R^2	0.0933	0.1001	0.1129	0.1190	0.1049	0.1051

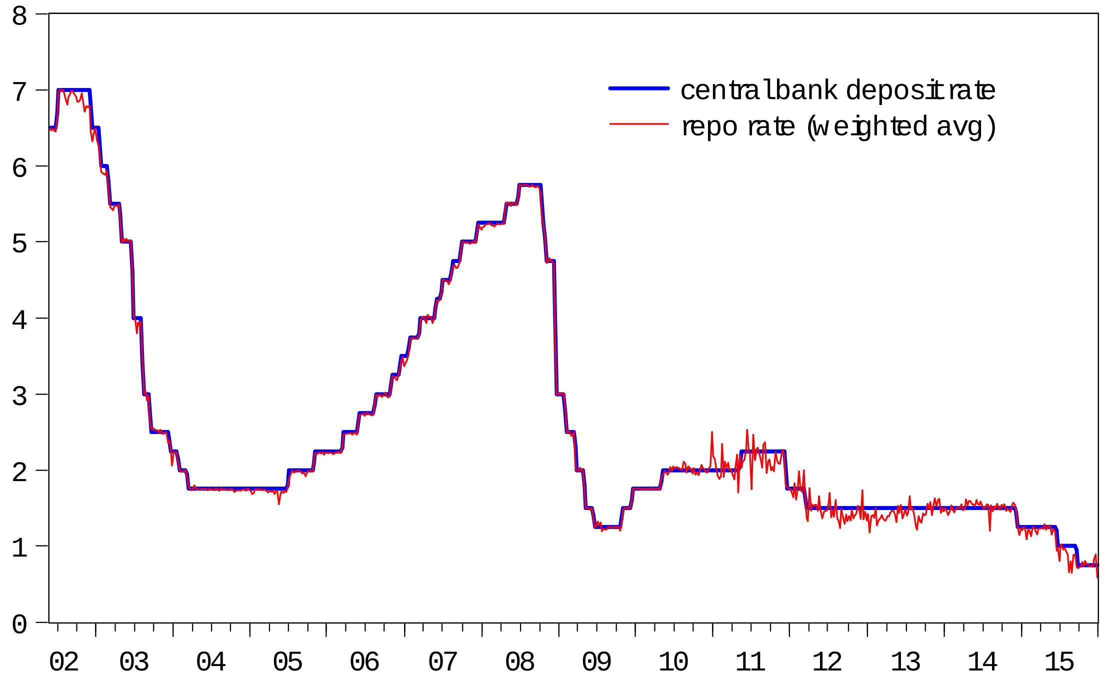

Figure 1: The repo rate in the bilateral repo market in Norwegian government bonds (weighted average of all repos) and the central bank deposit rate (the monetary policy rate). Weekly average from May 2002 to December 2015.

