STAFF MEMO

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Liquidity indicators for the Norwegian government bond market

Vetle Øye Opheim[1]

An objective of Norges Bank Government Debt Management is to meet the government's borrowing requirement at the lowest possible cost. At the same time, Government Debt Management shall seek to maintain a yield curve out to 10 years. Market liquidity is of importance for both objectives. This article investigates liquidity developments in the Norwegian government bond market since 2010 with the aid of four indicators that comprise a composite liquidity index. I also examine whether Norwegian banks' funding costs have affected government bond market liquidity in the period 2010–2018, but find no clear correlation.

Key words: Government bonds, liquidity, indicators.

1. Introduction

The Ministry of Finance is responsible for the management of central government debt but has delegated operational responsibilities to Norges Bank in a mandate. Under the mandate, Norges Bank shall meet the government's borrowing requirement at the lowest possible cost. In addition, government borrowing shall seek to maintain yield curve out to 10 years, which can serve as a benchmark for pricing in the bond market.

A government securities market with low liquidity premiums will help to meet the objective of borrowing at the lowest possible cost.[2] A liquid government securities market is also intended to function as a good benchmark. Market liquidity is an indication of the ease with which a security can be traded with limited price impact and transaction costs.

This article investigates liquidity developments in the Norwegian government bond market since 2010. Liquidity has several dimensions and is therefore difficult to measure. Various liquidity indicators may capture different aspects of a market's liquidity. I use transaction data to construct four different indicators in order to measure the liquidity of the

[1] The views and conclusions in this publication are the author's own and should not be taken to represent the views of Norges Bank. I would like to thank Qaisar Farooq Akram, Tom Bernhardsen, Olav Bø, Kathrine Lund, Thomas Svane Jacobsen and Anders Svor for useful comments.

[2] Investors will normally demand a higher return to buy illiquid securities. Illiquid securities are more difficult to sell in a short time at a limited cost. This extra return, often called the liquidity premium, is intended to compensate for this risk.

Norwegian government bond market in the period 2010-2018. I find that liquidity deteriorated during the European sovereign debt crisis in 2011 and 2012 but has since gradually improved. I also examine whether periods of impaired liquidity correlate with changes in bank funding costs. I find no clear correlation between bank funding costs and liquidity in the government bond market.

The article is arranged as follows: The next section provides a brief overview of the Norwegian government bond market, while Section 3 describes a number of liquidity indicators. Section 4 discusses the relationship between market and funding costs and reports the results of our empirical investigation. Section 5 is a summary, while more technical matters are elaborated in the appendices.

2. The Norwegian government bond market

At year-end 2018, the amount outstanding of Norwegian government bonds totalled NOK 400 billion, divided into eight bonds with residual maturity of up to 10 years. All bonds were originally issued with 10-year or 11-year tenors.[3] The bonds are reopened at different intervals at auctions up until the bonds have less than one year to maturity. For bonds with maturity of less than one year, Government Debt Management holds announced buy-back auctions and conducts buybacks with the aid of the Request for Quote (RFQ) functionality.[4] Buy-back operations enable investors to sell larger volumes of the bond nearing maturity and at the same time reinvest in other government securities. This may help to improve the liquidity of both the shortest bond and of the bonds at longer maturities.

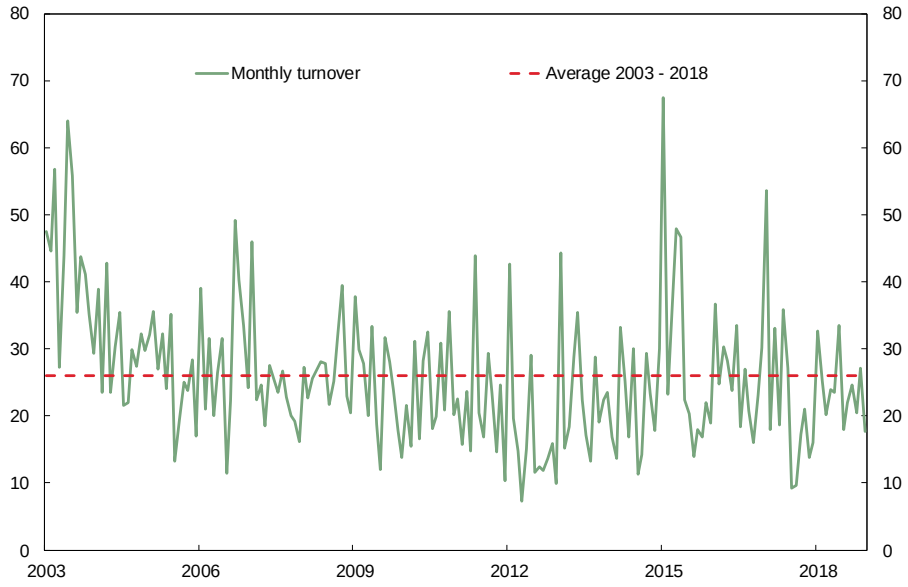
In order to understand developments in liquidity over time, accurate and reliable liquidity measures are necessary. It is easy to suppose that indicators such as number of transactions, transaction frequency and mean ticket size provide a good measure of a bond's liquidity. A more liquid bond is expected to have a higher number of transactions and higher mean ticket size.

The average monthly turnover in the secondary market for Norwegian government bonds has been around NOK 26 billion in the period 2003–

[3] After 2013, a new 10-year bond has been each year. Prior to this, an 11-year bond was issued every other year.
[4] A fixed income member of Oslo Børs sends an RFQ to Government Debt Management with a request to sell a bond with maturity of less than one year. Government Debt Management then sends out an invitation to fixed income members to quote a price and volume for the bond in question. Government Debt Management may then trade at one of the quotes or refrain from training at any of them.

2018, or 1.2 billion per day (Chart 1).[5] Over time, turnover has been fairly stable, if occasionally volatile, and does not appear to have been affected by periods of financial turbulence. Turnover in 2008, 2011 and 2012 was neither particularly high nor low.

