Safe and liquid mortgage bonds: Evidence from the Danish housing crash of 2008.*

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Abstract

This paper shows that conservative loan-to-value ratios combined with strict matched pass-through funding is sufficient to ensure safe and liquid mortgage bonds. Despite a 30% drop in house prices during the 2008 global crisis Danish mortgage bonds remained as liquid as the government bonds in both Denmark and other EU countries. The very low credit risk meant that funding liquidity was the main driver of mortgage bond market liquidity which created communality in liquid across markets and countries. These findings have implications for how to design a robust mortgage bond system and for the regulatory treatment of mortgage bonds.

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Introduction

"There is a safe way to securitize home loans.
(...) we ought to look to the Danish model."
— George Soros*, WSJ, October 10, 2008.*

The 2008 global housing market crash made it evident in most countries that mortgage backed securities were almost as risky and illiquid during a crisis as the underlying real estate market. The massive failure of mortgage bond markets has renewed the interest in optimal mortgage market design (Campbell (2013)). The main question is if it is possible to apply a security design which makes mortgage bonds both safe and liquid? Instead of reinventing a mortgage market design one could consider the Danish mortgage bond model.[1] The Danish mortgage bond market has been in existence since 1795 and has long been viewed as robust and sound (Soros (2008)). Critics have rightfully pointed out that this is no longer clear as the Danish market over the last two decades has transformed from being dominated by fixed-rate mortgages (FRMs) to being dominated by adjustable rate mortgages (ARMs).

This paper provides the first empirical study showing that the Danish mortgage bond market is still both liquid and safe. The Danish covered bond market is one of the most sophisticated housing markets in the world. By end 2011, the outstanding amount of covered bonds corresponded to around 140% of GDP. The size of the market relative to GDP reflects that the vast majority of Danish mortgage loans, retail and commercial, are funded by the issuance of covered bonds. Issuance is completely dominated by specialized covered bond institutions or independent subsidiaries of major banks. Despite the 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

[1] We do not directly compare the matched pass-through funding principle with alternative security designs, however the Danish mortgage bond system has been compared to the US mortgage bond system in Frankel et al. (2004) and in Campbell (2013). Soros (2008) discuss which specific changes would be needed to transform the current US system into mirroring the Danish system.

outstanding bonds precisely match those of the underlying loans; a *matched pass-through funding principle*.

Historically, the use of strict matched pass-through funding has been a unique and defining design characteristic of the Danish mortgage system. Essentially, regulation restricts the amount of market and prepayment risk that mortgage banks are allowed to hold. Therefore mortgage banks are required to fund their lending activity by issuing mortgage bonds with cash flows that fully match those of the underlying mortgage loans until maturity on a loan-by-loan basis. In line with this principle, interest period on the bonds exactly matches interest period for the home owner thereby creating a natural 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 against interest rate, currency, and prepayment risk. In addition, as the borrower pays the mortgage bank's cost-of-funds plus a margin, the mortgage bank is also hedged against rising funding spreads. Finally, on top of the matched funding principle, having a conservative, i.e. low, loan-to-value ratio in the range of 60-80% combined with a large and diversified pool of borrowers means that credit risk is low and robust to even large house price variations. Since the inception in 1795 there has still not been a loss to mortgage bond investors due to defaults on the underlying loan payments.

We use a complete record of bond transactions from Denmark[2] for the period 2007-2011 to measure covered bond liquidity[3]. Our findings suggest that Danish covered bonds were as liquid as government bonds - also in periods of market stress. During the crisis, market liquidity declined notably in the government bond market but was more robust in the market for covered bonds. Overall, secondary market liquidity has returned to the same levels as seen before the crisis, and have improved slightly for Danish government bonds

[2]Specifically, we rely on confidential regulatory transaction reports from the Danish FSA. Transaction reporting is mandatory under the European Union Markets in Financial Instruments Directive (MiFID).

[3]Our framework has been applied in the European Banking Authority (2013) study and in internal EBA studies evaluating liquidity for all broader asset classes in the EU. Our empirical findings also laid the foundation of a change in the final CRD-IV draft which was featured by Reuters (March 28th, 2013) under the headline "Danish covered bonds granted liquidity wish".

during the euro area sovereign crisis - a finding which is consistent with the substantial inflows into Denmark as a result of the credit risk concerns that have affected a number of euro area government bond markets in the last few years.

For covered bonds we take a more detailed look at the role of bond characteristics when it comes to market liquidity. We show that investor or ownership concentration as well as bond size matters little for the liquidity. This supports the claim that it is enough to have some large and liquid issues within a market segment which can then be used to price smaller issues within the same segment. Time to maturity matters for the level of liquidity both for government bonds and for covered bonds. We also find that market liquidity is higher in inter-dealer transactions than dealer-client transactions. However, average daily turnover in inter-dealer transactions declined dramatically during the crisis compared to dealer-client transactions. The substantial decline in inter-dealer markets could reflect that the funding constraints for the dealers became binding during the crisis.

Consistent with the very low credit risk for the covered bonds and the decline in inter-dealer activity, we show that market liquidity is primarily driven by short term funding issues, i.e. money market stress. As money market spreads between secure and unsecure loan rates widens the price impact of trading goes up indicating a more illiquid market. Spread changes lead changes in market liquidity for the Danish market supporting that funding liquidity is driving market liquidity. We do not find any evidence of a spiraling or feedback effect from market liquidity to funding liquidity. The Danish covered bond market design thus makes the market more sensitive to investor funding liquidity concerns than to actual credit risk concerns. Using a broader data sample which includes other European bond markets, we show that market liquidity in these markets were also driven by money market stress, and we show that Danish covered bonds were also very liquid compared to e.g. French and Spanish government bonds.

Our findings are interesting from a regulatory perspective for at least two reasons. First, since properly designed mortgage bonds are both safe and liquid even during a global crisis they become candidates for use in regulatory buffers as high quality liquid instruments. This has already been recognized in the EU implementation of the Basel III rules under CRD-IV where mortgage bonds are allowed to be used in the liquidity coverage ratio (LCR) with a haircut of just 7% (only second to government bonds). Second, we clearly show that the availability of short-term funding drives bond market liquid across covered and government bond market. Therefore regulation which impacts e.g. repo markets, which is a popular market for market makers to obtain funding, will have the side effect of lowering bond market liquidity. This is a negative externality which cannot be overlooked and it is currently a concern in the European corporate bond market. Specifically, the treatment of repo transactions in the net stable funding ratio (NSFR) and in the leverage requirement of the CRD-IV has increased funding costs and therefore also lowered bond market liquidity at least in Europe.

When evaluating our crisis period one should not forget that similar to the situation in many other countries (Fender and Gyntelberg (2008)), Danish policy makers introduced a number of policy measures in the autumn of 2008 to stabilizing the banking sector as well as to restore confidence among market participants. It seems likely that without these measures bond market liquidity would have been lower. Most effort was put into easing the money market freeze, but a few measures where directly linked to the covered bond market. First, to ensure continued access to funding for Danish banks and mortgage banks, bank support packages providing government guarantees (in return for a fee) on banks liabilities were introduced. These guarantees were in place until September 2010. Second, to avoid a significant drop in investor demand for mortgage bonds, pension funds were allowed to use a higher discount rate (partly linked to rates on covered bonds) for their liabilities during the crisis period. Third, in November 2008 the Social Pension Fund, which is managed by the Danish central bank on behalf of the government, invested around EURbn 3 in short-term covered bonds. This investment may have helped shore up investor confidence at the peak of the crisis[4]. Finally, the Danish central bank, in line with other central banks, established temporary lending facilities. The significant size of the covered bond market, however, meant that most banks had sufficient amounts of eligible collateral for central bank repo funding during the crisis. These stabilizing measures should in our context be seen as necessary because the covered bond market was integrated in a larger financial system, rather than because the mortgage contract design had flaws which first became visible during the housing crash.

