From Funding Liquidity to Market Liquidity: Evidence from Danish Bond Markets *

Jens Dick-Nielsen,† Jacob Gyntelberg,‡ Jesper Lund,§

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Abstract

This paper shows empirically that funding liquidity drives market liquidity. As it becomes harder to secure term funding in the money markets, liquidity deteriorates in the Danish bond market. We show that the first principal component of bond market liquidity is driven by the market makers' ability to obtain funding. This effect holds true across both long and short term, government and covered bonds. We use MiFID data which provides a complete transaction level dataset for the Danish market covering both the subprime crisis and the Euro sovereign crisis. Furthermore, we verify the findings for other European government bonds using MTS data. The findings suggest that regulatory bond based liquidity buffers for banks will have limited effectiveness.

JEL classification: E43, G12, G21.

Keywords: Market Liquidity, Funding liquidity, Government Bonds, Covered Bonds, Money Markets.

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† Corresponding author. Department of Finance, Copenhagen Business School. Email: jdn.fi@cbs.dk.

‡ Bank for International Settlements, Basel. Email: jacob.gyntelberg@bis.org.

§ Department of Finance, Copenhagen Business School. Email: jelu.fi@cbs.dk.

1 Introduction

During the 2008 crisis liquidity evaporated from the financial markets worldwide. This paper shows empirically that the ease with which you could trade an asset, i.e. market liquidity, was strongly influenced by the market makers' abilities to obtain term funding for their activities, i.e. funding liquidity. More specifically, we find that changes in money market stress predicts changes in bond market liquidity. As money market spreads between secured and unsecured loan rates widens the price impact of trading goes up indicating a more illiquid market. We find no evidence of a spiraling effect where the lower bond market liquidity in turn impairs the funding liquidity of the market makers.

The paper thus provides strong empirical support for the models by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009). They show theoretically that funding liquidity drives market liquidity. Under special circumstances market liquidity can also drive funding liquidity resulting in a spiraling effect in which liquidity deteriorates. We find support for the former implication across the entire universe of bonds. Furthermore, as an implication of funding liquidity driving market liquidity we also find a strong commonality in bond liquidity (Chordia et al. (2005), Karolyi et al. (2012)), because the small group of market makers in our sample dominate all types of bonds (Coughenour and Saad (2004)).

The financial crisis highlighted the importance of strengthening banks' liquidity risk management. A key part of the regulatory response after the crisis has been to require banks to hold larger liquidity buffers (e.g. the EU directive CRD IV based on the Basel III proposal), including more so-called high quality liquid assets. For example, the Liquidity Coverage Ratio (LCR) of Basel III requires banks to hold highly liquid assets to cover the net cash outflow during a 30-day period of acute financial stress. The definition of high quality liquid assets in Basel III will have huge implications for the day-to-day investment decisions made by banks.

One highly contentious issue during the CRD IV negotiations in Europe was whether the class of highly liquid bonds should only include government bonds, or whether certain covered bonds should be included as well. For Danish banks, this issue was of particular importance since Denmark is not part of the euro area, and the Danish government debt is relatively small compared to other EU countries. Because of this, the market for bonds denominated in Danish kroner is dominated by mortgage bonds.

The definition of highly liquid assets in CRD IV, when finalized, will of course have implications for other countries than Denmark. It could also be argued that government bonds are not liquid *per se*, and there are certainly differences in terms of liquidity between the various government bonds markets in Europe (Germany vs Greece, to take the extreme case). Politics aside, the classification as a highly liquid asset should ideally be based on objective measures of liquidity, supported by sound financial theory and empirical studies.

As of this writing (June 2013), the draft plan for CRD IV is to include certain European covered bonds in the definition of highly liquid assets. The covered bonds must be "traded on transparent markets with ongoing turnover", according to the draft agreement. An earlier version of this study [Dick-Nielsen et al. (2012)] was cited in a consultation report from the European Bankers Association.

Another question is how and to what extent money or funding market liquidity is linked to the bond market liquidity. In particular, since we find that severe funding market illiquidity leads to severe bond market illiquidity, it is not clear that the current regulatory efforts which insist that banks hold liquidity buffers in the form of bonds will foster a more robust financial system that can better withstand market wide liquidity stress.

We use a unique and novel data sample containing all bond transactions in Danish bonds. The analysis focuses on Danish government bonds and Danish covered bonds. The Danish mortgage bond market is one of the largest covered bond markets in Europe, even by the absolute size of the market (ECB (2012)). A complete bond transactions record is collected as part of the European MiFID regulation. The Danish market is dominated by a few large banks acting as market makers and the data sample thus give a unique opportunity to study the effect of funding liquidity on an actively traded bond market as a whole.

Comerton-Forde et al. (2010) show that shocks to market makers' positions and revenues impact effective bid-ask spreads for stocks. These two effects limit the available capital for market making and therefore indirectly limit funding liquidity. We take a more direct approach to measuring the costs of obtaining term funding for the market makers. The Danish market makers typically obtain term funding for their trading activities through the Danish or European money markets. Hence, we let money market spreads proxy for the cost of obtaining funding (Brunnermeier (2009)). This is similar to Hameed et al. (2010) who use commercial paper spreads to proxy for funding liquidity. We show that changes in the 3 month Danish CIBOR-CITA spread[1] lags changes in the 3 month EURIBOR-EONIA spreads[2]. The changes in the EURIBOR-EONIA spreads also lead weekly changes in measures of market liquidity for the Danish bond market. By proxying funding liquidity with money market stress we use a more direct link which is easier to measure and monitor than for example Drehmann and Nikolaou (2012), which use aggressive bidding at central bank auctions as a proxy. Our findings are consistent with the event studies of Aragon and Strahan (2012) and Dick-Nielsen et al. (2012) which show that the collapse of Lehman made those securities less liquid which depended upon funding or market making from Lehman. The effect of the Lehman bankruptcy can also be seen in the market liquidity of the Danish bond market. However, this effect goes through the money market channel (Frank et al. (2008), Chiu et al. (2012)).

We measure market liquidity by the average price impact of trades. In the stock market, price impact functions are generally upward sloping in transaction volume (Kyle (1985), Amihud (2002)). In over-the-counter bond markets price impact style liquidity measures can also be used (Dick-Nielsen et al. (2012)). However, even though Dick-Nielsen et al. (2012) and other studies apply an Amihud-type measure with success, we expect price impact functions to be downward sloping in volume because more sophisticated traders have higher bargaining power (Duffie et al. (2007)). This is empirically supported by Edwards et al. (2007) and Feldhutter (2012). We show that in our sample price impact is flat as a function of trade size. This is mainly because we only include large transactions and because the market is rather small and transparent. Hence, we only include transactions from a

[1]The Danish equivalent to the 3 month LIBOR-OIS spread.

[2]The Euro denominated equivalent of the LIBOR-OIS spread.

small number of sophisticated investors and as such the market participants are to a large extent homogeneous. Still, by focusing on these large transactions we cover most of the market as measured by total volume. We can split trades into interdealer transactions and dealer-customer transactions and there we find that the price impacts of interdealer trades are far smaller than those for dealer-customer transactions, providing more support for the hypothesis that the price impact depends on the identity and bargaining power of the participants. Another advantage of focusing on the large transactions is the analysis does not become influenced by retail traders (Bessembinder et al. (2009)). Time variations in the liquidity of these transactions need not have anything to do with funding liquidity for the market makers.

The time series of price impact measures for Danish government bonds and covered bonds are highly correlated with the money market spreads. Granger causality tests on weekly time series show that money markets impact bond liquidity but not the other way around. However, the money market spreads could contain a unit root and therefore we also do all the testing in changes. The results remain the same, namely that changes in money market spreads can be said to Granger cause changes in bond market liquidity with no feedback. A principal component decomposition of the different time series of bond market liquidity, short and long, government and covered bonds and of the Danish and Euro money market spreads shows that the first principal component of the bond market liquidity can be linked to the Euro money market spreads. The money market spreads can be decomposed into a common component and a country spread for Denmark. Again it is the common money market component that drives the first component of the market liquidity whereas the country spread is only related to changes in the liquidity of the short term covered bonds.

In the last part of the paper we extend the analysis to other European government bond markets using MTS data. Despite the lower data quality compared to MiFID data, the findings from the Danish market carry over to the other markets as well. In a principal component analysis of changes in our liquidity measure, we find that the first principal component explains 37% of the variation in the data and that the component is strongly related to lagged changes in the EU money market spread. Hence, we find also here that funding liquidity drives market liquidity.

The remainder of the paper is structured as follows. The following section provides a brief introduction to the Danish covered bond market. Section 3 describes the metric used to capture bond market liquidity and provides an overview of the data. The remaining sections present our empirical findings. The final section concludes.

2 The Danish covered bond market

The Danish covered bond market is one of the most sophisticated housing finance markets in the world. By end 2011, the outstanding amount of covered bonds reached DKKbn 2,500, corresponding to around 140 percent of GDP. The size of the market relative to GDP reflects that the vast majority of Danish mortgage loans, retail as well as commercial, are funded by the issuance of covered bonds. Issuance is completely dominated by specialized covered bond institutions or subsidiaries of major banks. The main covered bond issuers are Nykredit, Danske Bank, which has the subsidiary Realkredit Danmark, Nordea, which has the subsidiary Nordea Realkredit and BRF Realkredit.

Despite a significant transformation of the Danish covered bond market over the last 10–15 years, the issuing banks have continued to operate according to a model where the cash flows of the outstanding bonds precisely match those of the underlying loans (the so-called *strict balance principle* or *match funding* principle). Historically, this has been a defining characteristic of the Danish mortgage system. This practice, no doubt reflects that regulation for many years only allowed mortgage banks to hold very limited market or prepayment risk and therefore they only held credit risk.

This regulatory restriction essentially required mortgage banks to fund their lending activities by issuing mortgage bonds with cash flows that fully matched those of the underlying mortgage loans until maturity on a loan-by-loan basis. In line with the balance-principle, interest period on the bonds exactly matches the interest period for the home owner thereby creating a natural interest rate hedge for the mortgage bank. For each interest period of 1 year, the cash flow of the loans and the bonds issued to fund them match, and the mortgage bank is therefore fully hedged regarding interest rate, currency and prepayment risk. In addition, as the borrower pays the mortgage banks cost-of-funds plus a margin, the mortgage bank is also hedged against rising funding spreads. The issuing bank is however exposed to the risk of a complete freeze in the funding markets when the issuance of new bonds to roll over the funding of maturing bonds is impossible at any price.[3]

Fifteen years ago, the Danish mortgage market was dominated by one standard contract; long-term (up to 30 years) loans at a fixed rate with an option to make penalty-free prepayments. This 30-year fixed rate callable mortgage loan is funded by a cash-flow matching 30-year fixed rate callable bond. By end 2011, 30 year fixed rate mortgages with a coupon of 4 % were funded by each mortgage banks' issue of the 4 % fixed rate callable covered bond maturing October 2041. See Frankel et al. (2004) for an in-depth description of the Danish market for callable fixed rate mortgage bonds.

Over the last fifteen years, low stable short-term interest rates combined with product development has resulted in a dramatic shift towards 1-year adjustable rate mortgages (ARMs). These are by now the dominant loan type. Despite the change towards 1-year ARMs, the funding strategy used by the mortgage banks has not changed. The result has been that the by far most popular new loan type is a 30-year loan where the interest rate changes once a year based on the funding conditions at the time of refinancing of the underlying bonds. The loan is funded by a sale of fixed rate bullet bonds – the majority of which have a 1-year maturity. By end 2011 nearly two-thirds of all outstanding residential mortgages and almost 90 % of all new mortgages were of this type.