Chart 1: Turnover of Norwegian government bonds.
Monthly. In billions of NOK. January 2003 – December 2018



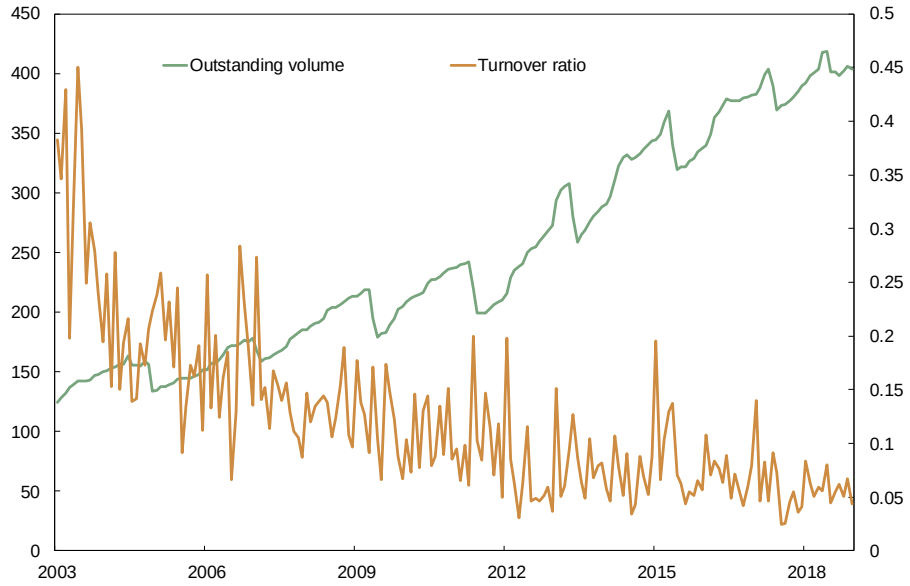
Sources: Oslo Børs and Norges Bank

The outstanding volume in the Norwegian government debt market has risen steadily in recent years (Chart 2). Over the past four years, annual borrowing has been around NOK 50 billion, and the outstanding volume has increased from NOK 130-140 billion in 2003 to NOK 400 billion at year-end 2018. The combination of higher outstanding volume and broadly unchanged turnover has resulted in a considerable fall in the turnover ratio, defined as monthly turnover divided by outstanding volume. In 2003, 30–40 percent of the outstanding volume was traded in the secondary market each month. By comparison, the turnover ratio in 2018 was around 5 percent.

Like turnover, the number of trades in the Norwegian government bond market also gives the impression of being fairly stable over time and unaffected by the financial crises (Chart 3). The number of trades appears flat in the main, but with substantial week-to-week variation. In the period May 2010 – December 2018, there were an average of 22 Norwegian government bond trades per trading day.

[5] Turnover data only refers to trades reported to Oslo Børs from Norges Bank's primary dealers. See Appendix A. for more details concerning the turnover statistics used.

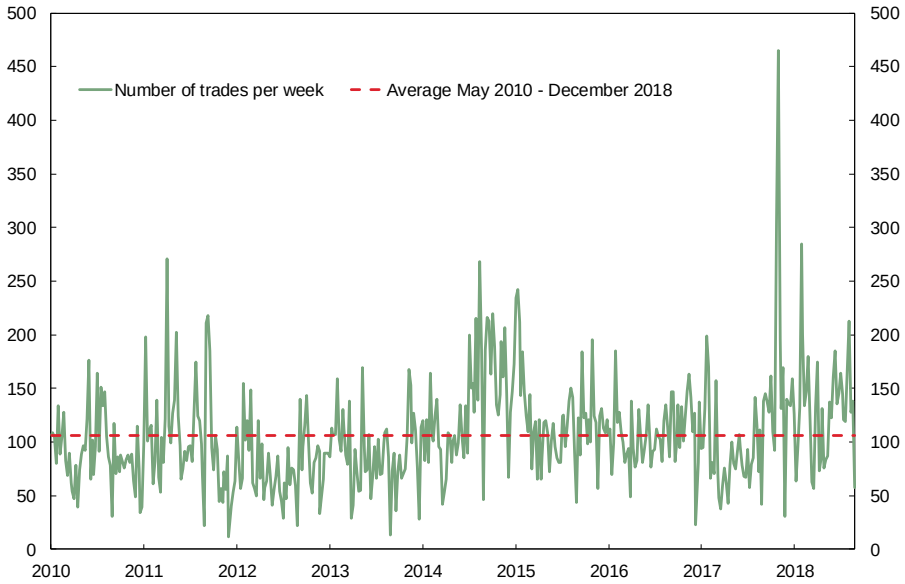
Chart 2: Outstanding volume of Norwegian government bonds. In billions of NOK. (l.h.s.) and monthly turnover ratio (r.h.s.). 2003 - 2018



Sources: Oslo Børs and Norges Bank

Fleming (2005) argues that volume-based indicators do not necessarily provide an accurate picture of market liquidity. Trade volumes can both rise and fall in periods of poorer liquidity, which makes volume-based indicators less reliable. In periods of financial market turbulence, safe investments, such as government bonds, might experience higher demand and turnover. This was the case for the US Treasury market in 2008 (Adrian, Fleming and Vogt, 2017a). Even though the turnover of US Treasury securities was high in 2008, turnover was primarily driven by a flight to safety. In such cases, liquidity indicators that are independent of turnover, such as price spreads and price impact, may provide a completely different picture of liquidity than turnover-based indicators.

Chart 3: Number of Norwegian government bond trades per week. May 2010 – December 2018



Sources: Oslo Børs and Norges Bank

Both turnover and number of trades in the government bond market will be affected by structural factors such as portfolio rebalancing, banks' regulatory requirements and management mandates. These transactions are often necessary even in periods of poorer liquidity. For that reason, these measures will not necessary provide a good description of market liquidity. Below we will take a closer look at liquidity indicators based on bid-ask spreads and price changes.

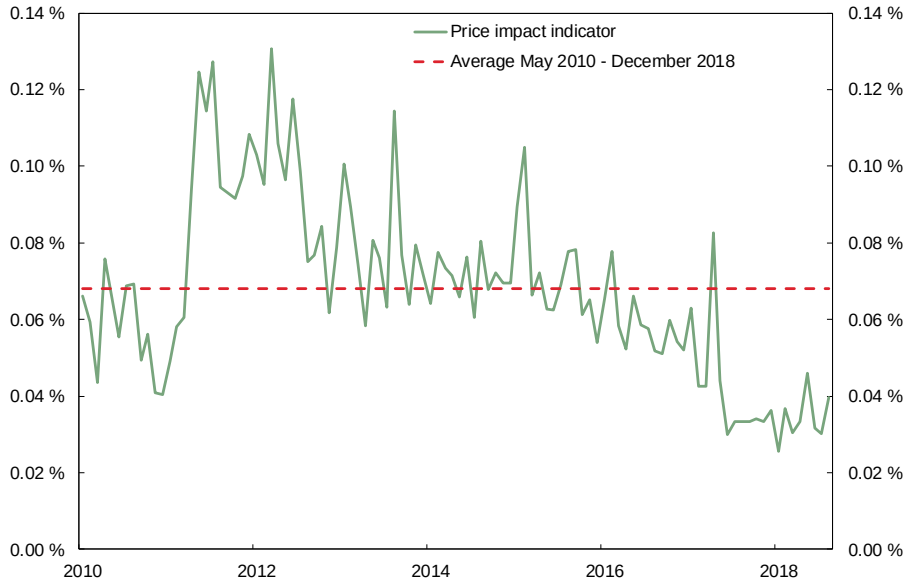
3. Liquidity of Norwegian government bonds

