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Document Version
Accepted author manuscript

Published in:
Quarterly Journal of Finance

DOI:
10.1142/S2010139220500019

Publication date:
2020

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Journal article (Accepted manuscript*)

Please cite this article as:
Dick-Nielsen, J., & Gyntelberg, J. (2019). Highly Liquid Mortgage Bonds using the Match Funding Principle. *Quarterly Journal of Finance*, [2050001]. https://doi.org/10.1142/S2010139220500019

The final publication is available from now publishers via
https://doi.org/10.1142/S2010139220500019

Highly Liquid Mortgage Bonds using the Match Funding Principle*

Jens Dick-Nielsen† Jacob Gyntelberg‡

Abstract

We show that pass-through funding of mortgages with covered bonds supported by strong creditor rights is one way of providing highly liquid mortgage bonds. Despite a 30% drop in house prices during the 2008 crisis these mortgage bonds remained as liquid as comparable government bonds with high trading volume and low bid-ask spreads. Market liquidity of these covered bonds is primarily driven by the availability of funding liquidity. Funding liquidity is the main concern because the pass-through funding approach effectively eliminates other types of risk from the investor's perspective. Banking regulators should take into account the implications of these findings, particularly when it comes to the interplay between liquidity and capital requirements.

JEL classification: E43, G12, G21.

Keywords: Mortgage bonds, Covered bonds, Liquidity, Financial intermediation, Match Funding Principle.

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*The authors wish to thank Stefano Corradin, Morten Bech, Nina Boyarchenko, Jean Helwege, Birgitte Søgaard Holm, Peter Hördahl, Bjarne Astrup Jensen, David Lando, Jesper Lund, Lasse Heje Pedersen, Angelo Ranaldo, Thomas Sangill, Zhan Shi, Christian Upper, Siri Valseth and participants at the 2013 ECB conference on Money Markets, the 2013 Young Scholars' Nordic Finance Workshop, the 2013 Midwest Finance Association conference, the 2015 CREDIT conference, the 2016 EFA conference in Oslo, and seminar participants at Copenhagen Business School, the Danish Central Bank, the Danish FSA, the Danish Ministry of Business and Growth, Nykredit, BRF Kredit, and the Danish CFA Society for useful comments and discussions. We thank the Danish Central Bank for providing the data used in this study. Jens Dick-Nielsen thanks the Danish Social Science Research Council for financial support and also acknowledge support from the Center for Financial Frictions (FRIC), grant no. DNRF102. This research was initiated while Jacob Gyntelberg was at Bank for International Settlements (BIS). The views expressed need not reflect those of any other staff or of the principals of the Bank for International Settlements or Nordea Group. All remaining errors are our own.

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

1 Introduction

The 2008 global housing market crash clearly demonstrated that during a crisis, mortgage backed securities can become very illiquid. Gorton and Metrick (2012) argue that concerns about potentially failing mortgage bond liquidity was one of the elements which led to the run on the US repo market. After the crisis, this failure in the mortgage markets renewed the interest in optimal mortgage market designs (Campbell (2013), Bardhan et al. (2012)) and many observers have for example called for a reform of the current US mortgage securitization model (Bernanke (2009), Acharya et al. (2011), Baily (2011), Jaffee and Quigley (2013), and Fuster and Vickery (2014)).

The main question from a financial intermediation perspective is whether it is possible to design mortgage bonds so that they become highly liquid without relying on government sponsoring. The findings presented here suggest that *the strict match pass-through funding principle* supported by strong creditor rights as implemented in Denmark offers one way to design such a system with robust and highly liquid mortgage bonds. Fundamentally, the system is based on funding from the issuance of covered bonds by specialized private institutions. The specific design is often referred to as the Danish mortgage market model (Soros (2008)) because the system was founded in Denmark in 1795 where it is still in effect.

The match funding principle has long been viewed as extremely robust (see e.g. Paulson (2009)) and since inception all promised bond payments have been repayed in full to investors. In other words, there has never been a default of a covered bond issued under the match funding principle and there has never been a default of a mortgage institution. Because of the perceived safety of the system and the anecdotally high liquidity of the bonds, researchers (Hancock and Passmore (2009), Lea (2010)) and major investors (Soros (2008, 2010)) have argued for transforming the current US system into a system relying more on match pass-through funding[1]. This paper provides the first empirical evidence verifying that the match funding principle does provide mortgage bonds which are highly liquid - including during the 2008 housing market crash. These mortgage bonds could be (and were) used as collateral in repo agreements during the crisis without increases in haircuts (see Gyntelberg et al. (2012)) unlike in the US market (see e.g. Fleming et al. (2010) and Gorton and Metrick (2012)). This meant that even though the Danish central bank did create temporary lending facilities during the crisis, most financial institutions had sufficient eligible collateral to use for central bank funding.

The empirical analysis presented in this study relies on an unique and complete data set from Denmark containing all transactions in Danish bonds between 2007 and 2011 collected under the MiFID regulation. Our findings suggest that the pass-through funding approach as implemented in Denmark results in covered bonds which are highly liquid and even on par with the liquidity of government bonds - also in periods of market stress. We find that during the crisis market liquidity did decline in the domestic Danish government bond market as well as in other European government bond markets but that liquidity proved to be more robust in the market for covered bonds. Despite the relative decline of government bond liquidity during the crisis both markets remained open and active. The similarity in liquidity between covered bonds and government bonds, that we find, is consistent with the historically very low credit risk for covered bonds making them information-insensitive

[1] The match funding principle has been contrasted to the current US system in Frankel et al. (2004), Lea (2010) and Campbell (2013).

(Dang et al., 2015). Both the covered bonds and Danish government bonds have maintained AAA ratings in modern times also during the 2008 crisis.[2]

We show that for the covered bonds in our sample, liquidity measured as price impact is independent of trade size, issuance size, and ownership concentration. The finding that liquidity is independent of issue size is in contrast to other bond markets (see e.g. Fleming (2002), Houweling et al. (2005)) and is a consequence of the high transparency brought by the match funding principle. The high transparency results in very little price uncertainty and adverse selection. Even infrequently traded issues can easily be benchmarked to other traded covered bonds. This means that the covered bonds in general are also attractive to use as part of the liquidity management in financial institutions alongside other safe assets. It is important to note that the covered bonds trade under the same institutional setting as government bonds, i.e. they are not special in this respect. Trading is primarily done through market makers, the bonds can be used as repo collateral, and investors are broadly the same as for other bond types.

We find that market liquidity in the covered bond market is primarily driven by the availability of short term funding for market makers and investors, i.e. by money market stress (Brunnermeier (2009)). As it becomes more expensive to acquire short term funding in the Euro money markets there is an increase in effective bid-ask spreads consistent with the model of Brunnermeier and Pedersen (2009). Furthermore, while interdealer transactions in the analysis, in general, have lower bid-ask spreads than in dealer-client transactions, the covered bond trading volume declined significantly for interdealer transactions when money markets were stressed during the crisis whereas trading volume actually increased overall,

[2] As a curiosity, the Kingdom of Denmark defaulted on its government debt in 1813 after an economic crisis while contemporaneous mortgage bond investors did not experience any missed payments.

driven by an increase in dealer-client transactions. This could reflect that funding constraints became binding for the dealers during the crisis (Frank et al. (2008), Chiu et al. (2012)).

Using a broader data sample which includes other European bond markets, it becomes clear that market liquidity in these markets was also driven by money market stress. The findings suggest a strong commonality in bond liquidity across countries and bond types as in Chordia et al. (2005) and Karolyi et al. (2012). Using this alternative dataset, we show that covered bonds issued under the match funding principle as implemented in Denmark remained highly liquid during stress periods compared to also e.g. French and Spanish government bonds where adverse selection did become an issue for these countries during the European sovereign debt crisis.

Our findings are interesting from a regulatory perspective for at least two reasons. First, since properly designed mortgage bonds are highly liquid and has been safe historically even during a global crisis, the bonds should become eligible for use in regulatory buffers as high quality liquid instruments similar to other safe assets. This has already been recognized in the EU implementation of the Basel III rules under CRD-IV where covered bonds are allowed to be used in the LCR requirement. Second, the paper clearly shows that the availability of short term funding drives bond market liquid across covered and government bond markets. Therefore, regulation impacting e.g. repo markets, which is a popular market for market makers to obtain funding, will have the side effect of changing bond market liquidity.

2 The match funding principle and covered bonds

In this section we go into detail with the description of the match funding principle as implemented in Denmark. We contrast the Danish mortgage system design to that used in the US and Germany. Both the US system and the German system had illiquidity concerns during the crisis whereas the Danish market remained highly liquid. We attribute these difference between markets to difference in market designs.