The Danish covered bond market

Covered bond market overview

Even though the Danish economy is relatively small, the Danish covered bond market, which is based primarily on household mortgages, is one of the largest in Europe and in the world (see eg. ECB (2012)). 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.[5]

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

[4]The aim of the investment was to cover the central-government's interest-rate risk related to financing of subsidized housing. Although this relatively small measure was attributed to the government's interest-rate risk management, it was widely interpreted by market participants as a signal that the government was ready to support the market in case of further turmoil related to the crisis.

[5]See Frankel et al. (2004) for an in-depth description of the Danish market for callable fixed rate mortgage bonds.

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. Since early 2014 the trend is again moving away from short-term ARMs towards longer term ARMs and the old fixed rate callable mortgage loan.

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, 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 perceived credit risk. During the crisis, not all issuer maintained the same level of credit risk and prices could depend upon the specific issuer.[6]

The matched pass-through funding principle which is the basis of the Danish mortgage contract design, minimizes the credit risk that the mortgage banks are exposed to. The issuing bank is only really exposed to the credit risk from 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.[7] Since credit risk have been a minor issue for investors historically and including the 2008 crisis, we will focus the following analysis on the liquidity of the covered bond market.

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[8] of a trade is defined as the

[6] In the analysis, we exclude bonds from BRF Realkredit because it was perceived slightly more credit risky than the other large issuers.

[7] To address this issue the Danish government in November 2013 presented a bill on compulsory, contingent maturity extension for mortgage bonds if refinancing is not possible.

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

absolute return between adjacent transactions:

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

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 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:

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

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, e.g. short term government bonds, 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:

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

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 important for the long term covered bond market since there exists a large number of very small long term covered bond series as will be explained in section . By weighting with amount outstanding the importance of these series are appropriately reduced in the weekly market measure. Note that we do not scale price impact with the transaction volume, we will motivate this choice in the following sections.

Data source

Our data bond transaction sample covers all transactions in the Danish bond market. These transactions are collected by the Danish FSA as part of the MiFID regulation[9] implemented in EU starting November 1st, 2007. More specifically, the data includes all transactions carried out with 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 the appendix.

As the aim of our analysis is to determine the liquidity 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 the covered bond and the government bond market 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.[10] A somewhat surprising empirical observation is that the price impact is independent of the trade size in the

[9]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.

[10]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.

Danish sample. This can be seen in table 1, 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 high frequency version of 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[11]. However, the observations in table 1 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 $\text{PI} = \lambda \times Q$ for some $\lambda > 0$ assumed for the Amihud measure would not be appropriate for the Danish data. Note that the high frequency 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.

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 bondholder information in the form of investor concentration in each bond.

[11] 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.

Covered bond data

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 (consistent with the unity market design discussed earlier).

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.[12] Thus, bonds with the same promised cash flow from different issuers trade in the market at the same 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. This greatly increases the number of observations and thereby the accuracy of our analysis.[13]

The short-term covered bonds in our sample are fixed-rate bullet bonds with a time to maturity of less than 1.2 years.[14] The 1-year bonds underlying the 1-year ARMs (in the Danish market they are often referred to as 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 2 we present summary statistics for the entire market (all issuers and including primary market auctions) as well as our sample (the 3 largest issuers and excluding auctions). 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

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

[13]We test the robustness of this approach in the robustness section.

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

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 2 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.[15] This reflects 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. 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 did 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.

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

Government bond data

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 2 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 few very large 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).

Money market data

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 3 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.

Market Liquidity - Danish covered versus government bonds

This section compares the liquidity in the four main bond market segments; short term and long term covered bonds, and short term and long term government bonds. Outside the 2008 financial crisis, government bonds are slightly more liquid than covered bonds. However, during the crisis the covered bond market performed better.

Figure 1 show that the average weekly price impact measure was broadly the same for short-term covered and government bonds before the 2008 crisis.[16] The estimated liquidity levels for the pre-crisis period in table 1 point to higher average liquidity in the government bond market for benchmark trading sizes. However, the actual difference in liquidity in terms of price impact 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.

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

In the post-crisis period we see that although liquidity has been lower than before the crisis 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 2. Looking at the price impact estimated in table 1 we can see that the pre-crisis levels for the liquidity measure are not very different (furthermore the difference is statistically insignificant). But they do show a lower level of liquidity for long-term bonds than short-term bonds. The difference in price movement compared to the short-term bonds is around 6 basis points on average, 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.

We run the following regression for each market segment and inter-dealer and dealer-client transactions separately:

$$\text{PI}_{t,k} = \alpha + \beta_1 \times \text{Crisis}_t + \beta_2 \times \text{Post-Crisis}_t + \beta_3 \times \text{Sovereign Crisis}_t + \epsilon_{t,k} \tag{4}$$

where k refers to the market segment (e.g. short term government bonds) and t refers to the week t. The crisis dummy is 1 between August 15th, 2008 and December 15th, 2008 and 0 elsewhere. The post-crisis dummy is one between December 16th, 2008 and April 30st, 2010 and 0 elsewhere. The sovereign crisis dummy is 1 between May 1st, 2010 and end 2011. The chosen starting point of the sovereign crisis is arbitrary. The results are robust to choosing an earlier starting date for the sovereign crisis.

The price impact in inter-dealer transactions are generally lower than those in dealer-client transactions as can be seen in table 3. We define dealers to be the large banks which have participated in the market maker arrangement for covered bonds and clients are defined as non-banks. These definitions thus exclude small banks from the sample. The striking although not surprising results from the table is that inter-dealer transactions have a price impact of roughly 2/3 of that for a dealer-client transaction. This is a consequence of the higher bargaining power for large banks compared to clients (as in Duffie et al. (2007)). The time series behavior mimic those for the full sample benchmark trade sizes in table 1.

While the inter-dealer market has the lowest price impact there is a clear effect of the crisis when looking at the turnover. 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 even if the bonds still traded actively.[17]

Determinants of market liquidity: Bond characteristics

While Danish covered bonds and government bonds are equally liquid, it is still interesting to know which characteristics explain variation in liquidity across bonds within asset classes. This section investigates time to maturity, issuance size and investor concentration as possible determinants of liquidity.

Time to maturity

For both covered and government bonds short term bonds are more liquid than long term bonds as can be seen in table 1. This is consistent with prior literature and can be explained by smaller price uncertainty for the short term bonds.

In our covered bond sample we have defined short term bonds as those used to fund 30 year ARMS. The short term bonds thus has a time to maturity between 2 to 14 months (these are often called F1 bonds in the Danish market). Similarly, we define F3 as having maturity of between 14 to 38 months, F5 as having maturity between 38 and 62 month

[17]In unreported results we also show that expected liquidity in the form of the variability of the price impact measure was rather persistent over time and showed very similar properties as that of the liquidity level.

and F10 as having maturity between 62 and 120 months. The plus 2 month which is contained in each group stems from the auctions being placed 2 month before the round maturities.

Figure 4 shows the time series of the average price impact measure for the F1, F3 and F5 bonds. The F10 series is omitted because the time series is very erratic and sparse which is evidence that this bond is much less liquid than the others. The figure shows that as the maturity increases so does the illiquidity. The time series behavior is the same as we have seen for the other market segments, there were less liquidity during the crisis after which the liquidity has recovered. Although, the long term ARMS have suffered after a little after the crisis.

The turnover trend seen for dealer-client transactions in the F1 bonds in table 4 is also true for the F3, F5, and F10 bonds (except that turnover is lower as maturity increases). The F1, F3 and F5 bonds have become increasingly popular after the crisis. This has happened as both financial and non-financial corporations have started to use these bonds in their liquidity management as an alternative to short term government bonds.

Even though there is a clear time to maturity effect in the tables, it is possible at this point that the effect could just as well be a issuance size effect. As time to maturity increases across these samples, the size of the aggregate market decrease. Hence, we are not able to completely rule out that the maturity effect is really a size effect. We investigate this further in the next section.

Issuance size

The issuance size varies a great deal within each market segment for the covered bonds. Given that the government bonds are few in numbers and large in sizes, we restrict the issuance size analysis to only include short and long-term covered bonds ie. the original covered bond samples.