In the literature, different indicators are used to measure the liquidity of a market. Liquidity is difficult to measure, and no single indicator is obviously better than another. Owing to the weaknesses of indicators like turnover and number of trades, we look instead at some price-based liquidity indicators. The advantage of price-based indicators is that they take account of costs connected with buying or selling the bond. Furthermore, indicators based on price impact and bid-ask spreads have proved to be more robust (Fleming, 2005). I calculate four different indicators for the Norwegian government bond market. The four indicators are then used to create a composite index of market

liquidity.[6] The indicators seek either to capture the size of market price movements connected with a trade or to measure the actual cost of executing a trade (transaction cost).

The first indicator I calculate is a price impact indicator (*PI*), which measures the price impact of a single trade as a percentage of the price of the preceding trade. Dick-Nielsen, Gyntellberg and Sangill (2012) use such an indicator in their study of the liquidity of the market for Danish government bonds and covered bonds. In periods of poorer liquidity, individual trades' price impact is expected to be higher than in periods when the market is more liquid. Chart 4 shows developments in this indicator in the period May 2010 – December 2018.

Chart 4: Price impact indicator.
Percentage price impact from one trade to the next. Monthly average.
May 2010 – December 2018



Sources: Oslo Børs and Norges Bank

The indicator shows that the average price impact of a trade was 0.007 percent of the mid-price in the period May 2010 – December 2018. In recent years, the price impact of individual trades has fallen, which may signal improved liquidity. The indicator is now somewhat lower than in 2010, and considerably lower than in the period 2011–2012, the time of the European sovereign bond crisis.

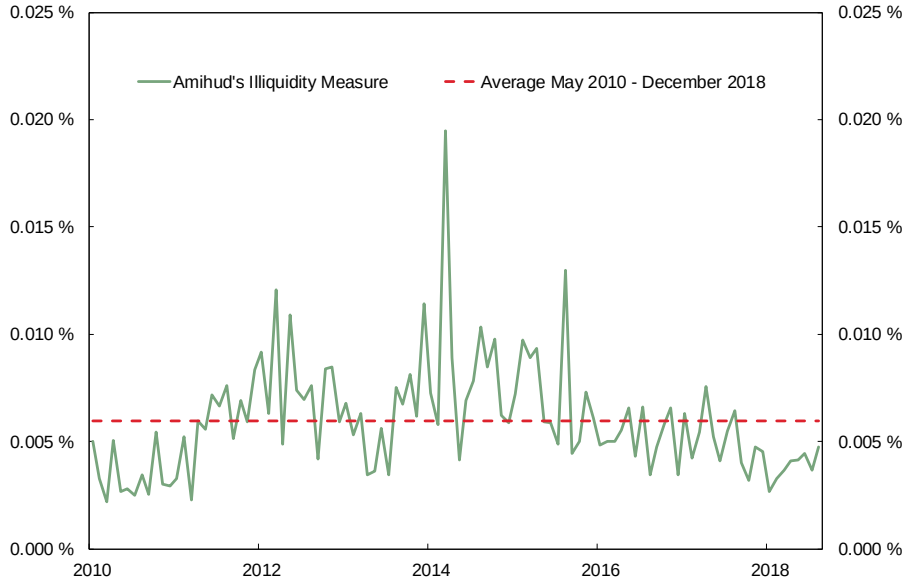
The size of price impacts is affected by the duration of the bond transacted. The price of bonds with lower duration are less sensitive to interest rate movements. This means a lower price impact on shorter

[6] Appendix B provides a more detailed account of how the indicators are calculated.

bonds than on long-dated bonds. Here I calculate the price impact indicator as the average price impact for all bonds. In periods of higher turnover of bonds with higher duration than of lower duration, the indicator will rise, all else equal.

The price impact indicator does not take account of transaction size. Larger trades will normally have a higher price impact. A higher price impact owing to a larger transaction size does not necessarily mean poorer liquidity. An indicator that measures price impact in relation to transaction size is the Amihud illiquidity measure (Amihud, 2002). A version of the Amihud measure can be calculated by dividing the price impact indicator by traded volume in millions of NOK (Dick-Nielsen, Feldhütter and Lando, 2012).

Chart 5: Amihud illiquidity measure.
Percentage price impact per NOK million in turnover. Monthly average.
May 2010 – December 2018



Sources: Oslo Børs and Norges Bank

The Amihud illiquidity measure can be interpreted as the size of the price impact for a given transaction volume. The average value of this measure since May 2010 has been around 0.006 percent, ie a single NOK 100 million trade has a price impact of 0.6 percent. This measure does not show a clear tendency for liquidity to improve in recent years like the price impact indicator. Nevertheless, the measure was below its long-term average in both 2017 and 2018.

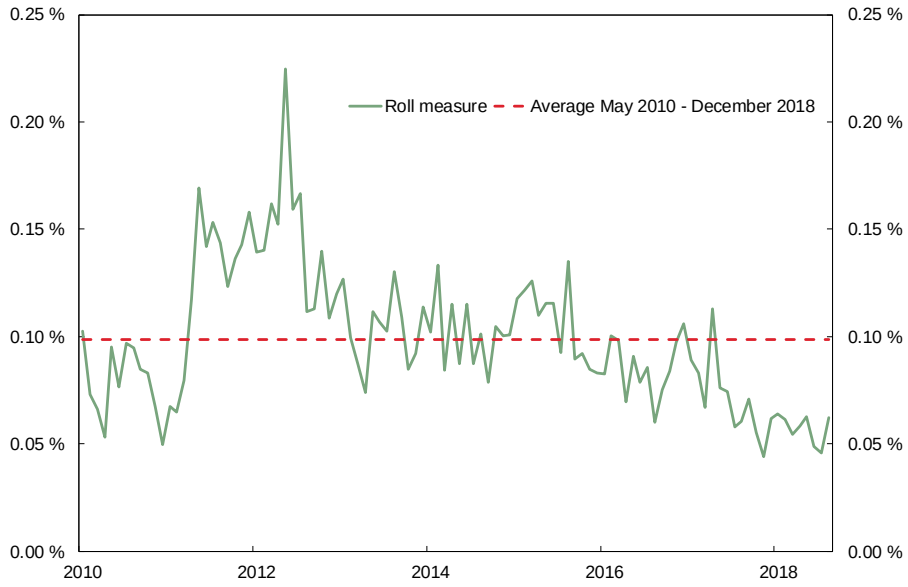
The bid-ask spread is often used as a measure of market liquidity. The bid-ask spread is a form of transaction cost in that a wider bid-ask spread reflects higher transaction costs for the buyer or seller. The bid-

ask spread can also be interpreted as the market maker's compensation for quoting prices in the market.