Before the financial crisis, the so-called unity market was taken as a given in the Danish mortgage-bond market. This meant that bonds with identical specifications (coupon rate,

[3]While the funding model used by the mortgage banks has not changed fundamentally, the Danish covered bond legislation was amended with effect from January 2008 to incorporate recent changes in the EU Capital Requirement Directive (CRD). The amendments introduced a new covered bond definition. A key change was a requirement for covered bond issuers to perform regular validation of LTV-ratios, which are limited to 80 % for residential mortgages and 60 % for commercial mortgages.

maturity and amortization structure) from different issuers, would trade at the same price as bonds from another issuer, with no or at least very little regard for potential differences in credit risk. During the crisis, not all issuer maintained the same level of crisis risk and prices could depend upon the specific issuer. In the analysis, we exclude BRF Realkredit because it was perceived somewhat more credit risky than the other issuers. See more details on the unity market during the crisis in the appendix.

3 Empirical methodology and data

3.1 Empirical Methodology

We use a price impact measure to assess the level of liquidity in the Danish secondary bond market. For a given transaction, the price impact[4] of a trade is defined as the absolute return between adjacent transactions:

$$\mathrm{PI}_{t,i,k} = \frac{|p_{t,i,k} - p_{t,i-1,k}|}{p_{t,i-1,k}} \tag{1}$$

where i refers to the ith transaction on day t in bond k. The price impact measures how much a single transaction moves the price. In a liquid market we do not expect prices to move much when trading, hence the price impact of a transaction should be low. Contrary, in a illiquid market trading is expected to cause a high price impact. We require that both prices in the calculation of the price impact are executed within the same day in order to minimize the possibility of new information arriving in the market. If most informationally motivated price movements can be eliminated from the price impact measure, the median price impact over a given period, for example one week, can be said to resemble an effective bid-ask spread over that period. This happens because the most common reason for a price impact is a bounce between a buy and a sell price.

We then define a weekly price impact measure as the average price impact for a given bond over that week:

$$\mathrm{PI}_{w,k} = \frac{1}{N}\sum_{i}^{N} \mathrm{PI}_{t,i,k} \tag{2}$$

where w is the wth week in the sample and N is the number of price impact observations in that week. Finally, the weekly price impact measure for a market segment is defined as the weighted average across all bonds belonging to that segment with weights being the amount outstanding (as free float) in the given bond:

$$\mathrm{PI}_{w}^{MARKET} = \frac{1}{s_1 + \ldots + s_M}\sum_{k}^{M} s_k \times \mathrm{PI}_{w,k} \tag{3}$$

where s_k refers to the amount outstanding of bond k and M refers to the number of bonds belonging to the market segment (in that week). The weighting scheme is especially impor-

[4]Price impact is at all times stated in basis points.

tant for the long term covered bond market. There exists a large number of very small long term covered bond series as explained in section 2. By weighting with amount outstanding the importance of these series are appropriately reduced in the weekly market measure.

3.2 Data

Our data sample covers all transactions in the Danish bond market. These transactions are collected by the Danish FSA as part of the MiFID regulation[5] implemented in EU starting November 1st, 2007. More specifically, the data includes all transactions carried out by an investment firm or credit institution in the EU as one of the counterparties. Our sample period is defined by the availability of MiFID data and therefore starts in November 2007. We have obtained the MiFID data up until end 2011. The raw MiFID data has been cleaned before usage as described in Dick-Nielsen et al. (2012).

As the aim of our analysis is to determine the liquidity drivers and characteristics of covered and government bonds from the perspective of banks' ability to liquidate these assets in times of market wide stress we focus on transactions with a nominal value of at least DKKm 10 (approximately EURm 1.34). By excluding transactions with a nominal value of less than DKKm 10 we exclude only a small fraction of the total turnover.

In both markets we find that a large part of the transactions takes place in standard trade sizes e.g. DKKm 20, 50, 100, and 200. Thus, some of our tables relate specifically to these numbers.[6] A somewhat surprising empirical observation is that the price impact is independent of the trade size in the Danish sample. This can be seen in table 2, which shows the price impact measure for four of the most frequently used trade sizes. In fact, in most periods the price impact of a DKKm 200 trade is smaller than one of DKKm 20. This finding is in line with bid-ask spreads for US corporate bonds also being downward sloping as a function of trade size (Edwards et al. (2007) and Feldhutter (2012)). The former definition of price impact is closely related to the Illiq-measure (Amihud (2002)) which is based on the model in Kyle (1985). Dick-Nielsen et al. (2012) show that a modified version of the Illiq/Amihud measure is a good proxy for the level of liquidity when looking at US corporate bonds[7]. However, the observations in table 2 strongly suggest not to scale the raw price impact measure with volume. There is no evidence of a positive linear relationship between price impact (PI) and trading volume (Q). The standard ex-ante relationship PI $= \lambda \times Q$ for some $\lambda > 0$ assumed for the Amihud measure would not be appropriate for the Danish data. Note that the Amihud measure predicts that the price impact for a DKKm 200 should be 10 times that of a DKKm 20. Such a relationship cannot be found anywhere in the data.

[5]According to article 25(3) and (4) of Directive 2004/39/EC investment firms and credit institutions are required to report transactions when trading a financial instrument admitted to trading on a regulated market. Furthermore, the transaction reports are to be passed on to the competent authority of the most relevant market in terms of liquidity. This directive is implemented by the Commission Regulation (EC) 1287/2006 clarifying the required content of these so-called MiFID transaction reports.

[6]Because transactions are conducted in standard trade sizes (round figures) by Danish kroner we keep DKK as currency throughout the paper. Denmark conducts a fixed-exchange-rate policy vis-a-vis the euro at a central rate of 7.46038 kroner per euro. Since 1997 Danmarks Nationalbank has kept the krone very close to its central rate.

[7]Even though Dick-Nielsen et al. (2012) show that the Amihud measure is a good liquidity proxy for US corporate bonds it may be possible to get an even better proxy by assuming a different relationship for US corporate bonds between price impact and volume in line with the methodology used in this study.

The MiFID transaction reports naturally include variables related to transactions only. However, as the MiFID transaction reports identify uniquely all instruments by the international securities identification number (ISIN) it is straightforward to add information from other data sources. Thus, bond specific data, i.e. outstanding volume, maturity, issuer, etc. has been added from another data source. We have obtained this information form the Danish central bank, Danmarks Nationalbank, which receives this information from the central securities registration agent in Denmark, VP-securities, on a monthly basis. They have also provided us with a Danish bondholder distribution divided by sector on a monthly basis for each ISIN. The residual bondholders are thus foreign investors. We have furthermore obtained various Danish and EURO money market rates from Bloomberg.

3.3 Covered bonds

When calculating the price impact measure in the covered bond market, all bond issues with matching cash flows are pooled into the same bond family and is regarded as a single issue, hence issuers are assumed to be indistinguishable (see section 2).

Throughout the paper we restrict our sample for covered bonds to bonds issued by the 3 largest issuers which cover around 65-85 % of the market. The market does not discriminate between these issuers in terms of credit quality.[8] Thus, bonds with the same cash flow from different issuers trade in the market at the sane price, This is referred to as the unity market for Danish covered bonds. Therefore, the so-called unity market allows us to effectively treat bonds with the same cash flow as one bond when calculating our liquidity measure (see section 3.1). This greatly increases the number of observations and thereby the accuracy of our analysis. We discuss this issue further in the following section.

The short-term covered bonds in our sample are fixed-rate bullet bonds with a time to maturity of less than 1.2 years.[9] The 1-year bonds underlying the 1-year ARMs (so-called F1 bonds) are usually auctioned off 14 month prior to maturing. At the auction the bonds are settled with a delivery 2 month later and right after the auction the bonds start to trade in the secondary market. In table 1 we present summary statistics for the entire market (all issuers) as well as our sample (the 3 largest issuers). We can see that for short-term covered bonds, our sample captures around 65 % of the amount outstanding and around 45 % of the turnover. The relatively low turnover for our sample can be explained by the fact that apart from conditioning on the issuer we also remove auction days from our sample. The auctions are removed as we are interested in secondary market liquidity.

The long-term covered bonds in our sample are the standard 30-year fixed rate callable bonds. Our sample captures around 85 % of the amount outstanding and 90 % of the turnover. The summary statistics in table 1 are based on actively traded issues. So where the market consists of 115 actively traded issues there are actually around 1,250 different callable fixed-rate bonds outstanding in the Danish covered bond market.[10] This reflects

[8]The issuers are Realkredit Danmark, Nordea Realkredit and Nykredit Realkredit. Furthermore, we include older issues from Totalkredit Realkredit, now part of Nykredit Realkredit.

[9]These bonds also exist with longer time to maturity but we restrict the analysis to look at only 1 year bonds. These are by far the most frequently used in the market.

[10]A bond is included in the monthly statistic if it had at least one wholesale transaction in that given month.

a large number of very small callable fixed-rate bonds mirroring that the mortgage banks issue bonds with cash flows that match those of their lending portfolio (as explained in the following section). Hence, a given covered bond issue exists until all borrowers which have their mortgages funded by this specific bond have paid off their mortgages completely.

On a more technical note, the data sample contains a high number of zero price impacts i.e. transactions where the price does not change between consecutive trades. This is an artefact of the reporting system and of the market maker arrangement. Firstly, it reflects that in a large number of transactions bonds are simply handed from one dealer to another and then passed on to a customer. These types of transactions are often reported with the same price for both trades (same clean price). Secondly, in the Danish bond market a group of market makers (large banks) post binding quotes for certain quantities. These quotes are not always adjusted after a transaction, hence it may be possible to execute several transactions at the same price. To avoid an artificially high number of zero price impacts this study adopts an order book view of the market. Thus, when consecutive transactions have the same price, all quantities are summed up and saved as a single transaction with the total volume executed at this given price. The summation is executed before price impacts are calculated. This procedure results in a strictly positive price impact measure for every observation.

3.4 Government bonds

The outstanding volume of Danish government bonds by end 2011 was just over DKKbn 750, corresponding to around 40 % of GDP (see Danmarks Nationalbank (2012)). The Danish government debt and hence the issuance of bonds is managed by the Danish central bank. The outstanding bonds consist of short-term T-bills and plain vanilla bullet bonds with standard maturities between 2 and 30 years. The sale of bonds takes place via auctions and tap sales, with auctions being the dominant issuance form since 2009. T-bills and a new 30-year bond were only in existence in part of our sample period. Therefore, we do not include these instruments as to keep our sample as homogeneous as possible over time.

In table 1 short-term government bonds are those with time to maturity of no more than five years while long-term bonds are those with time to maturity of between five and ten years. The summary statistics reflect that the government bond market is dominated by a few very large benchmark issues (average bond size of DKKbn 62.3 for short-term government bonds compared to the covered bond market (average bond size of DKKbn 22.3 for short-term covered bonds).

3.5 Money markets

We use two different measures for money market stress. As a proxy for stress in the Danish money markets, we use the spread between a three month CIBOR rate and a 3 month CITA rate (CITA is the Danish OIS contract). As the DKK is pegged to the euro, the Danish market is heavily influenced by European conditions, we also look at a EURO money market spread, namely the spread between 3 month EURIBOR and the 3 month EONIA swap rate.

Figure 5 shows a time series of these two money market spreads. Before the start of the subprime crisis both spreads were virtually zero indicating that it was fairly easy to obtain short-term funding, and that the perceived short-term credit risk of banks was very low. The first spike in the summer of 2007 is the start of the subprime crisis and the two money market spreads are highly correlated up to the peak of the crisis. After the peak of the crisis both spreads decrease although the EURO spread decrease at a faster pace than the Danish spread. The two spreads switch place again during the euro sovereign crisis.

4 Market Liquidity

This section compares the liquidity in covered versus government bonds during normal and stress periods. We do both a graphical inspection and a statistical analysis of our liquidity measure. Outside the 2008 financial crisis, government bonds are slightly more liquid than covered bonds. However, during the crisis the covered bond market performed better.