2.1 The match funding principle

The strict match funding principle requires mortgage banks to fund their lending activity by issuing covered bonds with cash flows that fully match those of the underlying mortgage loans until maturity on a loan-by-loan basis. The mortgage loans stay on the books of the covered bond issuer, unlike in the originate-to-distribute securitization model used in the US system. In case of a default on a mortgage loan the issuer will replenish[3] the loan without any losses to investors (unless the mortgage issuer also defaults). The pass-through funding thus forces the interest period on the bonds to exactly match the interest period for the home owner. Hence, for each interest period of 1 year, the cash flow of the loans and the bonds issued to fund them match with no maturity transformation, and the mortgage bank therefore has a natural and perfect hedge against interest rate, currency, market, and prepayment risk. Furthermore, the borrower pays the mortgage bank's cost-of-funds plus a margin, so that the mortgage bank is also hedged against rising funding spreads. Since the mortgage banks retain the borrower credit risk they operate with conservative loan-to-value ratios for new loans in the range of 60-80% and they furthermore tend to have a large and diversified pool of borrowers in order to minimize credit risk. By minimizing credit risk in the mortgage bonds and institutions, the mortgage system becomes robust to even large house price variations. Another stabilizing factor is that borrowers can make penalty free

[3]Consistent with the match funding principle, the theoretical model of Ahnert et al. (2016) highlights bankruptcy remoteness of the cover pool, the dynamically replenishment of loans, and to a lesser extent dual recourse as being the most important features of covered bond funding.

prepayments by either refinancing the loan at par value or by buying up the underlying mortgage bonds in the market. This creates an interest rate hedge for the borrower and it is possible because each loan is matched directly with a mortgage bond (see Frankel et al. (2004), Gyntelberg et al. (2012)). Finally, since essentially the only intermediation risk for the issuer is retained borrower credit risk the match funding principle incentivizes prudency in the loan underwriting process unlike the pre-crisis situation seen in the US system (Mayer et al. (2009), Mian and Sufi (2009), Keys et al. (2010), and Purnanandam (2011)).

In addition to the high lending standards induced by the match funding principle, credit risk also benefits from strong legal creditor rights.[4] Our study thus empirically analyzes the outcome of the match funding principle supported by strong creditor rights which is a unique combination. The strong creditor rights include foreclosure rules and an efficient title system that makes it easy and fast for the lender to take ownership of the collateral at a low cost in the case of a default on the mortgage. Furthermore, the lender has full recourse with the original borrower and the lender also has recourse right against all borrowers collectively. The latter means that in case of severe losses the lender has the right to collect higher margins from the entire group of borrowers. As a testament to the safety of this system, the highest loan loss level, including commercial lending, has been 0.2% annualized in the years during and following the 2008 crisis (Danmarks Nationalbank (2016)). These low levels were maintained despite a 30% drop in domestic house prices.

The 2008 financial crisis highlighted a number of flaws in the design of mortgage financing in the US and elsewhere (see e.g. Soros (2008), Bernanke (2008), Kofner (2009)). Perhaps most importantly, it became apparent that the US-style mortgage securitization model was

[4]As a comparison the mortgage system in Mexico is also modeled around the match funding principle. However, the Mexican system is less successful in terms of providing both safe and liquid mortgage bonds because creditor rights are weak and not efficiently enforced.

highly non-transparent and subject to moral hazard. This resulted in a rapid decline in the quality of mortgages underlying the issued mortgage bonds. The drivers of this development was in part that separate entities originated, securitized, and serviced the underlying mortgages. As a result, the incentives to originate sound mortgages and to service them well were shown to be inadequate. Also, a number of mortgage-backed securitizations, which were meant to reduce credit risk via diversification, actually increased losses by creating complex capital and credit risk structures that impeded the modification or renegotiation of mortgages in default. As explained above, moral hazard, credit risk, and lack of transparency were not a concern for the mortgage bonds issued under the match funding principle. The single key difference between the US system and the match funding principle is that the match funding provides transparency in the cash flows.

For a number of European covered bonds of the Pfandbrief-type which are for example used in the German housing market system, credit quality has historically been much less of a concern than in the US. However, during the crisis concerns did rise about the credit quality because of potential maturity mismatches for the bond issuer. While the bonds ex-post did remain safe, the liquidity was severely impacted. The low liquidity of the mortgage bonds significantly impacted refinancing costs and the market for Pfandbrief-like covered bonds seized to function for around a month (Prokopczuk et al. (2013), Gürtler and Neelmeier (2016), Beirne (2011)). We show that different from the Pfandbrief-like covered bonds, the covered bonds in our sample did not experience the same drop in liquidity. Again, the primary difference between these covered bond types is that with match funding the bond issuer also get a maturity matched portfolio which in effect increases transparency.

Disregarding credit risk which ex-post was low both in the German market and also in the US prime market, the primary benefit from having match funding is more transparent cash flows. Hence, when we in the following analysis document that mortgage bonds issued under the match funding principle were liquid during the crisis this can be attributed to the higher level of transparency which is the key difference separating this mortgage market design from other well-known mortgage bond systems.

2.2 The Danish covered bond market

Bond issuance in the Danish covered bond market is completely dominated by specialized private institutions or independent subsidiaries of major banks. The market has shifted slowly from being completely dominated by fixed-rate mortgages (FRMs) to having a sizable share of adjustable-rate mortgages (ARMs). These two main types of contracts are also the most used globally.

The dominating fixed rate contract is a long term (up to 30 years) loan (FRM) with an option to make penalty-free prepayments. Under the match funding principle this 30-year fixed rate callable mortgage loan is funded by a cash-flow matching 30-year fixed rate callable bond.[5] Low stable short term interest rates have over time created a demand for 1-year adjustable-rate mortgage contracts (ARMs) as well. This is the basis of 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. Under the match funding principle this loan is funded by a sale of fixed rate 1-year bullet bonds.[6]

An important characteristic of the market is that mortgage loans and the bonds used to fund them are highly standardized across issuers. Because of this standardization and the absence of credit risk, bonds with identical specifications (coupon rate, maturity and amortization structure) from different issuers are traded at the same price as bonds from

[5]See Frankel et al. (2004) for a further discussion of this contract.

[6]These bonds also come with other maturities which then match a different interest reset period.

another issuer. We verify later that there is no (or at least very little) discernible price-differentiation across issuers in our sample. During the crisis, all issuers maintained their high credit quality but covered bond prices did at times depend upon the specific issuer due to money market related concerns. In the analysis we therefore exclude bonds from the two smallest bond issuers, BRF Realkredit and DLR Realkredit, as these bonds were more impacted by the money market freeze during the crisis than the bonds from the dominant bond issuers. Still, the bonds issued by BRF Realkredit and DLR Realkredit did maintain a AAA rating also during the crisis.

2.3 Covered bond data

Our data includes all transactions in Danish bonds carried out with an investment firm or credit institution in the EU as one of the counterparties. The transactions data are collected by the Danish FSA as part of the MiFID regulation and the data has been obtained for the period 2007 to 2011.[7] Static bond data has been obtained from VP-securities, the Danish Central Bank, and Bloomberg.

Throughout the paper, our covered bond sample is restricted to bonds issued by the 3 largest issuers who in total cover around 65-85% of the market.[8] Table I presents summary statistics for the entire market (all issuers and including primary market auctions) as well as for our sample of the 3 largest issuers and excluding auctions. Since the match funding principle is not tied up to a specific mortgage loan contract, we consider both the bonds

[7]The regulation started November 2007. The raw MiFID data have been cleaned before usage as described in Dick-Nielsen et al. (2012).

[8]The issuers are Realkredit Danmark, Nordea Realkredit and Nykredit Realkredit. Furthermore, the analysis includes issues from Totalkredit Realkredit, which is part of Nykredit Realkredit. We therefore in total exclude two smaller issuers.

underlying the fixed rate-mortgages (long term covered bonds) and the adjustable rate-mortgages (short term covered bonds).

The short term covered bond sample captures around 65% of the amount outstanding and around 45% of the turnover. The relatively low turnover for the sample can be explained by the fact that apart from conditioning on the issuer the sample also excludes auction days (which is the bigger effect). The auctions are removed because the main interest is on secondary market liquidity. For the long term covered bonds our sample captures around 85% of the amount outstanding and 90% of the turnover. The summary statistics in Table I are based on actively traded issues. The FRM market consists of 115 actively traded issues whereas there actually exist around 1,250 different outstanding issues.[9] This difference reflects that there exists a large number of very small issues mirroring that the mortgage banks issue bonds with cash flows that match those of their lending portfolio following the match funding principle. A given covered bond issue therefore exists until all borrowers which have had their mortgage funded by this specific bond have paid off their loan completely. Despite the large number of excluded issues, these issues only make up a tiny fraction of the overall market measured by outstanding volume.