Table 5 shows the estimates from a size quartile regression. The price impact observations from each bond issue is assigned into a quartile based on the free-float amount outstanding of the bond on a monthly basis. Hence, the 1st quartile contains observations for the smallest bond issues and the 4th quartile contains price impact observations from the largest bond issues. In each month there are an equal number of bonds in each quartile bucket.

The table shows two things. First, the price impact increases slightly as issuance size decreases. The absolute increase in basis points is however not huge and lies in the range of 2 bps for short term bonds and 1 bps for long term bonds. This should be compared with the decrease in issuance size which is far more substantial. The bonds in the low quartile are of a median size over time of 4-9 DKKbn with the largest group ranging from 77-123 DKKbn over time for the short term bonds. Given this massive difference in issuance size, the price impact difference seems even smaller. The other thing to notice from the table, is that the activity is concentrated in the large issues. The number of price impact observations are naturally clustered within the larger issues. Activity measured by the number of transactions is thus also not strongly related to liquidity.

The bonds have approximately the same promised cashflows across the quartiles. So they are close substitutes with the main difference being that some of the series are still seeing new issuances at auctions.[18]

Given that the bonds are close substitutes from the same group of issuers, the minor effect of size is a consequence of a liquidity spillover. Part of the market is very large, active and liquid. This part makes it easy to value other but smaller issues. There is no preference for one issue over another which could distort this equilibrium. Of course there could be a problem for an investor seeking to buy a specific issue which is locked into a portfolio, but there is seldom any need for this. That would primarily be interesting for

[18] Some of the size differences is also due to the series being repo'ed in the Danish central bank. If this is the case we do not count it as part of the free float size of the bond. Hence, when we say issuance size we have subtracted all bonds used as collateral with the Danish central bank. However, this does not account for the majority of the size differences.

smaller investors if they wanted to exercise the delivery option in their mortgage loan but since we focus on whole sale trading this is not an issue.

Investor concentration

Investor concentration might matter for the liquidity of the covered bonds. The government bond issues are very large and rarely concentrated at a few investors. The covered bonds on the other hand might be held only by a few investors. For smaller investors trading in covered bonds it could be an advantage that the investor concentration is low so that it becomes more likely to meet a potential counterparty. For the large investors involved in whole sale trading the picture is not as clear. It might be easier to sell a large block than several smaller blocks. We divide investor concentration into three levels - high, medium and low. A high investor concentration is defined as a bond with maximum ownership fraction by a single investor of more than 50%. Medium is for a maximum ownership fraction of between 20% and 50%. Low is for a maximum ownership fraction below 20%.

Table 6 shows that investor concentration makes little difference for the liquidity of the issue. The bonds with high investor concentration was a little more illiquid before the crisis. During the crisis they performed better than the bonds with lower concentrations of investors. Most bonds however have a medium level of investor concentration and as such it is not an important factor for the covered bond market.

Determinants of market liquidity: Funding Liquidity

In this section we test for a relationship between funding liquidity and market liquidity (Brunnermeier and Pedersen (2009)). As a proxy for funding liquidity we use money market spreads between secured and unsecured loan rates. An alternative could be the level of the repo rate, but it yields similar results.

Dealers in the Danish bond market often have substantial gross long and short positions due to their market-making obligations. An active repo market is important to maintain these long and short positions. During our sample period, large Danish banks had invested part of their equity in highly leveraged positions of, especially, short term covered bonds. This increased their exposure to funding market liquidity. Also, both domestic and 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 via the repo market.

Market versus funding liquidity

As a first glance figure 5 shows a smoothed version of the weekly short-term government bond market liquidity from figure 1, plotted alongside the weekly EURO money market spread. The two graphs are indexed to fit the same scale and shows a very strong correlation between the two series. The graph thus gives a first indication of the empirical relationship between market and funding liquidity. Granger causality tests also confirm that the euro money market spread seems to predict market liquidity (p-values ¡ 0.0001). The only market with a weak connection (p=0.08) 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 EURO money market spreads it may just be a spurious relationship.

Instead of looking at the levels of the series, we look at the weekly changes and perform a principal component decomposition. 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 regressions on each principal component using changes in money market spreads as the independent variables:

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

where PC_t is the principal component and t refers to the week. The regression uses Newey-West corrected standard errors and resembles a Granger causality test.

All the principal components exhibit a strong mean-reversion indicating that liquidity is fairly stable over time as we could also see it in the earlier liquidity graphs.

The first principal component is also predicted by changes in the EURO money market spreads. Whereas 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 i.e. a country spread. The last two principal components are not related to money market spread changes.

Our Danish 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 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 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 Danish 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 Danish money market spread may be more noisy than the EURO spread, particularly in the beginning of the sample period.[19]

For the short term covered bonds, the country spread is a better predictor than the EURO or Danish money market spreads. 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

[19] We also perform a test for a feedback effect from market liquidity to funding liquidity as predicted by Brunnermeier and Pedersen (2009). However, we find no statistical significance (p¿0.05) supporting such an effect. This is possibly due to the weekly sampling, we may need to use a more granular sampling in order to capture this effect. This is however not possible with the current data.

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, foreign investors have increased their holdings of short covered bonds from approximately 1% to 15% (or DKKbn 60) of the amount outstanding over the sample period, and this is likely to increase the importance of the country spread in affecting the liquidity of the short covered bond market.

Comparison with other European government bonds

Here we compare 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 6 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 (we look at the difference in the robustness section), but are very close.

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 7 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 8. 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. Hence, even when we compare the liquidity of Danish covered bonds to those of other European government bonds markets, the Danish covered bonds are very liquid.

Table 9 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 was the case 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 10 runs a regression where the principal components are explained by lagged values of itself and lagged weekly changes 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.

Robustness analysis

In the empirical methodology we have taken some choices aimed at increasing the number of observations. We have chosen an easy-to-calculate high-frequency liquidity measure and we have chosen to pool observation from different issuers. Here we test the robustness of these two choices and show that the results are rather robust in this respect.

Market liquidity or realized volatility?

A valid critique of the unscaled price impact measure is that it resembles realized volatility. It would be exactly realized volatility if the returns had an expected (or realized) return of zero and if we switch the absolute return for the squared return. It is not clear that it makes a difference in our paper whether we analyze one or the other. The conclusions would more or less be the same. However, it would matter for some applications and it would of course be nice if we were actually measuring market liquidity when we say that we measure market liquidity.

Figure 6 showed the price impact calculated using MiFID data versus two bid-ask spread series calculated using MTS quotes. The quotes are supposed to be executable and binding and therefore of high quality. It is clear in the figure that the MTS bid-ask spread is above the MiFID price impact numbers during the crisis and in the post-crisis. Outside these periods, the measures match up very closely. The reason for the discrepancy during the crisis is that the dealers were funding constrained following the crisis. Anecdotal evidence suggest that the dealers were not really eager to trade but had to post quotes anyway (a requirement from the Danish central bank if the dealers wanted to stay primary dealers in Danish government bonds). The dealers thus posted wide spreads to deter investors. It was possible to trade inside the spread after negotiation with the dealers. This is what we see in the figure. The bid-ask spreads that are quoted (MTS data)) are wider than the spread inferred from actual trading (using the MiFID data). Still, the spreads are not so far apart that the MiFID price impact measure is unreliable.

Liquidity by issuer

In our analysis 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. Hence, we implicitly rely on the assumption that the the Danish covered bond market is a "unity market", i.e. that it has a fairly well-functioning OTC market-maker agreement with virtually no differentiation across bonds from different issuers as was the case prior to the financial crisis.

While the financial crisis did result in renewed focus on differences in perceived credit risk among bond issuers, conversations with market participants (including market makers) suggest that while market making arrangements did evolve in response to the the crisis, they did not disappear. For long-term callable mortgage bonds, the presence of unity market is a reasonable assumption through the period 2007–2011.[20] For the shorter term covered bonds, the validity of the unity-market assumption is less clear. There have been sub-periods with notable price differences due to the investor preferences discussed earlier. At any rate, a breakdown of the unity-market assumption would lead to an upward bias in our estimated price-impact measure, which would mean that we underestimate liquidity.