Our liquidity measure suggests (see figure 2) that liquidity was broadly the same for short-term covered bonds and government bonds before the 2008 crisis.[11] This is also evident from the regressions in table 3. The estimated liquidity levels for the pre-crisis period (the intercepts) statistically point to higher average liquidity in the government bond market. However, the actual difference in liquidity in terms of price impact implied by the regression is only in the 1-2 basis point range, corresponding to a difference in price movement of around 0.01-0.02 percent.

During the peak of the 2008 crisis there was a notable decline in liquidity in both short-term markets. The decline in liquidity was however significantly higher for the government bond market, where the average price impact of trade increased to nearly 15 basis points compared to roughly 4 basis points before the crisis. This constitutes a significant drop in liquidity. In contrast, the increase was only around 3 basis points from 6 to 9 basis points for short-term covered bonds. Furthermore, this increase was not statistically significant.

In the post-crisis period we see that although liquidity has been lower than before the crises both markets have remained fairly liquid with an average price impact of trade around 7 basis points – not far away from the pre-crisis level for the covered bond market. More recently, during the first years of the euro area sovereign debt crisis, liquidity in the short-term government bond market has returned to its pre-crisis level. In contrast, liquidity in the short-term covered bond market has remained below the level (i.e. higher price impact) seen before the 2008 crisis. Despite the decline in liquidity, both markets are, however, still quite liquid, with an average price impact of trade in the 4-7 basis point range.

Similar to the markets for short-term bonds, the average price impact was broadly the same for long-term covered and government bonds over the entire sample period as can be seen in figure 3. Looking at the regressions in table 3 we can see that the pre-crisis levels for the liquidity measure are not statistically different. But they do show a lower level of liquidity for long-term bonds than short-term bonds. The difference in price movement compared to

[11] Using different data, Buchholst et al. (2010) show that the pre-crisis liquidity level (from January 2005 to August 2008) was very stable.

the short-term bonds as implied by the regression is around 6 basis points, corresponding to a difference in price movement of around 0.06 percent.

During the peak of the crisis in October 2008 and the period leading up to the crisis there was a notable decline in the long-term government bond market liquidity as we also saw it for the short-term government bonds. In contrast, liquidity remained more or less the same in the covered bond market.

The average price impact decreased rapidly in the period after the crisis in both long-term markets. While market liquidity has returned to its pre-crisis level for government bonds, it has decreased somewhat for covered bonds during the later period of the euro area sovereign crisis. In general the crisis affected the long-term market far less than the short-term market. The price impact measure for short-term government bonds increased with a factor 3, whereas the long-term government bonds increased with a factor 0.5.

As the MiFID data contains counterparty identifiers, we can split our sample of bond market transactions into those between dealers (inter-dealer) and those between dealers and their clients. This makes it possible to perform a more granularly evaluation of bond market liquidity. In particular we are able to compare the liquidity of the inter-dealer market with the dealer-client market during both normal and stress periods. From a policy perspective, the value-added is that this sheds light on the ability of dealers to raise cash in inter-dealer markets versus dealer-client market under different market conditions.

The price impact in interdealer transactions are generally lower than those in dealer-client transactions. However, the number of observations decrease a lot especially for the interdealer transactions when splitting up the sample. Hence, it is most convenient to look at average turnover instead of price impact. As can be seen from table 4, turnover in the inter-dealer market declined dramatically during the crisis compared to the dealer-client market. The combination of notable increases in the price impact of trades combined with a dramatic decline in inter-dealer market turnover is suggestive of a situation where dealers found it difficult to sell bonds in the inter-dealer market and instead sold bonds to clients. This suggest that the inter-dealer community as a whole was liquidity-constrained during the crisis.

5 Relationship between market and funding liquidity

In this section we test for a relationship between funding liquidity and market liquidity. As a proxy for funding liquidity we use money market spreads between secured and unsecured loan rates.

Theory suggests that there should exist a link between funding liquidity and market liquidity (Brunnermeier and Pedersen (2009)). We test for such a relationship in the Danish bond market by relating our weekly price impact measure for each market segment to money market stress.

Dealers in the Danish bond market often have substantial long and short positions due to their market-making obligations. A well-functioning repo market is important to maintain these long and short positions. During our sample period, large Danish banks have invested part of their equity in highly leveraged positions of, especially, short-term covered bonds. This has increased their exposure to funding market liquidity. Foreign hedge funds and other speculative investors have traditionally played a fairly large role in the Danish mortgage market. These investors are highly dependent on the willingness of Danish banks to fund their positions.

When money markets are stressed as during the 2008 crisis dealers have trouble securing enough funding to perform a market making facility. The money market stress will ultimately lead to weaker market liquidity and, in our case, higher price impact. We first show that money market spreads predict market liquidity for the four different market segments. Then we show that the four market series have common components which can be said to relate to funding liquidity.

5.1 Main results

Figure 6 shows a smoothed version of the weekly short-term government bond market liquidity from figure 2, plotted alongside the weekly EURO money market spread. The two graphs are indexed to fit the same scale. At least for this market segment there seems to be a very strong correlation between the two series. The graph thus gives a first confirmation of the empirical relationship between market and funding liquidity. Table 5 shows Granger causality tests between money market spreads and the weekly price impact measures. The strong relationship from figure 6 is confirmed in the causality tests. For all the four market segments, the euro money market spread seems to predict market liquidity. The only market with a weak connection is the market for long-term covered bonds. The could be because this group of bonds is very inhomogeneous and perhaps therefore noisy. However, we cannot statistically reject that the money market spreads contains a unit root. So even though there is a strong correlation in levels between market liquidity and money market spreads in all four market segments it may just be a spurious relationship.

In over to see that the relationship between market liquidity and funding liquidity is not just spurious, we do the analysis in first differences. In table 6 we regress weekly changes in market liquidity on lagged changes in market liquidity and lagged money market spread changes:

$$\triangle \text{PI}_t = \alpha + \beta_1 \times \triangle \text{PI}_{t-1} + \beta_2 \times \triangle \text{EUspread}_{t-1} + \beta_3 \times \triangle \text{DKspread}_{t-1} + \epsilon_t$$

where PI_t is the weekly price impact measure for the given market segment. Note that even though the levels of the money market spreads are highly correlated, the weekly changes are not significantly correlated. The regressions resemble a Granger causality test between market liquidity and money market spreads. There is a strong impact from the EURO spread changes to the market liquidity of the government bonds. For the short-term covered bonds, changes in the Danish money market spreads are significant at the 10% level, whereas for the long-term covered bonds there seems to be no impact from money market spreads. The long-term covered bonds are also the most inhomogeneous of the four market segments which could explain why there is no sign influence from the money market.

5.2 Principal component analysis

The four individual bond market series may have a lot of idiosyncratic volatility which contaminate the former analysis. In order to get a cleaner picture of the market liquidity drivers, we perform a principal component decomposition of the four price impact series. Table 7 shows the factor loadings from the principal component decomposition of the correlation matrix of the weekly changes in the price impact measures. Even though the first two factors jointly explain 56% of the total variation, there is no single dominating factor driving market liquidity. The explanatory powers of the four factors are very close to each other. The first principal component loads with the same sign on all four markets and approximately with the same size loading on all markets except for the short-term covered bond market where the loading is half-size. Hence, shock to the first component seems to affect all markets more or less equally. The second principal component loads heavily on the short-term covered bond market and could be interpreted as a factor specific for this market. The last two factors are more mixed in their loadings. In table 8 we perform the same regression as in table 6, but switch the raw price impact series for the standardized principal components:

$$\text{PC}_t = \alpha + \beta_1 \times \text{PC}_{t-1} + \beta_2 \times \triangle\text{EUspread}_{t-1} + \beta_3 \times \triangle\text{DKspread}_{t-1} + \epsilon_t$$

where PC_t is the principal component from the PC decomposition of the correlation matrix of the weekly changes in bond market liquidity. Again the regression resembles a Granger causality test. The first principal component is predicted by changes in the EURO money market spreads. The second principal component is predicted by changes in the Danish money market spread.

The EURO spread is also weakly significant for the second principal component with the opposite sign of the Danish spread. This seems to suggest that the difference between the two spreads is important for the second principal component. The last two principal components are not related to the money market spread changes. The interpretation of the first component as the EURO spread is in line with the former regression in table 6. There the EURO spread was strongly related to the market liquidity of the government bonds and these two markets (together with long-term covered bonds) also loaded on the first component. The second component which was also related to the Danish money market or more specifically to the difference between the Danish and EURO money market spreads loaded heavily on the short-term covered bond market.

This is also consistent with the regression in Table 6 where the Danish money market spread was significant for the short-term covered bond market. The decomposition of the changes in the price impact measures, thus support that the analysis in levels where not just a spurious relationship. Since the levels of the money market spreads were highly correlated as seen in figure 5, it may be worth to also decompose changes in the money market spreads. Judge by the co-movements of the levels, it seems that one common component drives both money markets. In table 9 we perform a Granger causality test between changes in the Danish and in the EURO money market spreads. The conclusion is that changes in the EURO money market spreads drive changes in the Danish spread with no significant feedback effect. This is no surprising finding since Denmark is a small economy strongly influenced by European markets. Danish money market spread changes are in some sense then lagged EURO spread changes. Doing a principal component decomposition of the money market spread changes could possibly isolate the EURO effect and leave a second component more strongly related to idiosyncratic Danish conditions.

Table 10 shows the factor loadings from a principal component decomposition of the correlation matrix of changes in money market spreads. As expected the first component is very dominant and explains 80% of the total variation. The first component loads strongly on both money markets and can be interpreted as a level factor driving both markets. The second factor is then (by construction?) the difference between the two markets. Hence, it can be interpreted as a country spread between Denmark and the EURO. In panel A of table 11 we perform the same regression as before but now we switch in the principal components for the money market spread changes:

$$\text{PC}_t^{\text{BOND}} = \alpha + \beta_1 \times \text{PC}_{t-1}^{\text{BOND}} + \beta_2 \times \text{spreadPC1}_{t-1} + \beta_3 \times \text{spreadPC2}_{t-1} + \epsilon_t$$

where spreadPC1_{t-1} is the first principal component of the PC decomposition of the correlation matrix of weekly money market spread changes. The first bond component is related to the first money market component. This means that the bond market liquidity level factor is driven by the money market level factor. Hence, funding liquidity drives market liquidity. The second bond market factor is related to the second money market factor. This indicates that the country spread drives the market liquidity of the short-term bond market.

5.3 Country spread versus foreign investors

Our money market spread is a Danish kroner equivalent to a LIBOR-OIS spread. Hence it reflects in part the credit risk of banks as well as the liquidity premium for three-month interbank deposits versus overnight deposits. This type of money market spread is a widely used as a measure of bank funding liquidity risk.

The bond portfolio of the bank is however also part of liquidity reserves. Selling bonds in the secondary market to get cash is an obvious alternative to attracting funds through deposits or short-term loans. In addition, bonds can also be used to obtain cash via repos or collateralized funding. If an adverse liquidity shock hits the entire banking sector, or a large part of it, the selling pressure will increase the price impact of trades in the bond market. Furthermore, banks facing liquidity problems will reduce their funding to other investors such as hedge funds that invest in bonds through leveraged positions. If hedge funds are forced to reduce their leveraged bond positions because their counterparty banks withdraw funding, the resulting selling pressure (or buying pressure to close short positions) will also lower market liquidity.

Our empirical results in Tables 6 and 8 are consistent with the established theory of the relationship between funding and market liquidity. The EURO money market spread has a stronger causal relationship with the price impact measure than the DKK spread. This likely reflects the Danish peg to the Euro, which means that the Danish monetary policy is essentially indirectly determined by the European Central Bank (ECB). Moreover, the CITA market is less liquid than the EONIA market, so the DK money market spread may be more noisy that the EURO spread, particularly in the beginning of the sample period 2007–2012.