The evidence presented in this paper carries some weight since the Danish covered bond market is large both in relative and absolute terms. By the end of the sample in 2011, the outstanding amount of covered bonds issued under the match funding principle was EUR 310 billion corresponding to around 140% of Danish GDP and ranked number two worldwide measured by amount outstanding in absolute terms (see e.g. ECB (2012)). Our data also contain government bond transactions which provide a natural benchmark. The outstanding government bonds consist of short term T-bills and plain vanilla bullet bonds with standard

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

maturities between 2 and 30 years.[10] The outstanding volume of Danish government bonds by end 2011 was just over DKK 750 billion, corresponding to around 40% of GDP (see Danmarks Nationalbank (2012)).

3 Measuring liquidity

In the following analysis secondary bond market liquidity is measured by price impact. For a given transaction, we define the price impact of a trade as the absolute return between adjacent transactions:

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

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 prices are not expected to move by much when trading, hence the price impact of a transaction should be low. Both prices in the calculation are required to be executed within the same day in order to minimize the possibility of new information arriving in the market.

The weekly price impact measure is defined as the average price impact for a given bond over that week:

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

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

[10] T-bills and a new 30-year bond were only in existence in part of the sample period. Therefore, the sample does not include these instruments as to keep it as homogeneous as possible over time.

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:

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

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 where there exists a large number of very small bond series as explained earlier. By weighting with amount outstanding the importance of these series is appropriately reduced in the weekly market 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 an observed price impact is a bounce between a buy and a sell price. In practice calculated price impact will be slightly lower than actual bid-ask spreads because not all price movements are between buy and sell transactions. Later we use MTS quote data to verify that calculated price impact measures are fairly close to bid-ask spreads.

The price impact is deliberately not scaled with transaction volume. This choice is motivated by looking at the price impact for various transaction sizes. In both the covered bond and the government bond market a large part of the transactions take place in standard trade sizes e.g. DKK 20, 50, 100, and 200 million.[11] Table II shows the price impact measure for four of the most frequently used trade sizes. What we see is that price impact within our sample is more or less independent of trade size. In fact, in most periods the price impact of

[11]As transactions are conducted in standard trade sizes (round figures) by Danish kroner, DKK is kept 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.

a DKK 200 million trade is smaller than one of DKK 20 million. Based on this finding, we chose not to scale the price impact measure unlike Amihud (2002) and Dick-Nielsen et al. (2012). The independence of trading volume is likely because market participants have very similar bargaining power (Duffie et al. (2007)).

We are mainly interested in the ability of large investors to liquidate the bonds in times of market wide stress so we exclude transactions of less than DKK 10 million (approximately EUR 1.34 million). This should exclude retail investors and further ensure homogeneity among market participants. Also, when calculating the price impact measure for covered bonds all bond issues with matching cash flows are pooled into the same bond family and is regarded as a single issue. This approach is consistent with market practices and we specifically test the robustness of this approach in a later section and find support for it.[12]

4 Covered bond liquidity

This section compares covered bond liquidity to government bond liquidity. Before the 2008 financial crisis, government bonds were slightly more liquid than covered bonds. However, during the crisis the covered bond market performed better. Even though house prices declined by more than 30% during the crisis we show that this did not spill over to the covered bond issuers. Covered bonds remained highly liquid also at the height of the crisis. These findings supports that the match funding principle is capable of providing highly liquid mortgage bonds.

[12]Due to the structure of the MiFID data we make some additional technical choices which are explained in the appendix.

4.1 Covered versus government bond market liquidity

In Figure I we benchmark short term covered bond liquidity to that of government bonds with maturity less than five years. The average weekly price impact measure was broadly the same for the two markets before the 2008 crisis. The estimated liquidity levels for the pre-crisis period in Table II points to higher average liquidity in the government bond market. However, the actual difference in liquidity in terms of price impact is only in the 1-2 bps range.

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

In the post-crisis period although liquidity has been lower than before the crisis both markets have remained fairly liquid with an average price impact around 7 bps – 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 still quite liquid, with an average price impact in the 4-7 bps range.

Similar to the markets for short term bonds, the average price impact was broadly the same for long term covered and government bonds (with maturity between five and ten years) over the entire sample period as can be seen in Figure II. Looking at the price impact estimated in Table II it can be seen that the pre-crisis levels for the liquidity measures 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 impact compared to the short term bonds is around 6 bps on average. However, it is worth noting that the crisis in relative terms affected the long term market far less than the short term market.

4.2 Interdealer versus dealer-client market

We can go more into detail with the evolution of liquidity and test for differences across time. We do this by first splitting up the data sample into transactions between dealers (interdealer transactions) and those between dealers and their clients. By doing this, we can show that especially the dealer-client market was robust to the financial turmoil whereas the interdealer market suffered more.

To test for differences in liquidity over time between the interdealer market and the dealer-client market, we run a simple regression for each segment:

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

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 interdealer transactions is generally lower than the impact in dealer-client transactions as can be seen in Table III. The striking although not surprising result from the table is that interdealer 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 their clients (as in Duffie et al. (2007)). The time series behavior mimic those for the full sample benchmark trade sizes in Table II.

While the interdealer 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 IV, turnover in the interdealer market declined dramatically during the crisis compared to the dealer-client market. This is suggestive of a situation where dealers found it difficult to sell bonds in the interdealer market and instead sold bonds to clients. Hence, the interdealer community as a whole was liquidity-constrained during the crisis even if covered bonds still traded actively. The overall trading volume in the market increased during and after crisis, but the increase has been driven by more dealer-client transactions. The conclusion is that even though bid-ask spreads did increase during the crisis, the market stayed highly active driven by client transactions.

5 Determinants of market liquidity: Bond characteristics

While the match funding principle provides bonds that are as liquid as government bonds, it is interesting to know what drives liquidity both in the cross-section and in a time series perspective. This will give more insight into the effect of design variations within covered bonds and how policy measures can affect the market. This section investigates the effect of cross-sectional variation in the covered bond design and the next section looks at the time series determinants of liquidity.

5.1 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 II. This is consistent with prior literature and can be explained by smaller price uncertainty for the short term bonds (see e.g. Buhler and Vonhoff (2011)).

In the covered bond sample short term bonds are defined as the 1 year non-callable bonds used to fund 30 year ARMs. The short term bonds, also called F1 bonds, thus has a remaining time to maturity of one year or below. If the mortgage interest rate is reset less frequently for the loans then the underlying non-callable bonds also have longer (matching) maturities. Therefore similar definitions are F3 bonds as having maturity of between one to three years, F5 as having maturity between three to five years and F10 as having maturity between five to ten years.

Figure III 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 was seen for the other market segments; there were less liquidity during the crisis after which liquidity has recovered. However, the long term ARMs have suffered a little after the crisis.

The turnover trend seen for dealer-client transactions in the F1 bonds in Table IV 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 daily 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 an issuance size effect. As time to maturity increases across these samples, the size of the aggregate market decrease. Hence, the analysis is not able to completely rule out that the maturity effect is really a size effect. Next, we investigate this issue further.

5.2 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, the analysis of issuance size is restricted to only include short and long term covered bonds.

Table V 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 is the same 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 have a median size over time of DKK 4-9 billion with the largest group ranging from DKK 77-123 billion 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 trading activity is concentrated in the largest issues. Hence, the number of price impact observations are naturally clustered within the larger issues. Activity, measured by the number of transactions, is thus 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.[13] As explained earlier, bonds with matching cash flows are close substitutes even across issuers. The minor effect we find of issuance size is a consequence of a liquidity spillover due to the high transparency in the market brought by the match funding principle. Since part of the market is very large, active, and liquid, this part makes it easy to value other but smaller issues. Due to the match funding principle and standardization there is no preference for one bond 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 smaller investors if they wanted to exercise the delivery option in their mortgage loan but since the analysis focus on wholesale trading, this is not an issue.

The findings on issuance size is interesting from a policy perspective. In European banking regulation bonds are considered highly liquid based on their issuance size. While this may be a good indicator for bond liquidity in less transparent markets, it is clearly not correlated with liquidity for covered bonds under the match funding principle. This finding can be considered a further strength or benefit of a robust mortgage bond system.

