

Ødegaard, Bernt Arne

Research Report

Bond Liquidity at the Oslo Stock Exchange

Staff Memo, No. 5/2017

Provided in Cooperation with:

Norges Bank, Oslo

Suggested Citation: Ødegaard, Bernt Arne (2017) : Bond Liquidity at the Oslo Stock Exchange, Staff Memo, No. 5/2017, ISBN 978-82-7553-981-4, Norges Bank, Oslo, <https://hdl.handle.net/11250/2506377>

This Version is available at:

<https://hdl.handle.net/10419/210339>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<http://creativecommons.org/licenses/by-nc-nd/4.0/deed.no>

STAFF MEMO

Bond Liquidity at the Oslo Stock Exchange

NO. 5 | 2017

BERNT ARNE
ØDEGAARD



NORGES BANK

Staff Memos present reports and documentation written by staff members and affiliates of Norges Bank, the central bank of Norway. Views and conclusions expressed in Staff Memos should not be taken to represent the views of Norges Bank.

© 2017 Norges Bank

The text may be quoted or referred to, provided that due acknowledgement is given to source.

Staff Memo inneholder utredninger og dokumentasjon skrevet av Norges Banks ansatte og andre forfattere tilknyttet Norges Bank. Synspunkter og konklusjoner i arbeidene er ikke nødvendigvis representative for Norges Banks.

© 2017 Norges Bank

Det kan siteres fra eller henvises til dette arbeid, gitt at forfatter og Norges Bank oppgis som kilde.

ISSN 1504-2596 (online only)

ISBN 978-82-7553-981-4 (online only)

Bond Liquidity at the Oslo Stock Exchange

Bernt Arne Ødegaard*

April 2017

Abstract

We characterize the liquidity of bond trading at the Oslo Stock Exchange (OSE). We use the complete history of bond prices quoted at the OSE from 1990 to 2016.

We first characterize the market place, summarize trading grouped by type of issuers. The OSE can be characterized as a market place with a few bonds traded often, the rest traded seldom. The active bonds are Treasury securities, which typically trade on a daily basis. A second category of active bonds are *covered bonds*, a type of bond introduced as recent as 2008 (in the wake of the financial crisis). The remainder of bonds at the OSE are traded seldom. The activity of the bond market at the OSE has increased markedly in the post-2008 period. While Treasury securities remain the most active class, covered bonds has seen a marked increase in liquidity. We also see an increase in activity for the other bond groups. The number of bonds listed has doubled in the last ten years, with financial and industrial issuers increasing the most. The market had more than 3000 different bond issues active in the last five years. However, only half of these bonds trade more than five times a year.

The second part of the paper investigates the feasibility of measuring liquidity in the Norwegian bond market. Is it possible to construct liquidity measures that are informative about the state of the Norwegian financial market? We calculate three different measures that can be calculated from daily data: Bid/Ask Spreads, the Amihud [2002] ILLIQ measure, and the Corwin and Schultz [2012] spread estimate from high/low prices. Except for Treasuries, the liquidity measures are hard to calculate due to limited trading interest. Of the three liquidity measures, the Corwin and Schultz measure seem to be the preferred, although the measures are clearly correlated.

All measures show that aggregate bond market liquidity covary with slowdowns in the Norwegian economy, with liquidity worsening (trading costs/spreads increasing) around such events as the 1992 Banking Crisis and the 2008 Financial Crisis.

We also compare estimates of trading costs for various types of bonds with equities, and find that the most expensive to trade is equities. Trading costs for corporate bonds are lower than equities, but higher than Treasury bonds, which is the category with lowest estimated transaction costs. This is contrary to the evidence from the US, and most European bond markets, where estimates of transaction costs for corporate bonds are much higher than trading costs for equities.

Keywords: Bond Markets; Liquidity; Trading Costs; Norway; Oslo Stock Exchange

JEL codes: G10; G20

*Professor, University of Stavanger. This Staff Memo should not be reported as representing the views of Norges Bank. The views expressed are those of the author and do not necessarily reflect those of Norges Bank. I am grateful for detailed comments from members of Norges Bank Markets Operations and Analysis on an earlier draft.

Contents

1	Introduction	3
2	Literature - Fixed Income Liquidity	4
2.1	Liquidity and its measurement	4
2.2	What is different about bond markets?	7
2.3	Bond Valuation and liquidity premia	9
2.4	Measuring liquidity in bond markets	10
2.5	Linking financial market liquidity and the economy	10
2.6	The public policy perspective	11
3	The Norwegian Bond Market	12
3.1	Total bond issuance	12
3.2	The Bond Market on Oslo Stock Exchange	13
3.2.1	Development in market structure	14
3.3	Regulation of bond issuance	14
3.4	Off-exchange trading	15
3.5	Back to the market microstructure perspective	15
3.6	Groups of issuers and characteristics	15
4	Data Sources	16
5	Activity measures	17
5.1	Days with trading	17
5.2	Trading Volume	25
5.3	Turnover	28
6	Liquidity measures	30
6.1	Spreads	30
6.2	The Amihud (2002) illiquidity ratio (ILLIQ)	33
6.3	The Corwin and Schultz High/Low spread measure	35
6.4	Looking more closely at the liquidity of covered bonds	38
7	Links to equity market	40
7.1	Trading costs	40
7.2	Time series variation	40
8	Conclusion	44
A	Liquidity measures	45
A.1	The Amihud ILLIQ measure	45
A.2	Relative bid/ask spread	45
A.3	The Corwin and Schultz (2012) measure	45
A.4	Other spread measures	47
B	A Chronology of the Oslo Stock Exchange	48

1 Introduction

We analyze the liquidity of trading of bonds at the Oslo Stock Exchange. Specifically, we analyze tradable fixed income securities issued by Norwegian corporations and government. Norwegian corporations issue debt securities either locally, in the Norwegian market, in which case the securities are listed and traded at the Oslo Stock Exchange, or internationally.¹ Government and other agency issues will typically be targeted at the domestic market.

The liquidity of the bond market is obviously of interest to all traders in the market. Minimizing transaction costs when trading is of first order importance for portfolio managers. Liquidity also affect portfolio decisions, the ability to quickly get in and out of a position is valued by investors, leading to various notions of liquidity premia.

The liquidity of the domestic debt market is also of interest to regulators and other public institutions, such as Norges Bank (The Central Bank), for various reasons. The liquidity of the Norwegian debt securities market influences both the asset and liability side of Norwegian banks. Over the recent years, wholesale funding has become an important funding source for Norwegian banks. Specially for medium sized and smaller savings banks, the domestic market is an important long- and medium term funding market. On the asset side, the liquidity of Norwegian bonds is important when assessing the quality of their portfolio of liquid assets. Moreover, from 2015 the Basel III quantitative liquidity requirements are to be put in place for Norwegian banks through CRD IV. Inclusion of NOK denominated bonds in the Liquidity Coverage Ratio (LCR) is to some extent dependent on the secondary market liquidity of such bonds. Lastly, the liquidity of Norwegian government bonds is important when judging the suitability of the yields of these bonds as benchmarks for long term interest rates.

Liquidity may also be of interest for regulators as a broader measure of the health of financial markets, and employed as an “early warning” sign. There is a literature showing that equity market liquidity is a useful predictor for the real economy.² An obvious question is whether bond market liquidity also contain such predictive information.

For these possible purposes the first call is for calculable measures of liquidity. What liquidity measures can be calculated? Do they contain useful information? This is the main remit of this paper. We investigate properties of alternative liquidity measures and their suitability as liquidity measures for the overall market, with a particular focus on regulatory needs for market based indicators of financial health. The paper is partly an update of the analysis in Rakkestad, Skjeltorp, and Ødegaard (2012), adding data for the trading of bonds at the OSE for the period 2012–2016, as well as an earlier period, 1989–99. But, relative to that analysis, we add an interesting new method for liquidity measurement, a spread estimator due to Corwin and Schultz (2012).

The Corwin and Schultz estimator uses the differences between the highest and lowest trade price in a day to estimate a spread. Intuitively, the difference between the highest and lowest prices traded during a day is driven by two effects: The volatility of the underlying price process, and the bid ask spread. To do estimation, Corwin and Schultz uses two insights. First, that the *highest* price is likely to be a result of an impatient *buyer* crossing the spread, pushing the trade price up. On the other hand, the *lowest* price is more likely to be the result of an impatient *seller* accepting a low price. As a result the difference between the highest and lowest price during a day include the spread. But prices also move for other reasons (volatility). The second insight used by Corwin and Schultz is that volatility is increasing with the time period it is measured over (This is the insight underlying *variance ratio* type of estimates). Combining these two, Corwin and Schultz show how to simultaneously estimate volatility and an implicit bid/ask spread.

Schestag, Schuster, and Uhrig-Homburg (2016) shows that the Corwin and Schultz method result

¹Internationally issued securities will typically be issued in USD or Euro, and not necessarily have a listing at the OSE.

²See Næs, Skjeltorp, and Ødegaard (2011).

in “good” measures of bond liquidity (spread) in a sample of US corporate bonds. We investigate whether this method also results in reasonable liquidity estimates in the crosssection of Norwegian bonds, a market with much less trading interest. We find that this method in fact gives reasonable liquidity estimates for this thinly traded market, and therefore should be part of the tool chest when estimating liquidity. It may be particularly useful since its data requirements are minor, one only needs daily observations of the highest and lowest trade price during a day, not a continuous record of trading (high frequency data).

In terms of empirical observations of the Norwegian bond market relative to the results in the previous paper (Rakkestad et al., 2012), we show that the period 2011–2015 has seen an increased interest in trading of bonds in the secondary market at the OSE. The market in Norwegian government bonds (Treasury Market) continues to be the most active sector, but we also see a marked increase in trading of covered bonds, an asset class that has seen a lot of interest after the 2008 financial crisis. These two categories are the only ones where trading occurs on a regular basis. We do however see an increase in trading of all types of bonds, but by no means approaching a continuously traded market.

We also do some comparisons of estimates of trading costs for bonds with corresponding trading costs for equities. Somewhat surprisingly, we find that estimated trading costs for *all* types of bonds, be they issued by industrial corporations, financials or government, are *below* corresponding cost estimates for equities. This is in fact very different from the situation in for example the US corporate and municipal bond markets, which have much higher transaction costs than the US equity markets.

The structure of the paper is as follows. In section 2 we survey the relevant literature. In section 3 we give some background for the Norwegian Bond Market. Section 4 details the data sources. We split our discussion of bond liquidity in two sections. Section 5 looks at relatively simple measures of bond activity, such as the number of bonds traded, volume and turnover. In section 6 we then look at the more advanced measures of liquidity: bid/ask spreads, the Amihud ILR and the Corwin and Schultz spread estimate. We show some comparisons with the equity markets in section 7. We finally give a conclusion. We include several appendices. Appendix A gives detailed definitions of the measures of liquidity considered. Appendix B summarizes the chronology of the Oslo Stock Exchange.

2 Literature - Fixed Income Liquidity

The topic of this paper, the market-wide liquidity of a bond market, intersects several literatures. One is the general literature on *liquidity* – what is it? How can one measure it? Another concerns specifics of bond markets – pricing of fixed income securities, cost measurement of bond trading, which also involve liquidity estimation. In this literature review we go from the generic to the specific. We start by looking at liquidity in a generic fashion. We then ask what is different about bond markets.

Most of the academic literature concerns international, and in particular US financial markets. Our literature survey will therefore not be specific to the Norwegian Bond Market. We will return to the specifics of Norway later (in section 3.)

2.1 Liquidity and its measurement

Liquidity is a broad concept that is difficult to define precisely. At a very general level, a liquid market is characterized by the ability to transact a given volume quickly at a low cost and with a small, and short lived (i.e. temporary³) price impact. In addition, a liquid market is characterized by a quick

³Price movements associated with trades can generally be decomposed into a temporary and permanent movements. The permanent price movements reflect price discovery as new information enters the price through trades. The temporary price movements are due to liquidity trades that temporarily dislocate the price from equilibrium. In a liquid market, this

replenishment of liquidity and convergence to the equilibrium price after a trade. However, we need to be more precise when attempting to measure liquidity.

When discussing liquidity, it is impossible to do this divorced from the *trading protocol*. Most of the world's financial markets are moving towards trading through electronic *limit order books*, where all who want to trade need to do this by submitting orders electronically into an exchange's systems. Most of the recent literature on *market microstructure* (the broader academic field which is concerned with liquidity) therefore discusses liquidity in the context of a limit order market, a tradition we will continue.

Initially, one would want a measure of liquidity that says something about the expected cost of trading for the random investor's point of view. However, as will be discussed further below, the cost of taking (demanding) liquidity is a function of the characteristics and needs of a trader. For example, an impatient trader with a need to sell quickly is likely to incur a much higher cost of trading compared to a patient trader with the same selling need. Typically, the patient trader will submit limit orders (supplying liquidity), while the impatient trader will submit market orders (taking liquidity). A *limit order* to e.g. buy is a resting order to buy a specified volume for a specific maximum price ("limit"). A *market order* is an order to buy a specified volume of an issue without a limit price, which means that the order will execute at increasingly worse prices ("walk the book") until fully filled. An alternative to pure market orders are so-called *marketable limit orders*. Marketable limit orders are simply aggressively priced limit orders (e.g. to buy) that match (and hence immediately execute) against the best priced limit order (e.g. to sell) of the opposite side. If the marketable limit order is partially filled, the remaining part of the order will typically automatically be converted to a regular limit order at the limit price.⁴ Hence, regular limit order to buy or sell constitute liquidity supply, while market orders and marketable limit orders constitute liquidity demand.

As a useful starting point, Harris (1990) argues that liquidity can be defined along four dimensions; *width, depth, immediacy and resiliency*. These dimensions are interrelated, and most liquidity measures used in the literature typically capture several dimensions at once. On the other hand, no single measure is able to accurately capture all sides of liquidity, so typically one have to look at several measures, or extract common factors from a set of measures, to get a good picture. Before we go into the specific measures that we will look at in this study, it is useful to describe the liquidity dimensions proposed by Harris (1990) in more detail. For this purpose, it is useful to have a reference point. Figure 1 provides such a reference point by showing a general example of a limit order book (i.e. liquidity supply) at one point in time for one security.

Width Width reflects the cost of supplying liquidity (i.e. posting limit orders) versus demanding liquidity (posting market orders).⁵ For example, in figure 1, a patient buyer could post a limit order at p_b^1 and wait for an impatient to submit a marketable limit order or market order⁶. From the perspective of an impatient buyer, she would demand liquidity by posting a marketable limit order

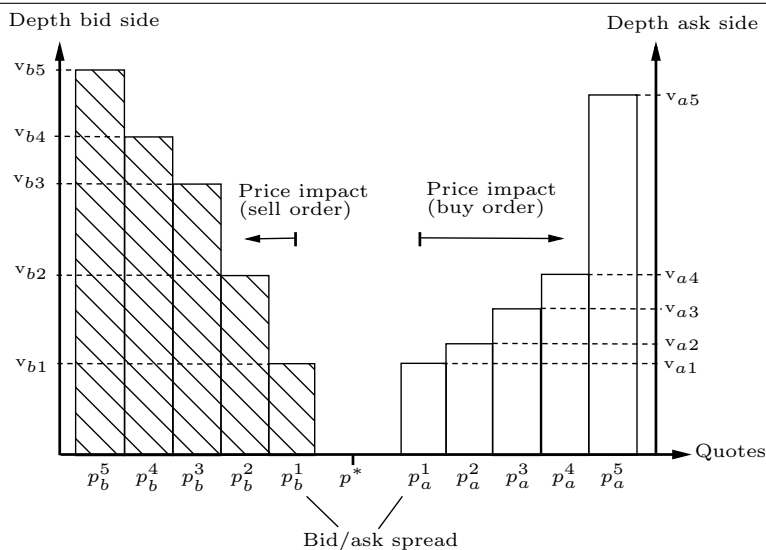
dislocation is quickly reverted as liquidity suppliers replenish the order book, while in an illiquid market, the temporary price dislocation lasts longer before prices revert to equilibrium.

⁴There are typically three types of order instruction sets; execution based, time based and period based instructions. Two standard *execution based* order instructions are; "execute and eliminate" (ENE) where the unexecuted part of the order will be canceled, and the "fill or kill" (FOK) instruction in which the order will be immediately canceled unless fully filled. The two standard *time based instructions* are; "Good till canceled" and "Good till time" orders which are similar to the ENE, but with an additional time limit for which the remaining part of the order will reside in the order book. The *period based* instructions include, "At the close", "At the open", "Good for auction" and "Good for day" instructions.

⁵A limit order is an order with a fixed price and volume, while a market order is an order to buy a specific volume at the best available prices. Hence, a limit order is a passive orders that executed when a market order is submitted.

⁶The difference between a market order and marketable limit order is that a market order instruction only specifies volume and direction without a specific price and will execute at the best available price(s) in the market. Hence, a large market order might execute across several price levels of the order book. A marketable limit order on will execute only up to a specified price point (limit).

Figure 1 Example of a limit order book



The figure illustrates the limit order book (liquidity supply) at a particular point in time for one security. The horizontal axis shows the quoted prices, where the subscript b and a denote bid and ask quotes, respectively, while the superscript denotes the level of the limit order book relative to the side, and p^* is the bid/ask midpoint price, which reflect the instantaneous “true” value of the security. The vertical axes show the accumulated depth on the bid (left axis) and ask (right axis) sides.

at p_a^1 (or a market order to buy) which would immediately execute. The difference between the price that the patient buyer would pay (p_b^1) and what the impatient buyer would pay (p_a^1) reflects the implicit cost per share for trading immediately. A more liquid security has typically a tighter spread (smaller width). Hence, width measures how much an investor needs to increase (decrease) the price to obtain immediate execution. There is a large theoretical literature that shows the existence of a positive spread in equilibrium. These models suggest that the spread reflect a compensation to the liquidity supplier for e.g. adverse selection risk, and costs associated with holding inventory and order-handling (see e.g. O’Hara (1995) for an overview of these models).

Depth While *width* measure the cost of demanding one unit of liquidity, it does not reflect how much liquidity is available at the various price levels. If an investor needs to buy (sell) a large volume quickly, the depth available at the various ask (bid) levels is important for the volume weighted average execution price that she will obtain. Typically, the prices at the best quotes (p_b^1 and p_a^1) are unlikely to be representative for a large trader, especially if the order book is dispersed. Looking at figure 1, an impatient buyer that needs to buy a volume equal to v_{a4} would have to pay an average price that is higher (“walk the book”) than a trader that needs a volume less or equal to v_{a1} . In addition, comparing the depth of the bid and ask sides we see that a seller would need to change his price less (relative to the best bid) to sell a similar volume as our buyer (relative to the best ask) indicated by the horizontal arrows.