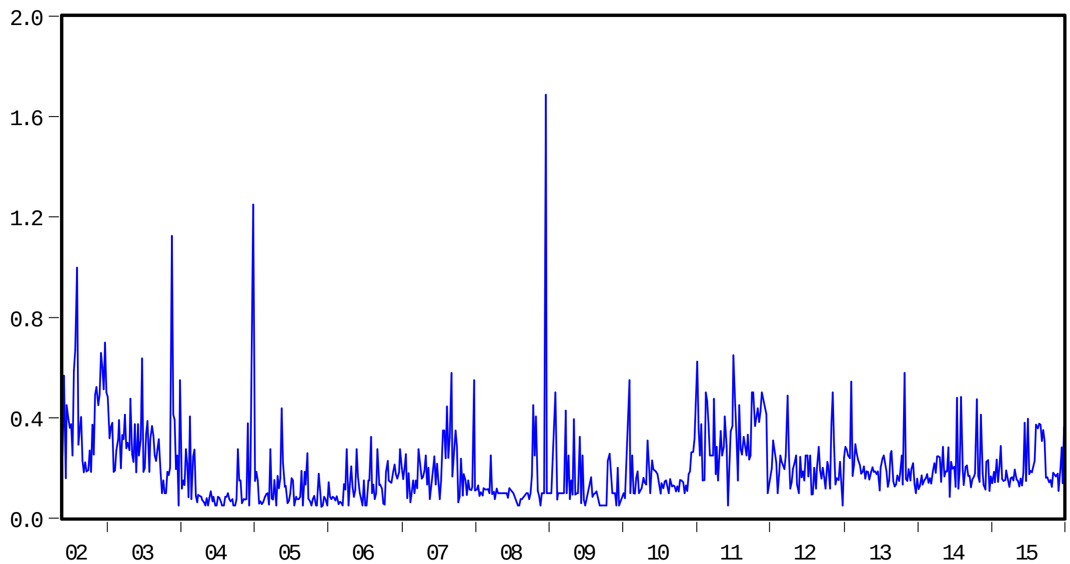

Figure 2: Repo specialness is measured as the difference between a measure of the GC repo rate (the central bank deposit rate) and the special repo rate. Weekly averages from May 2002 to December 2015.

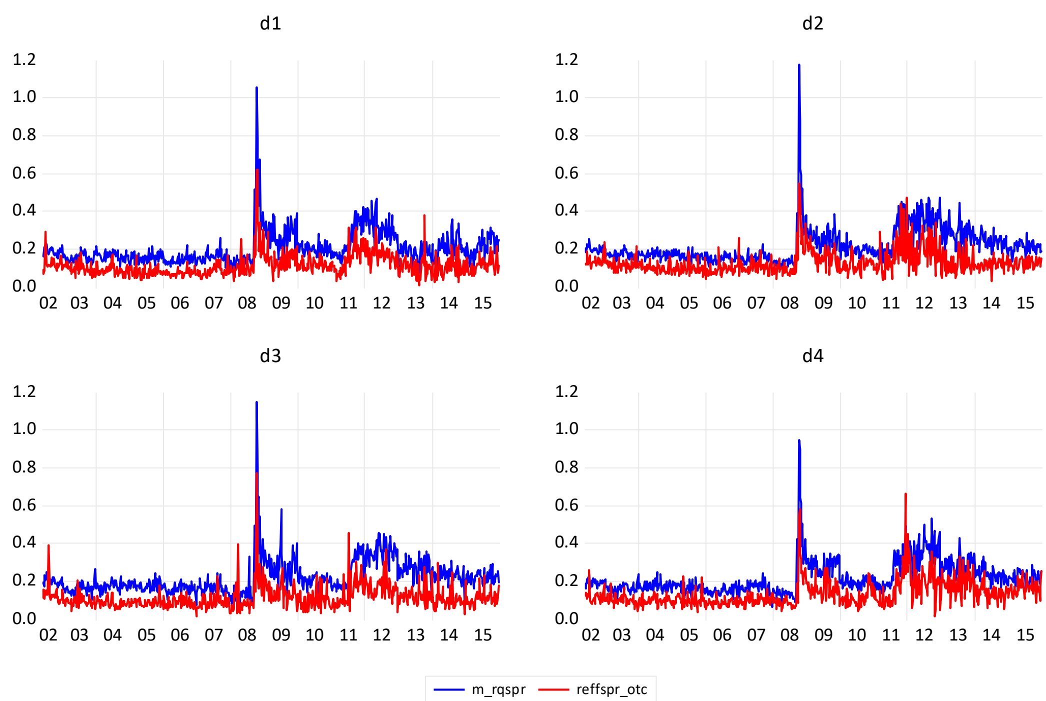

Figure 3: The figure shows the relative spreads provided by the four primary dealers in the interdealer electronic limit order book (LOB) and in the customer over-the-counter (OTC) market. The quoted spread in government bonds in the LOB is measured as the difference between the dealer's best bid and 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.