[13]Some of the size differences is also due to the series being repo'ed in the Danish central bank. If this is the case the analysis does not count it as part of the free float size of the bond. Hence, issuance size is net of bonds used as collateral with the Danish central bank. However, this correction does not account for the majority of the size differences.

5.3 Investor concentration

Investor concentration might matter for the liquidity of covered bonds. The government bond issues are very large and rarely concentrated with a few investors. The covered bonds on the other hand might be held by only a few investors.

We divide investor concentration into three levels - high, medium and low. A bond has high investor concentration if maximum ownership fraction by a single investor is more than 50%. Investor concentration is medium if maximum ownership fraction is between 20% and 50% and it is low otherwise.

Table VI shows that investor concentration makes little difference for the liquidity of the bonds (unlike e.g. in the stock market (Rubin (2007))). Bonds with high investor concentration were a little more illiquid before the crisis but during the crisis they performed better than the bonds with lower concentrations. Most of the covered bonds, however, have a medium level of investor concentration and as such it is not an important factor for the covered bond market.

The reason that investor concentration is not important in the covered bond sample is the same as for the impact of issuance size. The match funding principle results in a highly transparent market where there are usually plenty of benchmarks for pricing bonds. Bonds which are tightly held by a few investors can still be accurately priced because there is little uncertainty about cash flows and there exist other traded benchmarks (bonds).

6 Determinants of market liquidity: Funding Liquidity

In this section we analyze the link between market and funding liquidity (Brunnermeier and Pedersen (2009)) for covered bonds. Consistent with theory and other markets we find that funding liquidity is a primary driver of covered bond market liquidity. From a policy perspective it is thus important to maintain continued access to short term funding for market makers if the covered bond market is to stay liquid.

While it is already known from other markets that funding liquidity can drive market liquidity, the purpose of showing it specifically for the covered bond market is that it highlights that covered bonds and government bonds have indistinguishable liquidity characteristics. This similarity in liquidity behavior is consistent with both type of bonds being similar to safe assets (Dang et al., 2015). Finally, showing that funding liquidity is the primary driver of covered bond and government bond liquidity helps to understand how and why government interventions affected bond liquidity during the 2008 crisis (we return to this issue in the robustness section).

6.1 Market versus funding liquidity

Dealers in bond markets often have substantial gross long and short positions due to their market-making obligations. An active repo market is important for maintaining these long and short positions. During the sample period, many large banks active in the market 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 covered bond market. These investors are highly dependent on the willingness of market maker banks to fund their positions via the repo market. It is therefore not surprising that funding liquidity affects covered bond market liquidity consistent with the model of e.g. Brunnermeier and Pedersen (2009) and as was also the case in most other

European bonds markets. We verify the latter by explicitly benchmarking to the liquidity in other European bond market in the next section.

As a proxy for stress in the domestic Danish money markets, we use the spread between a three month CIBOR rate and a 3 month CITA rate (the domestic equivalent to the LIBOR-OIS spread). As the DKK is pegged to the Euro, the Danish market is heavily influenced by European conditions. Therefore, we also look at a Euro money market spread, namely the spread between 3 month EURIBOR and the 3 month EONIA swap rate. Figure IV shows a time series of these two money market spreads. Before the start of the 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 two spreads switch place during the European sovereign crisis which had little negative impact on the Danish economy.

As a first glance Figure V shows a smoothed version of the weekly short term government bond market liquidity from Figure I, plotted alongside the weekly Euro money market spread. The two graphs are indexed to fit the same scale and show a very strong correlation. Granger causality tests confirm that the Euro money market spread predicts market liquidity (p-values < 0.0001). The only market segment with a weak connection ($p=0.08$) is that for long term covered bonds. This is because this group of bonds is very inhomogeneous and perhaps therefore noisy. Unfortunately, it cannot statistically be rejected that the money market spreads contain 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 we then look at the weekly changes and first perform a principal component decomposition (PC) of these changes. Table VII shows the factor loadings from the PC 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, a 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 bonds and could be interpreted as a factor specific for this market segment. The last two factors are more mixed in their loadings and will not be considered further.

Table VIII shows estimates from the regressions on each principal component using changes in money market spreads as the independent variables:

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

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 PCs exhibit a strong mean-reversion indicating that liquidity is fairly stable over time as could also be seen in the earlier liquidity graphs. The first PC is predicted by changes in the Euro money market spread. Whereas the second PC is predicted by changes in the domestic money market spread. The Euro spread is also weakly significant for the second PC with the opposite sign of the domestic spread. This seems to suggest that the difference between the two spreads is important for the second PC, i.e. a country spread. For the short term covered bonds this country spread becomes significant which suggests that the liquidity of short term covered bonds is influenced by a separate factor which is not present (to the same extent) in the other segments of the bond market.

The empirical results are consistent with the established theory of the relation between funding and market liquidity (Brunnermeier and Pedersen (2009)) and with evidence from other markets during the crisis (Frank et al. (2008) and Chiu et al. (2012)). The Euro money market spread has a stronger causal relation with the price impact measure than the domestic spread. This likely reflects the Danish kroner 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 (domestic OIS) is less liquid than the EONIA market, so the domestic money market spread may be more noisy than the Euro spread, particularly in the beginning of the sample period.

There are several explanations for the empirical relationship between the country spread and the liquidity of short term covered bonds. First, the Danish central bank 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 the short term covered bonds using Euro funding, and for Danish banks to buy short term 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 term covered bonds, combined with FX swaps. Finally, foreign investors have increased their holdings of short term covered bonds from approximately 1% to 15% (DKK 60 billion) 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 term covered bond market.

6.2 Comparison with other European government bonds

Next we show that funding liquidity as a driver of market liquidity is not unique to the Danish market but rather a fundamental phenomenon across European bond markets. In addition, the benchmarking to other European markets also shows that the Danish market was highly liquid in a relative sense. We compare the results using MiFID data to other European government bond markets by 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). European covered bonds were also quoted on the MTS platform. However, the quoted volume in covered bonds dropped to 0 at the inception of the crisis and the trading moved to over-the-counter. The MTS data thus allow for a benchmarking of the covered bonds issued under the match funding principle to that of other European government bonds.

The MTS data contain a large amount of intra-day quotes. The quotes are supposedly executable, which should give 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 first compare the MiFID price impact measure for short term Danish government bonds to the equivalent measure using MTS quotes. The implicit MTS bid-ask spread is as follows:

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

The weekly time series is calculated by taking 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 VI shows the weekly price impact series calculated using MiFID versus MTS data. It is clear form the graphs that the MTS numbers and the MiFID numbers are very close. The price impact measure is fairly close to the bid-ask spread and both measures should be fairly good approximations of the market liquidity. The measures primarily differ because some transactions are executed within the bid-ask spread resulting in a lower price impact measure.

In the analysis using MTS data we include Germany, France and Spain as well as Denmark. We select these countries because they also have large covered bond markets. Although it is not possible to directly measure liquidity in these other covered bond markets it is reasonable to assume that government bond liquidity will provide an upper limit on how liquid the domestic covered bond markets are in each country (see e.g. Siewert and Vonhoff (2011) for the German case). Unlike the bonds issued under the match funding principle in Denmark, covered bonds in the other countries are expected to be a lot less liquid than comparable domestic government bonds.

Figure VII 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 segments are highly correlated and looks a lot like the figure seen earlier for Denmark using MiFID data. German bonds are the most liquid, whereas the sovereign crisis seems to be hard on especially Spain. Before and during the subprime crisis Spain, France and Denmark were all very similar in terms of liquidity. The same picture is more or less true for the long term government bonds (5-10 years maturity) in Figure VIII. German bonds are again the most liquid followed by Danish bonds. Liquidity in the long term bonds issued by France and Spain are very similar to that of Denmark and German up until the sovereign crisis hits Spain and also to some degree France. Hence, even when comparing the liquidity of Danish covered bonds, here proxied by Danish government bond liquidity, to those of other European government bonds markets, the Danish covered bonds are still highly liquid.

Table IX 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 segments; 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 PC 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 PC alone explains 37% of the total variation in the data. The second PC separates into markets affected by the sovereign crisis and those which as not (or less) affected. Those affected seem to be Spanish bonds and long term French bonds as we also saw it in the Figures. Table X shows a regression where the first four PCs are explained by lagged values of itself and lagged weekly changes in the Euro money market spread. The first two PCs are significantly and positively related to changes in the Euro money market spread. Hence, the conclusion from the Danish analysis carries over to the European market, namely that funding liquidity drives market liquidity. For the European market this can been seen by the fact that stress in the Euro money market spill over into a more illiquid market for government bonds. The results reported in the table and the PC analysis are for weekly changes in the price impact measures. For the same analysis in levels (not shown) the results are much more significance but there the time series could contain a unit root as was the case for the Danish data.