Roll (1984) shows how under certain assumptions, the effective bid-ask spread can be calculated from the covariance between the price change in two successive trades. Effective means that the bid-ask spread is calculated from prices of executed trades.[7] If the price of a bond is equal to its bid price, a sale trade will not involve a price change. If the trade is a buy trade, the price will "jump" to the ask price. At the next trade, the price change will either be equal to zero or move in the opposite direction of the previous price change. In that case, two subsequent trades will be negatively correlated, assuming that the bid-ask spread itself is not changed by market trades. The negative correlation will be higher if the bid-ask spread is wide. According to this indicator, the market is less liquid the more negative the covariance is.

Chart 6 shows developments in this indicator since 2010, which resemble developments for the price impact indicator. Liquidity deteriorated considerably in 2011 and 2012 but shows a gradual improvement thereafter.

Chart 6: Roll measure.
Bid-ask spread as a percentage of the price. Monthly average.
May 2010 – December 2018



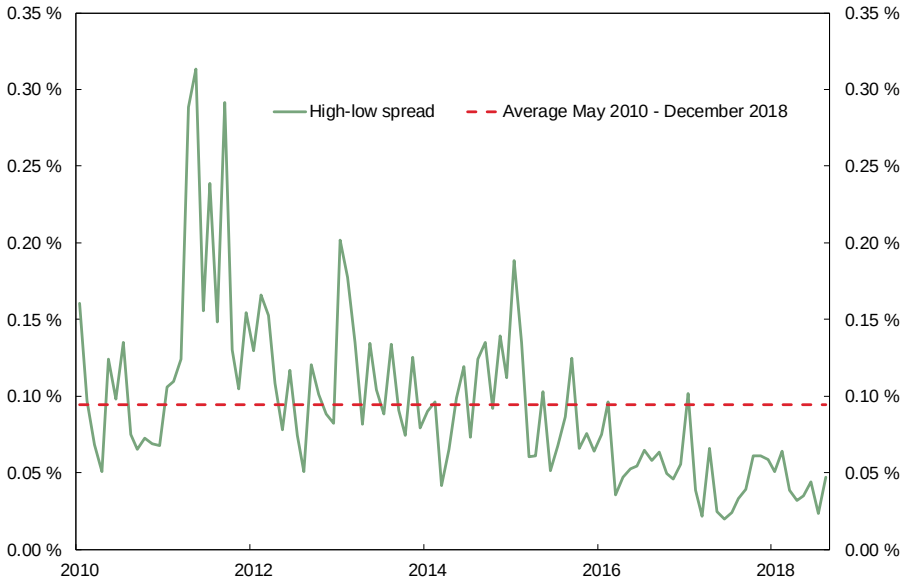
Sources: Oslo Børs and Norges Bank

[7] This is in contrast to quoted bid-ask spreads that can be calculated from quoted prices in order books. Quoted bid-ask spreads for Norwegian government bonds are available inter alia on Oslo Børs, when primary dealers quote prices under their primary dealer agreements. These bid-ask spreads are largely regulated by the primary dealer agreements.

The last indicator is the spread between the highest and lowest traded price in the course of a single trading day. This indicator rises if liquidity deteriorates. The high-low spread captures in part the bid-ask spread and in part intraday bond price volatility (Corwin and Schultz 2012).[8] Higher bid-ask spread and higher volatility are both signs of a less liquid market. Corwin and Schultz show that these two components can be separated so that an estimate of the effective bid-ask spread can be calculated.

Corwin and Schultz (2012) show that the estimated effective bid-ask spread becomes negative if the average volatility over two days is greater than the volatility in the bond price on a single day. This problem arises when I estimate the bid-ask spread with this decomposition for the Norwegian market. I therefore use the high-low spread on a single day as a separate indicator, as shown in Chart 7. Developments in the high-low spread estimator largely resemble the Roll measure and price impact indicator.

Chart 7: High-low spread estimator. Monthly average. May 2010 – December 2018



Sources: Oslo Børs and Norges Bank

3.1. Composite liquidity index

Because it may be unclear which indicators measure liquidity best, some studies have used composite indexes as a liquidity measure.

[8] The high-low spread will only capture the bid-ask spread on days with market trades at both bid and ask prices. On days with trades on only one side of the market, the indicator will, in many cases, overestimate market liquidity.

There are primarily two types of index: indexes calculated as a simple average of several indicators, and indexes based on a principal component analysis.[9]

The four indicators presented above can form the basis of a composite index for the Norwegian government bond market. Using what is called a principal component analysis, weights are calculated for the individual indicators in the composite index. The weights are summarised in Table 1.

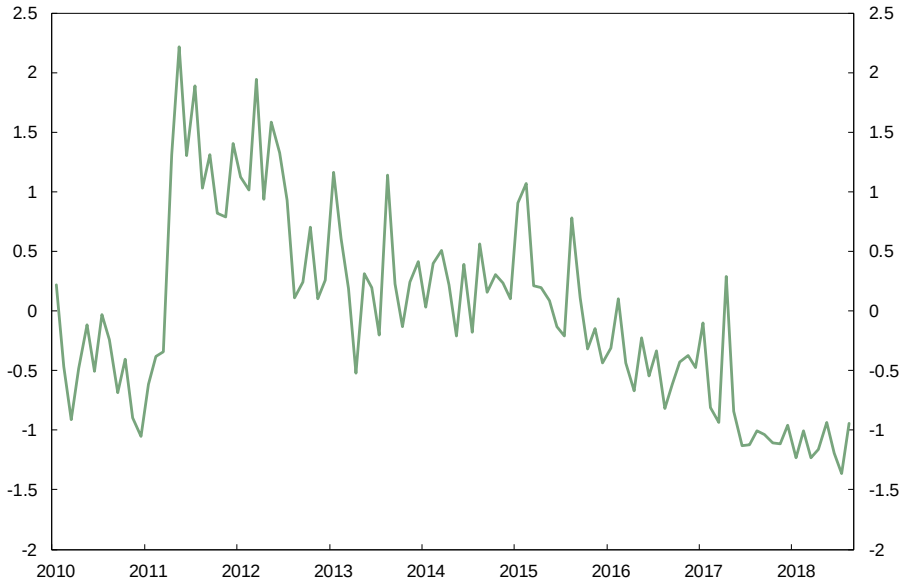
Table 1: Index weights for the liquidity indicators.