For the short term covered bonds, the country spread is a better predictor in the price impact regression than the EURO or DK money market spread. The country spread in this regression is the difference between the DK and EURO money market spreads. In Panel B of Table 11, the EURO money market spread is insignificant in the price impact regression for short covered bonds, whereas the country spread is significant at the 10% level. In Panel A of the same table, the second spread PC (principal component) is only significant for the second bond PC. By looking at the factors loading for two principal components, we see that the second spread PC is essentially a country spread, and the second bond PC has a very high factor loading on short covered bonds. This suggests that the liquidity of short covered bonds is influenced by a separate factor which is not present (to the same extent) in the other segments of the Danish bond market.

There are several plausible explanations for the empirical relationship between the country spread and the liquidity of short covered bonds. First, the Danish central banks generally maintains a higher interest rate than the ECB in order to support the Danish currency and enforce the fixed exchange-rate policy versus the EURO. This makes it attractive for speculators to buy Danish short covered bonds with EURO funding, and for Danish banks to buy short covered bonds and hedge the interest rate risk with EONIA contracts instead of CITA contracts. In either case, the market participants are exposed to the country spread. Second, Danish banks often face EURO funding problems since they have limited access to the funding facilities of the ECB. Danish banks obtain EURO funding through foreign exchange (FX) swaps, and their EURO funding pressure often leads to a premium (distortion) in the FX swap market and the implied forward exchange rate. EURO-based investors can exploit that by buying short-term Danish bonds, for example short covered bonds, combined with FX swaps. Finally, Figures 8 and 9 show that foreign investors have increased their holdings of short covered bonds, and this is likely to increase the importance of the country spread in affecting the liquidity of the short covered bond market.

5.4 Feedback effect from market liquidity

The former sections show that funding liquidity to a large extent drives market liquidity. This is consistent with the model from Brunnermeier and Pedersen (2009). Their model furthermore implies that market liquidity and funding liquidity can be reinforcing under certain circumstances thus resulting in a liquidity spiral. Here we test whether changes in market liquidity can help predict changes in funding liquidity. We do it by performing a Granger causality test (with one lag) between changes in price impact in each of the four market segments and changes in the money market spreads. Table 12 shows that all the causality tests are rejected on a 5% level. Hence, there is no evidence in our data sample that market liquidity should impact funding liquidity through a feedback effect. It may be that the effect only exists during the peak of the crisis but the data is not rich enough to test for the effect over such a short time period. In some sense it is not surprising that changes in the market liquidity of Danish bonds do not impact euro money market rates. The Danish bond market is only a minor part of the European financial market. However, if we believe that the relationship between funding liquidity and market liquidity is universal and applies to other markets than just the Danish bond market, it is highly likely that changes in the Danish bond market liquidity are strongly correlated with the liquidity in other European markets through the funding liquidity channel. If this is true then we would still have expected to see a feedback effect (i.e. correlation) from the Danish bond market liquidity to the money market spreads, which we do not.

6 Comparison with other European government bonds

This section compares the results using the Danish MiFID data to other European government bond markets using MTS data. The MTS platform is a trading platform mainly for European government bonds (see Gyntelberg et al. (2013) for a detailed description of MTS). Up until the start of the subprime crisis in the first half of 2007, European covered bonds were also quoted on the platform. However, the quoted volume in covered bonds dropped to near 0 with the inception of the crisis. Anecdotal evidence from the MTS platform providers suggests that the trading of European covered bonds moved from MTS to pure OTC. Hence, we do not have available transactions or quote data for the rest of the European covered bond market.

The MTS data contain a large amount of intra-day quotes. The quotes are supposedly firm and executable, which should give us a high quality data set. The fact that covered bonds dropped out of the trading platform during the crisis could be explained by the unwillingness of dealers to post firm quotes in these securities. In order to assess the quality of the MTS data we compare the price impact measure calculated for short term Danish government bonds to the equivalent calculated using MTS quotes. The MTS data allows us to calculate a daily average bid and ask price. We then calculate the price impact or implicit bid-ask spread as follows:

$$PI^{\text{MTS}} = \frac{\bar{P}^{\text{ASK daily}} - \bar{P}^{\text{BID daily}}}{\bar{P}^{\text{ASK daily}}}$$

In order to get a weekly time series we take the median over all bid-ask spreads calculated over the week within a given group of bonds e.g. Danish short term government bonds. Figure 10 shows the weekly price impact series calculated using MiFID and MTS data. It is clear in the graph that the MTS numbers do not match the MiFID numbers exactly. Before the subprime crisis and in the latter period of the sample the price impact measures match up approximately. However, during the crisis and in the period after the peak of the crisis the MTS price impact measures are substantially higher than those calculated for the MiFID data. This is not just because of the sample differences in that we include Danish T-bills in the MTS sample but not in the MiFID numbers. As can be seen from the graph, it does not make any notably difference for the MTS numbers if we also there exclude T-bills. In the following analysis we include the T-bills because we also include them for the other countries. The differences between MTS and MiFID price impact measures could be caused by MTS not being the primary marketplace for trading Danish government bonds. The same critique could carry other to other government issuers as well.

Even though the MTS data is not ideal in nature because it is quotes and not actual transactions, we still use it as the best available data. We include Germany, France and Spain as well as Denmark in the MTS analysis. These countries are selected because they also have large covered bond market although we cannot measure liquidity in these markets. Figure 11 shows price impact measures calculated using MTS data for short term government bonds (below 5 years to maturity) issued by Germany, France, Spain and Denmark. The time series behavior for the four subsamples are highly correlated and look much like the figure we already had for Denmark. German bonds are the most liquid, whereas the sovereign crisis seems to be hard on Spain. Before and during the subprime crisis Spain, France and Denmark were all very close together in liquidity. The same picture is more or less true for the long term government bonds (5-10 years maturity) in figure 12. German bonds are again the most liquid followed by Danish bonds. Liquidity in the long term bonds issued by France and Spain seems to be very close up until the sovereign crisis hits Spain and also to some extent hits France.

Table 13 shows principal components of the correlation matrix for price impact measures calculated using MTS data. The correlation matrix is for weekly changes in the price impacts for the eight different subsamples; short term (below 5 years) and long term (5-10 years) government bonds issued by Germany, France, Spain and Denmark. As for the Danish market alone, the first principal component is very close to having the same sign and value across maturities and countries. Changes in the price impact measures are thus strongly correlated across markets. The first principal component alone explains 37% of the total variation in the data. The second principal component separates into markets affected by the sovereign crisis and those which as not or less effected. Those affected seem to be Spanish bonds and long term French bonds. Table 14 runs a regression where the principal components are explained by lagged values of itself and lagged weekly differences in the EU money market spread. The last four principal components are not included in the table. The first two principal components are significantly and positively related to changes in the EU money market spread. Hence, the conclusion from the Danish analysis carries over to European markets, namely that funding liquidity drives market liquidity. Here given by the fact that stress in the EU money market spill over into a more illiquid market for government bonds. The results reported in the table and the principal component analysis are for weekly changes in the price impact measures. The same analysis in levels is much more significant but there the time series could contain a unit root as we also had in the Danish data alone. The results might also have been stronger if we had used a daily frequency instead of a weekly time lag. This is left for further investigation.

7 Conclusion

We find that funding liquidity drives market liquidity. In the Danish bond market benchmark short and long term bond are by and large as liquid as Danish government bonds. The time series variation in the price impact of trades is predicted by changes in money market spreads. When it becomes more expensive for market makers to secure term funding in the money markets to fund their activities the bond market becomes less liquid. Because the same group of financial institutions is market makers in both covered bonds and government bonds we see a strong commonality in market illiquidity. When the market maker is hit by funding stress all the securities traded by the market maker is affected. The empirical findings are consistent with the theoretical models by e.g. Brunnermeier and Pedersen (2009).

The Danish money market spread lags changes in the Euro money market spread. The latter spread is the main determinant of the liquidity in the Danish bond market, consistent with the market makers obtaining funding from the Euro-area. We find that the country-spread, i.e. the spread difference between Denmark and the Euro-area, is important only for short term covered bonds. Also when we decompose the market liquidity series, we find that the first principal component is linked to lagged changes in the euro money market spread.

During the 2008 subprime crisis both the covered bond market and the government bond market remained active but with a lot less activity in the interdealer market. Hence, trading activities during the crisis was mainly dealer-customer transactions.

The decrease in market liquidity measures and in trading activity during the subprime crisis show that when funding liquidity dries up it negatively affects the market liquidity. Theory suggests that there could be a feedback effect where market liquidity in turn decreases the market makers ability to obtain funding even further. However, we find no such spiraling effect in the data sample.

Using MTS data we extend the analysis to include German, French and Spanish government bonds as well. For these related market, we show that funding liquidity also here drives market liquidity.

Our findings have implications for the effectiveness of regulatory liquidity buffers for banks. The main argument for demanding banks to hold buffers of highly liquid assets (mainly high quality bonds) is that the banks can sell out of the bonds if it is difficult to obtain funding. However, if the funding stress is systemic and money markets are stressed, we show that it will be very hard to liquidate a bond portfolio at a fair price.

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A Unity Market for Covered Bonds

The financial crisis has clearly affected this market unity, resulting in a renewed focus on differences in perceived credit risk among bond issuers. This has mainly affected BRF Realkredit whose bonds trade at lower prices than the other mortgage institutions. For that reason, we have chosen to exclude BRF Realkredit bonds from our empirical analysis. A secondary effect is that now regulatory capital requirements and limits to counterparty exposure from time to time create preferences for certain issuers. This in periods leads to price differences. The explanation for this is, that when a Danish bank buys bonds from a 100%-owned subsidiary, the position is given a risk weight of 0% under the current rules for capital requirements. Thus, banks may have a preference for bonds issued by their own subsidiaries. For example, Danske Bank may have a preference for bonds issued by Realkredit Danmark, and Nordea Bank may have a preference for bonds issued by Nordea Realkredit. Mutual funds and other institutional investors (subject to regulation) have position limits towards a single issuer, and this can also create heterogeneities between bonds that should, in theory, be identical and trade at the same price. From conversations with bond traders, we learned that this sometimes affects prices in the market.

Prior to the financial crisis, the Danish mortgage-bond market was supported by a fairly well-functioning OTC market-maker agreement. Banks could request two-sided quotes from other participating banks with a fixed bid-ask spread, typically for a size of DKKm 50 from the counterparty and 10 bps bid-ask spread for benchmark 30-year callable mortgage bonds. With the implicit backing of the market-maker agreement, it was generally perceived as less risky for banks to trade relatively large positions with clients. If six banks participated in the marker-maker arrangement for DKKm 50, a single bank could offset DKKm 250 of risk to the other banks by calling them simultaneously and requesting a quote. The market-maker arrangement in 30-year callable bonds broke down during the financial crisis.

However, today the market-maker agreement only covers a futures contract on 30-year callable bonds with 10 bps bid-ask spread and DKKm 50 trade size for six out of seven participating banks. The futures contract is, of course, an excellent hedge for the underlying bonds even though there can be minor price differences between issuers due to differences in perceived credit risk or prepayment risk when the bond price is above par. The typical bid-ask spread in the inter-dealer market of long-term mortgage bonds is similar to the futures contract, that is around 10 bps. In the data, we see a substantial decline in inter-dealer trading activity for long-term covered bond, and the demise of the market-maker agreement has undoubtedly contributed to this development.

Furthermore, there is currently (as of late 2012) a market-marker arrangement in the F1 bond with 4 bps bid-ask spread and sizes up to DKKm 200. Before the financial crisis, the OTC marker-maker agreement also included benchmark government bonds with 10 bps bid-ask spread for the 10-year bond. This part has also vanished along with the rest of the pre-crisis OTC market-maker agreement, and currently there is only the primary dealer function of the MTS market. From our discussions with traders, a typical bid-ask spread for a 10-year government bond in the MTS market would be 20-30 bps for trade sizes between DKKm 25 and DKKm 100. This may suggest that Danish government bonds have become less liquid over the last couple of years. However, there are offsetting factors, such as the unofficial "flight to quality" status of Danish government bonds (along with German government bonds) in response to the ongoing European sovereign debt crisis.