The impact of credit risk concerns on bond liquidity is clear during the sovereign crisis when looking at the government bonds issued by Spain and France. For these two cases, an increase in credit risk substantially decreased liquidity. Such an effect is absent from the covered bonds under the match funding principle. Instead, availability of short term funding explains the time series variation in liquidity. The analysis highlight that the covered bonds are integrated into a larger global financial system where market making and short term funding play a vital role. Liquidity is thus heavily affected by factors which are not directly part of the mortgage market design but rather linked to the larger financial system.

7 Discussion of robustness

Two issues are relevant to discuss in connection to the robustness of the results. First, mortgage bonds are highly standardized across issuers and the bonds are assumed to trade without price differentiation. We test this assumption and show that there are no systematic differences between issuers. Second, we discuss the scale of government interventions during the crisis which were minor and not directly related to the mortgage market design.

7.1 Liquidity by issuer

The analysis groups together trades in the same bond (i.e. bonds with the same specifications) from different mortgage issuers. This is done because low credit risk and high competition ensures that there is virtually no price-differentiation across issuers. 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 there was no price discrimination during the crisis. In order to verify this, we look at short term covered bond liquidity decomposed on the issuer level. If liquidity did depend on the issuer during the crisis then it should matter the most for these bonds because of the low maturity.

Figure IX shows the issuer specific liquidity measures for the short term bonds. The liquidity measure is now specific to the ISIN-code before aggregating into a weekly issuer specific liquidity measure.

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 assumption that identical bonds can be pooled across issuers.

7.2 Government interventions

While the issuance process under the match funding principle does not rely on government sponsoring, Danish regulators did introduce a number of policy measures to stabilize the Danish financial sector in the autumn of 2008. However, these measures were aimed at easing the money market freeze and not needed in order to repair a flawed Danish mortgage bond system. In context of the covered bond market, the stabilizing measures should be seen as necessary because the covered bonds were integrated into a larger financial system. As we has also shown above, funding liquidity from money markets is vital in determining covered bond market liquidity.

Fender and Gyntelberg (2008) compares government interventions during the crisis around the world and Campbell (2013) notes that government interventions in Denmark were kept at a minimum compared to other countries. Most notably to ensure continued access to funding for Danish banks, bank support packages providing government guarantees (in return for a fee) on bank liabilities were introduced. These guarantees were in place until September 2010. However, covered bonds were explicitly and deliberately not included into the guarantees at *any* point. The covered bonds have also always been eligible as collateral for central bank repo funding - also during the crisis.

8 Conclusion

This paper presents empirical evidence that covered bonds issued under the match funding principle as in Denmark are highly liquid, also during times of market stress. The strict match pass-through funding principle as implemented in Denmark is thus one way to structure a robust house financing system. The study uses a unique and complete transaction data sample from Denmark to show that covered bonds under the match funding principle were as liquid as government bonds also during the 2008 housing market crash. An important feature of the Danish mortgage system is that it does not rely on government sponsoring and the government is not actively involved in the market in normal times.

Funding liquidity is a main driver of market liquidity consistent with other markets. Hence, regulation which positively or negatively impacts the availability of short term funding has a direct impact on covered bond liquidity. From a broader policy perspective, highly liquid and safe mortgage bonds open up for the possibility of allowing these bonds into various liquidity buffer similar to other safe assets. This has already been done with the

LCR-requirement implemented in the European Union where Danish covered bonds can be used alongside other safe assets such as government bonds.

Appendix: MiFID data

We first clean the MiFID data following the description given in Dick-Nielsen et al. (2012). On a more technical note, the bond data 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 arrangements in the market, including that the issuing legal entities are part of large banks and hence rely on the trading infrastructure of these banks. 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 necessarily adjusted after a transaction, and therefore 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.

References

Acharya, V., M. Richardson, S. van Nieuwerburgh, and L. White (2011). *Guaranteed to fail: Fannie Mae, Freddy Mac, and the Debacle of Mortgage Finance*. Priceton University Press.

Ahnert, T., K. Anand, P. Gai, and J. Chapman (2016). Asset encumbrance, bank funding, and financial fragility. *Bank of Cananda, Working Paper*.

Amihud, Y. (2002). Illiquidity and stock returns: Cross-section and time-series effects. *Journal of Financial Markets 5*(1), 31–56.

Baily, M. (2011). *The future of housing finance: Restructuring the US residential mortgage market*. Bookings Institutional Press.

Bardhan, A., R. H. Edelstein, and C. A. Kroll" (2012). *"Global Housing Markets: Crisis, Policies and Institutions"*. John Wiley and Sons.

Beirne, J. (2011). The impact of the eurosystems covered bond purchase programme on the primary and secondary markets. *ECB Occasional Paper No. (122)*.

Bernanke, B. (2008). The future of mortgage finance in the united states. Remarks by Chairman Ben S. Bernanke at the UC Berkeley/UCLA Symposium.

Bernanke, B. (2009). The future of mortgage finance in the united states. *The B.E. Journal of Economic Analysis and Policy 9*, 1–10.

Brunnermeier, M. (2009). Deciphering the Liquidity and Credit Crunch 2007-2008. *Journal of Economic Perspectives 23*, 77–100.

Brunnermeier, M. and L. Pedersen (2009). Market Liquidity and Funding Liquidity. *Review of Financial Studies 22*, 2201–2238.

Buhler, W. and V. Vonhoff (2011). *Term Structures of Liquidity Premia in the U.S. Treasury Market*. University of Mannheim, Working paper.

Campbell, J. (2013). Mortgage market design. *Review of Finance 17*, 1–33.

Chiu, J., H. Chung, K.-Y. Ho, and G. Wang (2012). Funding liquidity and equity liquidity in the subprime crisis period: Evidence from the etf market. *Journal of Banking and Finance 36*(9), 2660–2671.

Chordia, T., A. Sarkar, and A. Subrahmanyam (2005). An empirical analysis of stock and bond market liquidity. *Review of Financial Studies 18*(1), 85–129.

Dang, T. V., G. Gorton, and B. Holmstrom (2015). The information sensitivity of a security. *Working Paper Columbia Business School*.

Danmarks Nationalbank (2012). *Danish Government Borrowing and Debt 2011*. Danmarks Nationalbank.

Danmarks Nationalbank (2016). *Comments on consultation: Reducing variation in credit risk-weighted assets - constraints on the use of the internal model approaches*. Danmarks Nationalbank.

Dick-Nielsen, J., P. Feldtter, and D. Lando (2012). Corporate bond liquidity before and after the on-set of the subprime crisis. *Journal of Financial Economics 103*(3), 471–492.

Dick-Nielsen, J., J. Gyntelberg, and T. Sangill (2012). Liquidity in government versus covered bond markets. Technical report, BIS working paper no 382.

Duffie, D., N. Garleanu, and L. Pedersen (2007). Valuation in Over-the-Counter markets. *Review of Financial Studies 20*, 1865–1900.

ECB (2012). *European covered bond fact book*. European Central Bank.

Fender, I. and J. Gyntelberg (2008). Global financial crisis spurs unprecedented policy actions. *Bank for Inernational Settlements, Quarterly Review December*, 21–24.

Fleming, M. (2002). Are larger Treasury issues more liquid? Evidence from bill reopenings. *Journal of Money, Credit and Banking 34*, 707–725.

Fleming, M., W. Hrung, and F. Keane (2010). Repo market effects of the term securities lending facility. *American Economic Review 100*, 591–596.

Frank, N., B. Gonzlez-Hermosillo, and H. Hesse (2008). Transmission of liquidity shocks: Evidence from the 2007 subprime crisis. Working paper, International Monetary Fund.

Frankel, A., J. Gyntelberg, K. Kjeldsen, and M. Persson (2004). The danish mortgage market. *Bank for Inernational Settlements, Quarterly Review March*, 95–109.

Fuster, A. and J. Vickery (2014). Securitization and the fixed-rate mortgage. *The Review of Financial Studies 28*, 175–211.

Gorton, G. and A. Metrick (2012). Securitized banking and the run on the repo. *Journal of Financial Economics 104*, 425–451.

Gürtler, M. and P. Neelmeier (2016). Empirical analysis of the international public covered bond market. *University of Braunschweig, Working Paper*.