Indicator	Weight
Roll measure	0.279
High-low spread	0.438
Price impact indicator	0.322
Amihud measure	0.175

The composite index is shown in Chart 8. I find the largest impacts in the index in 2011–2012. This period was marked by the European debt crisis, which may have reduced the liquidity of Norwegian government bonds, like other countries' sovereign bonds. The Spanish and Italian markets in particular were less liquid during these two years (IMF, 2015). These were two of the countries hardest hit by the crisis. In the French market, there were also signs of lower liquidity, but the impacts appear to have been less pronounced than in the Spanish and Italian markets. On the other hand, the German and Dutch markets showed no signs of lower liquidity. After 2012, liquidity in the Norwegian government bond market has gradually improved, except for a brief period in 2015 when liquidity deteriorated.

[9] Adrian et al (2017a) and ADF (2015) are examples of the former, while Broto and Lamas (2016) is an example of the latter.

Chart 8: Liquidity index for the Norwegian government bond market. Monthly average. May 2010 – December 2018



Source: Oslo Børs and Norges Bank

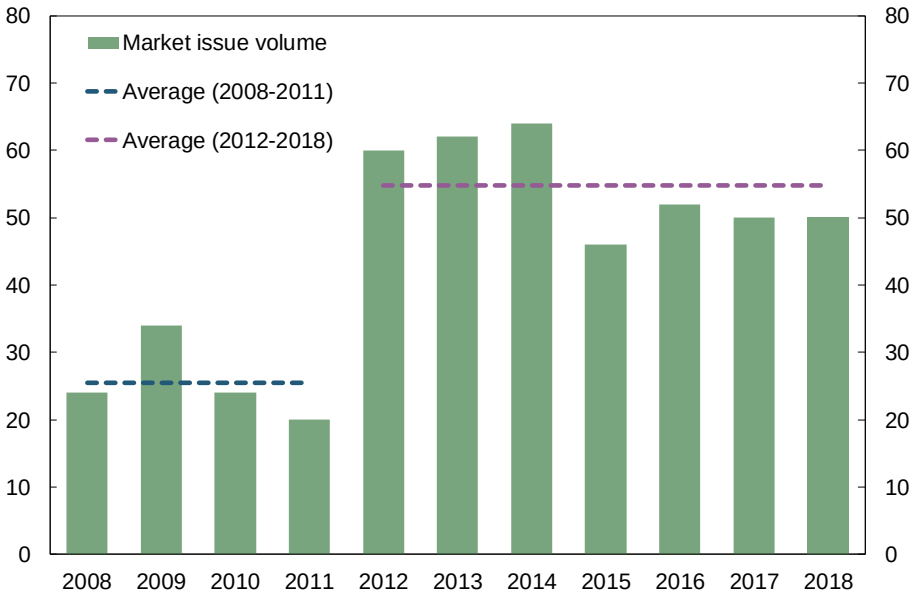
The only indicator that does not show the largest impact in the period 2011–2012 is the Amihud measure. Because this indicator shows somewhat different developments from the other indicators, it receives a lower weighting in the index. From a purely technical standpoint, it is because the Amihud measure is less correlated with the other indicators.

The liquidity index should be viewed as a supplement to the individual liquidity indicators and not as a replacement. The index is unit-free, which implies that a given index value has no clear interpretation. This also means that the average index value is equal to zero. The index must be interpreted as a relative scale. An index value of 1 indicates that liquidity is better than at an index value of 2, but it cannot be interpreted to mean that liquidity is twice as good. This contrasts with the individual indicators, where the numerical value has a clear interpretation. For example, the Roll measure of the effective bid-ask spread will express market participants' actual transaction costs.

The Norwegian market was also affected by purely domestic issues around the turn of the year 2011–2012. Towards year-end 2011, Eksportfinans ASA was prevented from further borrowing. The Government then transferred responsibility for the scheme to subsidise export financing from Eksportfinans ASA to a newly established state-

owned entity, Export Credit Norway.[10] This led to a substantial increase in government bond borrowing in early 2012 (Chart 9). The increase in bond issuance may have reduced the liquidity of the Norwegian government bond market. In that case, it coincides with the European sovereign bond crisis. After 2012, the index shows an improvement in the liquidity of Norwegian government bonds.

Chart 9: Government bond borrowing.
In billions of NOK. 2008–2018



Source: Norges Bank

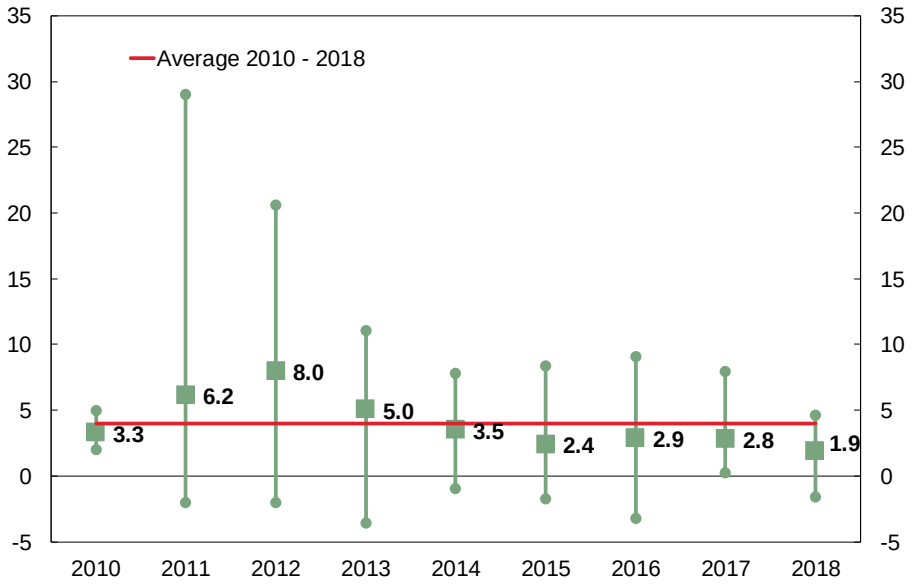
3.2. Liquidity and borrowing costs

The liquidity of the government bond market is a concern of Government Debt Management because improved liquidity lowers liquidity premiums and thus reduces the government's issuance costs. It is therefore relevant to investigate whether issuance costs are higher in periods of lower government bond market liquidity. One way to measure issuance costs is to look at the auction premium at government bond auctions. This is the spread between the allotment yield at bond auctions and the ask yield in the secondary market at the time of the auction on the bond being issued. Chart 10 shows that the auction premium at bond auctions rose considerably between 2010 and 2011 and 2012, after which it fell back to its historical average, which is between three and four basis points. In 2018, the auction premium fell