Our empirical analysis implicitly relies on the assumption of the unity market is still in place for the three main issuers as we batch together trades in the same bond from different mortgage issuers. We do this to avoid a substantial reduction in the number of valid price-impact observations for our empirical analysis. For long-term callable mortgage bonds, the unity market is a reasonable assumption through the period 2007–2011 as long as the bond is trading below par. For the F1 bond, the validity of the unity-market assumption is less clear since there could be sub-period with notable price differences due to the investor preferences discussed above. A breakdown of the unity-market assumption would lead to an upward bias in our estimated price-impact measure, that is we would underestimate the degree of liquidity in the F1 bond market.

Market	Long Covered		Short Covered		Long Government	Short Government
(Monthly average)	Market	Sample	Market	Sample	Market/Sample	Market/Sample
Amount outst. (DKKbn)	494	424	750	497	174	257
Number of Bonds	115.1	78.7	35.7	17.5	2.8	4.2
Bond Size (DKKbn)	4.3	5.4	22.1	29.7	63.6	62.3
Turnover (DKKbn)	115	104.7	332	155	76	65
Number of trades	2,109	1,891	1,763	928	591	405
Mean tradesize (DKKm)	54.2	55.1	158	156	136.6	169.4
Median tradesize (DKKm)	26.9	28.0	69.0	70.1	47.8	66.1
Time to Maturity	26.0	26.3	0.64	0.63	8.03	2.53

Table 1:
Desriptic statistics for the Danish bond market.
The table contains monthly average statistics for the aggregated market segments. The government bond sample contains the entire market, whereas the covered bonds sample only contains issues from the three highest rated issuers. Long term covered bonds are callable annuity bonds most commonly issued with a 30 year maturity. Short term covered bonds are non-callable fixed rate bullet bonds with 2 to 14 month to maturity. Short term government bonds are treasury bonds with less than 5 years to maturity. Long term government bonds are treasury bonds with between 5 to 10 years to maturity.

Period	Market	20 mill.	50 mill.	100 mill.	200 mill.
Pre-Crisis	Long Covered	7.90	8.18	7.52	7.33
	Short Covered	5.03	4.57	3.42	3.00
	Long Government	9.62	8.73	7.50	5.87
	Short Government	3.53	3.03	2.86	2.44
Crisis	Long Covered	5.79	10.28	11.42	9.25
	Short Covered	3.45	3.23	8.24	6.05
	Long Government	10.65	11.27	13.55	7.72
	Short Government	9.32	8.32	8.63	8.26
Post-Crisis	Long Covered	6.61	7.49	7.72	6.18
	Short Covered	3.28	3.26	3.42	2.98
	Long Government	7.90	8.47	7.13	5.76
	Short Government	2.93	6.28	4.58	3.93
Sovereign Crisis	Long Covered	8.74	9.64	9.65	8.61
	Short Covered	2.95	2.97	2.14	2.50
	Long Government	7.32	8.36	9.30	7.33
	Short Government	3.63	2.25	2.76	1.82

Table 2:
Price impact by trade size.
The table shows average price impacts (in bps)) for specific trade sizes (in DKK) within a given period. The trade sizes are the most commonly used in the market. The data period starts in November 2007. The crisis period is defined as running from August 15th to December 15th 2008. The post-crisis period runs from December 16th 2008 to April 30st 2009. The sovereign crisis period runs from May 1st 2009 to end 2011 (end of data).

Bond Series	Long Covered	Short Covered	Long Government	Short Government
Intercept	12.55***	6.13***	10.85***	4.81***
	(0.64)	(0.57)	(0.61)	(0.25)
Crisis_t	1.65	2.23	7.07***	8.51***
	(1.52)	(1.69)	(1.69)	(2.27)
Post-Crisis_t	-1.57**	0.37	0.49	2.77***
	(0.75)	(0.74)	(1.21)	(0.71)
$\text{Sovereign Crisis}_t$	1.23	-0.02	1.43	1.04**
	(0.85)	(0.64)	(1.04)	(0.48)
R^2	0.13	0.05	0.13	0.26
N	219	217	219	219

Table 3:
Regression of price impact on time dummies.
The table shows statistics for regressions of the weekly average price impact (in bps) for each market segment on time dummies. The regression is specified as:

$$\text{PI}_t = \alpha + \beta_1 \times \text{Crisis}_t + \beta_2 \times \text{Post-Crisis}_t + \beta_3 \times \text{Sovereign Crisis}_t + \epsilon_t$$

The data period starts in November 2007. The crisis period is defined as running from August 15th to December 15th 2008. The post-crisis period runs from December 16th 2008 to April 30st 2009. The sovereign crisis period runs from May 1st 2009 to end 2011 (end of data). Robust standard errors are calculated following Newey-West. Significance at 10% level is marked *, at 5% marked **, and at 1% marked ***.

Panel A: Dealer-Client transactions

Market	Pre-Crisis	Crisis	Post-Crisis	Sovereign Crisis
Short covered	1,240	2,670	3,860	3,530
Short Gov.	410	700	360	740
Long covered	1,800	2,170	1,330	1,330
Long Gov.	910	720	630	700

Panel B: Interdealer transactions

Market	Pre-Crisis	Crisis	Post-Crisis	Sovereign Crisis
Short covered	210	110	230	230
Short Gov.	170	50	50	130
Long covered	790	850	610	560
Long Gov.	180	110	90	80

Table 4:
Average daily turnover for different market segments.
The table shows average daily turnover for each bond market segment divided into interdealer transactions or dealer-clint transactions. Interdealer transactions are defined as transactions between the largest dealer banks to other large dealer banks (a large bank is defined as being member of the market marker arrangement). A dealer-client transaction is defined as a transaction between one of the large banks and a customer (a non-bank). The table thus leaves out transactions from smaller banks.

Granger Causality Test P-value	Short Cov	Long Cov	Short Gov	Long Gov
EUspread does not cause	<0.001	0.08	<0.001	<0.001
DKspread does not cause	0.003	0.93	<0.001	<0.001

Table 5:
Granger causality test from to funding liquidity to market liquidity in levels.
The table shows p-values from Granger causality tests from funding liquidity to market liquidity. Funding liquidity is proxied by money market spreads. All variables are kept in levels despite money markets spreads cannot be rejected as been unit root processes. The p-value shows the probability that changes in a market liquidity series does not cause changes in the money market spread (under the proper assumptions).

Bond Series	Long Covered	Short Covered	Long Government	Short Government
Intercept	-0.001	0.02	0.01	-0.005
	(0.16)	(0.13)	(0.21)	(0.16)
ΔPI_{t-1}	-0.38***	-0.43***	-0.52***	-0.43***
	(0.07)	(0.04)	(0.07)	(0.06)
$\Delta EUspread_{t-1}$	3.64	-2.54	10.98**	9.34**
	(3.50)	(2.77)	(5.22)	(3.96)
$\Delta DKspread_{t-1}$	-3.48	4.70*	-0.08	-0.29
	(4.29)	(2.82)	(4.30)	(3.91)
R^2	0.15	0.21	0.26	0.20
N	217	211	217	217

Table 6:
Regression of price impact changes on money market changes.
The table shows statistics for a regression of weekly average price impact changes for each market segment on lagged changes in money market spreads and lagged price impact changes:

$$\triangle PI_t = \alpha + \beta_1 \times \triangle PI_{t-1} + \beta_2 \times \triangle EUspread_{t-1} + \beta_3 \times \triangle DKspread_{t-1} + \epsilon_t$$

The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate. Robust standard errors are calculated as in Newey-West. Significance at 10% level is marked *, at 5% marked **, and at 1% marked ***.

	1PC	2PC	3PC	4PC
ΔLong Covered	0.50	-0.48	0.54	0.48
ΔShort Covered	0.18	0.84	0.13	0.50
ΔLong Government	0.68	-0.13	-0.81	0.25
ΔShort Government	0.51	0.23	0.18	-0.68
Cum. % explained	29%	56%	79%	100%

Table 7:
Principal component analysis of changes in price impact.
The table shows loadings from a principal component decomposition of the correlation matrix of the changes in the weekly price impact series.

PC Series	1. Bond PC	2. Bond PC	3. Bond PC	4. Bond PC
Intercept	-0.001	-0.02	0.01	-0.01
	(0.04)	(0.04)	(0.04)	(0.04)
PC_{t-1}	-0.37***	-0.47***	-0.45***	-0.52***
	(0.05)	(0.04)	(0.05)	(0.05)
$\Delta EUspread_{t-1}$	2.70**	-1.24*	-0.81	-0.49
	(1.15)	(0.74)	(0.80)	(0.79)
$\Delta DKspread_{t-1}$	-0.45	1.72**	-0.20	0.38
	(1.12)	(0.81)	(0.83)	(0.89)
R^2	0.15	0.25	0.22	0.26
N	211	211	211	211

Table 8:
Regression of bond components on money market spread changes.
The table shows statistics for a regression of the principal components of the weekly changes in price impact on lagged changes in money market spreads and lagged levels of the principal components:

$$PC_t = \alpha + \beta_1 \times PC_{t-1} + \beta_2 \times \triangle EUspread_{t-1} + \beta_3 \times \triangle DKspread_{t-1} + \epsilon_t$$

The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate. Robust standard errors are calculated as in Newey-West. Significance at 10% level is marked *, at 5% marked **, and at 1% marked ***.

Granger Causality Test P-value	ΔEUspread	ΔDKspread
ΔEUspread does not cause	-	0.01
ΔDKspread does not cause	0.90	-

Table 9:
Granger causality test for money market spreads.
The table shows p-values from Granger causality tests for the money market spreads. The p-value shows the probability that changes in one money market spreads does not cause changes in the other spread (under the proper assumptions).

	1PC	2PC
ΔEUspread$_t$	0.71	0.71
ΔDKspread$_t$	0.71	-0.71
Cum. % explained	80%	100%

Table 10:
Principal component analysis of changes in money market spreads.
The table shows factor loadings for a principal component analysis of the correlation matrix of the weekly changes in the money market spreads. The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate.

Panel A: Regression on money market principal components.

PC Series	1. Bond PC	2. Bond PC	3. Bond PC	4. Bond PC
Intercept	-0.005	-0.02	0.01	-0.01
	(0.04)	(0.04)	(0.04)	(0.04)
PC_{t-1}	-0.37***	-0.47***	-0.45***	-0.52***
	(0.05)	(0.04)	(0.05)	(0.05)
$spreadPC1_{t-1}$	0.13**	0.03	-0.06	-0.01
	(0.05)	(0.05)	(0.04)	(0.03)
$spreadPC2_{t-1}$	0.19	-0.18**	-0.04	-0.05
	(0.13)	(0.08)	(0.09)	(0.10)
R^2	0.15	0.25	0.22	0.26
N	211	211	211	211

Panel B: Regression on country spread.

Bond Series	Long Covered	Short Covered	Long Government	Short Government
Intercept	-0.001	0.02	0.01	-0.005
	(0.16)	(0.13)	(0.21)	(0.16)
ΔPI_{t-1}	-0.38***	-0.43***	-0.52***	-0.43***
	(0.07)	(0.04)	(0.07)	(0.06)
$\Delta EUspread_{t-1}$	0.15	2.16	10.98**	9.05**
	(2.60)	(2.44)	(5.22)	(3.96)
$\Delta Countryspread_{t-1}$	3.48	4.70*	-0.08	-0.29
	(4.29)	(2.82)	(4.30)	(3.91)
R^2	0.15	0.21	0.26	0.20
N	217	211	217	217

Table 11:
Regression of bond components on money market components.