In the analysis we have pooled the three largest issuers because the market sees them as being equally credit risky. The bonds therefore trade as though they had been issued by a single company. In order to test the robustness of the unity market assumption, we split the sample and generate issuer specific price impact measures. These are shown in figure 9 for short term covered bonds. The split by issuer means that we no longer assume a unity market for the short-term covered bonds and restrict the calculation of the price impact measures to transactions within the same bond (same ISIN-code).

We find that while there are smaller differences over time between the issuers, the variation seen in the graph is not statistically significant nor is it systematic over time. The results for the issuer specific series are both qualitatively and quantitatively the same with or without the unity assumption. Hence, the implicit assumption of a unity market does not affect our main findings. It does however boost the number of observations.

[20] At least as long as the bond is trading below par

Conclusion

We show that the Danish covered bond market and government bond market were equally liquid before, during, and after the 2008 housing market crash and financial crisis. We attribute this to the market design which revolves around the matched pass-through funding principle. Empirically, Danish mortgage bonds remained very safe and liquid during a period of severe market stress in contrast to the situation in many other countries.

The covered bond market liquidity is linked to both bond characteristics and the availability of investor funding liquidity. We identify the time to maturity as the main bond characteristic that matters for liquidity. This is identical to saying that the cashflow design is important for the liquidity. Other characteristics such as issuance size and investor concentrations have little impact in the Danish market design.

In the absence of credit risk concerns what is left to impact the time variation in market liquidity is available funding liquidity. Consistent with this we show that money market stress leads changes in market liquidity. This is true not just for the Danish market but also for other European markets.

The link to the money market also meant that the covered bond market benefitted from various government measures at the peak of the crisis. Because of the close tie between the liquidity in the covered bond market and money market stress it does not make sense to try and disentangle the effect of the government measures from the mortgage security design. However, we clearly show that the sum of the mortgage market design and government measures resulted in a covered bond market that remained safe and liquid during the crisis.

From a practical perspective our use of MiFID data, which should also be available in other European countries suggests a possible way forward for jurisdictions seeking to provide robust empirical evidence on the liquidity of their various bond markets or other asset classes (European Banking Authority (2013)). It should however be pointed out that the use of the highly granular transaction level data requires additional effort and investments in data structuring and quality control to be used for analysis of the kind presented here. However, data on actual transactions do provide the opportunity to look at what actually happened.

A benefit of our price impact measure is that it resembles an effective bid-ask spread over a given period. Hence, even though we do not have observed bid-ask spreads on executable or indicative quotes by trade size, price impact embeds information on actual market depth at given points in time.

Finally, from a broader policy perspective, the evidence on the similar liquidity of the government and covered bond markets, including during periods of severe market stress, explains why European Union regulators have decided to take into account the actual liquidity of different types of bonds when determining the size of the liquidity buffers that banks are required to hold.

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Appendix: MiFID data

Data fields

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. The requirement has applied since November 1st, 2007. Therefore, our dataset should include all transactions in Danish government and covered bonds carried out by an investment firm or credit institution in the EU as one of the counterparties since these transactions should have been reported and the reports passed on to the Danish FSA. The fields in the transaction report used in our analysis are shown in table .

Bond metadata

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. can easily be added from another data source. We have obtained this information form the Danish central bank, Nationalbanken, which receives this information from the central securities registration agent in Denmark, VP-securities, on a monthly basis.

Data cleaning

We have adjusted and cleaned the data in several steps:

Table: Transaction report variables

Variable	Description
Instrument identification	The International Securities Identification Number (ISIN) that uniquely identifies the transacted bond
Trading date time	The date, time and time zone when the trade was executed.
Unit Price	Price per bond excluding commission and accrued interest (clean price).
Quantity	The total nominal value of bonds included in the transaction
Currency	Currency in which the price is expressed.
Buy/sell indicator	Identification whether the transaction was a buy or a sell from the perspective of the reporting investment firm if acting as a principal, or of the client if acting as an agent.
Trading capacity	Identification whether the reporting firm executed the transaction ”on its own account, either on its own behalf or on behalf of a client” (Principal) or ”for the account, and on behalf, of a client” (Agent).
Reporter identification	A unique code to identify the firm which executed the transaction. An 11 characters ISO 9362 SWIFT/Bank Identifier Code (BIC).
Counterparty ID	The BIC code if the counterparty is a MiFID investment firm. The MIC code of the trading venue if the counterparty is a regulated market or a multilateral trading facility (MTF). Otherwise an internal code for the customer/client is used.
Client name	The name of the client/customer. This field is optional.

1. The aim of the analysis is to determine the liquidity characteristics of government and covered bonds from the perspective of banks ability to liquidate these assets in times of stress. Therefore, retail size trades should be removed as they will otherwise distort the analysis. In the case of Danish government bonds and covered bonds we remove all transactions with a nominal value of less than DKK 10,000,000 (approximately EUR 1,340,000).

2. The variable 'Trading capacity' is used to adjust the buy/sell indicator so that for all reports the buy/sell indicator reflects the perspective of the reporting firm. If the 'Trading capacity' variable indicates that the reporting firm is acting as an Agent and therefore reports the transaction as seen from the perspective of the

counterparty we change the buy/sell indicator from buy (sell) to sell (buy). This ensures that the indicator reflects the perspective of the reporting firm.

3. A large number of errors were identified in the counterparty identifiers. Reporting firms often use an internal code for MiFID investment firms instead of the BIC-code. By manually inspecting the most frequent internal codes in the field; 'counterparty identification' and using the optional variable 'Client name' we were in most cases able to correct this.

4. Although repo transactions should not be reported, some firms nevertheless report repo transactions. We were able to detect and remove repo transactionin cases where we found two transactions in opposite direction (buy/sell) and different prices, with the same counterparty in the same bond and of the same amount at exactly the same point in time.

5. Transactions between two investment firms are to be reported by both parties. Therefore, these transactions will be reported twice. This is also the case for transactions on a regulated market or a MTF as both parties trading on a regulated market or a MFT will be required to report the transaction. All transactions that are reported twice need to be detected and only one of the transactions should be kept in the dataset. Fortunately this is straightforward as one can easily identify all transactions between two investment firms or between and investment firm and a regulated market or a MTF.[21] For all these transactions either only the sell side or the buy side transaction report should be kept. Specifically, we choose to keep only the sell side transactions. We have observed that some counterparties that are investment firms never report any transactions themselves. To adjust for this error in the data we also require that counterparties that are investment firms should

[21] A complete list of MIC codes can be found at the ESMA webpage `http://mifiddatabase.esma.europa.eu/`

have reported at least one transaction themselves before we delete the buy-side transactions.

6. Although primary market activity is not required to be reported under the MiFID directive, we find that transactions at the primary market are nevertheless reported in some cases. Furthermore, at days of auctions in short-term covered bonds the activity is often much higher than in normal days. This heighten activity do not reflect the normal situation faced by a bank that need to liquidate (parts of) its bond portfolio. Therefore we have decided to remove these observations from our dataset. As compared to the preliminary findings in Buchholst et. al. (2010) this is an improvement in our data cleaning process. For the covered bond market, auction dates are identified from announcement on auction schedules made by the mortgage banks. On a date where a mortgage bank conduct auctions we remove all trades in short term bonds issued by this particular bank. This method will inevitably result in too many trades being removed as the auctions do not necessarily involve all short term bond issued by the bank. However, it would have been highly time-consuming to identify exactly the bonds involved in the auctions. Apart from the auction dates themselves we have also identified some circumstances of unusual heightened activity in the days close to the auctions involving bonds with very short time-to-maturity. Apparently this reflects that sometimes the mortgage banks for operational reasons buy back some of the bonds that are anyway maturing very soon. We define such unusual high trading activity as days within a month of refinancing where we observe at least 5 trades of more than DKK 5 billion in the same bond. We then remove that trading day for the bond in which we observed the very large trades. Government bond market information on auctions and tap sales are obtained from the Danish Debt Management Office. We do not observe an elevated turnover at days with auctions or tap sales. Thus, we decided not to remove these days. Instead we

have removed all transactions that involve the Danish central bank as the Debt Management Office carries out all its transactions through the central bank.