[10] See https://www.eksportfinans.no/about-us/the-company/

further to right below two basis points. The auction premium therefore indicates that the government's costs are higher in periods of lower market liquidity.

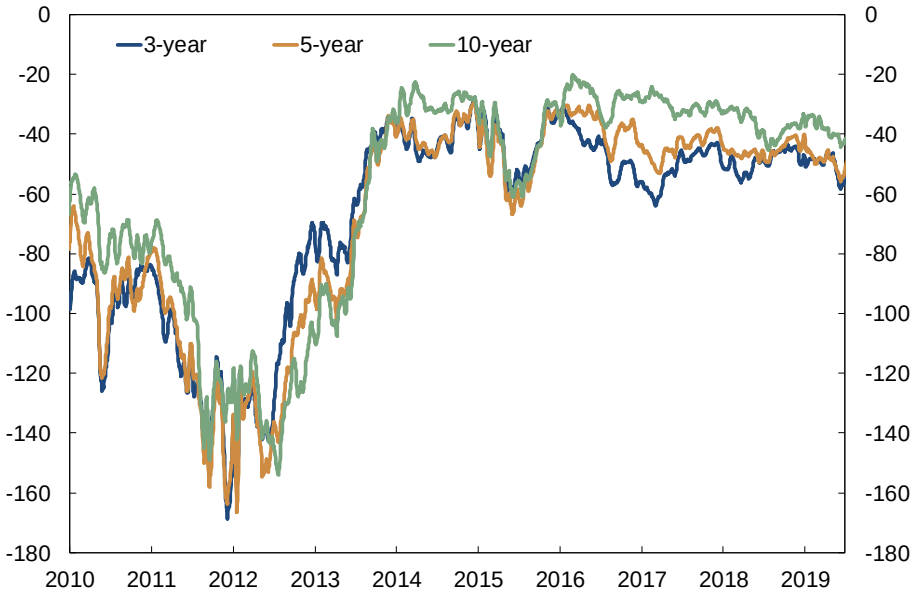
Chart 10: Auction premium at government bond auctions. Average and sample space. Basis points. 2010–2018



Source: Norges Bank

The auction premium is a measure of costs of primary relevance to the government as issuer. For investors in the government bond market, the spread between government bond yields and swap rates are often a more relevant measure of the premium they must pay for buying government bonds. Because there is no bankruptcy risk on government bonds, an increase in swap rates compared with government bond yields indicates investor willingness to accept a lower return in exchange for the safety of investing in government bonds. This means lower borrowing costs for the government compared with the rest of the market when the spread widens (becomes more negative). Chart 11 shows that the spread between government bond yields and swap rates was far wider (more negative) in 2011 and 2012. This may be interpreted to mean a shortage of Norwegian government bonds in these years, presumably owing to the turbulence arising during the European sovereign debt crisis. From 2014 however, the spread has narrowed considerably, and up until year-end 2018 has been between 20 and 40 basis points, depending on maturity.

Chart 11: Spread between government bond yields and swap rates at three- five- and 10-year maturity. Basis points. 2010–2018



Sources: Norges Bank and Thomson Reuters

Thus, the spread between government bond yields and swap rates suggests that the government's borrowing costs fell substantially in 2011 and 2012. However, it is difficult to conclude with certainty that the government's borrowing costs were actually as low during these years as indicated by the spread between government bond yields and swap rates. This was also a period of turbulence in the government bond market, which the auction premium and liquidity index both suggest.

If we disregard 2011 and 2012, however, the government's borrowing costs appear to have fallen at the same time as liquidity has improved. The spread between government bond yields and swap rates has largely moved within a 20-60 basis point range, with a steady fall in the auction premium.

4. Market liquidity and funding costs

Market participants' funding costs have been suggested as a key driver of market liquidity. Brunnermeier and Pedersen (2009) argue that market liquidity and funding costs may be linked. Market makers for Norwegian government bonds depend on funding a stock of government bonds. The cost associated with this stock of government bonds depends on the market maker's funding costs. When these funding costs rise, market makers will require additional compensation for higher costs and risks, which may, for example, result in wider bid-ask spreads.

Here I investigate whether banks' funding costs may have impacted liquidity in the Norwegian government bond market using two measures of banks' funding costs. The first measure is the spread between three-month Nibor and the OIS rate, hereinafter referred to as the Nibor premium. The Nibor premium is intended to measure banks' short-term funding costs and to rise when banks' access to funding deteriorates or becomes more expensive.[11]

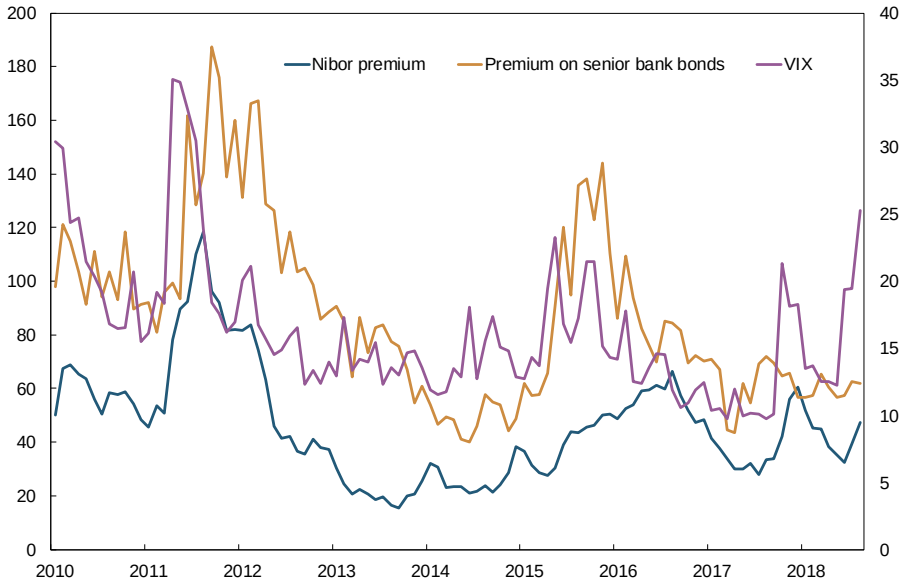
The other measure of funding costs is the change in the premium on outstanding senior bank bonds over three-month Nibor. This premium will rise in periods when banks' access to funding is tight or more expensive. The premium on senior bank bonds will reflect how expensive banks' long-term funding is.