Panel A shows statistics for a regression of the bond principal components of the weekly changes in price impact on lagged principal components of changes in the money market spreads and lagged levels of the bond principal components:

$$PC_t^{BOND} = \alpha + \beta_1 \times PC_{t-1}^{BOND} + \beta_2 \times spreadPC1_{t-1} + \beta_3 \times spreadPC1_{t-1} + \epsilon_t$$

Panel B shows the regression of the raw weekly price impact series on lagged changes in euro money market spread and lagged changes in the country spread as regressors:

$$\triangle PI_t = \alpha + \beta_1 \times \triangle PI_{t-1} + \beta_2 \times \triangle EUspread_{t-1} + \beta_3 \times \triangle COUNTRYspread_{t-1} + \epsilon_t$$

The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate. The country spread is calculated as the difference between the Danish and the Euro spreads. Robust standard errors are calculated as in Newey-West. Significance at 10% level is marked *, at 5% marked **, and at 1% marked ***.

Granger Causality Test P-value	ΔEUspread	ΔDKspread
ΔLong Covered does not cause	0.47	0.16
ΔShort Covered does not cause	0.67	0.36
ΔLong Government does not cause	0.22	0.34
ΔShort Government does not cause	0.41	0.32

Table 12:
Granger causality test from market liquidity to funding liquidity.
The table shows p-values from Granger causality tests from market liquidity to funding liquidity. Funding liquidity is proxied by money market spreads. All tests are performed in changes. The p-value shows the probability that changes in a market liquidity series does not cause changes in the money market spread (under the proper assumptions).

	1PC	2PC	3PC	4PC	5PC	6PC	7PC	8PC
ΔShort DE	0.46	0.17	0.23	-0.08	-0.22	-0.50	-0.63	0.09
ΔShort DK	0.33	0.47	-0.27	0.14	0.33	0.59	-0.34	-0.08
ΔShort ES	0.42	-0.48	-0.07	-0.09	-0.02	0.05	0.01	-0.76
ΔShort FR	0.11	0.08	0.73	0.03	0.64	-0.07	0.17	-0.08
ΔLong DE	0.35	0.32	0.33	-0.29	-0.53	0.32	0.44	0.04
ΔLong DK	0.35	0.31	-0.47	-0.05	0.25	-0.51	0.49	0.00
ΔLong ES	0.35	-0.50	-0.11	-0.43	0.25	0.19	-0.02	0.58
ΔLong FR	0.35	-0.25	0.06	0.83	-0.14	0.04	0.16	0.26
Cum. % explained	37%	54%	70%	79%	87%	93%	97%	100%

Table 13:
Principal component analysis of changes in price impact using MTS data.
The table shows loadings from a principal component decomposition of the correlation matrix of the changes in the weekly price impact series using MTS data. The eight series used in the correlation matrix is short (<5 years time to maturity) and long (5-10 years time to mauturity) government bonds. The bonds are issued by Germany (DE), Denmark (DK), Spain (ES) and France (FR).

PC Series	1. Bond PC	2. Bond PC	3. Bond PC	4. Bond PC
Intercept	-0.001	-0.003	-0.004	-0.006
	(0.12)	(0.08)	(0.07)	(0.06)
PC_{t-1}	-0.003	-0.09	0.42***	-0.30***
	(0.07)	(0.07)	(0.06)	(0.07)
$\Delta EUspread_{t-1}$	3.31**	1.72*	-1.36	0.68
	(1.44)	(0.94)	(0.84)	(0.67)
R^2	0.03	0.02	0.19	0.08
N	216	216	216	216

Table 14:
Regression of bond components on money market spread changes using MTS data.

The table shows statistics for a regression of the principal components of the weekly changes in price impact using MTS government bond data on lagged changes in money market spreads and lagged levels of the principal components themselves:

$$PC_t = \alpha + \beta_1 \times PC_{t-1} + \beta_2 \times \triangle EUspread_{t-1} + \beta_3 \times \triangle DKspread_{t-1} + \epsilon_t$$

The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The regressions for the last four principal components are omitted for brevity. Robust standard errors are calculated as in Newey-West. Significance at 10% level is marked *, at 5% marked **, and at 1% marked ***.

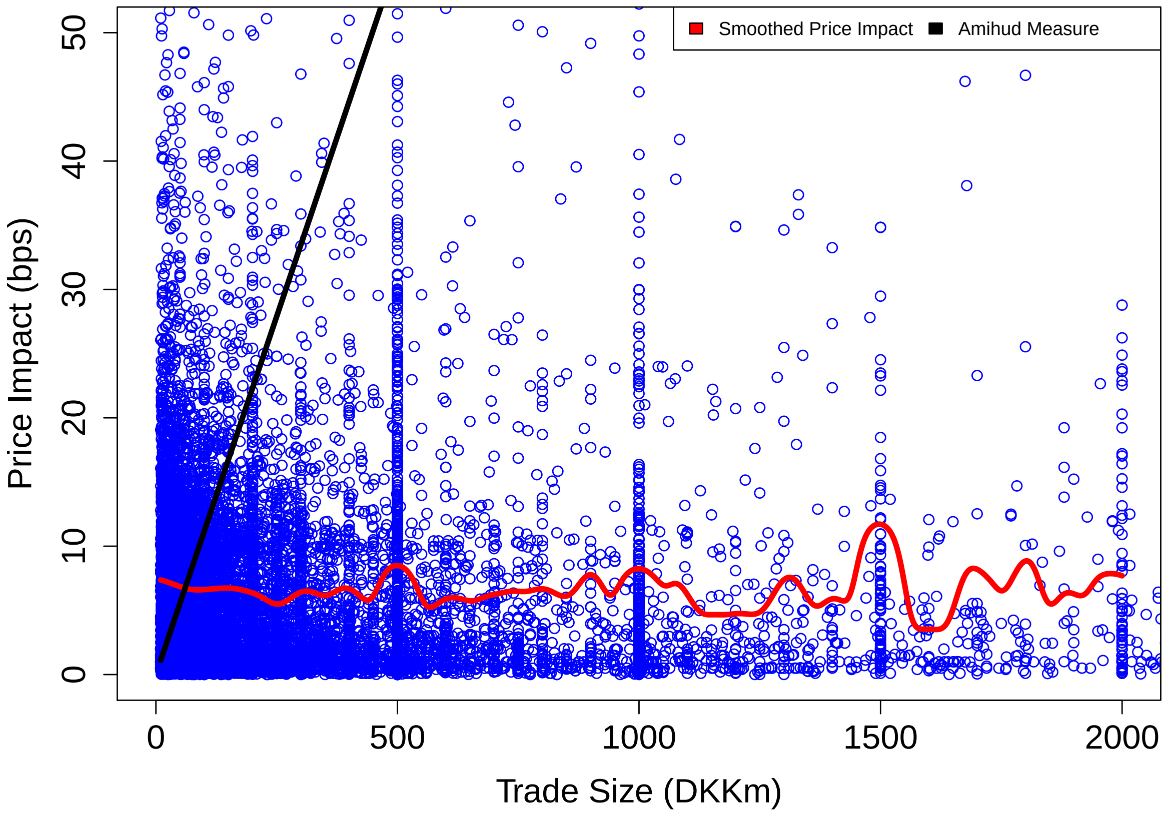

Figure 1:
Price impact versus trade size.
The figure shows raw price impact observations plotted against the trade size for short term covered bonds. The black line is the estimated functional relationship ($\mathrm{PI}_i = \lambda * Q_i$) implied by the Kyle model (Kyle 1984) or the Amihud measure (Amihud 2002). The red line is a non-parametric relationship obtained by kernel smoothing with a gaussian kernel (bandwidth is DKKm 25)

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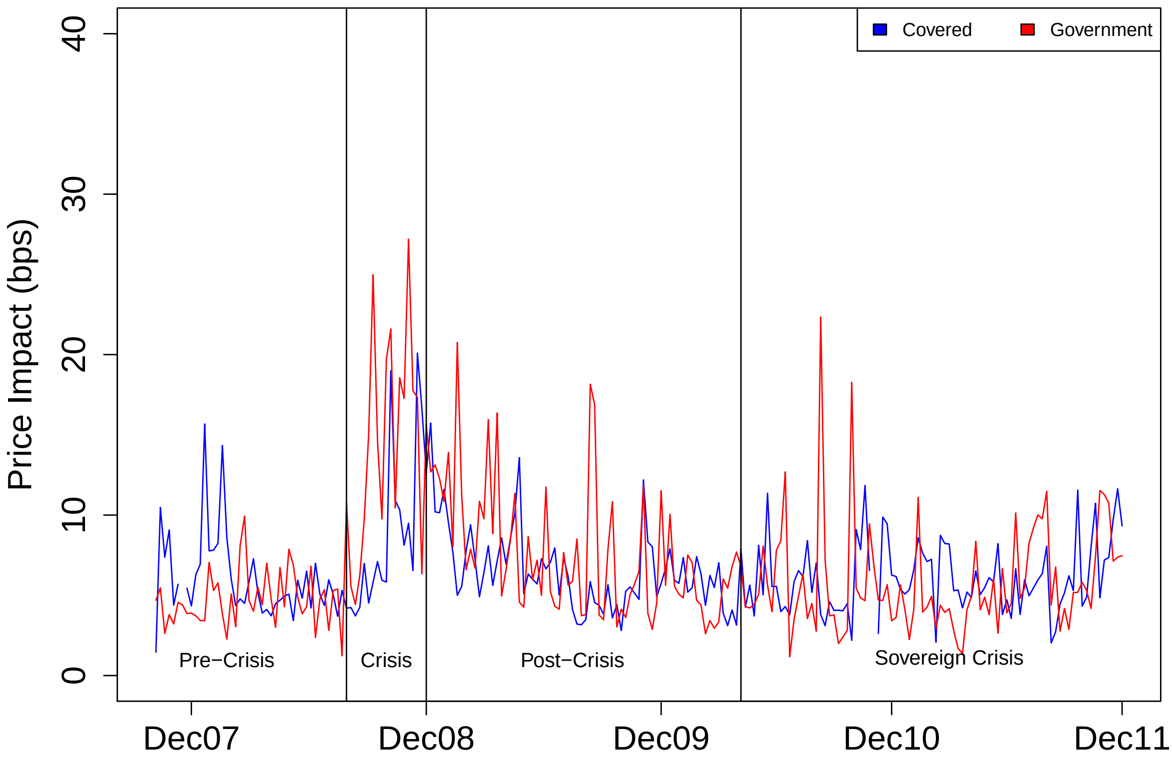

Figure 2:
Price impact for short term bonds.
The figure shows the weekly average price impact. The blue line is for short term covered bonds and the red line is for short term government bonds. The data period starts in November 2007. The crisis period is defined as running from August 15th to December 15th 2008. The post-crisis period runs from December 16th 2008 to April 30st 2009. The sovereign crisis period runs from May 1st 2009 to end 2011 (end of data). Short term covered bonds are defined as non-callable fixed rate covered bonds with time to maturity between 2 to 14 month. Short term government bonds are treasury bonds with less than 5 years to maturity.