Immediacy Another important aspect of liquidity is how quickly one can find opposite side trading interest. This is generally not a problem in a market with an intermediary standing between the buyers and sellers (i.e. market makers/dealers). However, in a pure limit order market without any intermediaries, the arrival of buyers and sellers might not always be synchronized in time. In a liquid market, the number of buyers and sellers supplying liquidity is typically greater than in an illiquid market, which reduces the time needed for a patient trader to fill an order at a reasonable cost.

Resiliency The fourth dimension proposed by Harris (1990) is *resiliency*. This dimension is notoriously difficult to measure, but captures a very important aspect of secondary market liquidity. The resiliency of the market reflect how quickly the liquidity supply is replenished and the price moves back to equilibrium after a large uninformed liquidity demand has been filled. In figure 1, if the aggressive buy order we looked at earlier takes out the depth of the first four levels of the ask side, resiliency reflect how long it takes before competitive liquidity suppliers come in and reduce the to spread and depth to its pre-trade level. This dynamics is modeled theoretically in a recent paper by Foucault, Kadan, and Kandel (2013), where they show that the resiliency is a function of liquidity suppliers ("makers") monitoring intensity, the fee structure at the trading venue and the fraction of liquidity suppliers.

Trade- versus order-based measures For empirical purposes it is also useful to distinguish between trade-based and order-based measures of liquidity. Aitken and Comerton-Forde (2003) define measures that capture liquidity supply directly (depth, bid/ask spread etc) as order based measures, while measures that look at realized transactions (e.g. trading volume, number of trades, trade size etc) are defined as trade based measures. The main distinction between the two comes from the fact that order based measures are closer to ex-ante measures of liquidity provision while trade based measures only reflect the consumed liquidity. While the two are cross-sectionally related, the results in Aitken and Comerton-Forde (2003) show that measures from the two categories have a low time-series correlation. More importantly, they show that trade-based measures have a tendency to signal favorable liquidity conditions also during periods of stress, even though implicit costs of trading is high. Based on this, they argue that order-based measures are superior proxies for liquidity as such measures more accurately reflect the true costs of obtaining liquidity in periods of stress. They advocate a combination of the bid/ask spread, order-book depth and the probability of order execution to measure liquidity. Notably, their measures are closely linked to the three first dimensions proposed by Harris (1990); i.e. width, depth and immediacy.

2.2 What is different about bond markets?

Bonds, opposed to stocks, are securities with a fixed payment schedule, and a finite maturity. The finite maturity part has implications for liquidity. Many of the holders of bonds (the buy side) are pension funds and similar institutional investors, which hold many bonds till they mature, and then reinvest the received principal. Such behavior from the bondholders lead to less trading than for other financial assets, such as for example equities. The growth of bond holdings by institutional investors has in fact been argued as a factor that led to a decline in exchange trading of bonds.⁷

When looking at the market places for bonds, these differ for different types of issuers. The most active markets for fixed income securities are the markets for Sovereign Debt (Treasury Securities), of which the market for US Treasury Securities by far is the largest. Most countries will have two other distinct types of issuers. Firstly, public and semi-public debt which is not Treasury debt. For example, in the US, the market for municipal bonds is a large market. Secondly, corporate debt.

Different countries will have different market places for these various categories of bonds. We will use the US case as the primary example. Let us first look at trading of US Treasuries. In 1999, trading of US Treasury securities was completely phone-based. If one wanted to trade Treasuries, one called one or more of the *primary dealers*, of which the biggest was Cantor Fitzgerald, for quotes, before choosing the dealer to trade with. This structure also lead to a distinction between two markets: A dealer-to-dealer market, where dealers trade exclusively with one another, and a dealer-to-customer

⁷As discussed in Biais and Green (2007), most bond trading left the NYSE in the twenties. It never came back.

market, where dealers trade with customers.⁸ Fifteen years later the picture is completely changed.⁹ All trading is now electronic, through competing electronic systems. The electronic systems can be grouped into single-dealer and multiple-dealer systems. The first is the electronic equivalent of picking up the phone to ask for a quote, while the second type allows for competing quotes, and are closer to a limit order book. The growth of the competing electronic systems has also led to introduction of fully automatic trading technology. In fact, over half of the trading in the most liquid US Treasury contracts are done by automated systems (Algorithmic Traders / High Frequency Traders).¹⁰

On 15 October 2014, the US Treasury market saw its own “flash crash,” with extreme levels of volatility in Treasury securities, futures and other closely related markets. For example, the yield of a 10-year Treasury bond fell 16 basis points before rebounding back, all in a 12 minute interval. These events have led to a comprehensive look at the US Treasury markets from the various regulatory agencies involved (The US Treasury, The Federal Reserve, The Securities and Exchange Commission, etc). One result of the Oct ’14 events is that The Securities and Exchange Commission has recently proposed centralized trade reporting of all trades in US Treasury bonds.¹¹

The move towards electronic trading follows the example of equity markets, which has made the transition from floor based trading to electronic limit order books. A difference is that the equity markets start from a position with one dominant market place (NYSE/Nasdaq), with public display of trading, which has been challenged by numerous competing market places, some with publicly displayed order books, other trading in less public market places (dark pools). The equity markets still maintain this notion of “main” markets and “satellite” markets. The bond markets had no such dominant market place. The electronic markets for trading bonds are more diverse, but they are continuously evolving, and we may still see a concentration in trading, although it has not happened yet.

The driving forces behind the move towards electronic trading for bonds are the same as for equities. The most important is costs. Costs of computing and electronic communication has fallen dramatically. Automated trading can replace relatively expensive humans. The movement towards electronic trading is in some sense replacing human labor with capital, a feature of all industries. The financial industry is finally catching up to the industrial revolution.

The introduction of electronic trading in bond markets is different from equities in terms of how market structures change. The bond markets start from a dealer market, where trading is phone-based and non-anonymous. The introduction of an electronic market results in anonymous interaction on screen, which may change how bond traders actually trade.

The other US bond markets have seen similar changes, although to a lesser degree. Take the corporate bond market. As of 1999, similarly to Treasuries, this was a dealer market. The market was opaque. While there was posting of indicative quotes on e.g. Bloomberg, these were not binding. A major event in this market was the introduction of *post-trade transparency* through the Transaction Reporting and Compliance Engine (TRACE) in July 2002. Bond dealers thereafter have to report all trades in publicly issued corporate bonds to the National Association of Security Dealers, which publishes this data.¹² Academic studies of this event, such as Edwards, Harris, and Piwowar (2007), find a large decrease in transaction costs following the introduction of post-trade reporting. Edwards et al. (2007) also show that the the cost structure of trading in the corporate bond market is one with costs *decreasing* in trading volume, the completely opposite picture from equity markets, where price

⁸Fleming (2003) shows the possibilities of estimating liquidity in this environment.

⁹See Mizrach and Neely (2006) for the early history, and Bech, Illes, Lewrick, and Schrimpf (2016) for the current status.

¹⁰See estimates in the Appendix of US Commission (2015).

¹¹“Statement on Trade Reporting in the U.S. Treasury Market”, Securities and Exchange Commission, Washington D.C., May 16, 2016. See also “Statement Regarding Progress on the Review of the U.S. Treasury Market Structure since the July 2015 Joint Staff Report” SEC, Aug. 2, 2016.

¹²See Bessembinder and Maxwell (2008) for a summary of this event.

impact increases with trade size. Edwards et al. (2007) shows that much of the cost improvement following TRACE was a reduction in costs for smaller transactions. Bessembinder and Maxwell (2008) reports much whining among bond dealers post-TRACE. To outside observers this sounded like a good sign, a result of increased competition, and led to calls for even higher transparency from the SEC (Spatt, 2006).

The regulatory zeal following the 2007 Financial Crisis has potentially lead to large changes in the bond trading environment. The Volcker Rule of The Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 may inhibit the market making capacity of large banks. Concerns about the consequences in terms of under-provision of market liquidity, has been repeatedly raised. While the evidence is that the large US financial institutions are shedding inventory of bonds from their balance sheets, there is as yet little evidence of large negative effects on bond liquidity, in particular that of US Treasuries.¹³ Regarding other US market places, academics in particular are vocal about the need for more transparent trading. Harris (2015) argues that there is still lots of room for improvement in the corporate bond market, and Ang and Green (2011) makes the same point for municipal bonds.

Other countries differ in how markets are organized. A common theme, though, is that the most active bond market is the market for Treasuries (government debt). Another common theme is that bond trading is OTC, either with electronic posting of trading interest, or phone-based.¹⁴ In such markets transparency is limited to post-trade reporting. There are very few examples of active limit order bond markets with pre-trade transparency. A single example is the Tel Aviv Stock Exchange (Abudy and Wohl, 2016), where all bonds trade in active limit order markets, and where bond trading costs are lower than equity trading costs.

2.3 Bond Valuation and liquidity premia

In valuing bonds investors will typically have two main effects in mind. First, the change in value through changes in interest rates (the term structure), and second, the risk of default. The effect on bond prices of the term structure is a first-order effect. This underlying structure affects all traded bonds. It brings with it a need to estimate a single term structure across all available bonds. Bond pricing is thus a more analytic exercise, with stricter cross-sectional arbitrage restrictions coming from the term structure, than for example pricing of equities.

Default risk is not a problem for Treasury securities. Treasuries have therefore been used as a vehicle to show evidence of liquidity (market microstructure) effects in the cross-section of bonds.¹⁵ The clearest evidence comes from comparison of the market for the most recently issued Treasuries (called *on-the-run* bonds) with earlier issued (*off-the-run*) bonds. The recently issued bonds trade more, with more of it on electronic platforms. They also contain a liquidity premium.

From a theoretical perspective, the source of this liquidity premium is unclear. The theoretical literature on market microstructure was developed to model trading in equity markets. The typical theory in this literature models how (private) information about firm values (future cash flow) is reflected in prices through trading. For Treasury bonds, such private information is less relevant. Instead, the main driver of value is public policy, in particular central bank actions. The information one is primarily concerned with here is the what affects future interest rates. Liquidity is driven by expectations about the future demand/supply of individual bonds.

Unlike Treasury securities, for corporate bonds, information about individual corporations is clearly relevant. But here the information is mainly used to estimate default probabilities, not, as in equity markets, being mainly concerned with future growth (in dividends). But it still means that the market microstructure theory from equity markets is also relevant for such bonds, in addition

¹³See Trebbi and Xiao (2015), Adrian, Fleming, Stackman, and Vogt (2015b) and Adrian, Fleming, Shachar, and Vogt (2015a).

¹⁴For some evidence on the European Corporate Bond market, see Biais and Declerck (2013)

¹⁵See Mizraich and Neely (2008) for a summary of this literature.

to the more specific interest-rate driven intuition used in analyzing trading of Treasuries and similar bonds. The potential losses due to default are a limited part of the promised future cashflows from a bond (interest and principal). Bond prices are therefore less volatile than equities, since information about future cash flows to a corporation is only relevant when they affect the likelihood of default. This also has implications for liquidity premia. If bond prices are less volatile, we would expect the liquidity premia linked to uncertainty to be lower for bonds than for equities. The lower volatility of bond prices should also be important for bond transaction costs. If prices are less volatile, the risk of e.g. posting limit orders should be less for bonds than for equities.

Looking at the general empirical evidence on liquidity and bond prices, not just for Treasury bonds, there is a large number of studies that document a liquidity premium. For example, Chen, Lesmond, and Wei (2007) find that liquidity is priced in corporate yield spreads. Using a set of several liquidity measures they find that more illiquid bonds earn significantly higher yield spreads, and that an improvement in liquidity causes a significant reduction in yield spreads. These results hold after controlling for common bond-specific, firm-specific characteristics, and macroeconomic variables. Another example is Bao, Pan, and Wang (2011), which establish a strong link between bond liquidity and bond prices, both in aggregate and in the cross-section. They also argue that the illiquidity in corporate bonds is substantial, significantly greater than what can be explained by bid-ask spreads. More specifically, they establish a strong link between bond illiquidity and bond prices. In aggregate, changes in market-level illiquidity explain a substantial part of the time variation in yield spreads of high-rated (AAA through A) bonds, overshadowing the credit risk component. In the cross-section, the bond-level illiquidity measure explains individual bond yield spreads with large economic significance.

2.4 Measuring liquidity in bond markets

As already discussed, liquidity is a many-faceted concept. It should come as no surprise that there are also many different empirical measures of liquidity. Most of them are measures introduced in the context of equities. As discussed, some of the theoretical basis for why liquidity matters is different for bonds. It is therefore not obvious that it is unproblematic to use directly the same empirical measures in the context of bonds, and something to have in mind when interpreting results.

In a recent study, Schestag et al. (2016) surveys the available empirical measures, and compare them in the context of measuring the liquidity of the US corporate bond market. They find that most measures used in equity markets also seem to be implementable for bonds. The various measures are highly correlated, and thus seem to measure some underlying concept of liquidity.

In our study we are limited to using liquidity measures calculable from daily data. We calculate three different liquidity measures, all of which were investigated in Schestag et al. (2016): Quoted Bid/Ask spreads; the Amihud Illiquidity measure, and the Corwin and Schultz (2012) estimate of spread from high/low prices.

Spreads are of course the best known measure of trading costs. If you want to trade you need to “cross the spread” to close the deal, and pay the spread. Amihud (2002)’s ILLIQ measure is an estimate of the elasticity dimension of liquidity. ILLIQ is the most common measure of illiquidity in the literature, due to its modest data requirements. As an elasticity measures of liquidity it measures how much the price moves as a response to trading volume. Kyle (1985) defines price impact as the response of price to order flow, and the Amihud ILLIQ measure is essentially an empirical version of Kyle’s lambda.

The Corwin and Schultz (2012) estimator uses the differences between the highest and lowest trade price in a day to estimate the spread. Intuitively, the difference between the highest and lowest prices traded during a day is driven by two effects: The volatility of the underlying price process, and the bid ask spread. To do estimation, Corwin and Schultz (2012) uses two insights. First, that the

highest price is likely to be a result of an impatient *buyer* crossing the spread, pushing the trade price up. On the other hand, the *lowest* price is more likely to be the result of an impatient *seller* accepting a low price. As a result the difference between the highest and lowest price during a day include the spread. But prices also move for other reasons (volatility). The second insight used by Corwin and Schultz is that volatility is increasing with the time period it is measured over. (This is the insight underlying *variance ratio* type of estimates.) Combining these two, Corwin and Schultz show how to simultaneously estimate volatility and an implicit bid/ask spread.

2.5 Linking financial market liquidity and the economy

While it is widely recognized that the liquidity is important for the pricing of securities, it is only recently that one has noted a wider link between financial market liquidity and the macroeconomy. In the context of equity markets, Næs et al. (2011) shows that one can use aggregate measures of equity liquidity to predict the business cycle. Stock market liquidity worsens leading up to and during the early part of recessions. It also start improving before the bottom of the business cycle. This effect is stronger for smaller than larger stocks. This suggest that investors shift their portfolios into safer (flight-to-quality) and more liquid (flight-to-liquidity) stocks during recessions.¹⁶

For Treasury bonds, Goyenko, Holden, and Trzcinka (2011) examine the liquidity of the US Treasury market across different maturities and the bonds on- or off-the-run status.¹⁷ They measure liquidity by the relative quoted spread and find that liquidity worsens in recessions across all maturities, but that this effect is most pronounced for short-term bonds. They argue that this suggest that investors shift into short-term bonds during recessions. They also find that the more illiquid off-the-run bonds are more sensitive to shocks to inflation and monetary policy surprises than their more liquid on-the-run counterparts, and use this to identify a significant liquidity risk premium in the Treasury market. Goyenko and Ukhov (2009) also show that there is a strong relationship between stock and bond Treasury bond market liquidity, with a two way causality relation, consistent with flight-to-quality or flight-to-liquidity episodes.

Beber, Brandt, and Kavajecz (2009) examine detailed data from the Euro-area government bond market to study to what degree investors value credit quality and liquidity. Their main result is that there is a negative correlation between credit quality and liquidity, and that cross-sectional variation in sovereign yield spreads is mainly explained by differences in credit quality. However, they also show that liquidity plays an important role especially for low credit risk countries and during times of heightened market uncertainty. The liquidity component is thus most prevalent in times of market stress.

2.6 The public policy perspective

From a public policy perspective, the most common question asked in the context of market microstructure is: Do we have an optimal trading environment? Secondary market liquidity is important to the economy because it “oils the gears” driving capital allocation. Secondary markets is also an important source of price information, affecting financial decisions throughout the economy. Regulators are therefore concerned that these aspects of a given financial market “works.”

Bond markets actually have less regulatory structure imposed upon them than equity markets. The structure of today’s US equity markets stems from introduction of “Reg-NMS” by the SEC in

¹⁶The study by Næs et al. (2011) showed this in the context of US (and Norwegian) equity markets and macroeconomic conditions. These results have been expanded on. For the US, Chen, Chou, and Yen (2015) show that liquidity can predict turning points in the business cycle. The results have also been shown to hold in numerous other countries. For example, Galariotis and Giouvris (2015) looks at six of the G7 countries, and Smimou and Khallouli (2015) shows it works for the Euro-zone.

¹⁷Once issued, the security is considered as on-the-run and the older issues are off-the-run for the same maturity.

2006, which opened up for competing exchanges, but mandated the dissemination of a Nationwide “Best Bid and Offer” (NBBO). The current best bid and offer prices (regardless of which market place has the best prices) must be displayed to all markets. The US bond markets has no such regulatory structure. One reason is that most of the traders are large financial institutions, which are not seen as in need of protection to the same degree as private individuals, which is driving much of the regulation in equity markets.

Academics and market observers argue that improving transparency and liquidity of the bond trading process may result in large benefits for traders (and issuers). The typical market structure for fixed income securities is still OTC style markets, even if the interaction is electronic. This style of trading is much less transparent than an open limit order book. So why do we see so little movement away from OTC trading? It is an open research question whether today’s structure for trading fixed income securities ended up where it is because it is the “best” structure for this particular asset class, or whether it is more of a historical accident. Arguments in favor of the latter is provided by Biais and Green (2007), which shows how in the early part of the Twentieth Century, most corporate bond trading in the US was done on the NYSE. The trading costs for bonds at that time was actually lower than the cost estimated today. This has been used to argue that the opaque nature of the US fixed income markets leaves too much money on the table.¹⁸ There are also international counterexamples to the inevitability of OTC style trading of fixed income securities. Israel, for example, has a thriving exchange market for bonds (Abudy and Wohl, 2016).