Chart 12 shows that these two indicators rose sharply in 2011 and 2012 at the same time as the liquidity index for Norwegian government bonds indicated a deterioration of liquidity. The VIX measures the volatility in the S&P 500 index implicitly priced into options linked to the index. The VIX is therefore often used as an indicator of financial market turbulence.

After 2012, the short-term funding cost indicators fell back to lower levels. The exception is 2015 and 2016, when the premium on senior bank bonds in particular rose considerably. This is also a period when we noted a temporary deterioration of liquidity in the Norwegian government bond market. The Nibor premium also rose somewhat during these years, but far less than the premium on senior bank bonds.

[11] In Norway, there is no OIS market. Nevertheless, Norges Bank performs a daily estimate of the Nibor premium. See Lund, Tafjord and Øwre-Johnsen (2016) for further details.

Chart 12: Indicators of banks' funding costs (l.h.s.) in basis points and the VIX (r.h.s.). Monthly average. May 2010 – December 2018.



Sources: Norges Bank and Thomson Reuters

I have also considered whether to use other indicators of banks' funding costs in the analysis. These are the spread between three-month Nibor and the three-month Norwegian sovereign yield and the spread between swap rates and government bond yields at different maturities. They are indicators of funding costs that are partly calculated with the aid of sovereign yields. However, we cannot say with certainty that developments in sovereign yields are independent of the liquidity of the government securities market. In that case, the indicators that use sovereign yields in the calculation will be affected by the liquidity of the government securities market. Sovereign yields may fall in response to a shortage of government bonds or treasury bills. A shortage of government securities may contribute to lower market liquidity. If sovereign yields fall, the spread between three-month Nibor and the three-month government bond yield will widen, with Nibor held unchanged. The spread between Nibor and sovereign yields widens because the government securities market is less liquid. In such periods, it is doubtful whether the spread between Nibor and sovereign yields is a good indicator of banks' funding costs.

To study this relationship empirically, I estimated the following model of liquidity in the Norwegian government bond market:

$$Liquidity\ index_t = b_0 + b_1 \Delta f_t + b_2 VIX_t + a_1 Liquidity\ index_{t-1} + \varepsilon_t$$

f_t is either the Nibor premium or premium on senior bank banks.[12] To correct for changes in liquidity stemming from turbulence in global financial markets, I include the VIX index as an indicator of this.

The model is estimated with monthly data, using the last observation of the month. This is done to reduce the autocorrelation in the residual term that arises if a daily, weekly or monthly average is used. The results are summarised in Table 2.

Table 2: Regression results

	Premium on senior bank bonds	**Nibor premium**	**VIX**
Regression 2 $\boldsymbol{R^2 = 0.11, N = 104}$	-0.00577		0.059***
Regression 3 $\boldsymbol{R^2 = 0.11, N = 104}$		-0.66859	0.0567***
*****:significant at the 99% level, **: significant at the 95% level, *: significant at the 90% level**			

The indicators of banks' funding costs show no significant covariation with the liquidity index. A possible interpretation is that banks' funding costs do not appear to have a significant effect on government bond market liquidity. Primary dealers are expected in principle to hold their own stocks of government bonds in order to function as market makers. This stock imposes funding costs on the banks, which in turn affects the price spreads they quote to their customers. However, it is conceivable that funding costs primarily affect the liquidity of other bonds, and that the effect on the liquidity of government bonds is limited.

Adrian, Fleming and Vogt (2017b) investigated whether there is an empirical correlation between market participants' funding costs and US Treasury market liquidity. Unlike our results, their results indicate a significant correlation between funding costs and US Treasury market liquidity. Furthermore, this correlation appears to be strongest in periods of high Treasury market volatility.

[12] The Nibor premium and the premium on senior bank bonds are included in the regression in differential form. Both indicators show signs of having a unit root. See Appendix C for results of the ADF tests.

The VIX index is, as expected, positively correlated with the liquidity index. A possible interpretation for this is that global financial market turbulence has a negative impact on government bond market liquidity.

5. Summary

I have examined developments in the liquidity of the Norwegian government bond market in the period between 2010 and 2018. I calculate five price-based liquidity indicators to obtain a picture of market liquidity in the period 2010–2018. I also calculate a composite indicator based on these five. The composite index shows that liquidity in the Norwegian government bond market deteriorated considerably during the European sovereign debt crisis in 2011 and 2012. Liquidity has gradually improved in recent. The index shows that liquidity was better in 2017 and 2018 that it was prior to the European sovereign debt crisis in 2011 and 2012.

I have also investigated whether banks short-term and long-term funding costs have affected government bond market liquidity. For the period May 2010 – December 2018, I find no clear correlation between banks' funding costs and the liquidity of Norwegian government bonds.

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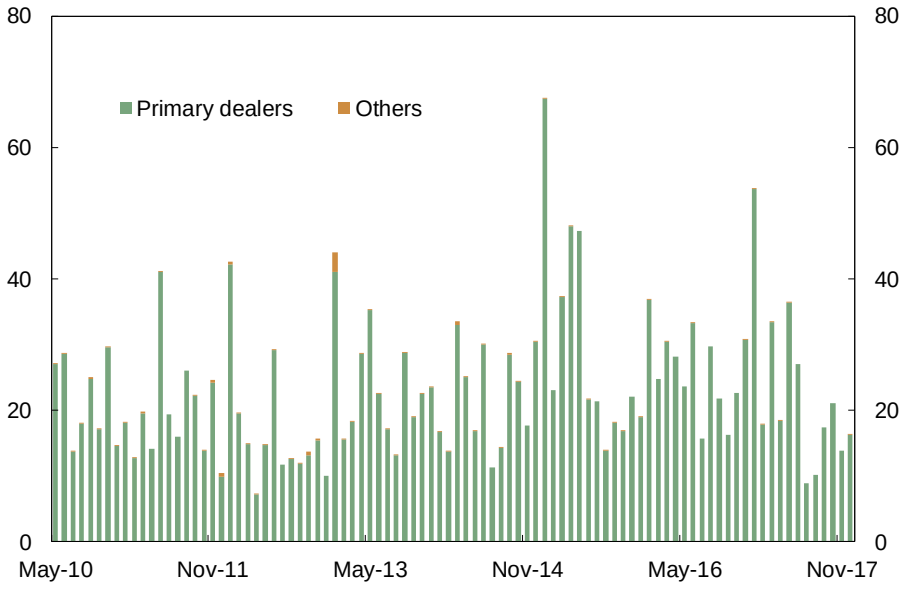
Appendix A. Data