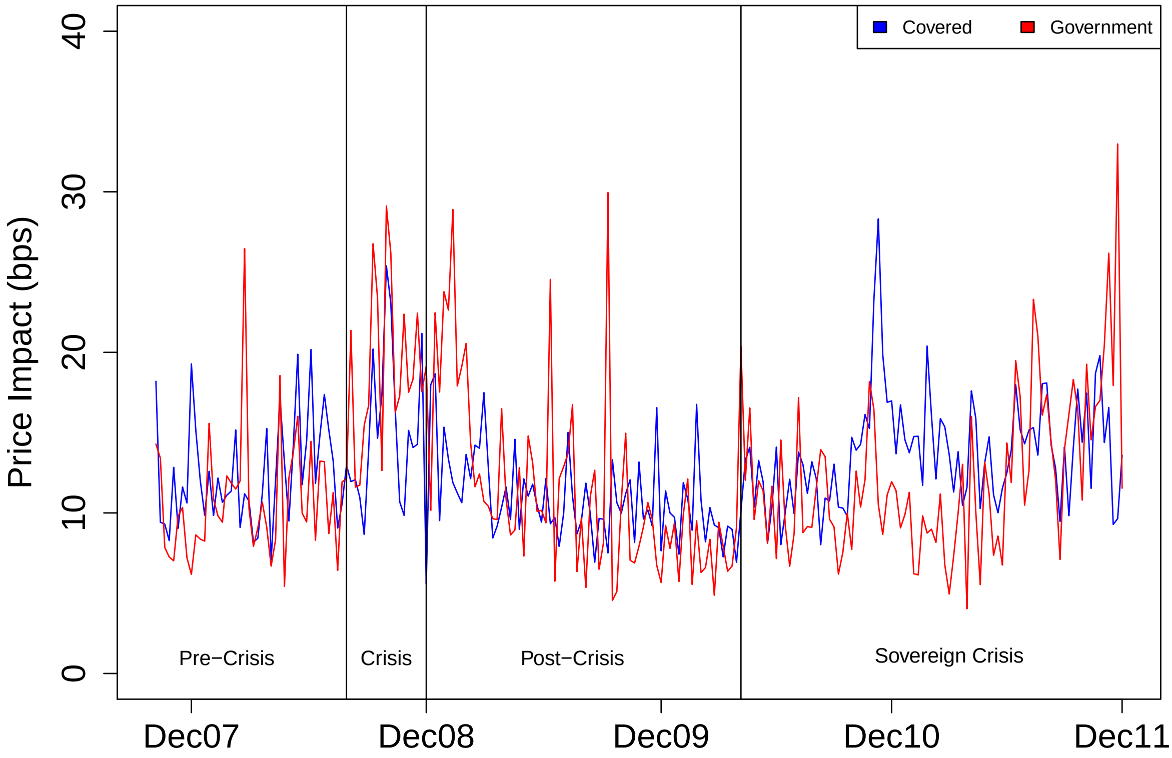

Figure 3:
Price impact for long term bonds.
The figure shows the weekly average price impact. The blue line is for long term covered bonds and the red line is for long term government bonds. The data period starts in November 2007. The crisis period is defined as running from August 15th to December 15th 2008. The post-crisis period runs from December 16th 2008 to April 30st 2009. The sovereign crisis period runs from May 1st 2009 to end 2011 (end of data). Long term covered bonds are defined as callable annuity covered bonds. Long term government bonds are treasury bonds with time to maturity between 5 to 10 years.

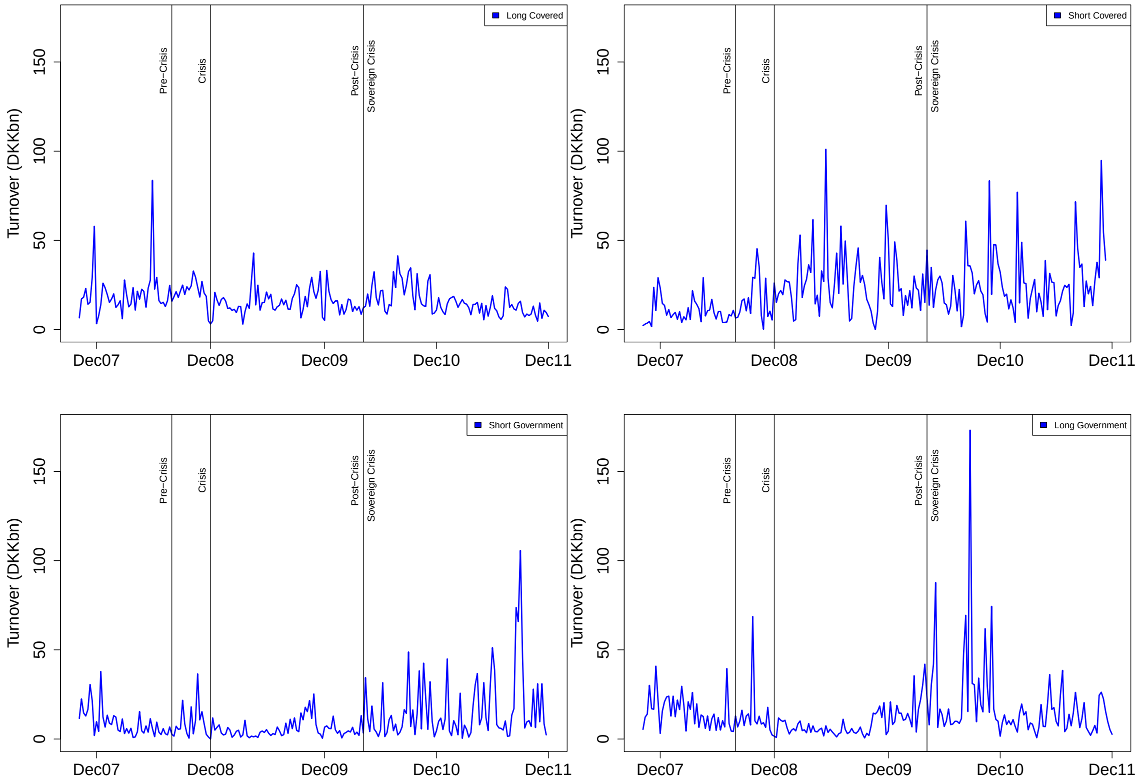

Figure 4:
Weekly turnover.
The figure shows weekly turnover in DKKbn for each bond market segment. The volume is only taken for transactions for which a price impact could be calculated. The data period starts in November 2007. The crisis period is defined as running from August 15th to December 15th 2008. The post-crisis period runs from December 16th 2008 to April 30st 2009. The sovereign crisis period runs from May 1st 2009 to end 2011 (end of data).

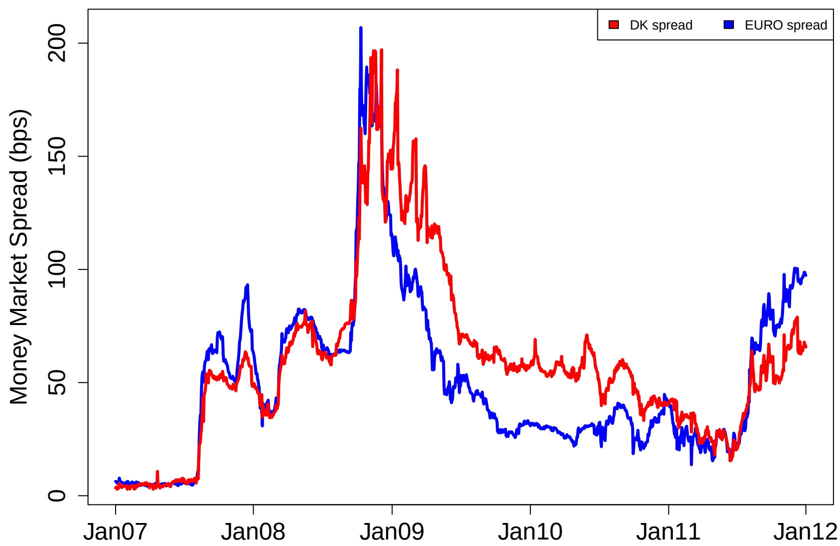

Figure 5:
Money market spreads.
The figure shows weekly observations of the money market spreads. The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate.

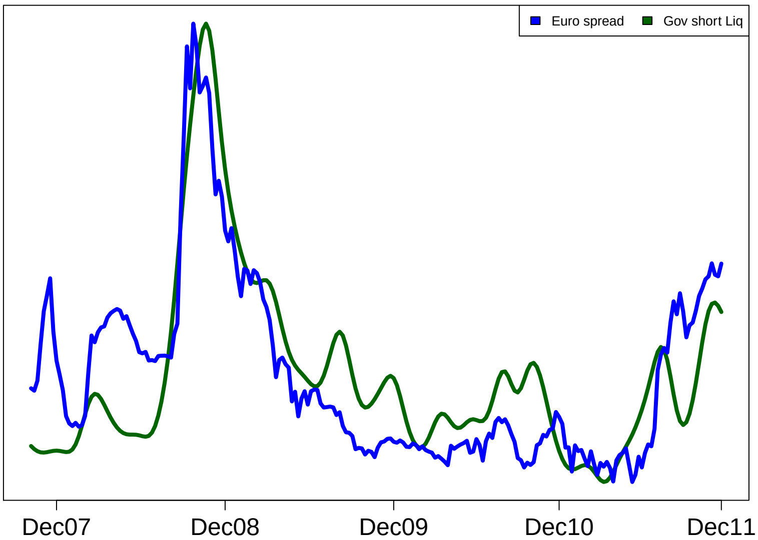

Figure 6:
Euro money market spread versus smoothed price impact for short term government bonds.
The figure shows the euro money market spread (the blue line) calculated as as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The green line is the smoothed weekly price impact series for short term government bonds. The smoothing is done by kernel smoothing with a gaussian kernel.

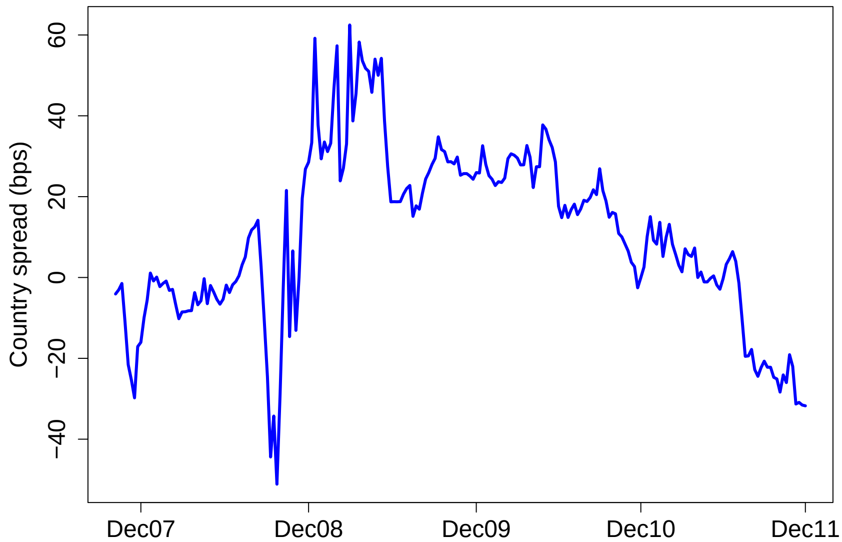

Figure 7:
Country money market spread.
The figure shows weekly oservations of the money market country spread. The country spread is defined as the Danish money market spread minus the euro money market spread. Where the euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate and the Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate.

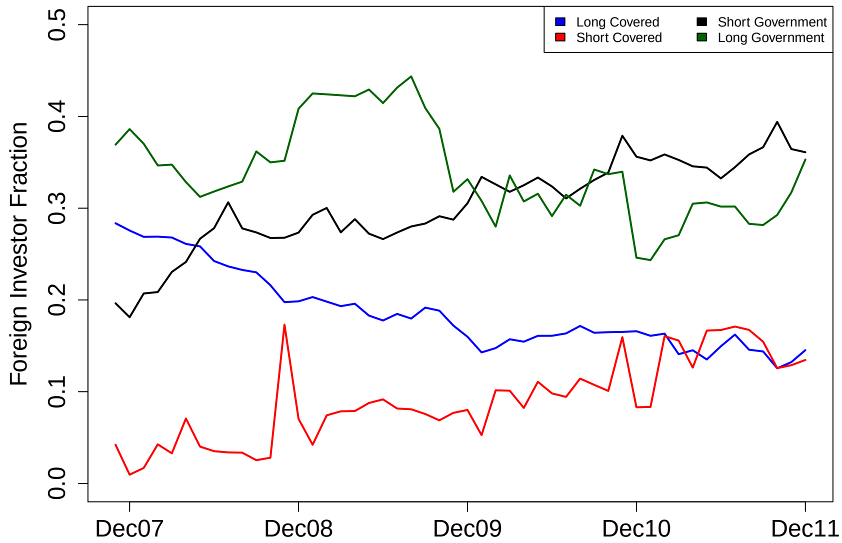

Figure 8:
Foreign investor fraction in Danish bonds.
The figure shows the fraction of bonds (based on volume) in each market segment held by foreign investors. The numbers are adjusted on a monthly basis and is provided by the Danish central bank.