7. We have removed outliers by deleting all trades at prices below DKK 50 or above DKK 150 as any breach of these limits would result in implausible yields for our sample of bonds. We also delete trades involving a higher volume than the outstanding amount of the bond. Finally, we manually inspected all trades with a price impact (see section 3) of more than 100 basis points. In most cases we found that the high price impact is due to a single transaction reported at a very odd price compared to other transactions at that time. Thus, we end up deleting (almost) all transactions giving rise to price impacts of more than 100 basis points.

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 1:
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).

Market Segment	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 2:
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.

Panel A: Dealer-Client transactions

Bond Series	Long Covered	Long Government	Short Covered	Short Government
Intercept	11.403***	11.503***	4.599***	5.237***
	(0.837)	(0.680)	(0.285)	(1.055)
Crisis_t	2.446***	6.505***	2.866	10.067***
	(0.412)	(1.463)	(2.470)	(0.978)
Post-Crisis_t	3.475***	0.407	1.564***	1.680
	(1.415)	(0.656)	(0.391)	(1.721)
$\text{Sovereign Crisis}_t$	5.128***	2.863**	2.706***	2.077
	(1.477)	(1.401)	(0.755)	(1.943)
N	10,946	5,294	4,327	6,383

Panel B: Interdealer transactions

Bond Series	Long Covered	Long Government	Short Covered	Short Government
Intercept	7.705***	7.255***	2.471***	3.224***
	(0.605)	(0.789)	(0.193)	(0.310)
Crisis_t	-0.463	2.434	-0.127	4.046**
	(0.823)	(1.509)	(1.076)	(2.377)
Post-Crisis_t	-1.787**	1.403	2.150***	1.783***
	(0.688)	(0.986)	(0.647)	(0.559)
$\text{Sovereign Crisis}_t$	0.335	3.029***	0.947	-0.299
	(0.767)	(0.644)	(0.658)	(0.467)
N	8,174	1,040	1,123	722

Table 3:
Regression of price impact on time dummies for different market participants.
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.

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 participants.
The table shows average daily turnover in DKKm 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.

Panel A: Short Covered

Size Quartiles		1st	2nd	3rd	4th
Intercept	Est.	7.98***	5.98***	6.27***	5.85***
	Std.Dev.	(0.73)	(0.40)	(0.53)	(0.23)
	Size	9.1	16.6	35.2	77.5
Crisis_t		1.96	2.23*	0.67	3.64***
		(1.71)	(1.28)	(1.15)	(0.59)
		5.6	11.8	30.3	81.7
Post-Crisis_t		-0.39	1.00*	0.52	0.95***
		(0.91)	(0.54)	(0.63)	(0.34)
		8.1	18.5	50.5	123.6
$\text{Sovereign Crisis}_t$		3.64***	1.49**	0.95	0.52
		(1.21)	(0.66)	(0.60)	(0.35)
		4.0	16.9	54.2	99.0
N		925	1,701	3,106	7,320

Panel B: Long Covered

Size Quartiles		1st	2nd	3rd	4th
Intercept	Est.	13.10***	11.4***	11.14***	12.88***
	Std.Dev.	(0.55)	(0.39)	(0.38)	(0.35)
	Size	1.5	5.0	13.2	29.8
Crisis_t		-0.48	1.36*	1.55	3.37***
		(1.04)	(0.79)	(0.64)	(0.73)
		2.0	4.6	11.3	25.5
Post-Crisis_t		0.19	-1.04**	-0.22	-2.32***
		(0.76)	(0.48)	(0.46)	(0.42)
		1.6	4.3	9.9	20.4
$\text{Sovereign Crisis}_t$		1.36*	2.83***	2.78	1.61***
		(0.75)	(0.59)	(0.53)	(0.46)
		1.4	4.5	9.5	19.9
N		3,997	6,888	8,933	12,061

Table 5:
Regression of price impact size quartiles on time dummies for covered bonds.
This table shows regression estimates for short and long term covered bonds divided by bond size quartiles. Each week bonds are assigned into a quartile based on the free float amount outstanding of the bond. The first quartile is the smaller bonds. The size measure in the table is the average free float amount outstanding in DKKbn for all the transactions in that quartile. The regression is specified as:

$$\text{PI}_{it} = \alpha + \beta_1 \times \text{Crisis}_{it} + \beta_2 \times \text{Post-Crisis}_{it} + \beta_3 \times \text{Sovereign Crisis}_{it} + \epsilon_{it}$$

Note that this regression uses individual transactions instead of a weekly measure to illustrate where the transactions are concentrated 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). Robust standard errors are calculated following Newey-West. Significance at 10% level is marked *, at 5% marked **, and at 1% marked ***.

Panel A: Short Covered

Investor Concentration	Low	Medium	High
Intercept	6.04***	6.05***	6.42***
	(0.23)	(0.31)	(0.48)
Crisis_t	2.07**	4.27***	0.74
	(0.81)	(0.74)	(1.03)
Post-Crisis_t	-0.33	1.24***	-0.02
	(0.53)	(0.39)	(0.55)
Sovereign Crisis_t	2.76***	0.61	2.50***
	(0.74)	(0.37)	(0.80)
N	2,322	8,439	2,265

Panel B: Long Covered

Investor Concentration	Low	Medium	High
Intercept	11.67***	12.10***	11.98***
	(0.43)	(0.24)	(0.83)
Crisis_t	1.52**	2.22***	-0.75
	(0.67)	(0.49)	(2.45)
Post-Crisis_t	-0.82*	-1.07***	-0.68
	(0.48)	(0.31)	(1.14)
Sovereign Crisis_t	1.61***	2.68***	4.93***
	(0.51)	(0.36)	(1.50)
N	10,579	20,013	1,108

Table 6:
Regression of price impact on time dummies for covered bonds with different investor concentrations.

This table shows regression estimates for short and long term covered bonds divided into subsamples based on the investor base concentration in the specific bond issues. Investor concentration is measured on a monthly basis as being low, medium or high. A high investor base concentration means that the bond is held by a very limit number of market participants. The regression is specified as:

$$\text{PI}_{it} = \alpha + \beta_1 \times \text{Crisis}_{it} + \beta_2 \times \text{Post-Crisis}_{it} + \beta_3 \times \text{Sovereign Crisis}_{it} + \epsilon_{it}$$

Note that this regression uses individual transactions instead of a weekly measure to illustrate where the transactions are concentrated 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). Robust standard errors are calculated following 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 ***.

	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 9:
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 10:
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:

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

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 ***.