Bond markets have gone through large changes in the last fifteen years. Going forward, the pace of innovation is not likely to slow. We are likely to see new electronic markets introduced, old venues disappearing. It will be interesting to see if we eventually see more a more transparent structure appearing endogenously. But innovation may also be driven by changes to the regulation of the market places.

3 The Norwegian Bond Market

In this section we introduce the institutional features of debt issuance in Norway, with particular emphasis on the role played by the Oslo Stock Exchange.

3.1 Total bond issuance

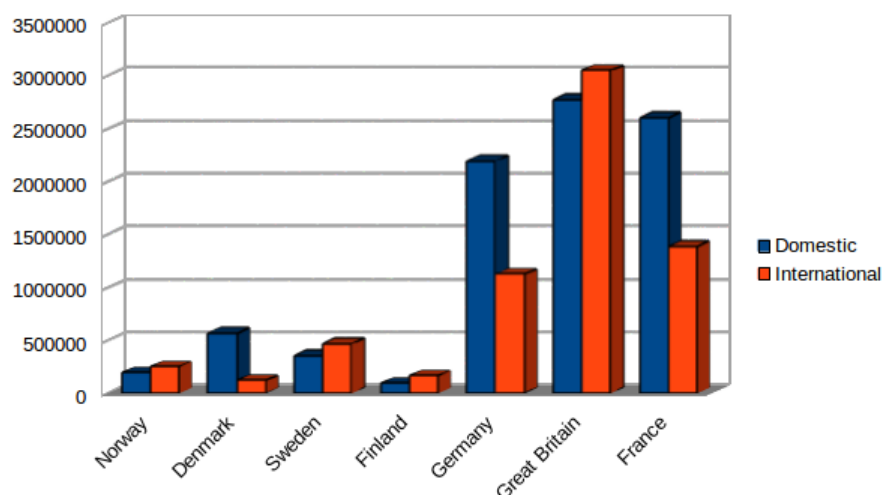
Let us first use data from the Bank for International Settlement (BIS)¹⁹ to give some broader perspective on the amounts of bonds outstanding by Norwegian issuers. As figure 2 shows, the Norwegian domestic bond issuance is small compared to the debt markets in the large European countries like Germany, France and UK. By the end of 2015 the total outstanding amount in the Norwegian market was the equivalent of 190 billion USD. In other Nordic countries like Sweden and Denmark the corresponding amounts are 353 and 569 billion USD.

Norwegian corporate firms and financial institutions also issue debt in international markets. At the end of 2015 the outstanding amount of Norwegian debt securities in international markets was the equivalent of 247 billion USD. The amounts issued by financial corporations was 197, other corporations 50, which means that financial issuers amounts to about 80 per cent of Norwegian international bond issuance. For Swedish issuers, like Norway, the outstanding amount in the international market is similar to the amount in the domestic market, while domestic issuance dominates in Denmark.

¹⁸See Harris (2015) and O’Hara, Wang, and Zhou (2016) for some comments on the US corporate bond market. Another market place in need of more transparency is that for US municipal bonds. See Ang and Green (2011) for some comments on that. See also the comprehensive overview of the structure of the muni market from the SEC (Securities and Commission, 2012)

¹⁹Data from BIS - Debt Securities Statistics: <http://www.bis.org/statistics/secstats.htm>. Note that these data do not completely agree with the aggregates given by the Oslo Stock Exchange.

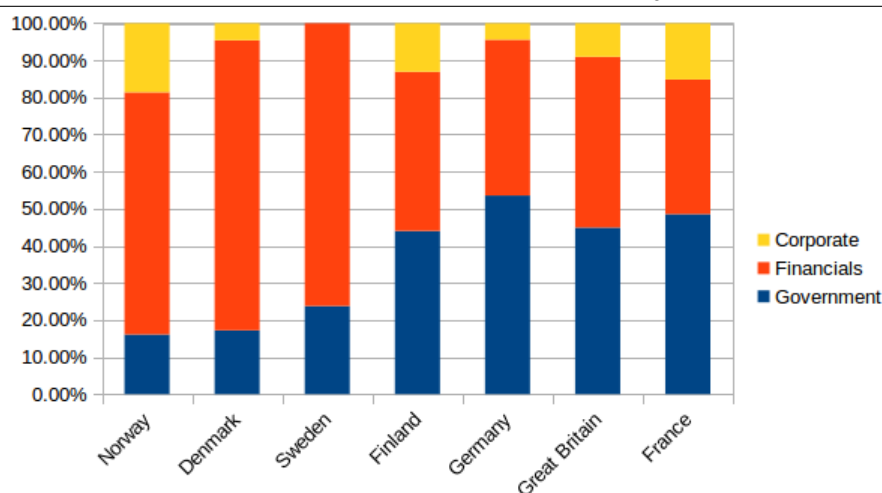
Figure 2 Outstanding debt securities, international, 2015:Q4



The figure shows the total outstanding amount in bonds issued either in domestic markets or international markets. Numbers in millions of USD. Data from BIS - Debt Securities Statistics: <http://www.bis.org/statistics/secstats.htm>. Data from Q4, 2015.

Norwegian Government bonds and Treasury bills amounted to 67 billion USD in 2015. Norway has no Government debt issued in international markets, i.e. no Government debt issued in other currencies than NOK. According to BIS all the other European countries issue Government debt in international markets, but the outstanding domestic amount is larger. As Figure 3 shows, the share of Government debt in Norway is similar to Sweden and Denmark, but less than in France, Germany and UK.

Figure 3 Sector distribution of bond issuance, international, 2015:Q4



The figure shows the total debt issuance (both domestic and international) distributed on the three sectors government, financial and nonfinancial corporations. Data from BIS - Debt Securities Statistics: <http://www.bis.org/statistics/secstats.htm>. Data from Q4, 2015.

Financial institutions constitute a large proportion of the outstanding private sector debt securities in Norway as well as in the other Nordic countries. In the Norwegian market the outstanding amount issued by banks and other financial institutions were almost 91 billion USD by the end of 2015.

A special category among the financial issuers is covered bonds, which is a recent innovation. The first issuance of Norwegian covered bonds took place when the Norwegian legislation entered into force in June 2007. According to Norwegian legislation covered bonds cannot be issued by banks, but must be issued by a separate institution (mortgage company) and secured on loans owned directly by that company. The loans are transferred from a bank or issued by the company directly. Since 2007 the Norwegian covered bond market has grown rapidly, with significant issuance both in the domestic and in international markets. The swap arrangement with the government greatly increased the issuance of covered bonds in the domestic Norwegian market. Covered bonds worth more than NOK 230 billion or 40 billion USD were used in the swap arrangement. By 2011 about 40 per cent of issued debt by financials was covered bonds.

Issuance by Norwegian non-financial companies is of limited scale compared to financial institutions, both in the domestic and international debt securities markets. By the end of 2015 it amounts to 18 per cent of the outstanding total debt.

3.2 The Bond Market on Oslo Stock Exchange

The Norwegian domestic debt securities market is essentially the bonds, notes and other debt instruments listed on Oslo Stock Exchange (OSE). OSE has two distinct market places for bonds. Their main market, and their Alternative Bond Market (ABM). Debt securities have been traded at the OSE since 1881. The ABM was established by Oslo Stock exchange in 2005, and is an unauthorized market place according to MiFID and not regulated under the Stock Exchange Act. The listing process and reporting requirements at the ABM are simplified in comparison with the main OSE market. The trading rules and system are however similar. Since its start-up, the ABM has been dominated by issues from banks and other financial institutions.

At the end of 2011 the outstanding amount of debt securities listed on Oslo Stock Exchange main market was approximately three times as large as the outstanding amount listed on ABM. However, both the number of issues and issuers were larger on ABM, reflecting smaller volumes per issue and small companies making use of the simplified listing and reporting requirements.

3.2.1 Development in market structure

In 1988 Oslo Stock Exchange introduced an electronic trading system for stocks and derivatives. In October 1989 this system was also launched for bond trading. The electronic trading system opened up for decentralized trading, in the sense that brokers could trade from office terminals linked to the system.

For Treasury Securities, in 1995 a system of *primary dealers* were introduced, where the primary dealers were given privileges in the primary auction, but had obligations on quoting prices in the secondary market.

Ten years after the introduction of electronic trading, in September 1999, a new decentralized trading platform (ASTS) was introduced, allowing for direct routing of orders via brokers to the trading system. For trading in Treasury securities, this system entailed a change from indicative prices to automatic matching of orders. Auto-matching amounted to about 20-30 per cent of the trades in government bonds in the first years after the system was introduced, but this share has fallen to approximately 10-15 per cent.

Auto-matching was not introduced for trading in non-government bonds, which continued being phone-based. However, all trades in non-government bonds were to be reported to the stock exchange within 5 minutes after the trade had taken place, but with a possible application for delayed publication until the end of the day.

Since September 1999 the Oslo Stock Exchange has changed its trading system three times. The main characteristics, including decentralized trading and auto-matching of bonds, are the same

across the three systems. The first change was in the spring of 2002, when the Oslo Stock Exchange joined the strategic Nordic alliance NOREX, a common trading platform for the Nordic exchanges (Københavns Fondsbørs, Stockholmsbörsen and Islands Fondsbørs) was introduced. This made it easier for international brokers to trade directly in the Norwegian market.

The Norex alliance ended in 2009 when Oslo Børs entered into a strategic partnership with the London Stock Exchange. The partnership also included the bond market, and caused a transfer from SAXESS to TradElect in April 2010, a common trading system with London Stock Exchange.

The third change came in November of 2012, when the Oslo Stock Exchange moved its equity and fixed income trading onto the London Stock Exchange Group Millennium Exchange trading platform. Millennium Exchange is an ultra low latency, highly scalable trading platform.

3.3 Regulation of bond issuance

The regulation of listing of bonds (IPOs) on the OSE has been strengthened in recent years. The most important part of the listing process, approval of the *prospectus*, used to be done by the Oslo Stock Exchange, as part of the listing process. This, in 2009, moved to The Financial Supervisory Authority (FSA) of Norway (Finanstilsynet). When a bond is to list on the OSE, the issuer now needs a dual approval of the prospectus from the FSA and the OSE. This regulation follows EU rules, which the Norwegian Financial Authorities implement.

3.4 Off-exchange trading

It is important to note that while the Oslo Stock Exchange (OSE) electronic trading platforms has been organized as an continuous electronic limit order market, a public limit order book is not a complete description of the Norwegian bond market due to the large fraction of trading that occurs outside the exchange system (*over the counter*). For treasury securities, there are designated primary dealers. that are required to post bid and ask quotes, such that the bid / ask spread will typically be available through the trading day. For other government and corporate securities on the other hand, there are no such designated market makers. Off-market transactions by bond brokers at the OSE are required to be reported to the OSE immediately or by the end of the trading day.

All trades that occur on the OSE is classified into various types. There are two main types of trades; *automatic* trades and *manual* trades. With respect to the automatic trades, when orders are executed by the electronic trading system, trades are automatically created, trade details are disseminated to the involved parties, and public information is published. With respect to the manual trades, these are trades that execute away from the order book and is reported manually into the system.

3.5 Back to the market microstructure perspective

If we now look at bond trading in Norway from the microstructure perspective, and compare it to some of the worlds' other bond markets, we see that the Norwegian market is actually one of the more open. In the Norwegian market, traders has the choice of using the public market or trade off-exchange (OTC). The public market is an electronic limit order book, with both pre- and post transparency. For off-exchange trading there is post-trade transparency through the daily reporting of trades through the exchange's systems.

However, few of the participants in the Norwegian bond market choose to route their trades through the exchange's systems. This may be a result of decisions that are individually optimal (it is in the interest of each trader to hide information about her trades) but collectively result in a suboptimal equilibrium. As we discussed in the context of the US corporate bond market, the academic community argues that there will be large gains (significant lowering of transaction costs)

by moving to a system with greater transparency, and where liquidity is collectively displayed. This is not saying that we need a single market, the US equity markets for example solve the problem of pre-trade transparency by mandating the display of an across-markets best bid and offer (NBBO)q.

3.6 Groups of issuers and characteristics

In our later analysis of the Norwegian bond market, in addition to totals for the market, we will construct liquidity and activity measures for subgroups of bonds. The market place is however limited in the degree to which one can subsample and still retain meaningful numbers. The only dimension we split the sample is therefore by type of issuer.²⁰

Figure 4 gives an overview of the investigated issuer groups at the OSE. All the results in the rest of the analysis will be presented separately for these groups. At the general level, we split the issues into government issues and corporate issues. The government issues is further split into securities issued by central (state) and local government (non-state). The state securities are actually just the Treasury Bonds, and we will later just label them Treasuries. We do not look at trading of shorter term Treasury Bills (statskasseveksler). The corporate group is split into bonds issued by financials (with covered bonds (OMF) as a subgroup) and bonds issued by non-financials. We also include bonds issued by foreign institutions, which may be either financial or industrial issuers.²¹ We employ sector classifications given by the Oslo Stock Exchange.²²

Figure 4 Groups of issuers

1. **State** – The Norwegian State (Treasury Securities)
2. **Govmnt, non-state** – State enterprises (Norw: Statsforetak), Municipal (Kommune), County (Fylke), Government Backed Issues (Statsgaranterte).
3. **Financials** – Banks, Mortgage Institutions (Kredittforetak)
 - **Covered Bonds** (OMF) - Subgroup of Financials.
4. **Industrials** – Industrial Companies (Industriforetak)
5. **Foreign** – Foreign issuers using the Oslo Stock Exchange as a listing exchange

The figure gives an overview of the groups and sub-groups of issuers we are looking at in the analysis. Source of grouping: Classification by the Oslo Stock Exchange. Note that covered bonds are also included in the estimates for financials.

4 Data Sources

The main dataset is obtained from Oslo Børs Informasjon (OBI). We use data for all bond trading, both at the main OSE market, and the Alternative Bond Market (ABM). For convenience we will use OSE to refer to both these market places. The dataset starts in 1989, although we have some price quotes for 1988. The last observation is in June of 2016. Each day, the exchange records the last trade price, the last best bid and asks, the high and low trade prices during a day, as well as the number of bonds traded. This is supposed to be observed daily for all bonds listed at the OSE. For many bonds, though, they trade very seldom, and as a result, the data contains only a few dates with any of these

²⁰It would be interesting to also subsample on dimensions like time to maturity, age, issue size, etc, but in our view there is not enough data to make these meaningful exercises.

²¹Note that the sector definitions are slightly different than those used in our earlier study (Rakkestad et al., 2012).

²²For the earliest part of the sample (1988-2000) the OSE does not provide sector definitions. These have been filled in manually.

are observed. The data feed splits trading volume into two types, “official” and “non-official” volume. The use of these two categories seem to change over time, and we therefore only use the sum of the two, total volume.²³

To supplement the market data, we also combine the OBI data with the Stamdata database,²⁴ which contains information on the terms and characteristics of each individual issue, as well as the complete history of repayments of the individual loans. These data will mainly be used to handle the outstanding volume when calculating turnover. We also use the Stamdata data to identify the covered bonds.

In the analysis of the paper we use the whole period to maximize the number of data points. Note though that data before 1999 may be less reliable, as the trading was not fully electronic. We therefore also in some cases show results for just the period after trading in fixed income securities was organized as a fully automated electronic order book system; i.e. from 1999 onwards. This period is likely to be relatively stable with respect to the underlying market structure, and also more representative going forward.

5 Activity measures

A natural starting point for our analysis is to examine the trading activity in the listed securities. We will measure the number of days (during a quarter) that the issues are traded to get an overall measure of trading intensity. We also calculate the total NOK trading volume, average volume and turnover (transacted volume relative to outstanding volume of the loan at any point in time). Trading activity can be high both in normal periods as well as during turbulent periods (Aitken and Comerton-Forde (2003)), which means that trading activity by itself is not necessarily a good measure of aggregate liquidity variation. However, in the cross section, securities with high trading activity are typically more liquid (i.e. have lower implicit transaction costs).

Let us first look at the number of bonds available at the OSE. In table 1 we count, for five year intervals, the number of bonds in the crosssection at the OSE. We do not include completely inactive securities. For a bond to enter the count we require either a price quote (Panel A) or a reported trade (Panel B) at least once during a five year period.

As both the numbers quoted and traded show, the number of bonds listed at the OSE has increased substantially in recent years. The sectors with the largest increases are Financials and Industrials. Firms in both these sectors are increasingly using listed bonds for funding.

Looking first at the government securities, we see that there has been a decline in number of local government securities over 2000-2016 period. The structure of the Treasury market has also changed. Currently, the Treasury maintains only a few active treasury bonds, typically issuing one 10 year bond once a year.

For corporate issues on the other hand there has been a steady increase in number of issues over the period. In particular the number of financial issues have more than doubled since 2000. Part of the increase in financials is from bank issues. The increase in bank issues from 2005 corresponds to a period of increased credit growth, and increase in wholesale funding for Norwegian banks due to

²³During the Saxess period (until April 2010) the official volume field contained a mix of various trade types (repos, reported trades etc.), while this was changed when the TradElect system was introduced from April 2010. During the TradElect period the official volume field was changed to only include auto-matched trades, uncrossed trades, regular trades that is immediately disseminated and regular trades with delayed reporting. Since we are unable to split the official and non-official volume into finer sub-categories (in particular during the Saxess period), we dismiss these volume variables in the analysis and only look at total volume.

²⁴Through Stamdata, Nordic Trustee (earlier “Norsk Tillitsmann”) delivers reference data for Norwegian debt securities. The data includes detailed information on i.a. bonds, certificates and structured debt securities issued by governments, municipalities, banks and corporate borrowers. The core business of Nordic Trustee is to offer trustee services to bond loan investors. It is mainly owned by Norwegian and Danish banks, life assurance companies and securities companies.