Gyntelberg, J., P. Hördahl, K. Ters, and J. Urban (2013). Intraday dynamics of euro area sovereign cds and bonds. Working paper no. 423, Bank for International Settlements.

Gyntelberg, J., K. Kjeldsen, M. B. Nielsen, and M. Persson (2012). The 2008 financial crisis and the danish mortgage market. In A. Bardhan, R. H. Edelstein, and C. A. Kroll (Eds.), *Global Housing Markets: Crises, Policies, and Institutions*, Chapter 3. Hoboken, NJ, USA: John Wiley and Sons.

Hancock, D. and W. Passmore (2009). Three initiatives enhancing the mortgage market and promoting financial stability. *The B.E. Journal of Economic Analysis and Policy 9*, 1–26.

Houweling, P., A. Mentink, and T. Vorst (2005). Comparing possible proxies of corporate bond liquidity. *Journal of Banking and Finance 29*, 1331–1358.

Jaffee, D. and J. Quigley (2013). *The future of the government-sponsored enterprises: The role for the government in the U.S. mortgage market.* Housing and the Financial Crisis (NBER book).

Karolyi, G., K.-H. Lee, and M. Dijks (2012). Understanding commonality in liquidity around the world. *Journal of Financial Economics 105*, 82–112.

Keys, B., T. Mukherjee, A. Seru, and V. Vig (2010). Did securitization lead to lax screening? evidence from subprime loans. *Quarterly Joournal of Economics 125*, 307–362.

Kofner, S. (2009). The german pfandbrief system facing the financial crisis. *European Network of Housing Research papers*.

Lea, M. (2010). *Alternative Forms of Housing Finance: What Can We Learn from Other Countries.* San Diego State University, Working paper.

Mayer, C., K. Pence, and S. Sherlund (2009). The rise in mortgage defaults. *Journal of Economic Perspectives 23*, 27–50.

Mian, A. and A. Sufi (2009). The consequences of mortgage credit expansion: Evidence from the us mortgage default crisis. *Quarterly Journal of Economics 124*, 1449–1496.

Paulson, H. (2009). Statement on covered bond best practices. *U.S. Treasury Press Center*.

Prokopczuk, M., J. B. Siewert, and V. Vonhoff (2013). Credit risk in covered bonds. *Journal of Empirical Finance 21*, 102–120.

Purnanandam, A. (2011). Originate-to-distribute model and the subprime mortgage crisis. *Review of Financial Studies 24*, 1881–1915.

Rubin, A. (2007). Ownership level, ownership concentration and liquidity. *Journal of Financial Markets 10*, 219–248.

Siewert, J. B. and V. Vonhoff (2011). Liquidity and credit risk premia in the pfandbrief market. Working paper, University of Mannheim.

Soros, G. (2008). Denmark offers a model mortgage market. *Wall Street Journal*.

Soros, G. (2010). Reforming a broken mortgage system. *www.politico.com*.

Market Segment	Long Covered		Short Covered		Long Government	Short Government
(Monthly average)	Market	Sample	Market	Sample	Market/Sample	Market/Sample
Amount outst. (DKK billion)	494	424	750	497	174	257
Number of Bonds	115.1	78.7	35.7	17.5	2.8	4.2
Bond Size (DKK billion)	4.3	5.4	22.1	29.7	63.6	62.3
Turnover (DKK billion)	115	104.7	332	155	76	65
Number of trades	2,109	1,891	1,763	928	591	405
Mean tradesize (DKK million)	54.2	55.1	158	156	136.6	169.4
Median tradesize (DKK million)	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 I:
Desriptic statistics for the aggregate 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. The 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 II:
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).

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 III:
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 IV:
Average daily turnover for different market participants.
The table shows average daily turnover in DKK miilion 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 V:
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 VI:
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 VII:
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 VIII:
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:

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

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 IX:
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 maturity) 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 X:
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:

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

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 ***.

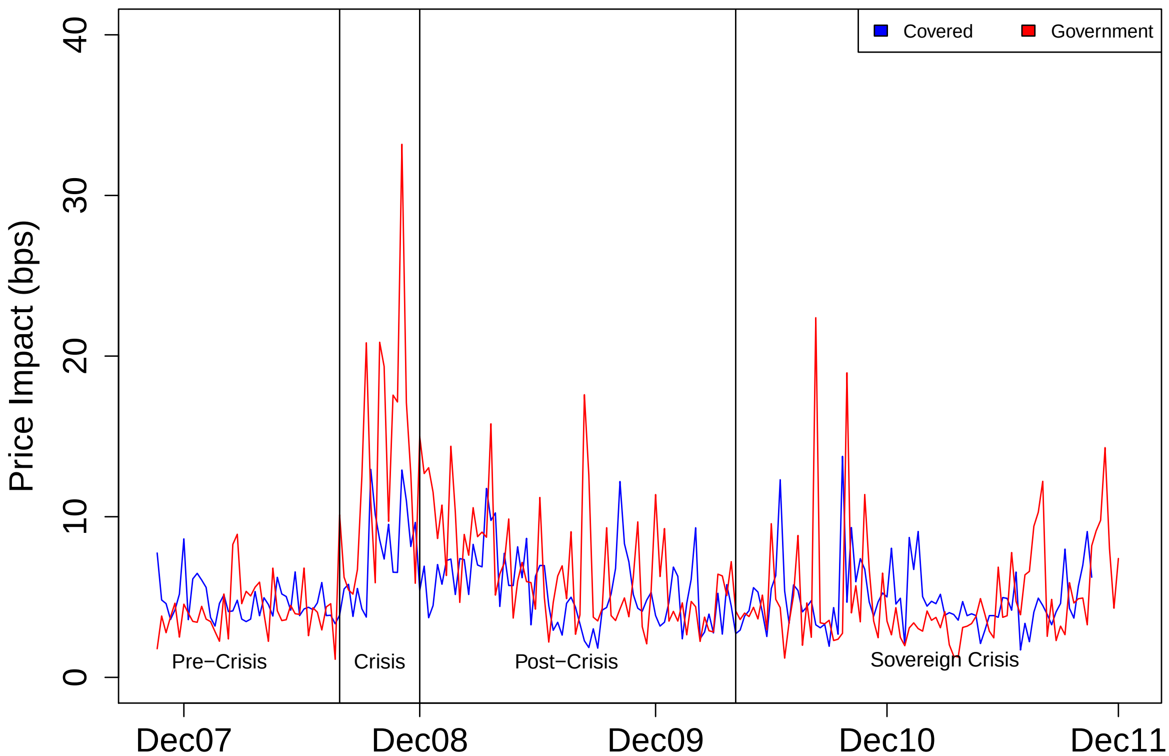

Figure I:
Price impact for short term bonds.
The figure shows the weekly average price impact. The blue line is for short term covered bonds and the red line is for short term government bonds. The data period starts in November 2007. The crisis period is defined as running from August 15th to December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