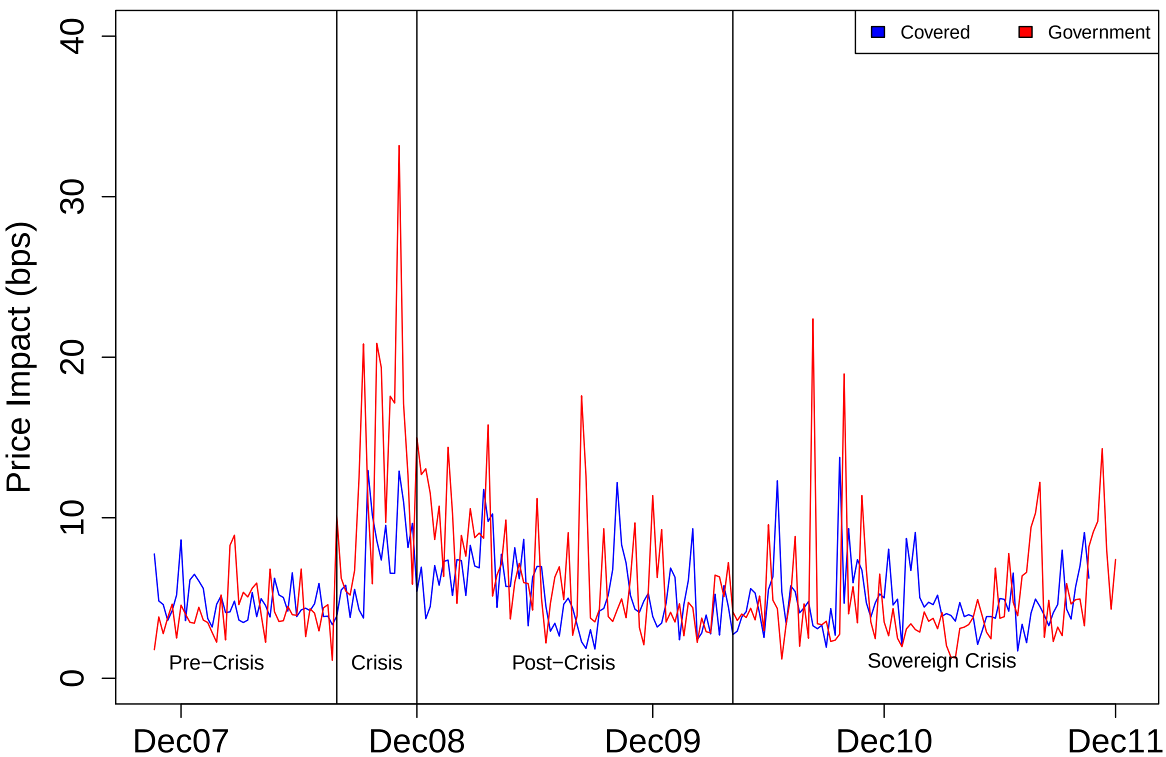

Figure 1:
Price impact for short term bonds.
The figure shows the weekly average price impact. The blue line is for short term covered bonds and the red line is for short term government bonds. The data period starts in November 2007. The crisis period is defined as running from August 15th to December 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.

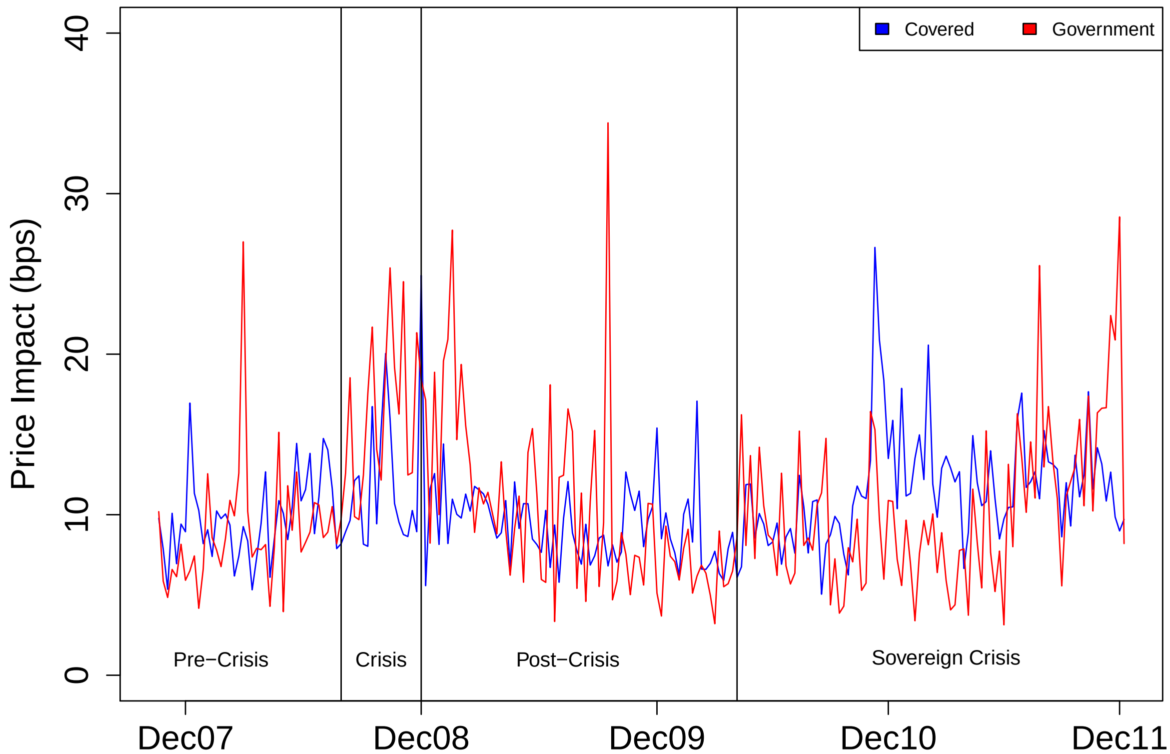

Figure 2:
Price impact for long term bonds.
The figure shows the weekly average price impact. The blue line is for long term covered bonds and the red line is for long term government bonds. The data period starts in November 2007. The crisis period is defined as running from August 15th to December 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.

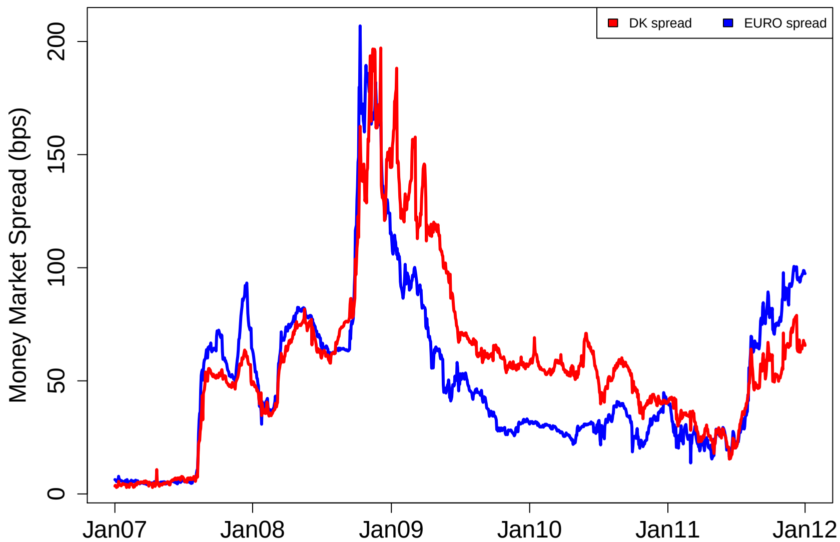

Figure 3:
Money market spreads.
The figure shows weekly observations of the money market spreads. The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate.