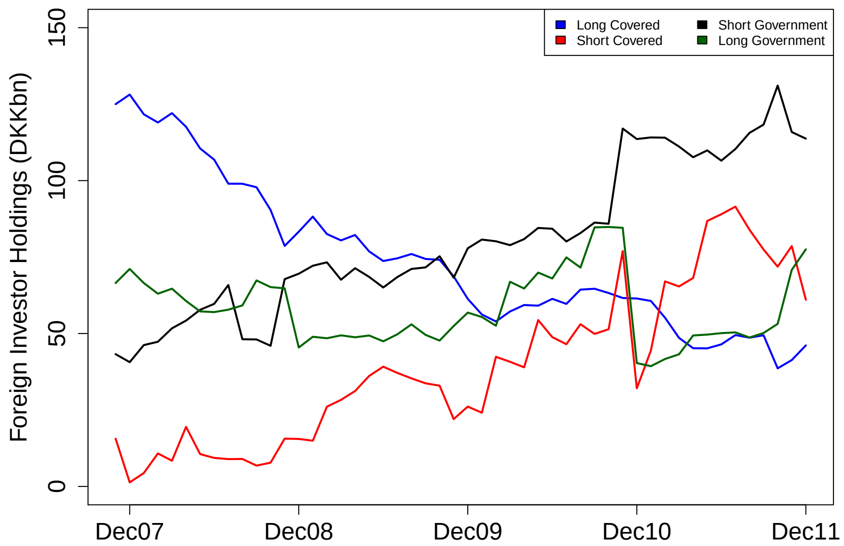

Figure 9:
Foreign investor holdings in Danish bonds.
The figure shows the amount in DKKbn of bonds in each market segment held by foreign investors. The numbers are adjusted on a monthly basis and is provided by the Danish central bank.

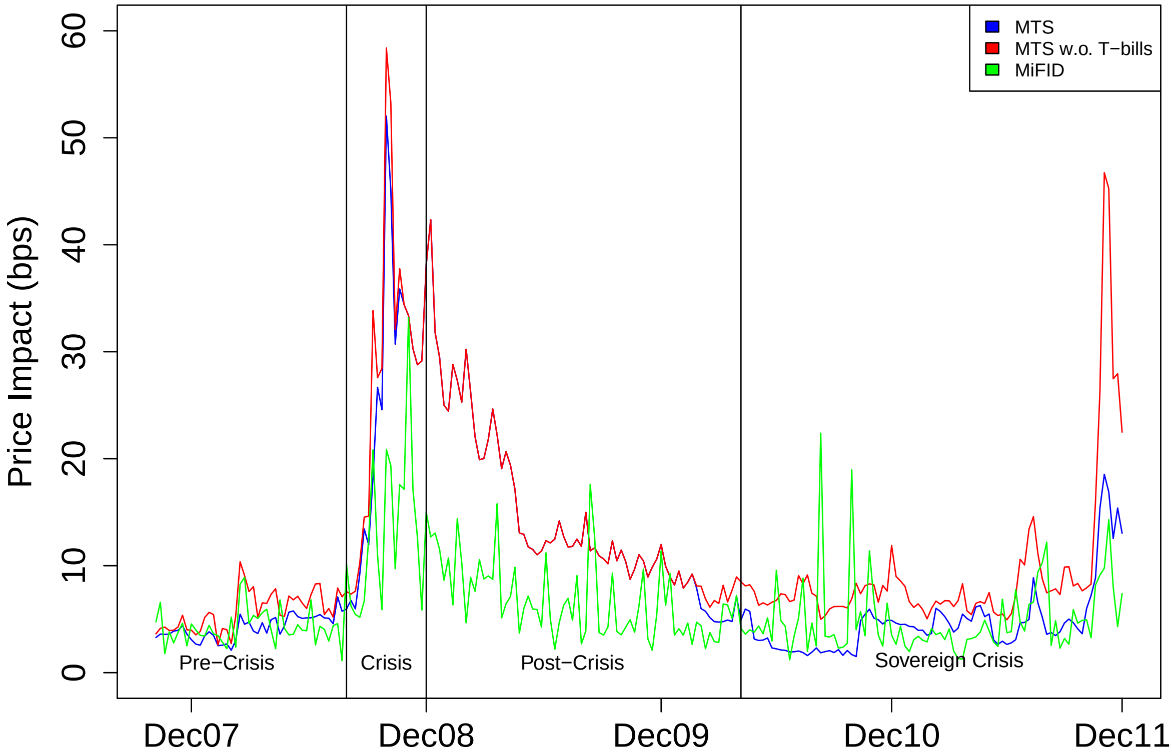

Figure 10:
Price impact for short term Danish Government bonds using MiFID and MTS data.
The figure shows the weekly average price impact. The blue line is for short term Danish government bonds using quoted prices from the the MTS platform. The green line is using MiFID data. Finally, the red line is also using MTS data, but in this case restricting the MTS sample to Treasury bonds, thus excluding Danish T-bills. The green line using MiFID data is also excluding T-bills.

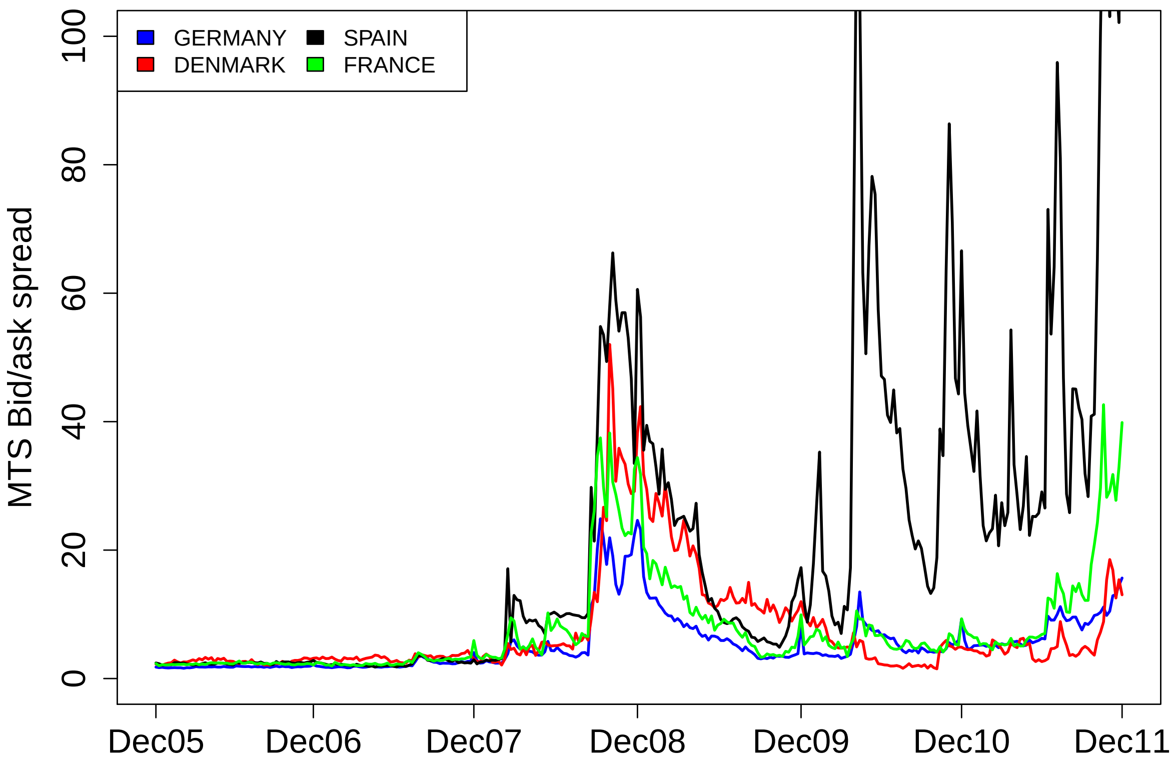

Figure 11:
Price impact for short term government bonds using MTS data.
The figure shows the weekly median price impact measures calculated using MTS quoted prices. The four lines are all short term government bonds with time to maturity less than 5 years. The blue line is for government bonds issued by Germany, the black line is for Spain, the red line is for Denmark and the green line if for France.

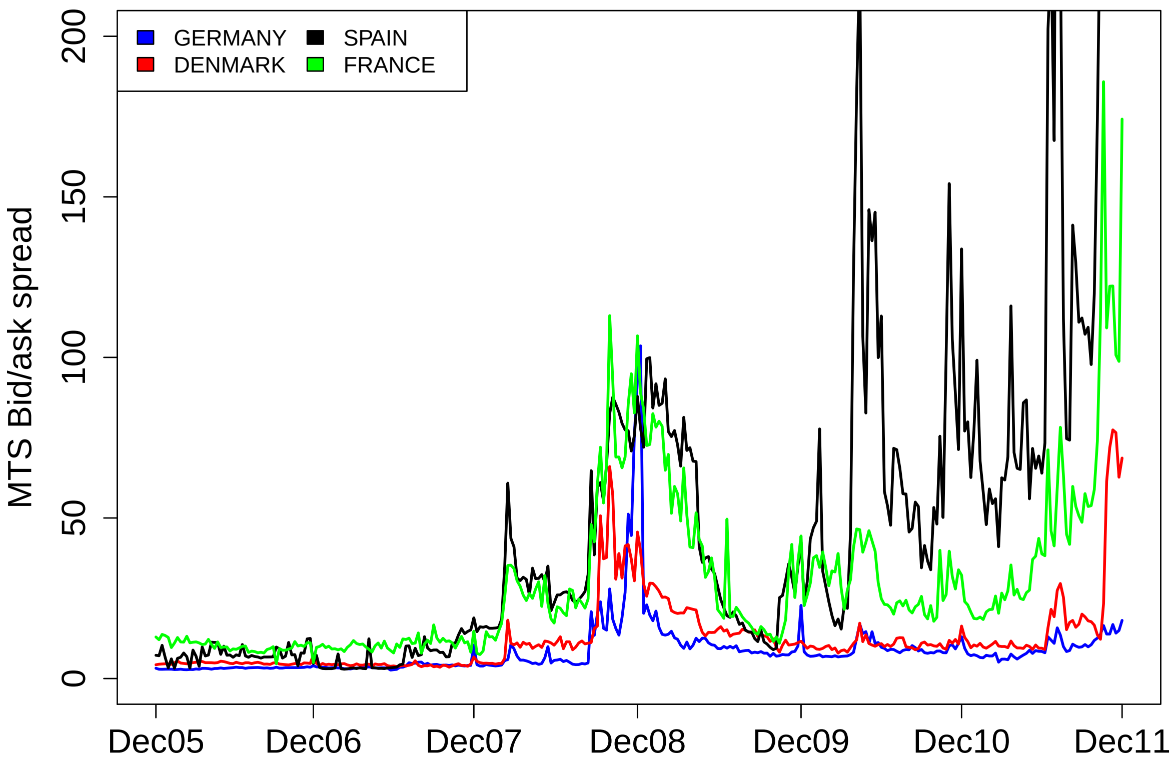

Figure 12:
Price impact for long term government bonds using MTS data.
The figure shows the weekly median price impact measures calculated using MTS quoted prices. The four lines are all long term government bonds with time to maturity between 5 and 10 years. The blue line is for government bonds issued by Germany, the black line is for Spain, the red line is for Denmark and the green line if for France.