The liquidity indicators are calculated on the basis of Oslo Børs transaction data in the period May 2010 – December 2017. For 2018, transaction data are used that was reported by primary dealers to Norges Bank. From 2018, fixed income members of Oslo Børs are no longer required to report to the exchange Norwegian government bond transactions. This follows from MifiD II, which requires market participants to report transactions to an "approved publication arrangement (APA)". This means that turnover data published by Oslo Børs for Norwegian government bonds from 2018 cannot be compared with turnover data published prior to 2018.

As a consequence, Government Debt Management introduced a reporting system for primary dealers effective from 2018. This means that all transactions involving Norwegian government securities, where at least one party is a Norwegian primary dealer, is reported to the unit. Based on this reporting, monthly turnover data are published on Norges Bank's website on the 15th of every month.

Of the turnover reported to Oslo Børs, around 99 percent was with at least one of the primary dealers in the period 2010-2017 (Chart A.1). However, turnover reported to Oslo Børs does not include transactions between parties neither of whom is a fixed income member of Oslo. Nor is the volume of transactions known that were not reported to Oslo Børs in this period.

Chart A.1: Turnover in Norwegian government bonds on Oslo Børs. Broken down by primary dealers and other. In billions of NOK. 2010—2017



Appendix B. Calculating liquidity indicators

The **price impact (PI) indicator** is calculated as:

$$PI_t = \frac{1}{N_{it}} \sum_{j=1}^{N_{it}} \frac{|P_{ij} - P_{i,j-1}|}{P_{i,j-1}} \qquad (1)$$

N_{it} is the number of trades in the course of a day of a given bond. This indicator can be calculated for days on which two or more trades have taken place. This means that price changes from the last trade on one day to the first trade the following day are not used in the calculation. The indicator is calculated separately for each bond, after which an average value is calculated for all bonds outstanding in the market.

The **Amihud illiquidity measure** is calculated as:

$$Amihud_t = \frac{10^9}{N_{it}} \sum_{j=1}^{N_{it}} \frac{\frac{|P_{ij} - P_{i,j-1}|}{P_{i,j-1}}}{Q_{ij}} \qquad (2)$$

Q_{ij} is the transaction volume for trade j in bond i. This indicator is multiplied by one billion so that it indicates price change per NOK billion in turnover. The indicator is calculated for each bond separately, after which and average value is calculated for all outstanding bonds.

The **high-low spread** on a given trading day is calculated as:

$$HL_t = \ln\left(\frac{H_{it}}{L_{it}}\right) \qquad (3)$$

Where O_t is the number of outstanding bonds on t. This indicator is calculated for each bond separately, after which an average value is calculated for all outstanding bonds.

The **Roll measure** is calculated as:

$$Roll_{it} = \sqrt{-4cov\left(\frac{\Delta P_{it}}{P_{i,t-1}}, \frac{\Delta P_{i,t-1}}{P_{i,t-2}}\right)} \qquad (4)$$

$\frac{\Delta P_{it}}{P_{i,t-1}}$ is the percentage price change from one trade to the next of a given bond. The Roll measure was originally calculated using daily price changes. However, we follow the method of Gungor and Yang (2017) and calculate this indicator using price changes from one trade to the next. I follow the practice of setting the indicator equal to zero where the

covariance is positive.[13] I then calculate a simple average for all bonds to obtain an indicator for the entire market.

All of the indicators are, at the outset, calculated on a daily basis but can be converted to weekly or monthly values by taking a simple average for all bonds on all trading days in a given week or month.

The **composite index** is calculated as a weighted average of the four indicators. The weights are calculated on the basis of a principal component analysis, where the index is he first principal component of the indicators.

Calculation of the weights begins with a matrix $\mathbf{X}$, which contains all observations for the four indicators after standardisation. Let $\widetilde{\mathbf{X}}$ be the correlation matrix of $\mathbf{X}$. $\widetilde{\mathbf{X}}$ is a 4x4 matrix and has four eigenvalues, $\lambda_1, .., \lambda_4$ with related eigenvectors $\mathbf{v_1}, \dots, \mathbf{v_4}$. If λ_1 is the greatest eigenvalue of $\widetilde{\mathbf{X}}$, $\mathbf{y} = \mathbf{X}\mathbf{v_1}$ will be the first principal component of the four liquidity indicators. $\mathbf{y}$ is then the liquidity index.

Table B.1: Results of the principal component analysis

Variable	PC1	PC2	PC3	PC4
Roll measure	0.6289	-0.0209	-0.0255	-0.7768
High-low spread	0.3408	0.7953	0.4401	0.2401
Price impact indicator	0.5444	0.0138	-0.6992	0.4633
Amihud measure	0.4382	-0.6057	0.5628	0.3526
Eigenvalues	2.1212	0.9705	0.6428	0.2656
Share of total variance	53.03%	24.26%	16.07%	6.66%

[13] Corwin and Schultz (2012) provide a detailed description of various methods for solving the positive covariance problem.

The table shows that the liquidity indicators' first principal component covers 58.2 percent of the total variance in the dataset. The weights given in Table 1 are a transformation of $\mathbf{v_1}$ and are calculated as:

$$weight_i = \frac{v_i}{\sum_{i=1}^{4} v_i} \qquad (8)$$

Appendix C. Non-stationarity tests

Of the measures of funding costs, two show signs of having a unit root (Table 4). Both the Nibor premium and the premium on senior bank bonds show signs of having a unit root based on an augmented Dickey-Fuller (ADF) test.

Table C.1: Results of ADF tests

Variable	t-value
Liquidity index	-8.013903***
Nibor premium	-2.274158
Premium senior bank bonds	-2.623544*
***:significant at the 99% level, **: significant at the 95% level, *: significant at the 90% level	
Significance level with constant term	
99%	-3.49502
95%	-2.88975
90%	-2.58190