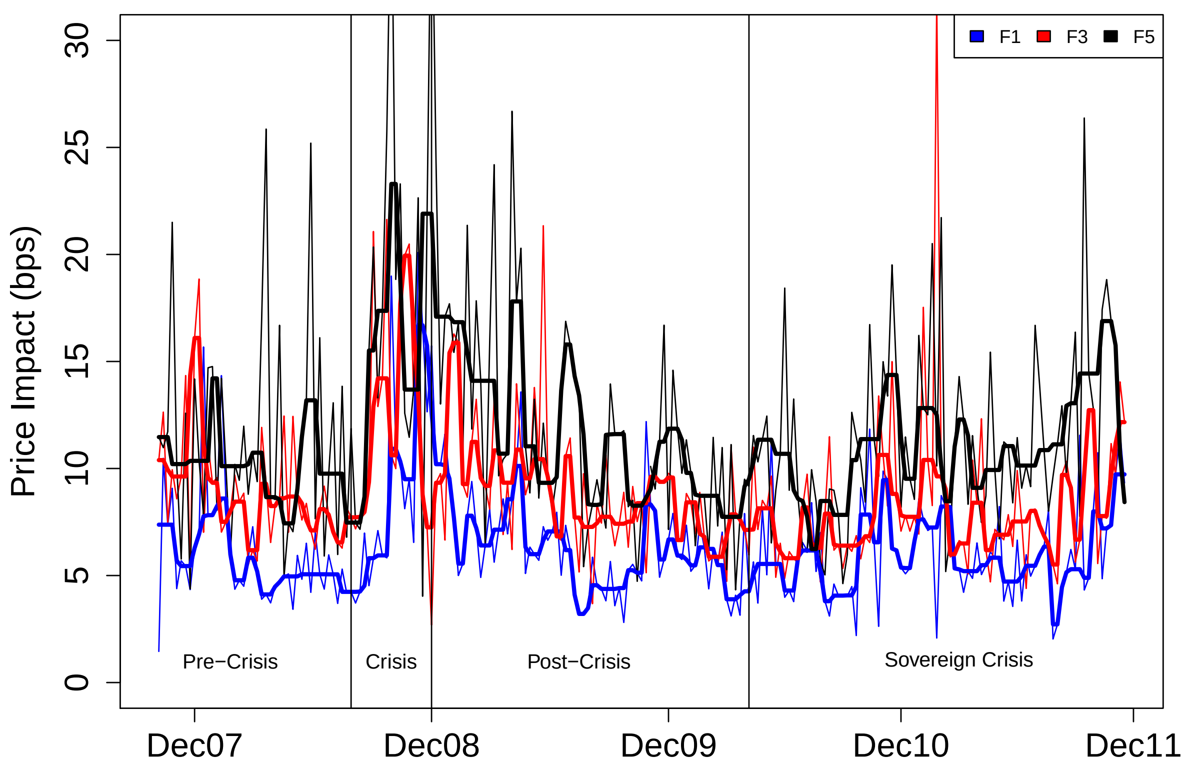

Figure 4:
Price impact for different ARMS with different maturities.
The figure shows weekly average price impact for the three major groups of bonds used to fund ARMS. F1 bonds are bonds with less then 1 year to maturity (what we have called short term covered bonds in the rest of the paper). F3 bonds have between 2 to 3 years time to maturity, and F5 have between 3 to 5 years to maturity. The thick lines are smoothed versions of the raw weekly series. The smoothing is done by a running median (Tukey 3S). 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).

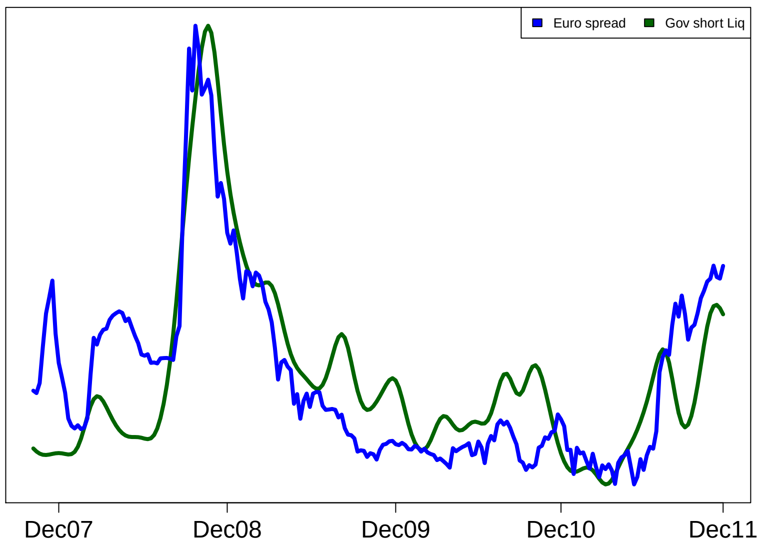

Figure 5:
Euro money market spread versus smoothed price impact for short term government bonds.

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.

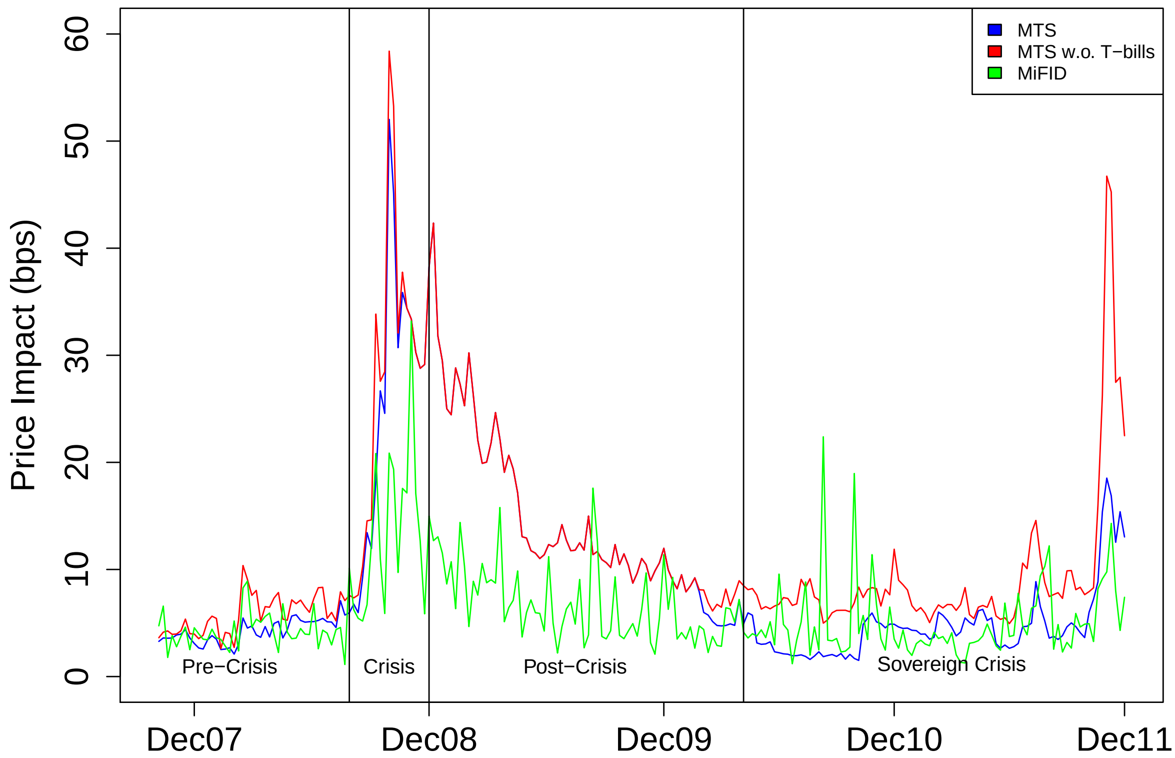

Figure 6:
Price impact for short term Danish Government bonds using MiFID and MTS data.
The figure shows the weekly average price impact. The blue line is for short term Danish government bonds using quoted prices from the the MTS platform. The green line is using MiFID data. Finally, the red line is 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. 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).