Table 1 The total number of active bonds at the OSE. Subperiods

Panel A: Bonds with price quotes

		Subperiod					
		91-95	96-00	01-05	06-10	11-15	16-
	All	666	798	1320	1961	3023	1816
Sector:	Treasury	31	45	11	9	9	7
	Govmnt, non-state	256	275	324	180	173	128
	Financials	245	366	641	1176	1916	1268
	of which Covered Bonds	0	0	0	80	329	207
	Industrial	132	106	307	538	867	395
	Foreign	2	3	9	34	35	10

Panel B: Bonds with reported trades

		Subperiod					
		91-95	96-00	01-05	06-10	11-15	16
	All	794	1145	1433	2015	3045	1840
Sector:	Treasury	31	54	18	9	9	7
	Govmnt, non-state	323	421	366	199	176	129
	Financials	275	505	684	1206	1925	1283
	of which Covered Bonds	0	0	0	80	330	211
	Industrial	163	159	326	543	877	403
	Foreign	2	3	11	34	35	10

The table counts, for five year periods, the number of distinct bonds with price quotes (panel A) or reported trades (Panel B). We count the number of distinct bond id's with at least one of these. Note that bonds are listed for long times, so some bonds will be present in several subperiods. Each column is a five-year period. Data 1990–2016. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

a decrease in the deposit-to-loan ratio. For industrial issuers there has also been an increasing trend over the sample period. Finally, after the covered bond legislation was adopted in June 2007, we see the growth in number of covered bonds issues by specialized mortgage credit institutions.²⁵

5.1 Days with trading

During the most recent five year period there were more than three thousand bonds listed at the OSE. But a listing does not necessarily mean a liquid bond. Let us take some very simple looks at the crosssection. A first requirement of liquidity is that the bond trade now and then. To check on that, in table 2 we ask how many of the above bonds are traded more than five and ten days in a year.

Table 2 Bonds with a nontrivial number of reported trades

Panel A: The number of bonds traded more than five times a year

		Subperiod					
		1991-95	96-00	01-05	06-10	11-15	2016
	All	604	658	941	1390	2131	1320
Sector:	Treasury	29	50	10	8	9	7
	Govmnt, non-state	243	191	154	87	97	75
	Financials	238	335	514	900	1430	933
	of which Covered Bonds	0	0	0	54	287	197
	Industrial	93	77	228	345	545	288
	Foreign	1	3	7	26	27	9

Panel B: The number of bonds traded more than ten times a year

		Subperiod					
		1991-95	96-00	01-05	06-10	11-15	2016
	All	387	439	672	863	1470	930
Sector:	Treasury	23	43	9	8	9	7
	Govmnt, non-state	119	99	81	35	56	40
	Financials	177	241	392	557	1004	641
	of which Covered Bonds	0	0	0	34	244	176
	Industrial	67	52	160	226	359	229
	Foreign	1	2	2	13	20	6

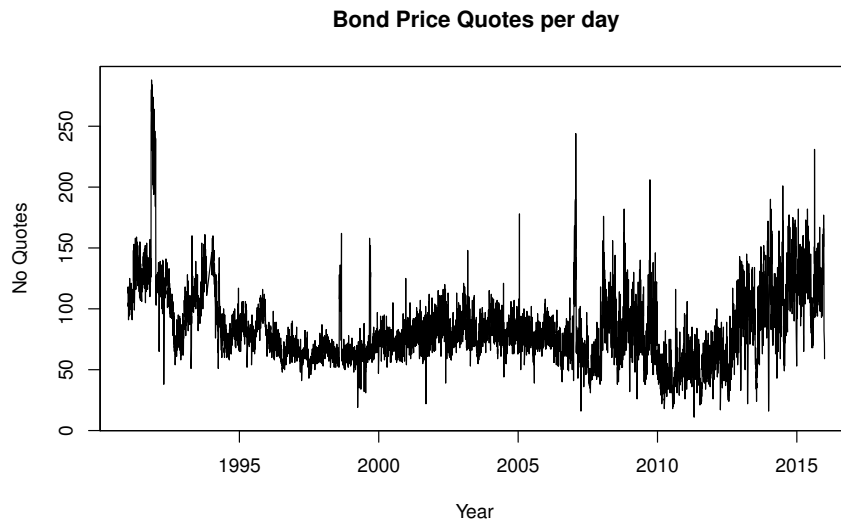
The table counts, for five year periods, the number of distinct bonds with more than five (ten) reported trades per year. For each bond, we count the number of trades in each five year interval. We then divide this by the total time within those five years the bond was listed (five years if the bond was listed the whole period, a smaller number if the bond was listed after the beginning of the five years, or matured before the end of the five year period). For the last half year we count the number of bonds with more than respectively two and five trades. Note that bonds are listed for long times, so some bonds will occur in several subperiods. Each column is a five-year period. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

The numbers show that while the crosssection of available bonds is large, many bonds do not trade all that often. Consider the 2011-2016 period. Of the roughly three thousand bonds which traded once during that period, only half traded more than five times a year, and a third more than ten times a year. With so many bonds not traded, on a given day, we can not expect that all bonds have quoted prices. To illustrate that, consider figure 5, where we on a daily basis count the number of prices observed. For most of the period this has been between fifty and a hundred, and in the most

²⁵A commercial bank or a savings bank is not allowed to issue such bonds in its own name, but may establish a mortgage credit institution as a subsidiary. Alternatively, a mortgage credit institution may be established as an independent institution with several shareholders.

recent period increased towards hundred and fifty. Comparing that to the almost three thousand bonds available towards the end of the sample, it is clear that not many bonds have regular trading interest.

Figure 5 Daily Number of Quotes



The figure shows the number of price quotes reported each day. Each trading day, we count the bonds with reported price quotes (if a bond trades, it will automatically have a price quote, but this figure also include bonds with quotes without trades.)

The daily quoting behaviour show a marked activity increase in the bond market in the last ten years. Bonds do seem to be traded more often. To make this point in a different manner, let us look at a different frequency, and aggregate to a quarterly basis. To look at activity we count days with trading in an individual bond. We look at each quarter of the year, and count the number of bonds that trades one day, more than two days, more than five days, etc. Figure 6 illustrates this calculation for all bonds at the OSE.

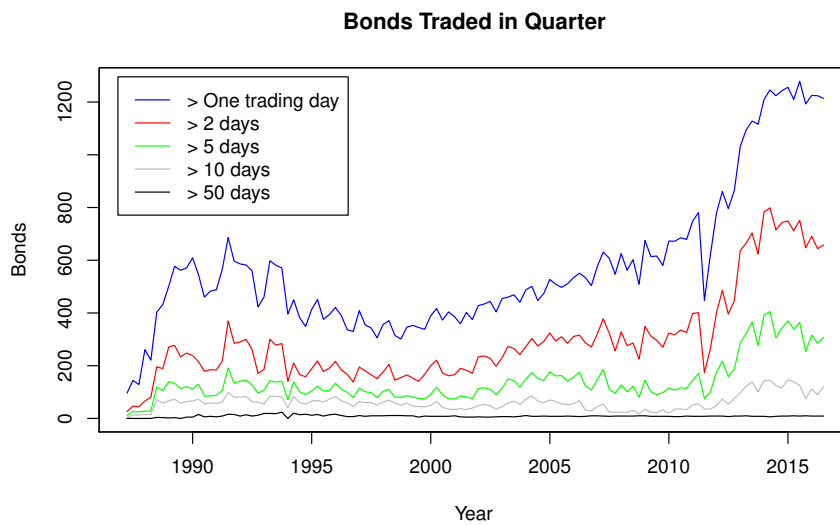
Here, we see a remarkable increase in activity in the post-financial crisis period, and particularly after 2011. Note that there is a “down-spike” in 2011. This is happening when the exchange is changing its trading system. For some reason, which we have not clearly identified, the *number* of bonds traded in that quarter falls markedly. We will see later that this is made up for by the volume/turnover in the bonds actually traded. The turnover in these bonds increases, and the total volume traded in the period has no such downward spike.

To look closer at where the trading increase is happening, let us also look at similar plots for the six issuer categories. Figure 7 breaks the above total into numbers for the different categories. Several observations can be made here.

First, that the only type of bond which trades continuously is Treasuries. There are no other type of bond which trades more than fifty times a quarter. The time series behaviour of Treasury Bonds can be explained by policy decisions of the Norwegian Treasury. In theory, the Norwegian state currently does not need to borrow (issue Treasury securities), due to the surplus channeled into the “Oil Fund” (Government Pension Fund Global). Treasuries are however important for the functioning of the Norwegian financial markets, and the Norwegian Treasury therefore borrows enough to maintain a few actively traded Treasury bonds.²⁶ Hence, the fall in the number of outstanding issues, but increase in Treasury Bonds with active trading. The increase in trading of Treasuries is also influenced by the

²⁶The Funds raised by the Treasury is used to cover lending in State banks. See “*Nasjonalbudsjettet 2016, seksjon 3.8.2.*”

Figure 6 Intensity of bonds traded in each quarter.



We count bonds traded in each quarter. We separately count bonds traded at least once, more than twice, more than five days, more than ten days, and more than fifty days. All bonds listed at the Oslo Stock Exchange.

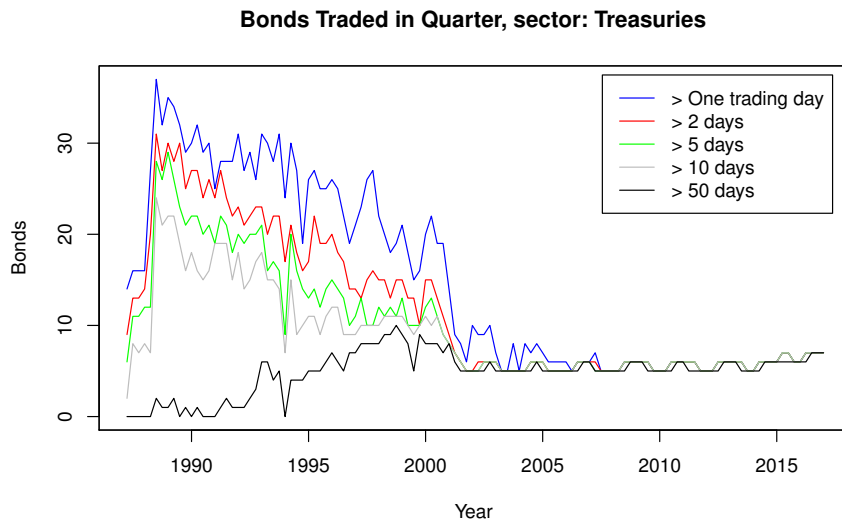
Central Banks introduction of a system of primary dealers, in 1995. The primary dealers have an obligation to maintain active quotes for Treasury Securities.²⁷

Second, we see that the activity in bonds issued by other government agencies than the Treasury declined until 2010. There is a small increase in activity post 2010, but nothing major. Thirdly, note the marked increase in trading in the financial and industrial issuer categories in recent years. The increase in activity for the non-financials is a result of reduced corporate financing by banks. A good deal of this increased activity is in lower graded debt, issued by oil related companies. Finally, note that the “down-spike” in 2011 observed in the total is limited to the financial issuers.

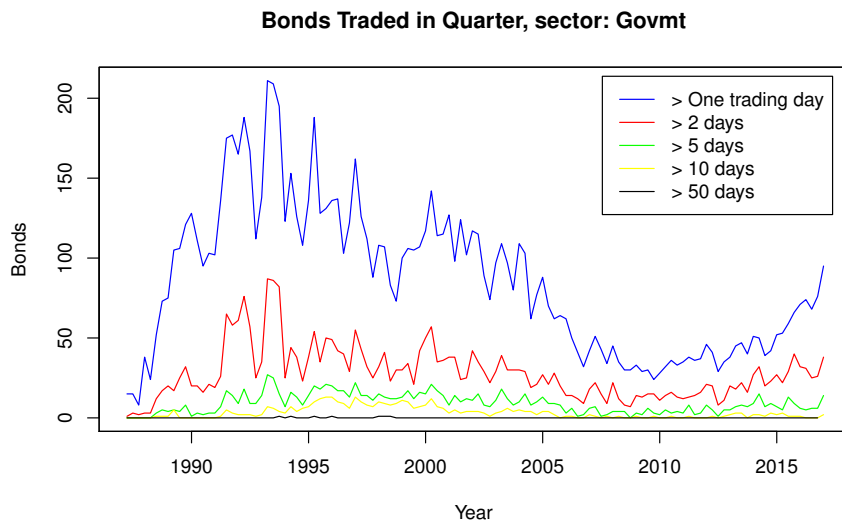
²⁷The primary dealers in return can bid in the Treasury auctions.

Figure 7 Intensity of bonds traded in each quarter. Separately for each bond issuer sector

Panel A: Treasury Bonds



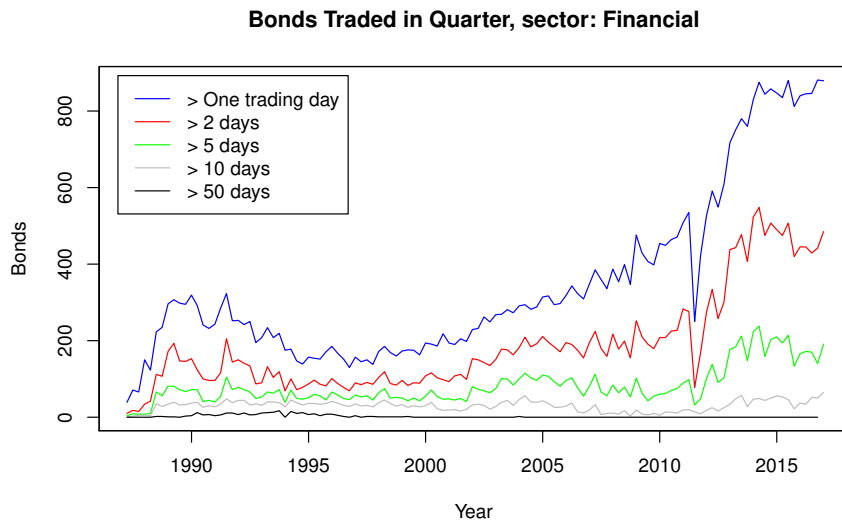
Panel B: Government (non-state)



We count bonds traded in each quarter. We separately count bonds traded at least once, more than twice, more than five days, more than ten days, and more than fifty days. All bonds listed at the Oslo Stock Exchange. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

Figure 7 (Continued)

Panel C: Financial issuers



Panel D: Covered Bonds (subgroup of Financials)

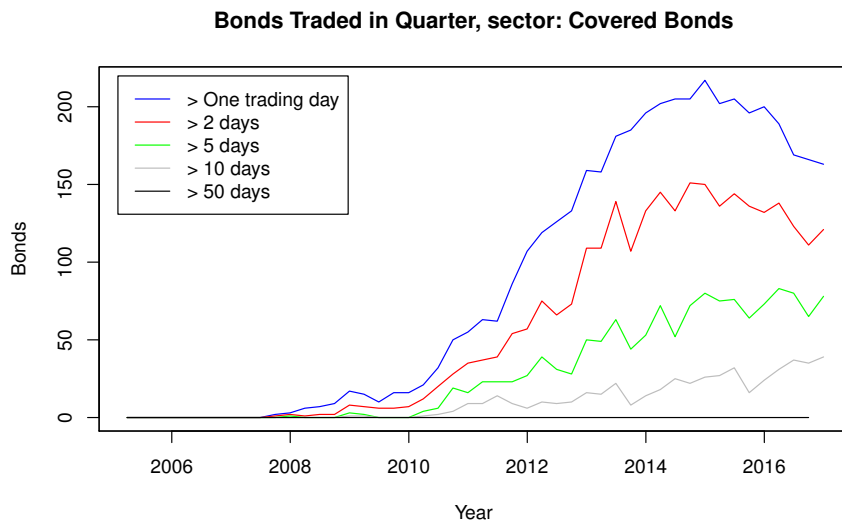
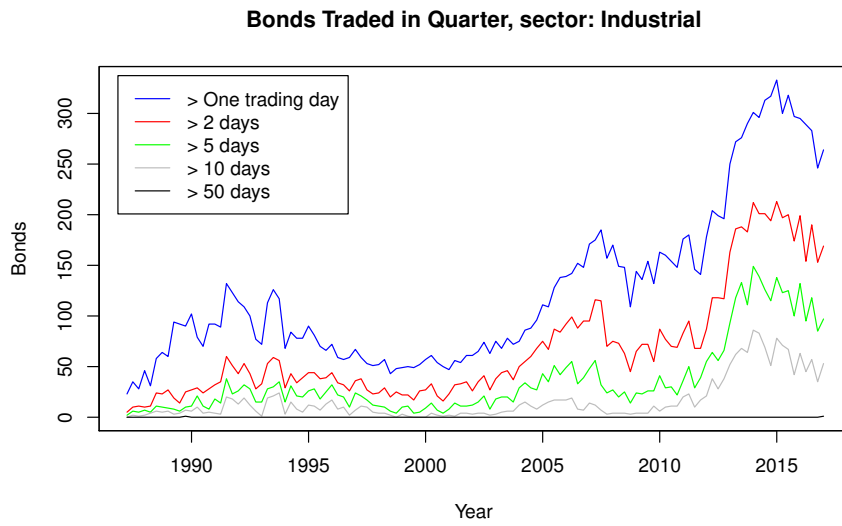
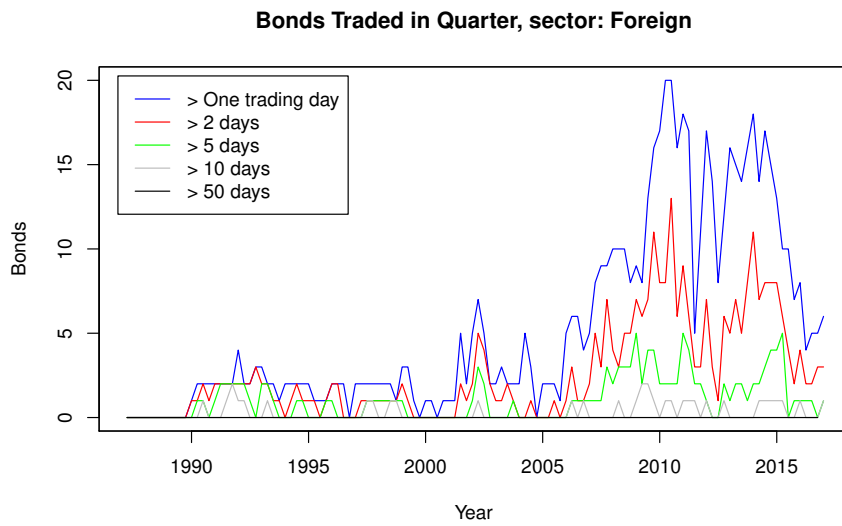


Figure 7 (Continued)

Panel E: Industrial issuers



Panel F: Foreign issuers



5.2 Trading Volume

Figure 8 show total trading volume for the various categories. Panel A includes all bonds, and show that in volume terms, Treasury securities are the dominant bond type in trading at the OSE. To get a clearer picture for the other categories Panel B shows quarterly volume figures for the other, non-treasury categories.

For Treasury securities, we see a top of activity in the aftermath of the financial crisis in 2008, with a gradual decline back to the levels of the early 2000's. Part of the explanation for why Treasuries are so active is their role as security in derivatives transactions.