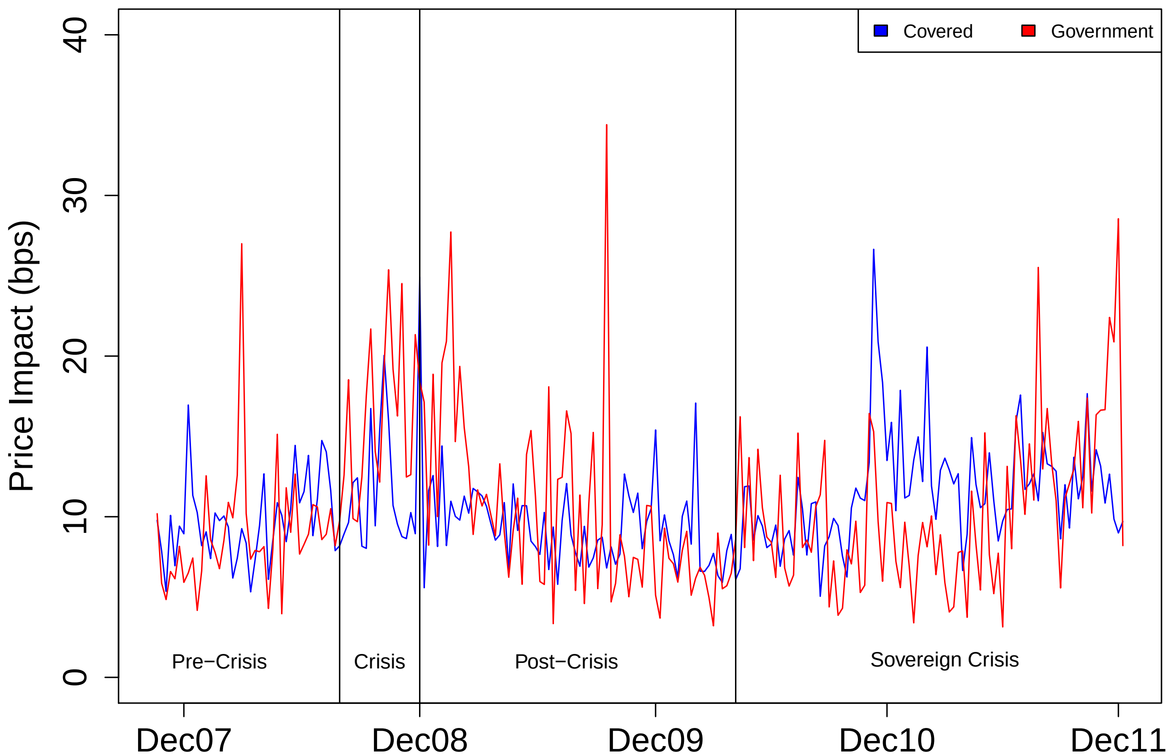

Figure II:
Price impact for long term bonds.
The figure shows the weekly average price impact. The blue line is for long term covered bonds and the red line is for long term government bonds. The data period starts in November 2007. The crisis period is defined as running from August 15th to December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

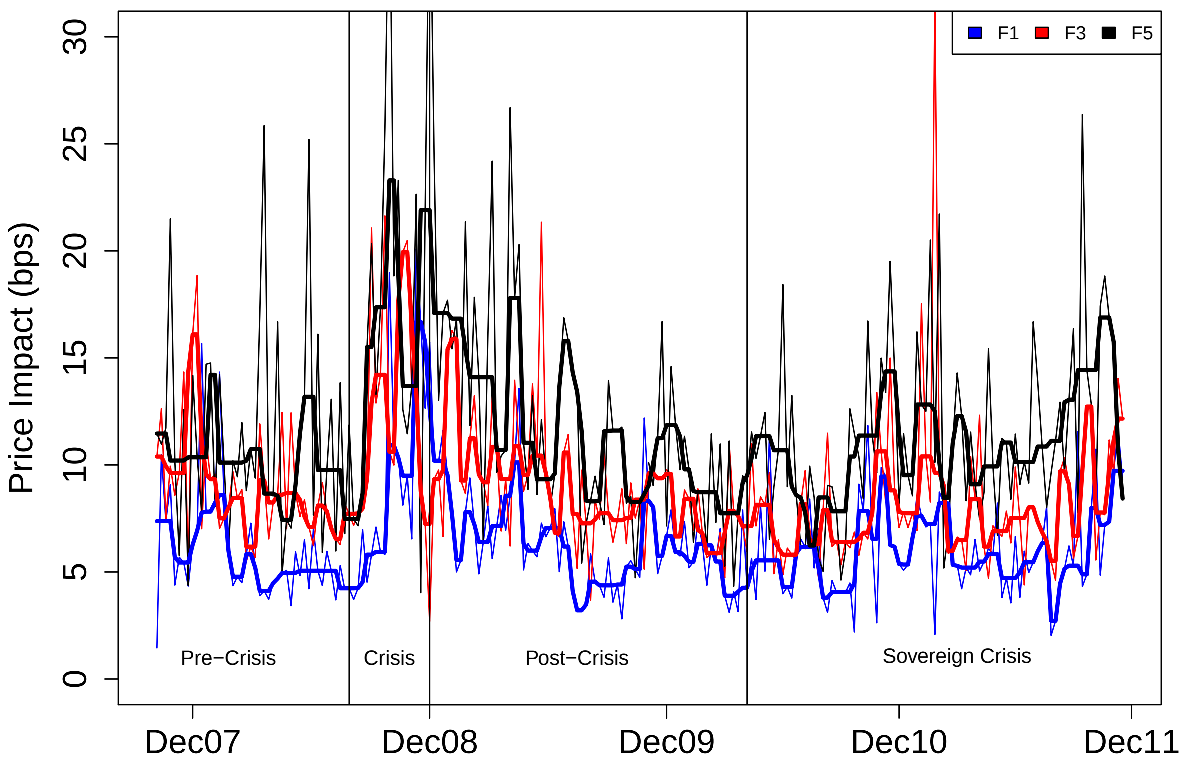

Figure III:
Price impact for ARMs with different maturities.
The figure shows weekly average price impact for the three major groups of bonds used to fund ARMs. F1 bonds are bonds with less then 1 year to maturity (what is called short term covered bonds in the rest of the paper). F3 bonds have between 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).

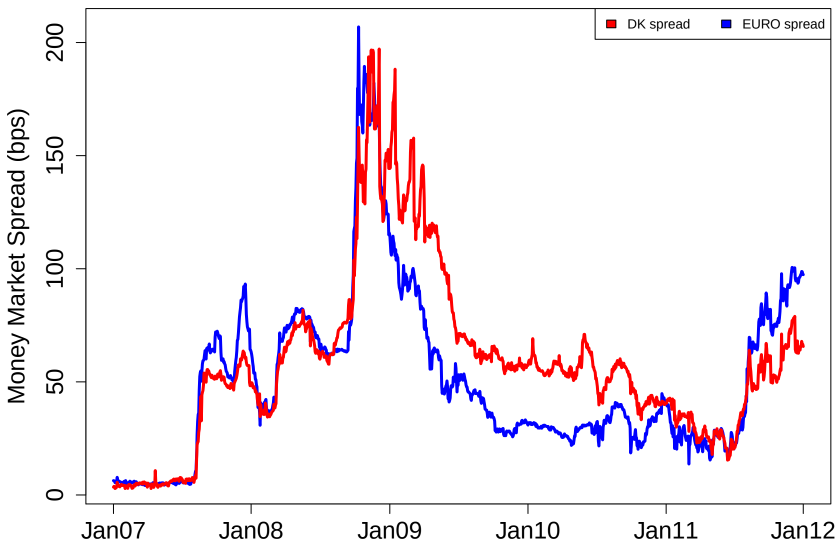

Figure IV:
Money market spreads.
The figure shows weekly observations of the money market spreads. The euro money market spread is calculated as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The Danish money market spread is the 3 month CIBOR rate minus the 3 month CITA rate.

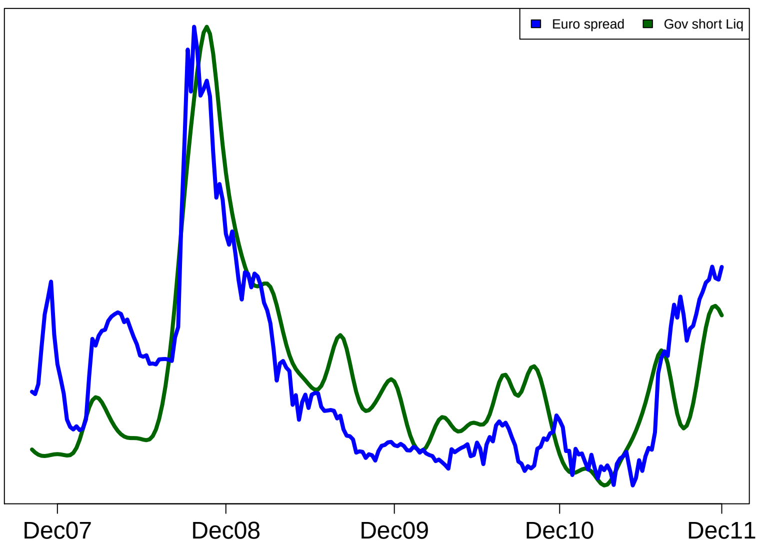

Figure V:
Euro money market spread versus smoothed price impact for short term government bonds.
The figure shows the euro money market spread (the blue line) calculated as as the 3 month EURIBOR rate minus the 3 month EONIA swap rate. The green line is the smoothed weekly price impact series for short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