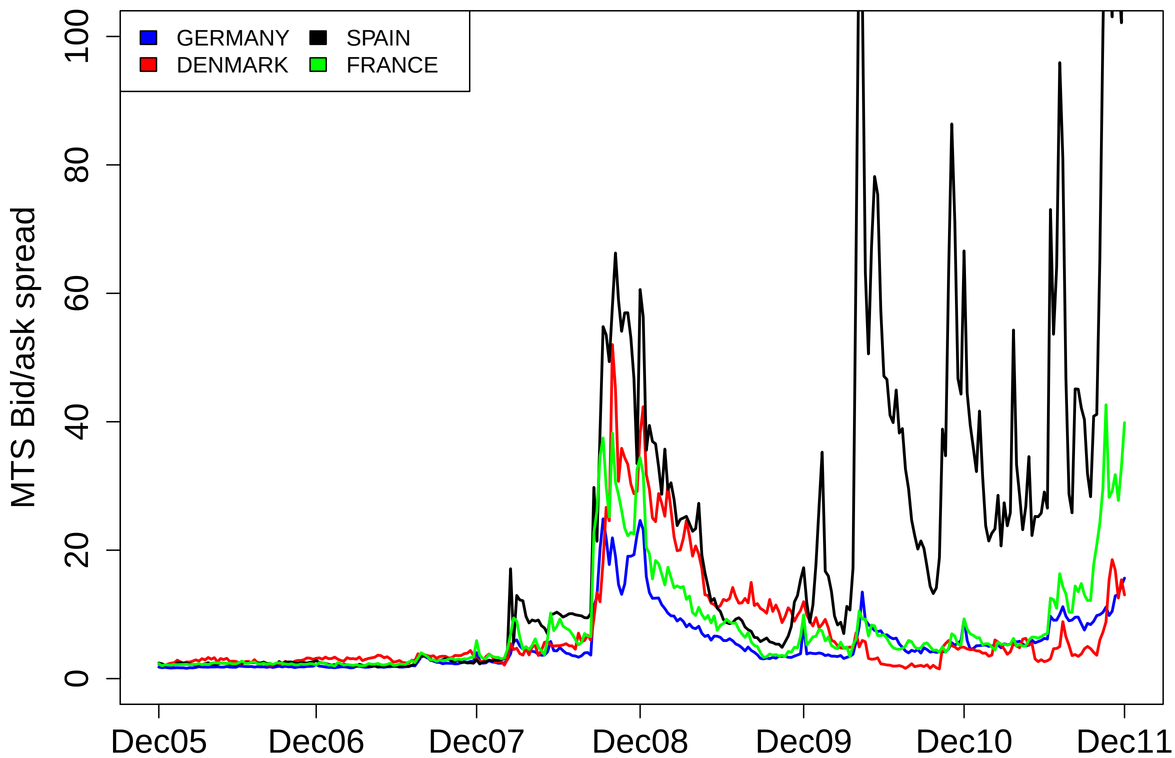

Figure 7:
Price impact for short term government bonds using MTS data.
The figure shows the weekly median price impact measures calculated using MTS quoted prices. The four lines are all short term government bonds with time to maturity less than 5 years. The blue line is for government bonds issued by Germany, the black line is for Spain, the red line is for Denmark and the green line if for France.

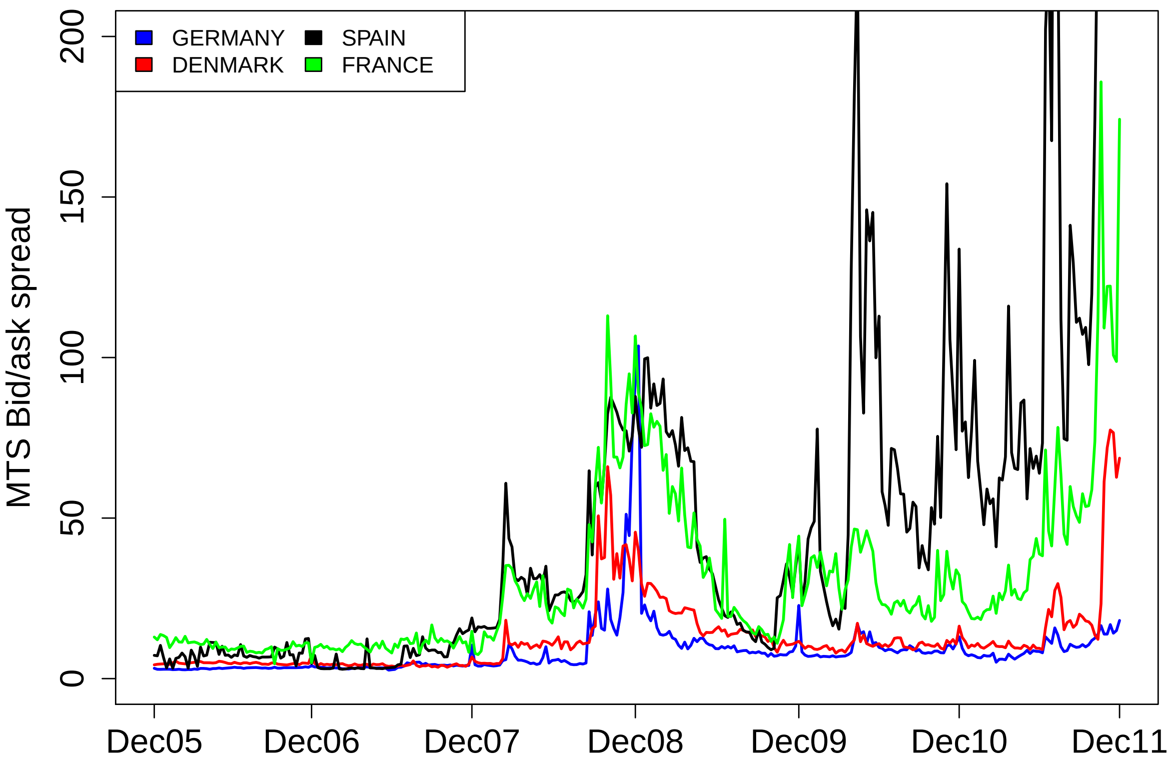

Figure 8:
Price impact for long term government bonds using MTS data.
The figure shows the weekly median price impact measures calculated using MTS quoted prices. The four lines are all long term government bonds with time to maturity between 5 and 10 years. The blue line is for government bonds issued by Germany, the black line is for Spain, the red line is for Denmark and the green line if for France.

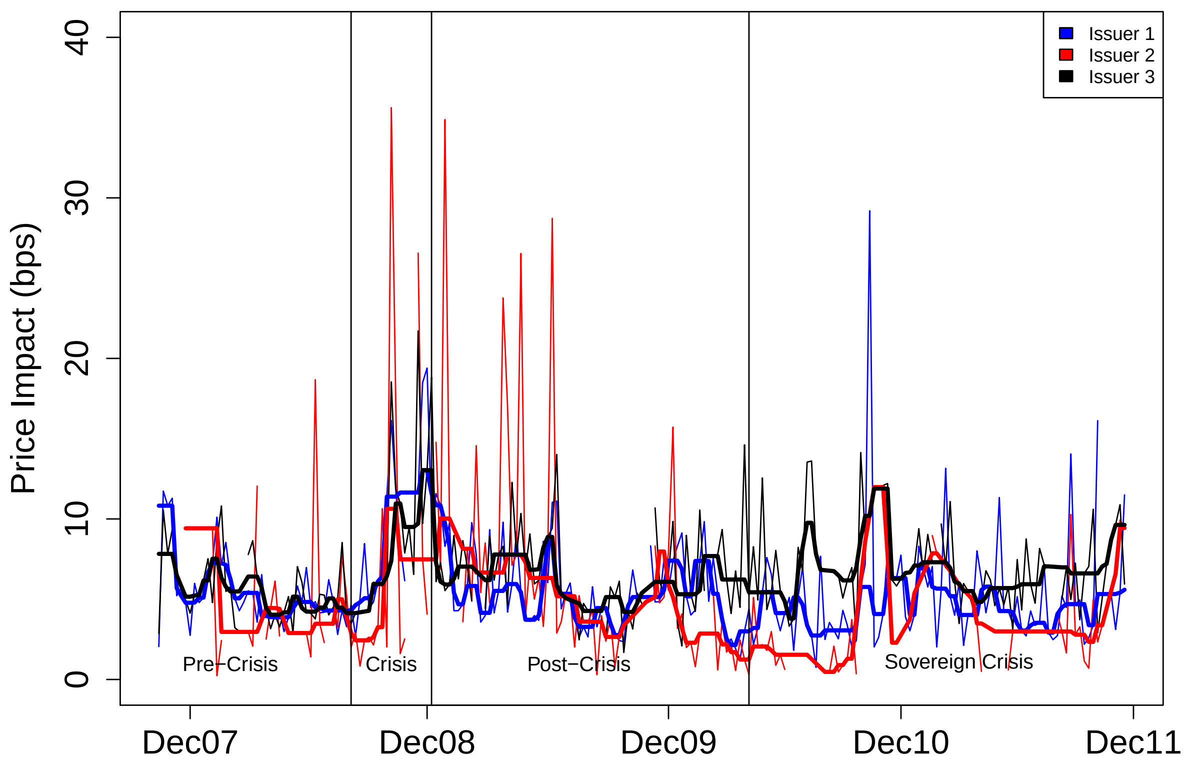

Figure 9:

Weekly price impact for different short term covered bonds issuers.

The figure shows weekly average price impact for short term covered bonds. The sample is split according to bond issuer. The thick lines are smoothed versions of the raw weekly series. The smoothing is done by a running median (Tukey 3S). 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). The issuers have been assigned a random number in the graph to maintain anonymity.