The volume numbers also include repo transactions. Unfortunately, the reporting of repo volumes by the OSE is inconsistent over time. We believe that during the period april 2010 to november 2012 the reported volume for a repo transaction only include one "leg" of the trade, while after that both "legs" are included.

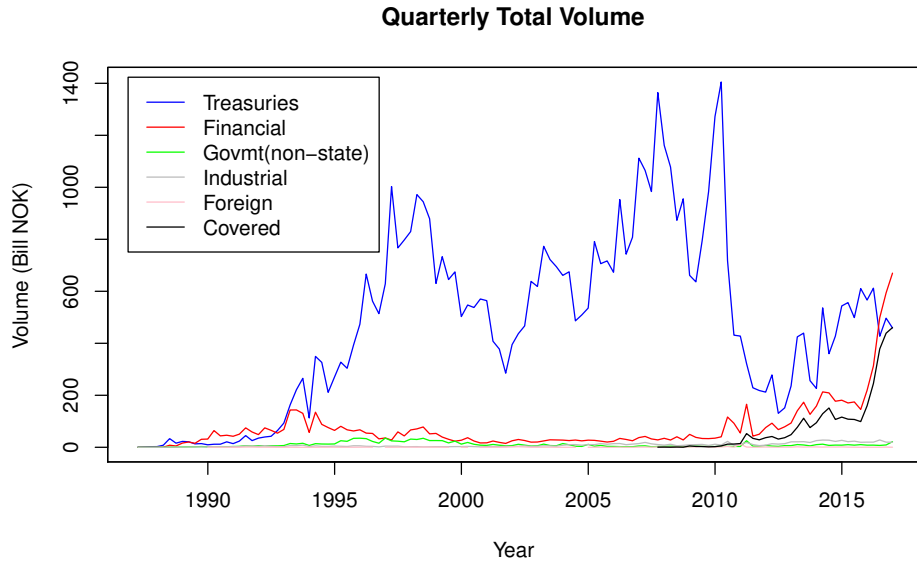
For the bonds which are not Treasuries, the largest category in volume terms are financial issuers, which has seen a formidable increase in trading interest in the years after 2010. This is mainly driven by the activity in covered bonds. The non-state government issuers have been declining. Industrial issues have seen a gradual increase in trading. The increase among industrials is related to the increased use of traded bonds instead of bank debt for many Norwegian companies. The increase in the market for non-investment grade debt, typically listed at ABM, was also to some degree triggered by the financial crisis, and the need for banks to slim their balance sheet, although this market had started in Norway before the crisis.

In addition to the total volume, it is of interest to look at volume on a per-bond basis. We therefore also show, in figure 9, average trading volume for the various categories. Even more than the totals, average volumes are dominated by Treasuries. This is partly due to the way the Norwegian Treasury issues debt. Many Treasury bonds are "on tap," the Government can just add new borrowing as volume to an existing bond. This result in few bonds outstanding. As we saw earlier, only about 10 Treasury securities were actively traded. This explains the huge disparity of average volume between Treasuries and the other categories, the huge Treasury volumes are divided among just a few outstanding bonds.

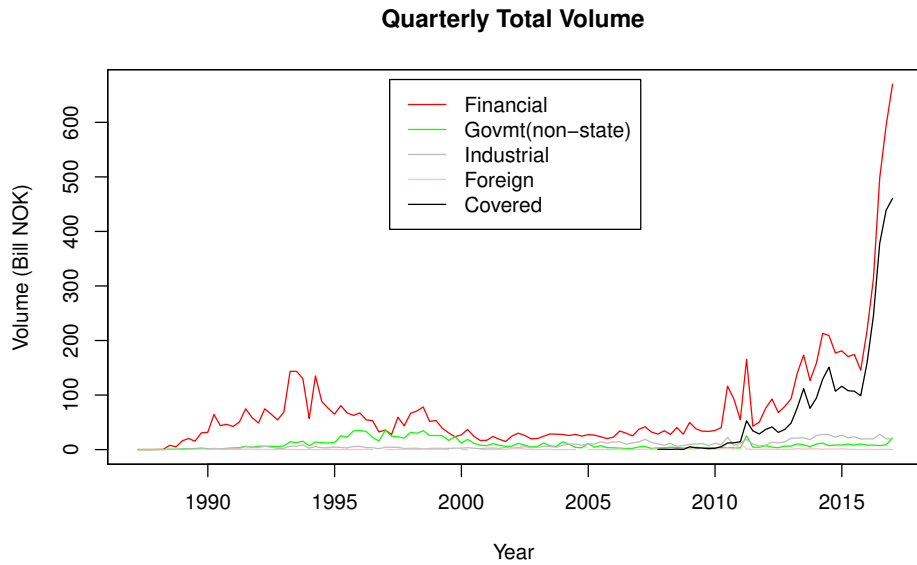
This makes it more important to look separately at the other sectors, which is shown in panel B. Here we see that currently, after 2010, most of the activity is driven by covered bonds, which has seen a huge increase in average volume.

Figure 8 Total trading volume

Panel A: Total trading volume, split on issuer sector



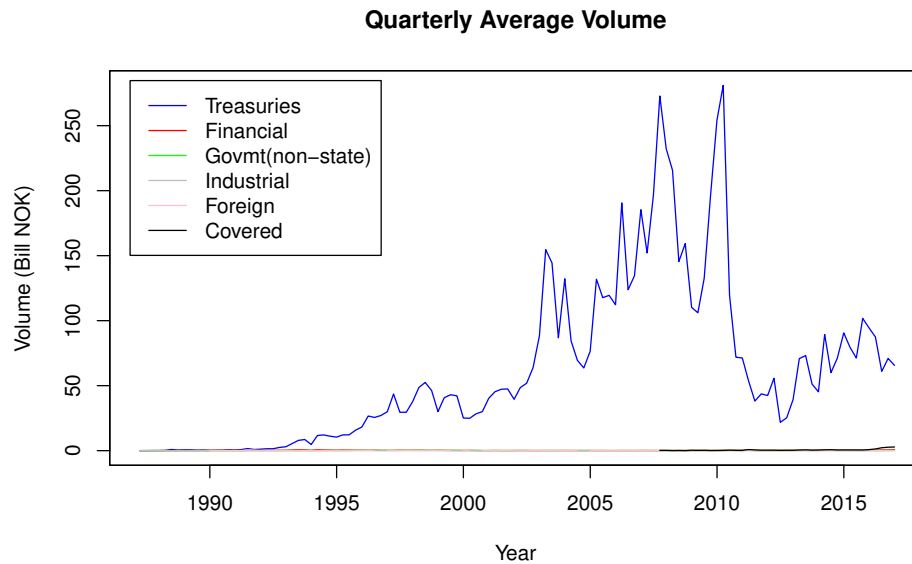
Panel B: Total trading volume, split on issuer sector, excluding Treasuries.



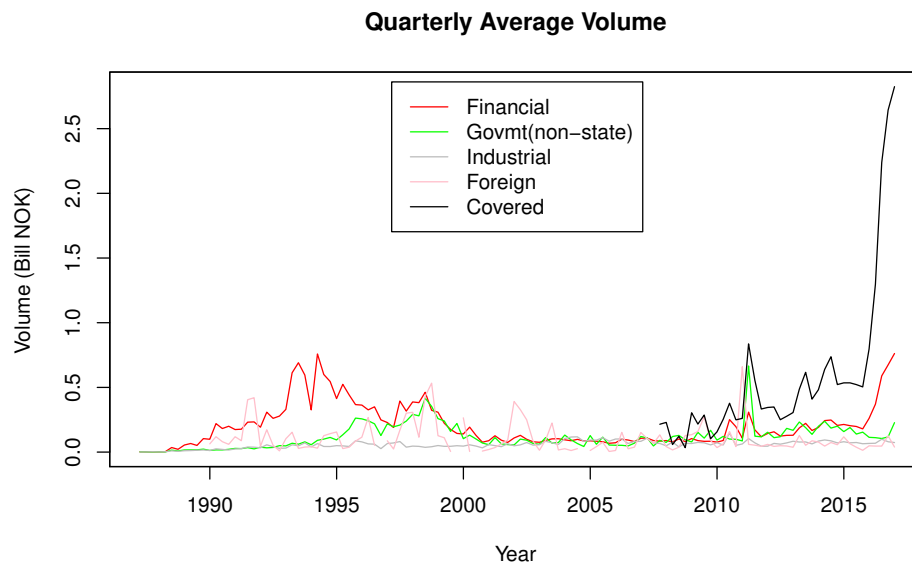
Total trading volume per quarter, in billions NOK (Norw: Milliard). We sum volumes across all bonds with trading in a quarter. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

Figure 9 Average trading volume

Panel A: Average trading volume, split on issuer sector



Panel B: Average trading volume, excluding Treasuries.



Average trading volume per quarter, in billions NOK (Norw: Milliard). For each bond with trading, we calculate the total trading during a quarter. The reported number is the average of these total. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

5.3 Turnover

The previous activity measures do not say anything about how much of the outstanding volume is changing hands. It is therefore also useful to calculate the turnover relative to the outstanding volume of a given bond.²⁸ Panel A of Figure 10 shows the average quarterly turnover for Treasury issues, and Panel B shows the similar turnover for the other sectors.²⁹

Looking first at the government securities, we see that the Treasuries have a significantly higher turnover than local government securities. Much of this is caused by the large fraction of the activity in the Treasury securities related to repo activity. However, note that the inconsistency discussed earlier in methods for reporting Repo activity (one leg: 2010-2012, both legs after) contaminates the picture for Treasuries.

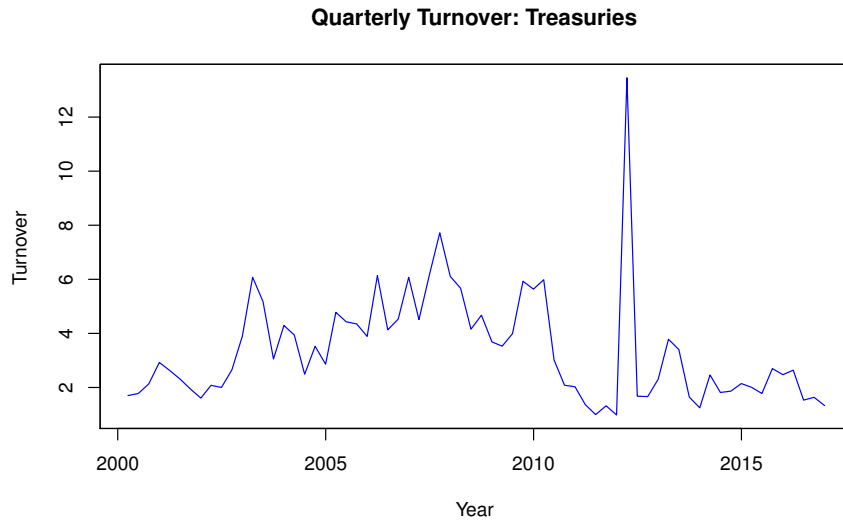
For the other issues, there is no clear trend, except that there is high, and increasing, variation in turnover over the sample period. The turnover numbers are very noisy given the low number of days traded for the individual issues each quarter. In addition, these numbers are affected by the changing composition of bonds and the size of new issues over the period. Note by the way the spike in 2010/2011 in turnover for several bond categories. This coincides with the fall in number of bonds traded in the same period. Hence, we confirm that trading interest in that quarter was concentrated in fewer bonds.

²⁸We calculate turnover velocity as the transaction volume in NOK divided by the quarter divided by the nominal outstanding NOK volume at the beginning of the quarter.

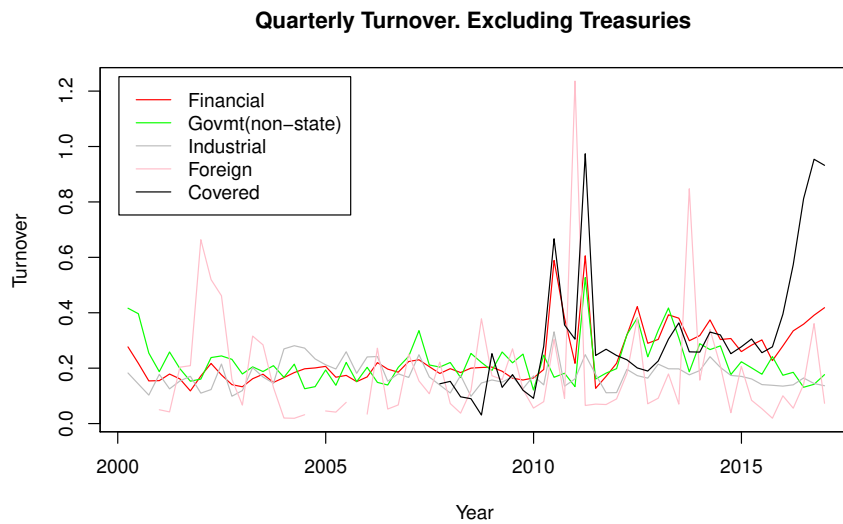
²⁹Note that the figure starts in 2000. This is due to a lack of data on the number of bonds outstanding in the earlier period. The number of bonds is sourced from Stamdata, which does not include historical data.

Figure 10 Turnover

Panel A: Turnover, Treasuries



Panel B: Turnover, non-Treasury issuers



Turnover is Total trading volume per quarter divided by total amount issued. The turnover is only calculated for bonds with trading in the given quarter. The estimate in the figure is the average of turnovers for all these bonds. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

6 Liquidity measures

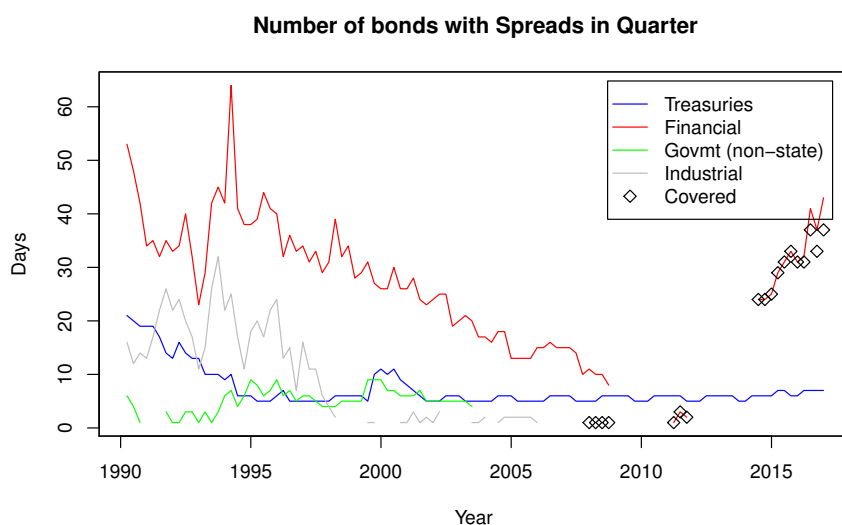
In the previous we looked at some basic measures of trade activity. While these are important measures of liquidity (it is hard to have a liquid market without trading going on) they do not provide the full picture in terms of prices' sensitivity to volume, or how much one needs to change prices to achieve a sale (or purchase). We therefore looks at liquidity measures that attempts to say something about these aspects of liquidity. The data available to us restricts the possible measures. In particular, we do not have trade information at finer granularity than daily, and are therefore constrained to measures that can be constructed from daily data. The three measures we consider are the bid/ask spread, the Amihud illiquidity ratio, and the Corwin and Schultz spread measure. We have earlier given some intuitive explanations of these measures. Detailed definitions are provided in appendix A.

6.1 Spreads

The first liquidity measure we calculate is the relative bid ask spread. This is a measure within the class of order based measures, as defined by Aitken and Comerton-Forde (2003). In an active limit order market or in a market with many competing market makers, the spread is a measure of the cost required to supply liquidity.

Note that to calculate the spread, we need there to be both a bid and ask quote for the same day for a security. To check on how commonly the participants on the exchange quote spreads, in figure 11 we count the number of bonds of the various categories where we see at least one spread quote within a quarter.

Figure 11 Number of bonds with quoted spreads



We count the number of bonds each quarter with at least one case of a spread (both bid and ask quotes observed at the same date). We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

The only category with a consistently positive number of observations is Treasury bonds. Given the market structure at the fixed income market at the Oslo Stock Exchange, it is essentially only for Treasury securities that there is a continuous market with designated market makers (primary dealers) required to quote bid and ask prices as well as accept orders from other participants. For corporate bonds, there is an opening and close auction similar to equities, and order entering and

manual trade reports. For the Oslo ABM segment there is order entering and manual trade reporting, but not any opening or closing auction. As opposed to Treasury securities, there are no designated market makers in corporate bonds. The last couple of years we see an increase in quotes among financials. This is due to the new interest in covered bonds, for which there has developed an active market.

Let us now look at estimated spreads. We calculate the equally weighted average relative bid ask spread (in percent of the midpoint price) for all quarters with observed spreads, no matter how many bonds underly the average. Figure 11 shows the resulting averages.

Starting around 1995/96, Treasuries establish a lower bound for bid/ask spreads. The other categories have higher spread, with the “Other government (non-state)” having on average lower average spreads than the financials. The Treasuries spreads fall when Norges Bank (the Central Bank) in 1995 introduces a system of primary dealers, where the dealers have an obligation to provide two sided quotes.

Interestingly, in the earliest period, 1988-95, Treasury securities seem to on average have higher spreads than financials (and other government issuers). In this period, the financials are primarily bonds issued by banks. Also, in this period before 1995 much of the quoting activity in the Treasuries is done on behalf of Norges Bank. That risk free Treasuries have higher spreads than corporate bonds (albeit issued by banks) is not a typical picture. Note also that in this period, around the introduction of electronic trading of bonds, spreads are actually quoted for a substantial number of financial bonds. The typical number of quotes in a crosssection, as shown in figure 11, lie between forty and fifty in the period.

Industrials have high estimated spreads compared to e.g. financial issuers. But note that there are fewer industrial bonds with quoted spreads.