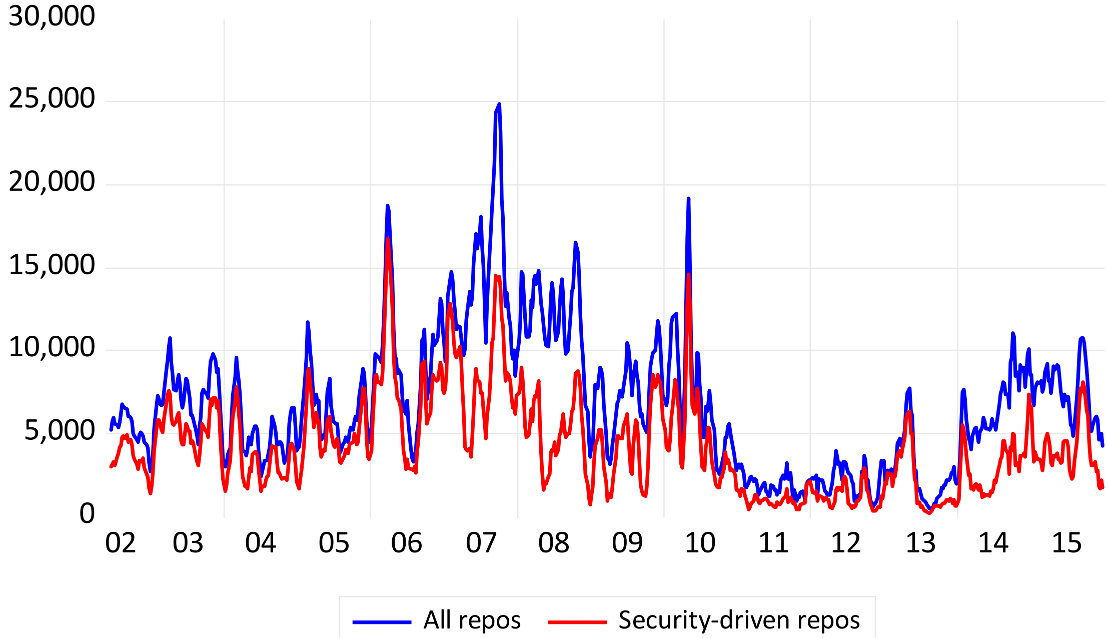

Figure 4: Aggregate weekly repo volume for all private repos (blue) and aggregate repo volume for repos classified as security-driven repos (red). Some private repos do not have information about the repo rate and cannot be classified as either cash-driven or securuity-driven. Four week moving average. 2002-2015. Mill. NOK.

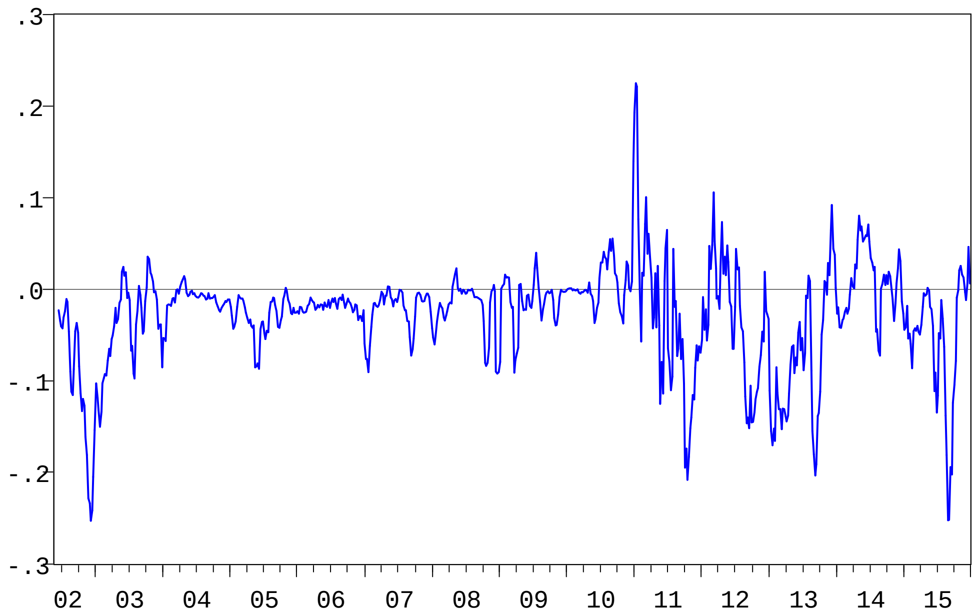

Figure 5: The repo spread in He et al. (2022). They define it as the spread between dealers' reverse repo and repo rates, i.e. the difference between the repo rates at which they lend and borrow cash. A proxy for this spread in the Norwegian government bond market is calculated as the difference between the volume weighted bilateral repo rate and the central bank deposit rate. Four week moving average from May 2002 to December 2015.