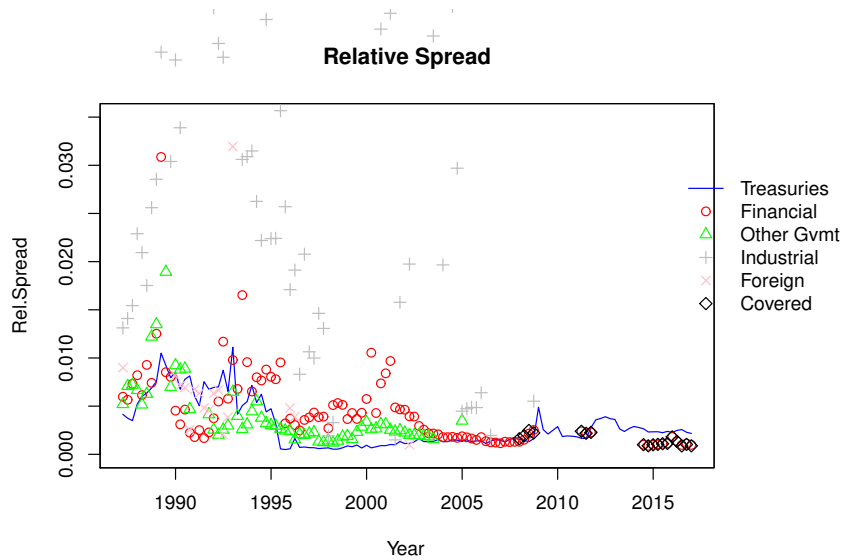
As discussed earlier, a potential use of liquidity measures is as an “early warning” signal about the state of the economy. Let us look at the time series with this perspective. There are several points when the bid ask spread series widens at times that coincides with stressful times in the Norwegian economy. Government bond spreads widen during the 2008 financial crisis. Spreads for financials widen during the burst of the “DotCom bubble” in 2000/2001. Looking further back, spreads for both Treasuries, and in particular financial issuers, widen during the 1991/92 banking crisis. This reflect that the implicit cost of demanding liquidity increases during times of stress. Note that while there is an significant increase in spreads for government securities during 2008, this may be much lower than what we would have observed for corporate issues (similar to what we observe for the 2000/2001 period). Unfortunately in the 2008 time frame it is only Treasuries for which we see much quoted spreads.

The previous results looked at the whole history, and it is hard to get the details. We are obviously interested in what can be done in the current environment. What securities should we watch? Let us look at the recent history of quarterly spreads, post 2000. For this period, there are essentially two categories with sufficient observations, Treasury securities, and covered bonds.

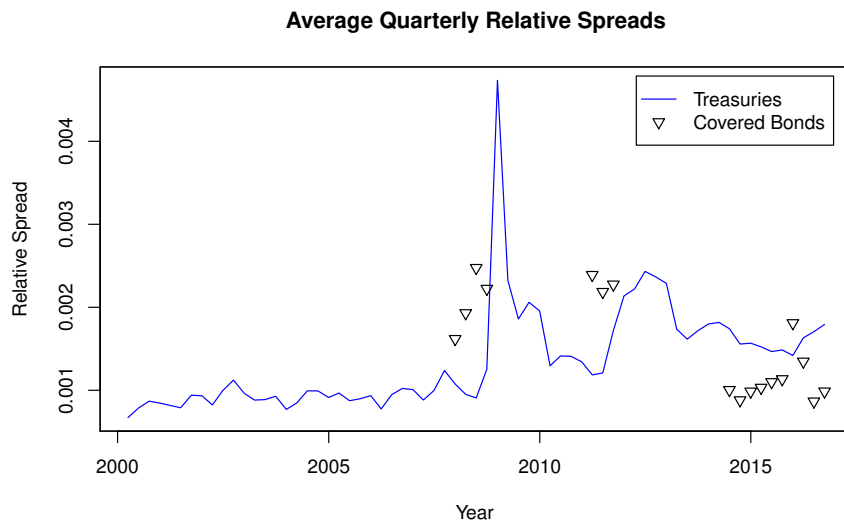
Panel B of Figure 12 shows the time series of these. Note that covered bonds are relatively new to the Norwegian market, and up to 2014 only a couple of bonds were quoted with both bids and asks. In the recent period 2014-16, with some activity in the market, spreads for covered bonds are actually lower than for Treasuries. This is again puzzling, one tend to think of the market for Treasury securities as extremely competitive. It is therefore worth while to return to this topic after we have investigated some alternative liquidity measures.

Figure 12 Relative Spreads for different categories

Panel A: Relative spreads split different groups of issuers



Panel B: Relative Spreads for Treasury Securities and Covered Bonds, 2000-2016



We collect all cases with observed bid and ask prices. For each such case we calculate the relative bid and ask spread as the difference between the best bid and ask, divided by the mid price. We then average the all these estimates for each quarter for each bond, before taking averages of these quarterly averages. Note that in the top figure there are some observations of industrials above the top. They have been left out because the primary interest here is in the other bond categories. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

6.2 The Amihud (2002) illiquidity ratio (ILLIQ)

The Amihud illiquidity ratio (ILLIQ) is aimed at measuring how much prices move as response to one currency unit of trade. Securities for which the price move more as response to trades are considered less liquid as the average price impact per currency unit is larger. As mentioned earlier, the calculation of ILLIQ is less data intensive compared to what is required to calculate the bid ask spread. Also, the ILLIQ is potentially more informative since it is a trade-based measure that does not rely on posted limit orders/quotes, but only that all actual trades that are reported to the exchange. Hence we do not need to restrict the calculation to only trades that are done in the Oslo Stock Exchange system.

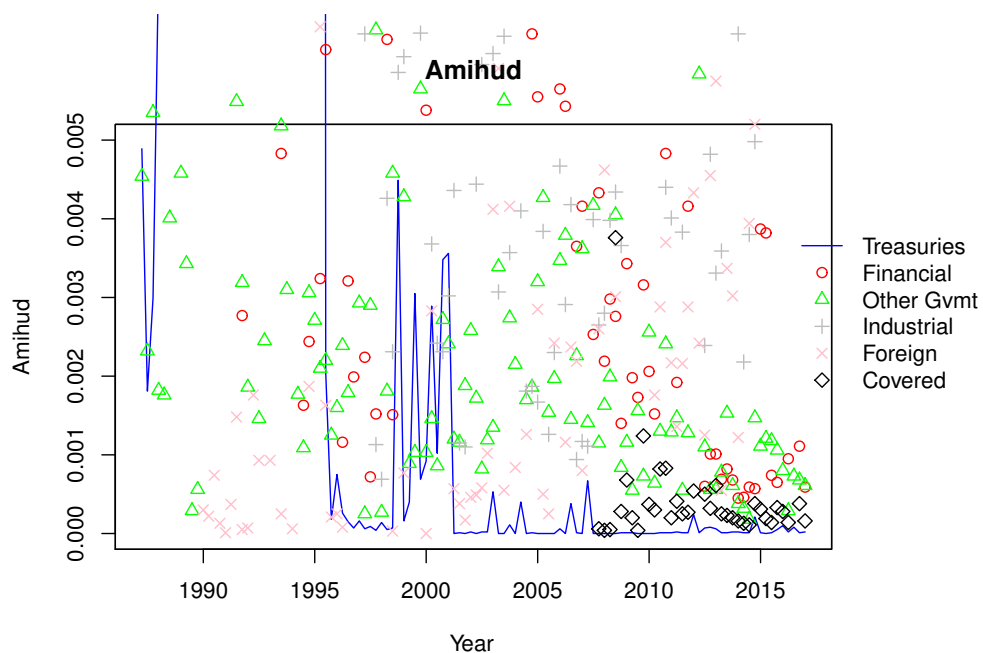
We calculate the ILLIQ as defined in appendix A. For each issue we calculate the Amihud ILLIQ for each quarter when the issue trades. We then take the equally weighted average ILLIQ across all issues with trading to construct the quarterly observation. Note that there is a potential source of inaccuracy in the calculation of the Amihud measure for Treasuries. As discussed earlier, there was some inconsistencies in the reporting of Repo activity that has for some periods inflated the volume. In the following we do not attempt to correct for that, we use the volume reported by the exchange.

Figure 13 illustrates how the Amihud measure behaves for the different groups. Essentially, the Treasuries are the most liquid by this measure. In recent years, the covered bonds are slightly less liquid than Treasuries by the Amihud measure, while the other groups are much less liquid. For other these groups the Amihud measure is very noisy, though. Note that for most types of issuers there are some large outliers in the sample, which are cut from the figure.

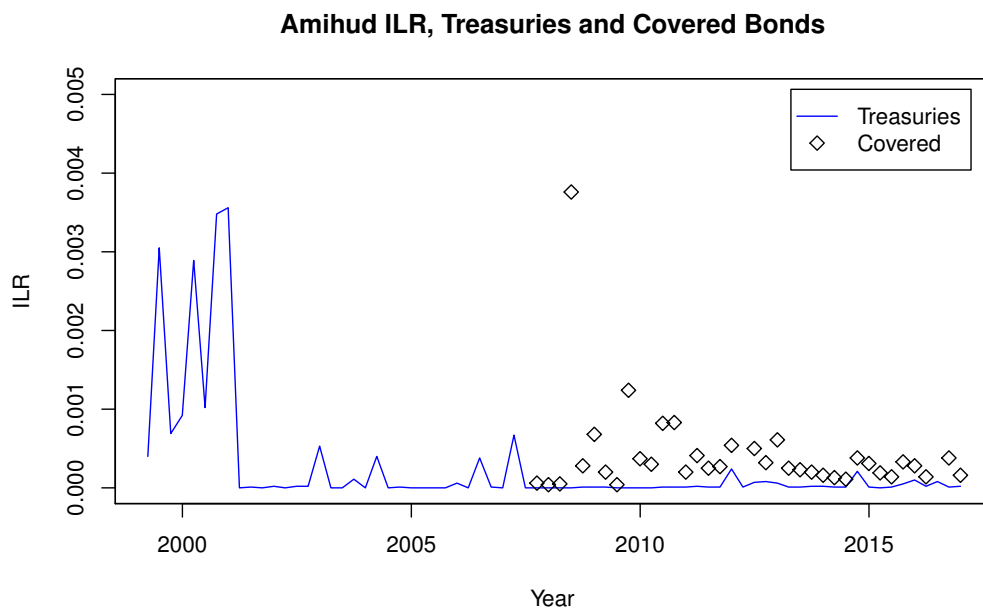
With respect to the time series patterns, note that for Treasury securities the ILLIQ dropped to a very low level from 2002 and onwards. There was not a very large reaction during the financial crisis in 2008. This non-reaction is likely to be partly explained by the large increase in trading volume and turnover (the denominator in the ILLIQ expression) in Treasury securities during the crisis. Of the other categories, most are extremely noisy, it is hard to discern any clear pattern, with the possible exception of covered bonds. We therefore, as we did for spreads, show the numbers for covered bonds and Treasuries in the period 2000 onwards separately, in Panel B. Particularly in the recent, post 2011 period, the covered bonds seem to agree strongly with the government securities. There are a few exceptions early on, but this is in periods with only a couple of issued covered bonds.

Figure 13 Amihud

Panel A: Amihud, all sectors, 1990–2016



Panel B: Amihud, only Treasuries and covered bonds, 2000–2016



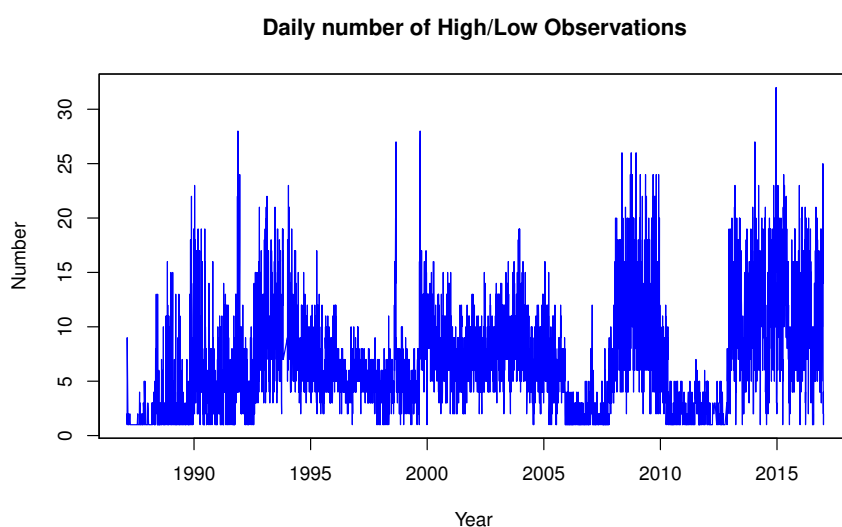
Amihud liquidity measure, for different types of issuers. Note that the picture in panel A is truncated, there are some extremely large observations left out. See appendix A for a definition of the Amihud measure. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

6.3 The Corwin and Schultz High/Low spread measure

We now turn to our third liquidity measure, the Corwin and Schultz (2012) method for estimation of implicit spreads from observing the intra-day variation in trade prices, the *high* price (highest price during a day) vs the *low* price (lowest trade price during the same day). As we have seen, both the spread and Amihud measures seem limited for the OSE bond market. Spreads rely on only a few observations, and a few securities. The Amihud measure either has too little variation (treasuries) or too much variation (other sectors). Since the high/low measure uses *additional* information relative to the above measures, it can potentially give better liquidity estimates.

To use the high/low spread estimate, we need recorded data where bonds were traded at different prices. To investigate the feasibility of using this measure, we check, on a daily basis, the number of such observations. This is shown in figure 14. There seems to be enough data to do some estimation, although one should be sceptical to estimates around 2008 and 2011.

Figure 14 Number of Potential High/Low observations



Daily count of cases with high/low price observations where the high price is greater than the low price.

Figure 15 shows the resulting estimates. Now, these numbers are interesting. For one thing, looking at this relative to the time series of quoted bid/ask spread estimates, the High/Low estimates seem remarkably similar, when both are defined. So both these measures seem to be measuring similar properties of the bond market.

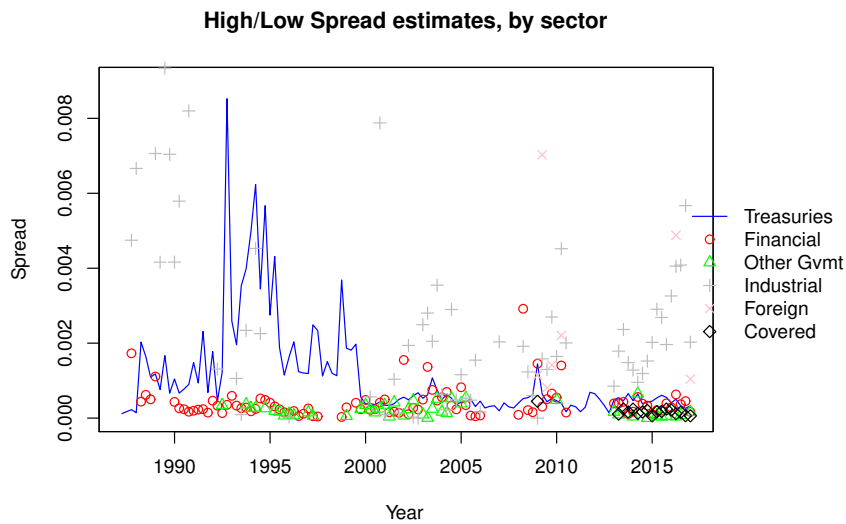
We also see two features we saw in spreads, that treasuries have higher estimated transaction costs than financials in the pre-2000 period, and similarly, that treasuries have higher estimated high/low spreads than covered bonds in recent years.

Hence, both measures of trading costs for treasuries, the bid/ask spread, and the high/low spread, agree that trading costs are lower than for covered bonds than for treasuries in the post-2011 period. This is a puzzling result, and clearly interesting to pursue.

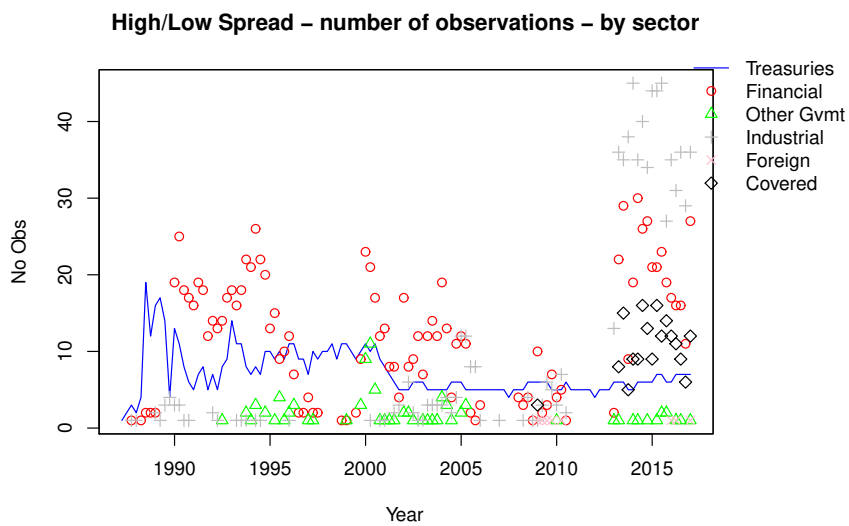
In terms of the potential use of liquidity measures as early warning measures, the high/low spread estimates may actually be more informative than the alternative measures. We see that the high/low spread for the Treasury bonds have more variation than the other liquidity measures. The high/low spread estimates widen for Treasuries around the banking crisis of 1992, the post-2000 period, and the 2008 crisis. The 1992 banking crisis also seem to be captured by the implied high/low spreads for financials. Unfortunately, during the 2008 crisis there is little data to reliably calculate estimates

Figure 15 High Low, Estimates by sector

Panel A: Quarterly Estimates of Spread using the Corwin and Schultz (2012) method, grouped by sector



Panel B: Number of observations used in calculating the averages



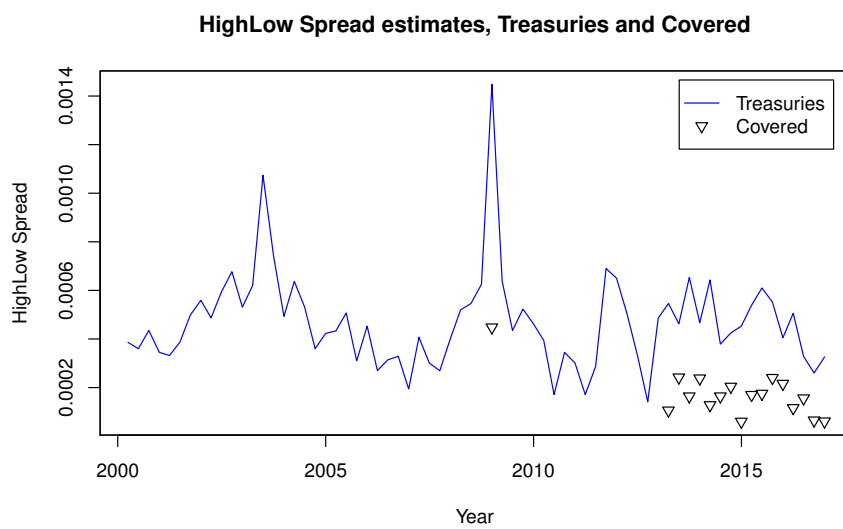
The figures describe estimates of the Corwin and Schultz (2012) spread estimator. The top panel shows estimated spreads, the bottom panel the number of bonds each quarter for which we have been able to calculate an estimate. We include estimates for the following issuer categories: Treasury Bonds. Government, non-state (County, Municipal, State enterprises, State Guaranteed). Financials (Banks, Mortgage Institutions). Covered bonds (subgroup of financials). Industrials. Foreign.

for the high/low spreads of financials, but they do seem to have widened just after the crisis. These patterns are consistent with the link between equity market liquidity and market conditions as seen for the US in Næs et al. (2011) and for Norway in Skjeltnor and Ødegaard (2009)

Regarding industrials, we see the same pattern here as for the bid/ask spreads, higher estimated transaction costs than for the other bond types. However, we do see some interesting patterns in the last couple of years. The number of high/low estimates involving industrials is actually larger than the other types of issuers, and the estimated transaction costs is much closer to state/financials in this period than earlier. This may be sign of a more active market in industrial bonds, driving trading costs down.

Similarly to our other liquidity measures, we illustrate separately estimates for high/low spreads for Treasuries and covered bonds in the period 2000-2016. These are shown in figure 16. This shows clearly the lowered estimated spreads for covered bonds.

Figure 16 High/Low Estimates for Treasuries and covered bonds, 2000-2016



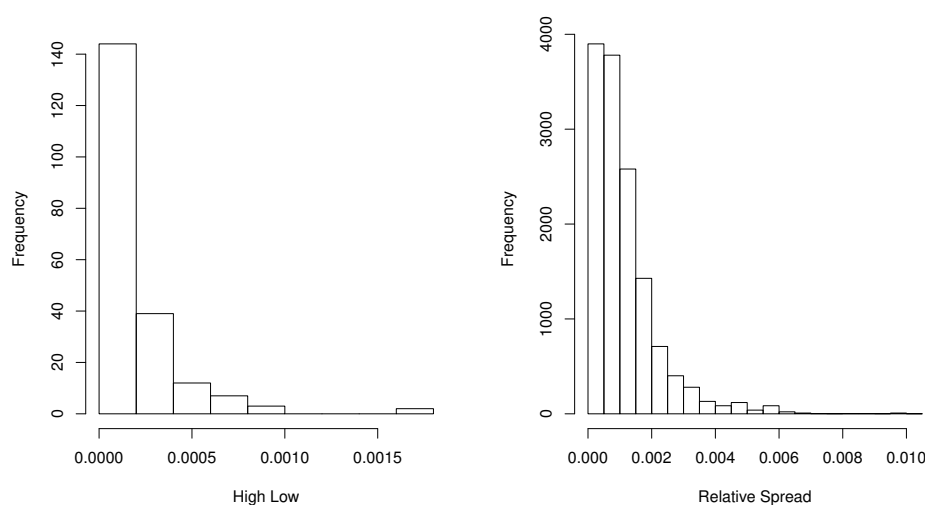
The figure shows estimates of the Corwin and Schultz (2012) spread estimator. Time period 2000-2016. Treasuries and Covered Bonds.

6.4 Looking more closely at the liquidity of covered bonds

Once we have measured liquidity, it is always of interest to understand what is driving it. In this market place we have (at least in recent years), two categories of liquid bonds, Treasuries and covered bonds. While both of these are potentially interesting to investigate, we will not look at Treasuries. For Norwegian treasuries we refer to Valseth (2016), which uses more detailed data on trading of Treasuries to investigate their liquidity.

We instead look at the liquidity of covered bonds, and investigate determinants of this liquidity.³⁰ We limit ourselves to a relatively simplistic investigation. We use the crosssection of estimates of liquidity of covered bonds for the period 2014-2016, and ask whether the liquidity estimates can be explained by properties of the bonds. Figure 17 describes the distribution of the measures we want to explain.

Figure 17 Crossectional Distribution of Liquidity of Covered Bonds



The figures shows the distribution of the estimates of liquidity of covered bonds in the 2014-2016 period. On the left the high-low estimator, on the right relative spreads. We use all observations of each liquidity measure (these are not quarterly averages).

We look at two hypotheses that may explain bond liquidity. First, since presumably more bonds issued means more bonds available for trading, we ask whether the size of a given issue³¹ explains its liquidity. Second, we want to look for the kind of behaviour we find in other bond markets, that bonds tend to disappear into portfolios of institutional investors. If that is the case, we should find that older issues have less bonds available for trading, and hence are less liquid.³²

To investigate these hypothesis in the Norwegian covered bond market we run regressions with estimates of liquidity as dependent variables, and proxies related to the above two hypotheses as explanatory variables. The first proxy is the number of available bonds in a given issue, measured as the total amount outstanding. The second proxy is the age of the bond, measured by the time (in years) since the issue date. The results of various regression specifications are shown in table 3.

If the first hypothesis is relevant, we would expect to see negative coefficients on the size of the

³⁰There is another study of the liquidity of a covered bond market, in Denmark: Dick-Nielsen, Gyntelberg, and Lund (2015). Their study also looks at crosssectional determinants of the liquidity of covered bonds, but they have access to more detailed trading data.

³¹The number of bonds in a given issue times the face value.

³²This corresponds to the comparisons of “on-the-run” versus “off-the-run” Treasury bonds in the US markets.

bond when the dependent variable is spreads, and a positive coefficient when the dependent variable is the illiquidity measure (Amihud's ILLIQ). Unfortunately, none of the specifications have significant coefficients on the issue size. Regarding the age, we in fact have significance, but the coefficients are the “wrong” sign relative to the “bonds disappearing” hypothesis. The strongly significant negative coefficient on the two spread measures show that liquidity of covered bonds is improving with time since issuance, a result that is hard to reconcile with extant theories.

Table 3 Explaining estimates of liquidity of covered bonds

	<i>Dependent variable:</i>				
	HL	RS	ILLIQ	HL	RS
	(1)	(2)	(3)	(4)	(5)
log Issue Size	0.00002 (0.00002)	-0.00003 (0.0001)	0.002 (0.003)	0.00002 (0.00002)	-0.00001 (0.00002)
Age	-0.00004*** (0.00001)	-0.0003*** (0.00002)	0.001 (0.002)	-0.00005*** (0.00001)	-0.0003*** (0.00000)
Constant	-0.0002 (0.0004)	0.003 (0.002)	-0.031 (0.062)	-0.0001 (0.0005)	0.002*** (0.0004)
Observations	113	241	1,563	195	12,425
Adjusted R ²	0.100	0.410	-0.001	0.071	0.278

Note:

*p<0.1; **p<0.05; ***p<0.01

We show the results of a number of regressions where the dependent variable is estimates of liquidity of covered bonds. We use three different liquidity measures: The High/Low measure (HL), Relative Spreads (RS), and Amihud's ILLIQ measure. The first three regressions are using quarterly averages of the dependent variable. The last two regressions (Labeled (4) and (5)) use all available estimates of respectively high/low spreads and relative bid/ask spreads. The explanatory variables are the log of the amount outstanding in each bond issue, and the age (time since issue date in years). Data for 2014–2016.

7 Links to equity market

In this section we look at links to the *equity* market at the Oslo Stock Exchange. At the OSE, equities trade within the same trading system as bonds, even though the bond traders at the OSE do not use the capabilities of the system to the degree that equity traders do. It is therefore interesting to both compare levels of estimated trading costs between equities and bonds, and whether bonds and equities liquidity capture some of the same business cycle information. The most relevant measures for doing this comparison are direct estimates of trading costs. In terms of the liquidity measures we have calculated before, these are the two spread measures. We compare spreads for bonds with spreads for equity, both in terms of levels, and in terms of the link to business cycle.³³

7.1 Trading costs

We look at the two measures of trading costs we have calculated for bonds, quoted spreads, and the high/low spread estimate of implicit spread. Regarding equities, we choose to only look at the most liquid equities at the Oslo Stock Exchange, the constituents of the OBX index, which contains the 25 most liquid equities on the exchange.³⁴ In figure 18 we show average spread estimates for the stocks constituting the OBX index.

We next compare these estimates of trading costs for equities with corresponding costs for bonds, in figure 19. We see that by both measures, bonds are cheaper to trade than equities. This differs from the case in other countries. In the US, estimates of bond transaction costs, particularly of corporate and municipal bonds, are usually much higher than corresponding estimates for equities.³⁵ Here, particularly using the Corwin and Schultz (2012) estimator, we find that Norwegian bonds are cheaper to trade than equities. Using the OBX constituents as a comparison can be argued to be an unfair comparison for most bonds, as the bonds are traded much less than the OBX shares. If we were to use the liquidity for the least liquid equities, the picture would be even better for Norwegian bonds.

That estimated trading costs of, for example, corporate bonds in Norway are so much lower than equities, is an interesting observation. It should be investigated further. What is it about the Norwegian case that gives us these low estimates for trading costs of corporate bonds? While in principle OSE is a limit order market for corporate bonds, in practice it is mainly OTC with post-trade reporting. It is thus similar to trading of US corporate bonds post-TRACE, but the Norwegian costs (at least the estimates we report) are much lower. We leave this question for future research.

7.2 Time series variation

Looking at the figures it looks like bonds and equities have some of the same time series variation. To look at that in a more quantifiable way we calculate correlations between the time series. Are bond liquidity and equity liquidity covarying? This is shown in table 4. Of these, the most interesting is the correlations between Treasury securities and equities, as Treasuries are the most liquid bond category, with the longest time series. Here we see that changes in these liquidities are positively correlated across bonds and equities. I.e. when spreads widen for bonds, they also widen for equities.

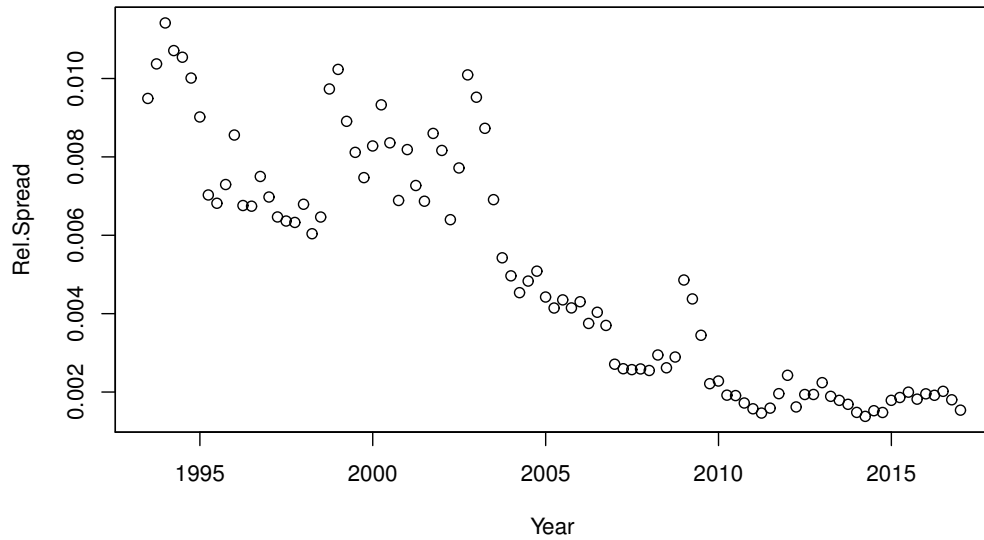
³³Numbers for the Norwegian equity market is reported in Ødegaard (2016).

³⁴The OBX index contains the 25 most liquid shares at the OSE. The index constituents change two times a year, in June and December, based on the measured liquidity of the stocks in the previous half year.

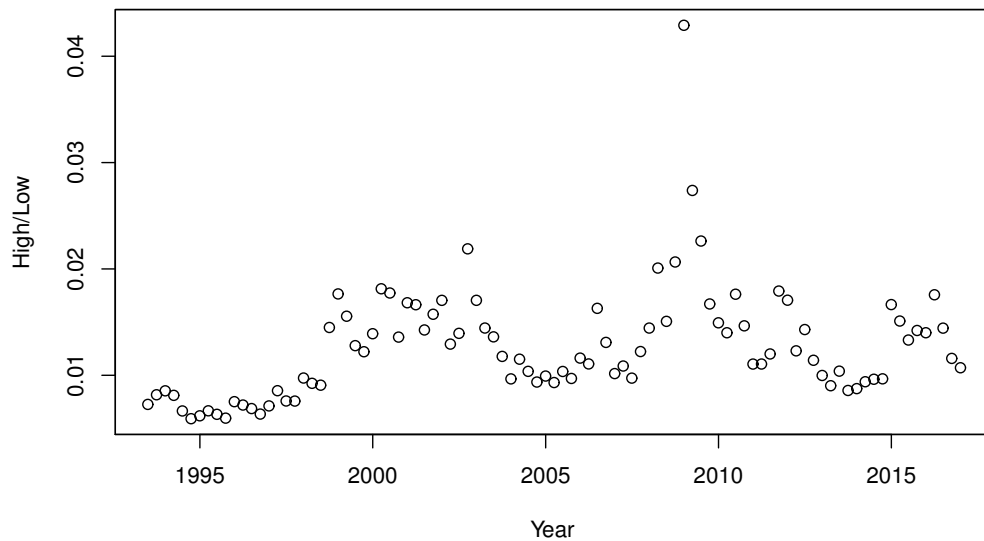
³⁵Estimates of trading costs for European corporate bonds in Biais and Declerck (2013) are also higher than for equities.

Figure 18 Time series spread estimates OBX stocks

Panel A: Relative bid/ask spread



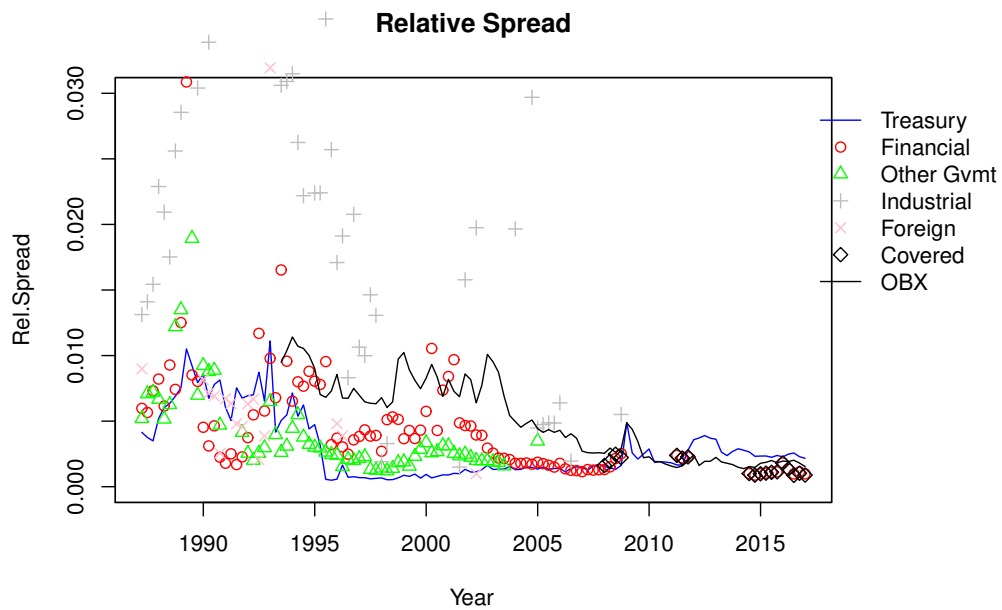
Panel B: High/Low implied spread



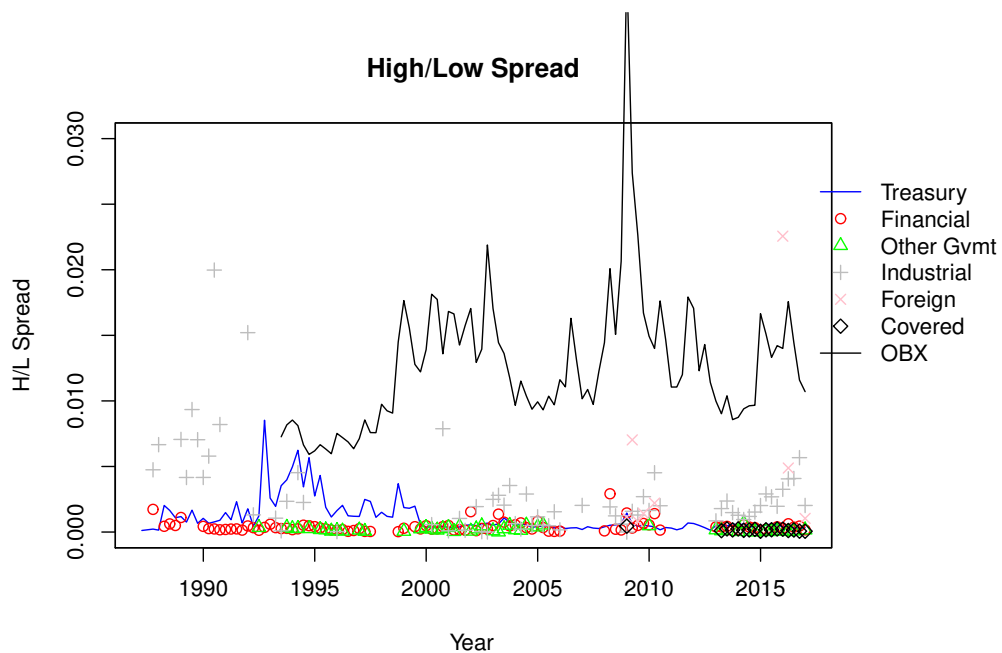
The figures show averages of spread estimates for the stocks included in the OBX equity index. For each stock we calculate the closing relative bid/ask spread, and the Corwin and Schultz (2012) estimator, on a daily basis. The numbers in the figure are cross-sectional averages of the resulting estimates. The averages trim the most extreme observations.

Figure 19 Time series spread estimates, bonds and OBX stocks

Panel A: Relative bid/ask spread



Panel B: High/Low implied spread



The figures show averages of spread estimates for the bond categories discussed earlier, and stocks included in the OBX equity index. For each stock we calculate the closing relative bid/ask spread, and the Corwin and Schultz (2012) estimator, on a daily basis. The numbers in the figure are cross-sectional averages of the resulting estimates. The averages trim the most extreme observations. Note that in the both figures there are some observations of industrials above the top. They have been left out to focus on the most interesting range of observations.

Table 4 Correlations between Bond Liquidity and Equity Liquidity

	High/Low	Rel Spread	Amihud
All	0.17	-0.01	0.01
Treasuries	0.19	0.31	0.03
Financial	0.41	-0.05	0.00
Govmt	-0.11	0.21	0.18
Industrial	-0.23	0.18	-0.49
Foreign	-0.88	-	-0.01
Covered	-0.41	-0.19	-0.28

The table reports correlations between (changes) in liquidity measures for bonds and equities. The column labeled Spread reports correlations between spreads estimated for the given bond category and spreads estimated the same way for equities (averages of OBX stocks). The same holds for the High/Low and Amihud liquidity measures.

8 Conclusion

In this paper we use the complete price history for fixed income securities traded on the Oslo Stock Exchange (OSE) for the period 1989 through 2016. The main purpose of the project has been to assess whether there is sufficient activity to construct useful liquidity indicators.

At the aggregate level, the trading activity and volume has increased over the sample period. Treasuries are the most actively traded bonds, with trading activity concentrated in a few “benchmark” bonds, where we see trading on a daily basis. For corporate bonds, there has been a marked increase in overall activity in the post-2008 period, but we are nowhere near the continuously traded market place which we see for equities.

With the low trading activity, measuring liquidity is challenging. We attempt to calculate an order based measure (bid ask spread), but find that this is particularly difficult to measure for corporate securities, as there are very few two sided quote observations. This is mainly due to the low trading activity in corporate bonds and the fact that most trading is conducted over the counter (OTC). For corporate bonds there is not enough observations to calculate the spread series after 2008. For Treasuries, on the other hand, there are enough two sided quote observations to produce the spread series throughout the sample period, and we see that the spread series increases during the major stress periods in our sample.

Due to the reporting rules at the Oslo Stock Exchange, where OTC transactions are to be reported to the exchange at least by the end of the trading day, trade-based liquidity measures are potentially more representative measures of liquidity of the Norwegian market. The Amihud Illiquidity ratio (ILR) is such a trade based measure, and is calculated using the total volume transacted both on- and off-market. We are able to calculate the Amihud measure for more securities, but find this a very noisy measure.

To these two standard liquidity measures we add a third, recently developed liquidity measure, the Corwin and Schultz (2012) estimate of spread. While this is also hampered by low number of observations, it does seem to be the “best” way of squeezing water out of stones (the OSE bond market), as it shows similar liquidity to bid/ask spreads, but can be calculated more often than bid/ask spreads.

Regarding time series patterns related to business cycle, we do find patterns of liquidity coinciding with the state of the economy, liquidity worsens around slowdowns in the economy. This is similar to the findings for equity markets, but the liquidity measures for bonds at the OSE are noisier.

For future use of bond liquidity at the OSE, we do see some light at the end of the tunnel (sample). In the recent years we have seen an increased activity in covered bonds, a recently introduced bond category. For these bonds we see that it is feasible to calculate all the three liquidity measures. Watching the liquidity of covered bonds together that of treasuries, for which it is similarly possible to construct liquidity indicators, may give useful information about the state of the Norwegian financial markets.

Finally, we make some interesting observations comparing estimates of trading costs of bonds with equities. All bond categories trade at costs lower than equities. This in contrast to US markets, where corporate and municipal bonds in particular, trade at costs way above those of equities. Looking into the trading costs at the OSE, why they are so low, is clearly an interesting avenue for further research.

APPENDICES

A Liquidity measures

In this appendix we give detailed definitions of the liquidity measures used in this study.

A.1 The Amihud ILLIQ measure

Amihud (2002)'s ILLIQ measure is a trade based liquidity measure. ILLIQ is a measure of the elasticity dimension of liquidity and is the most broadly applied measure of illiquidity in the literature due to its modest data requirements. As an elasticity measures of liquidity it measures how much the price moves as a response to trading volume. Kyle (1985) defines price impact as the response of price to order flow, and the Amihud ILLIQ measure is essentially an empirical version of Kyle's lambda. The daily Amihud measure is calculated as,

$$ILLIQ_{i,T} = \left[1/D_T \sum_{t=1}^T \frac{|R_{i,t}|}{VOL_{i,t}} \right] \cdot 10^6 \quad (1)$$

where D_T is the number of trading days within a given time window T , $|R_{i,t}|$ is the absolute return over period t for security i , and $VOL_{i,t}$ is the trading volume (in units of currency, which is NOK in our case) over period t . It is standard to scale the estimate up by 10^6 for practical purposes. The Amihud measure is referred to as an illiquidity measure since a high estimate indicates low liquidity (high price impact of trades). Thus, the ILLIQ measure captures how much the price moves for each volume unit of trades. Relative to Figure 1, a low ILLIQ estimate would indicate that there is a large depth in the limit order book that would reduce the average price impact, while a high ILLIQ estimate is an indication that the liquidity supply is low causing prices to move more in response to liquidity demand.

A.2 Relative bid/ask spread

The bid/ask spread is an order based measure. The relative bid ask spread is calculated as,

$$RS_t = \frac{p_t^a - p_t^b}{p_t^m} \quad (2)$$

where p_t^a and p_t^b are the best ask and bid quotes respectively, and p_t^m is the quote midpoint measured as $p_t^m = (p_t^a + p_t^b)/2$. For direct measurement of the spread, two sided quotes at the same point in time is needed.

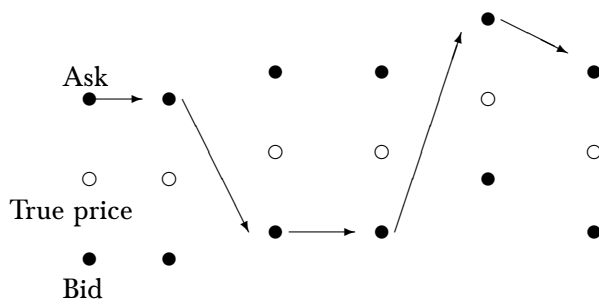
A.3 The Corwin and Schultz (2012) measure

Corwin and Schultz (2012) introduce an estimator for spreads which are estimated from data which at least historically typically were collected and published at the end of a trading day: The highest and lowest prices during a day.

Let us give some of the intuition behind this measure, as it is a novel feature of this research. We are in a situation with continuous trading, either on a trading floor, or in an electronic limit order book. In such a continuous trading situation there are two things going on:

1. The (true) price of the security is changing, or at least the market's estimate of the price is changing. The parameter determining this process is the volatility of (true) price changes.

Figure 20 Trade Process



2. There is a spread between buy and sell orders, so that the *observed* price differs from the true price.

The situation is illustrated in figure 20. Here the arrows indicate the sequence of trades. One want to estimate two things here: The degree of variability of the underlying price process, and the spread, the difference between the bid and ask price. To do this estimation, Corwin and Schultz (2012) assume a constant variance σ for the process of the underlying price, and a constant spread s .

Their analysis relies on two insights:

- When prices are bouncing back and forth during the trading day, the highest price is most likely to have been the result of a price improving trade, where the buyer was the active part in pushing the price (and crossing the spread). The highest price is therefore likely to have been at the ask. Similarly, the lowest price is likely to have been the result of crossing the spread downwards. The lowest price is thus likely to have been at the bid.
- To estimate the *volatility*, one can use the insight of the classical *variance ratio* analysis in the time dimension: If prices are random walks, variance should be proportional to the time interval the variance is measured over.

Combining these two insights results in two restrictions on the data that can be used to estimate the two parameters variance (σ) and spread (s).

The data used for estimation is a sequence of intra-day high H_t^0 and low L_t^0 observations. From these one calculate two day high and low observations:

$$H_{t,t+1}^0 = \max(H_t^0, H_{t+1}^0), \text{ and}$$

$$L_{t,t+1}^0 = \min(L_t^0, L_{t+1}^0),$$

which one uses to calculate sample estimates of $\hat{\gamma}$ and $\hat{\beta}$.

$$\hat{\gamma} = \left[\ln \left(\frac{H_{t,t+1}^0}{L_{t,t+1}^0} \right) \right]^2$$

and

$$\hat{\beta} = \left(\ln \left(\frac{H_t^0}{L_t^0} \right) + \ln \left(\frac{H_{t+1}^0}{L_{t+1}^0} \right) \right)^2$$

These estimates are used in closed form expressions for the spread (and volatility)

$$\alpha = \frac{\sqrt{2\hat{\beta}} - \sqrt{\hat{\beta}}}{3 - 2\sqrt{2}} - \sqrt{\frac{\hat{\gamma}}{3 - 2\sqrt{2}}}$$

$$\hat{S} = \frac{2(e^\alpha - 1)}{1 + e^\alpha}$$

We follow Corwin and Schultz (2012) and introduce an adjustment for an overnight jump in price. If the close on the first day is outside of the range of high and low prices the second day, one adjust the second days' prices with the difference between these.

A.4 Other spread measures

There are also several methods that can be applied to estimate implicit spread measures that does not require quote observations. Two widely used estimators are those proposed by Roll (1984) and Lesmond, Ogden, and Trzcinka (1999) (LOT). The Roll estimator exploits the serial covariance of successive price movements to identify the bid ask spread. The LOT measure uses the zero return days of individual stocks relative to overall market returns to estimate an implicit trading cost. More specifically, the LOT cost is an estimate of the implicit cost required for the price *not* to move when the market as a whole moves, and Lesmond et al. (1999) shows that their estimator is closely related to both the level and variation in the bid ask spread. Næs, Skjeltorp, and Ødegaard (2008) provides a detailed explanation of these measures with an application on the Norwegian stock market for the period 1980 through 2008, but they are problematic to apply to our bond market data.

To calculate the LOT measure, one need (the returns of) a broad market index. Since we lack a broad corporate bond market index for Norway, estimation of LOT is infeasible. We have also tried to estimate the Roll measure for Norwegian issues, however, the low number of transaction prices for individual issues that is not too distant in time makes the Roll measure very noisy, and in many cases negative. Due to these problems, we have left both the LOT and Roll results out of the analysis.

B A Chronology of the Oslo Stock Exchange

- 1881 First listing of debt securities at the OSE
- 1988 Oslo Børs Informasjon (OBI) established
- 1989 Decentralization of the bond market (brokers moved out of the exchange floor)
- 1993 Electronic registration of quotes and trades
- 1995 Introduction of Primary Dealers for Treasuries.
- 1999 ASTS fully automated trading system launched
- 2001 Oslo Børs became a limited company, fully owned by Oslo Børs Holding ASA.
- 2002 Oslo Børs moved onto the SAXESS trading system (NOREX platform)
- 2007 Oslo Børs Holding ASA merged with VPS Holding ASA to create Oslo Børs VPS Holding ASA.
- 2009 Oslo Børs entered into a strategic partnership with London Stock Exchange Group (exited the NOREX alliance)
- 2010 TradeElect system adapted during the period 2009-2010 for equities and bond trading.
- 2012 Oslo Børs introduced the Millennium trading platform, which is the platform used by the London Stock Exchange.

References

- Menachim (Meni) Abudy and Avi Wohl. Corporate bond trading on a limit order book exchange. Working Paper, March 2016.
- Tobias Adrian, Michael Fleming, Or Shachar, and Erik Vogt. Has U.S. Treasury market liquidity deteriorated? Liberty Street Economics, Blog of Federal Reserve Bank of New York, October 05 2015a.
- Tobias Adrian, Michael Fleming, Daniel Stackman, and Erik Vogt. Has U.S. Treasury market liquidity deteriorated? Liberty Street Economics, Blog of Federal Reserve Bank of New York, August 17 2015b.
- Micael Aitken and Carole Comerton-Forde. How should liquidity be measured? *Pacific-Basin Finance Journal*, 11: 45–59, 2003.
- Yakov Amihud. Illiquidity and stock returns: Cross-section and time-series effects. *Journal of Financial Markets*, 5: 31–56, 2002.
- Andrew Ang and Richard C Green. Lowering borrowing costs for states and municipalities through commonmuni. Working paper, Columbia Business School and Tepper School of Business at Carnegie Mellon University, February 2011.
- J Bao, Jun Pan, and Jiang Wang. The illiquidity of corporate bonds. *Journal of Finance*, LXVI:911–946, 2011.
- Alessandro Beber, Michael W Brandt, and Kenneth A Kavanecz. Flight-to-quality or flight-to-liquidity? Evidence from the euro-area bond market. *Review of Financial Studies*, 22(3):925–957, 2009.
- Morten L. Bech, Annamaria Illes, Ulf Lewrick, and Andreas Schrimpf. Hanging up the phone - electronic trading in fixed income markets and its implications. *BIS Quarterly Review*, pages 79–94, 2016.
- Hendrik Bessembinder and William Maxwell. Markets transparency and the corporate bond market. *Journal of Economic Perspectives*, 22(2):217–234, Spring 2008.
- Bruno Biais and Fany Declerck. Liquidity, competition & price discovery in the european corporate bond market. Working Paper, Toulouse School of Economics, February 2013.
- Bruno Biais and Richard C Green. The microstructure of the bond market in the 20th century. Working Paper, Carnegie Mellon University, August 2007.
- Long Chen, David Lesmond, and Jason Wei. Corporate yield spreads and bond liquidity. *Journal of Finance*, 62:119–149, 2007.
- Shiu-Sheng Chen, Yu-Hsi Chou, and Chia-Yi Yen. Predicting US recessions with stock market illiquidity. *BE Journal of Macroeconomics*, 16:93–123, July 2015.
- Shane A Corwin and Paul Schultz. A simple way to estimate bid-ask spreads from daily high and low prices. *Journal of Finance*, LXVII(2):719–759, April 2012.
- Jens Dick-Nielsen, Jacob Gyntelberg, and Jesper Lund. Safe and liquid mortgage bonds: Evidence from the danish housing crash of 2008. Working Paper, Copenhagen Business School, December 2015.
- Amy K. Edwards, Lawrence Harris, and Michael S Piewowar. Corporate bond market transaction costs and transparency. *Journal of Finance*, LXII(3):1421–1462, June 2007.
- Michael Fleming. Measuring Treasury market liquidity. *FRBNY Economic Policy Review*, pages 83–108, September 2003.
- Thierry Foucault, Ohad Kadan, and Eugene Kandel. Liquidity cycles and make/take fees in electronic markets. *Journal of Finance*, 68(1):299–341, 2013. ISSN 1540-6261.
- Emilios Galariotis and Evangelos Giouvriss. On the stock market liquidity and the business cycle: A multi country approach. *International Review of Financial Analysis*, 38: 44 – 69, 2015. ISSN 1057-5219.
- Ruslan Y Goyenko and Andrey D Ukhov. Stock and bond market liquidity: A long-run empirical analysis. *Journal of Financial and Quantitative Analysis*, 44:189–212, 2009.
- Ruslan Y Goyenko, Craig W Holden, and Charles A Trzcinka. The term structure of bond market liquidity. *Journal of Financial and Quantitative Analysis*, 46(1):111 – 181, 2011.
- Lawrence Harris. *Liquidity, Trading Rules and Electronic Trading Systems*. New York University Salomon Center, 1990. New York University Salomon Center Monograph Series in Finance and Economics.
- Lawrence Harris. Transaction costs, trade throughs, and riskless principal trading in corporate bond markets. Working paper, Available at SSRN, October 2015.
- Albert Kyle. Continuous auctions and insider trading. *Econometrica*, 53:1315–35, 1985.
- David A Lesmond, Joseph P Ogden, and Charles A Trzcinka. A new estimate of transaction costs. *Review of Financial Studies*, 12:1113–1141, 1999.
- Bruce Mizrach and Christopher J. Neely. The transition to electronic communications networks in the secondary Treasury market. *Federal Reserve Bank of St. Louis Review*, page 527, November/December 2006.
- Bruce Mizrach and Christopher J Neely. The microstructure of the U.S. Treasury market. Working Paper, St. Louis Fed, April 2008.
- Randi Næs, Johannes Skjeltorp, and Bernt Arne Ødegaard. Liquidity at the Oslo Stock Exchange. Working Paper Series, Norges Bank, ANO 2008/9, May 2008.

- Randi Næs, Johannes Skjeltorp, and Bernt Arne Ødegaard. Stock market liquidity and the Business Cycle. *Journal of Finance*, LXVI:139–176, February 2011.
- Bernt Arne Ødegaard. The liquidity of the Oslo Stock Exchange – a source book 1980-2015. Manuscript, University of Stavanger, August 2016.
- Maureen O’Hara. *Market Microstructure Theory*. Blackwell, 1995.
- Maureen O’Hara, Yihui Wang, and Xing Zhou. The execution quality of corporate bonds. Working Paper, Cornell University, June 2016.
- Ketil Rakkestad, Johannes Skjeltorp, and Bernt Arne Ødegaard. The liquidity of the secondary market for debt securities in Norway. Norges Bank FSR Memo 1/2012, June 2012.
- Richard Roll. A simple implicit measure of the effective bid–ask spread in an efficient market. *Journal of Finance*, 39 (4):1127–1139, September 1984.
- Raphael Schestag, Philipp Schuster, and Marliese Uhrig-Homburg. Measuring liquidity in bond markets. *Review of Financial Studies*, 29(5):1170–1219, 2016.
- Securities and Exchange Commission. Report on the municipal securities market. Technical report, Securities and Exchange Commission, July 2012. Release No.34-62853.
- Johannes Skjeltorp and Bernt Arne Ødegaard. The information content of market liquidity: An empirical analysis of liquidity at the Oslo Stock Exchange. Working Paper, Norges Bank (Central Bank of Norway), November 2009.
- K Smimou and W Khallouli. Does the euro affect the dynamic relation between stock market liquidity and the business cycle? *Emerging Markets Review*, 2015.
- Chester S Spatt. Discussion: An overview of bond market transparency, January 2006. Speech by Chief Economist and Director of the Office of Economic Analysis, U.S. Securities and Exchange Commission.
- Francesco Trebbi and Kairong Xiao. Regulation and market liquidity. Working Paper 21739, National Bureau of Economic Research, November 2015.
- US Commision. Joint staff report: The U.S. Treasury market on october 15, 2014. Technical report, U.S. Department of the Treasury, Board of Governors of the Federal Reserve System, Federal Reserve Bank of New York, U.S. Securities and Exchange Commission, U.S. Commodity Futures Trading Commission, 2015.
- Siri Valseth. Likviditeten i det norske statsobligasjonsmarkedet. Arbeidsnotat, Universitetet i Stavanger (UiS), July 2016.