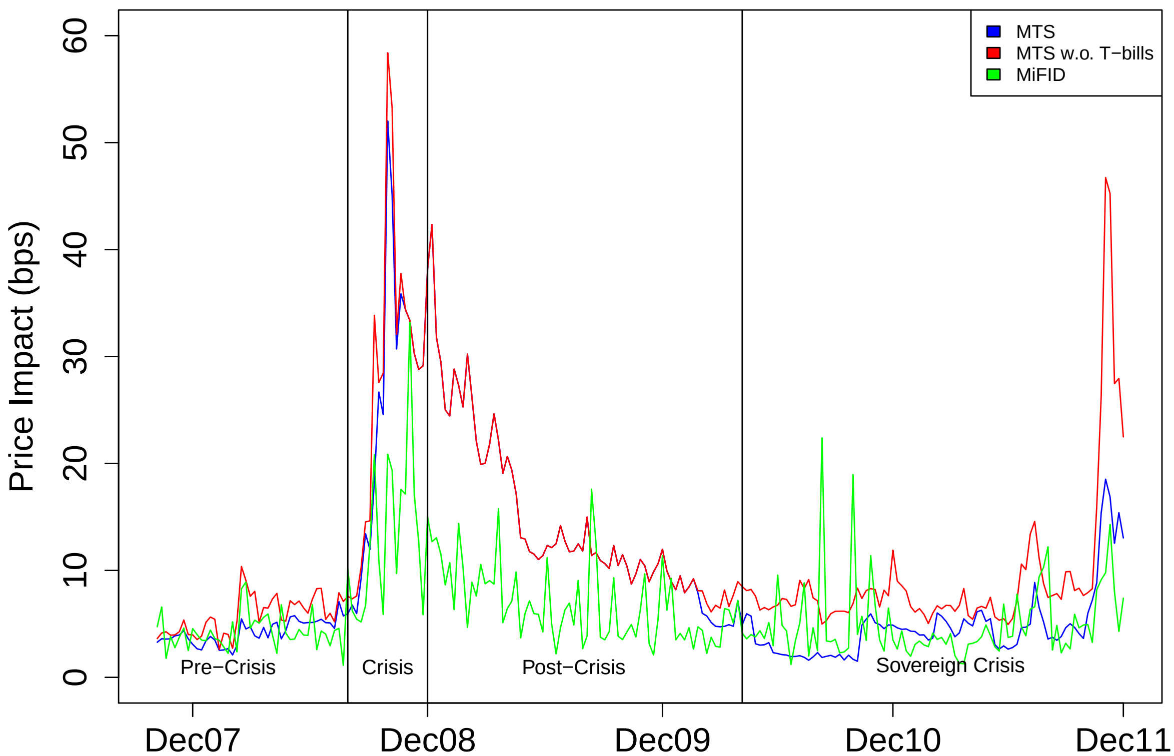

Figure VI:
Price impact for short term Danish government bonds using MiFID and MTS data.

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).

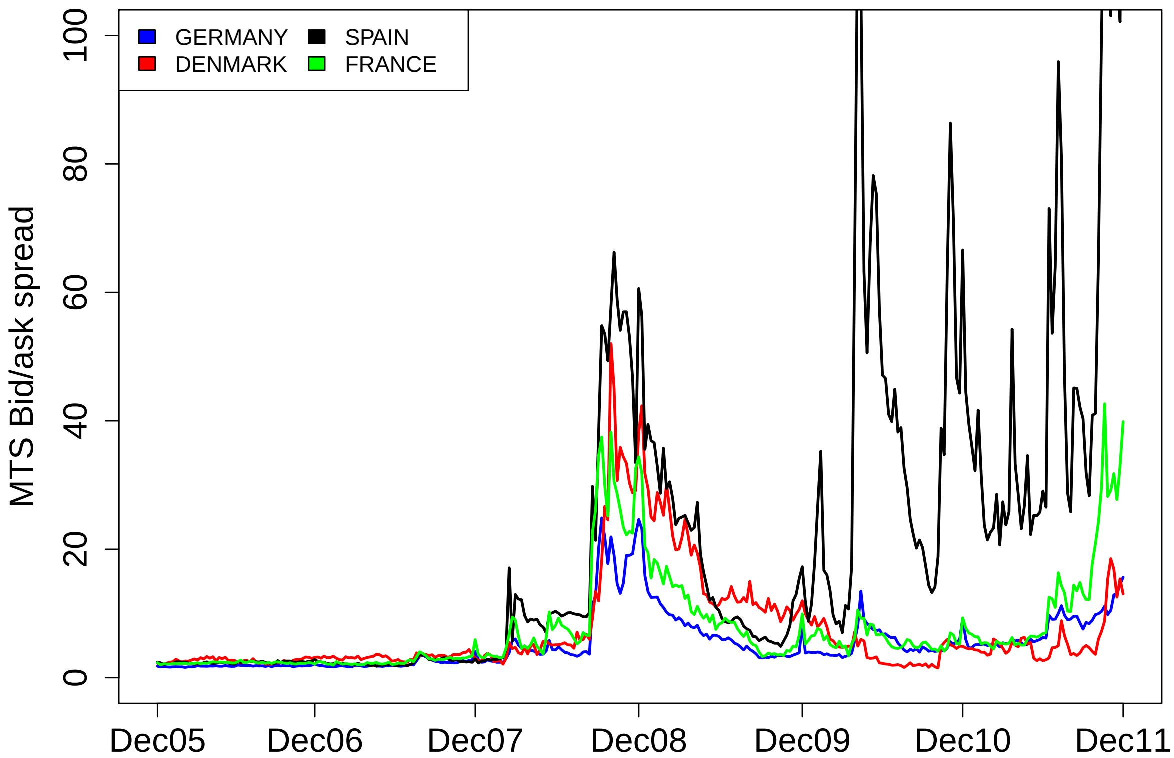

Figure VII:
Price impact for short term government bonds using MTS data.
The figure shows the weekly median price impact measures calculated using MTS quoted prices. The four lines are all short term government bonds with time to maturity less than 5 years. The blue line is for government bonds issued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

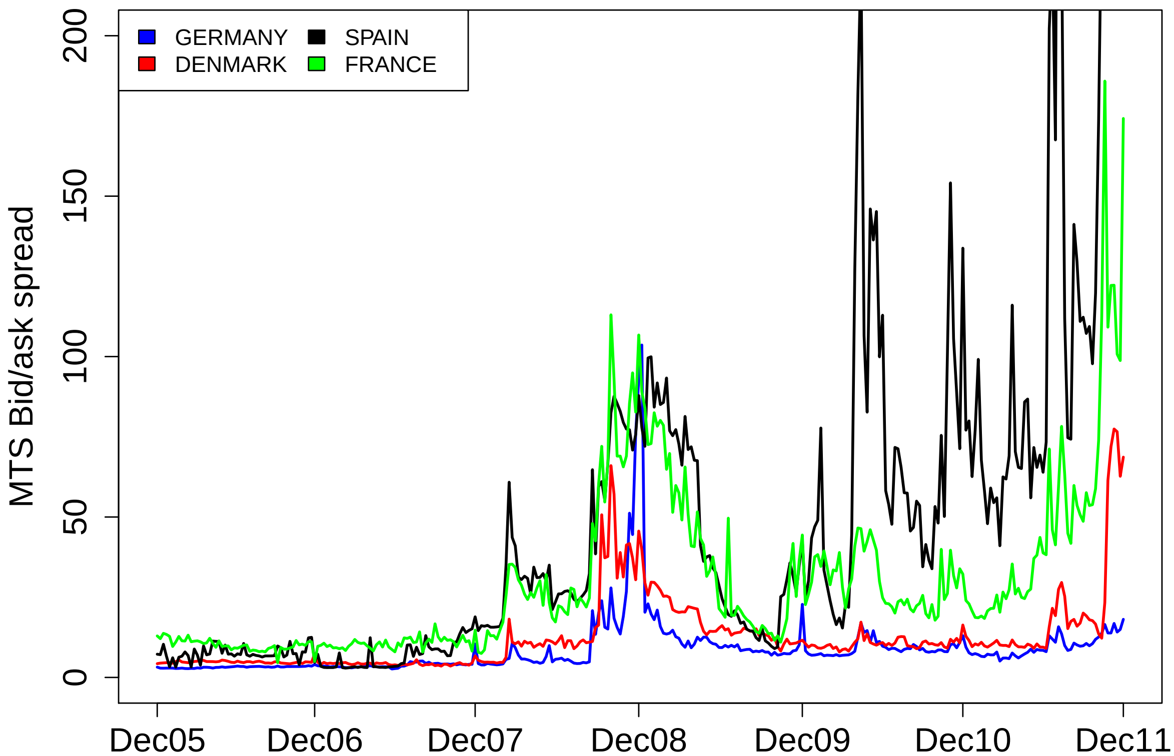

Figure VIII:
Price impact for long term government bonds using MTS data.
The figure shows the weekly median price impact measures calculated using MTS quoted prices. The four lines are all long term government bonds with time to maturity between 5 and 10 years. The blue line is for government bonds issued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

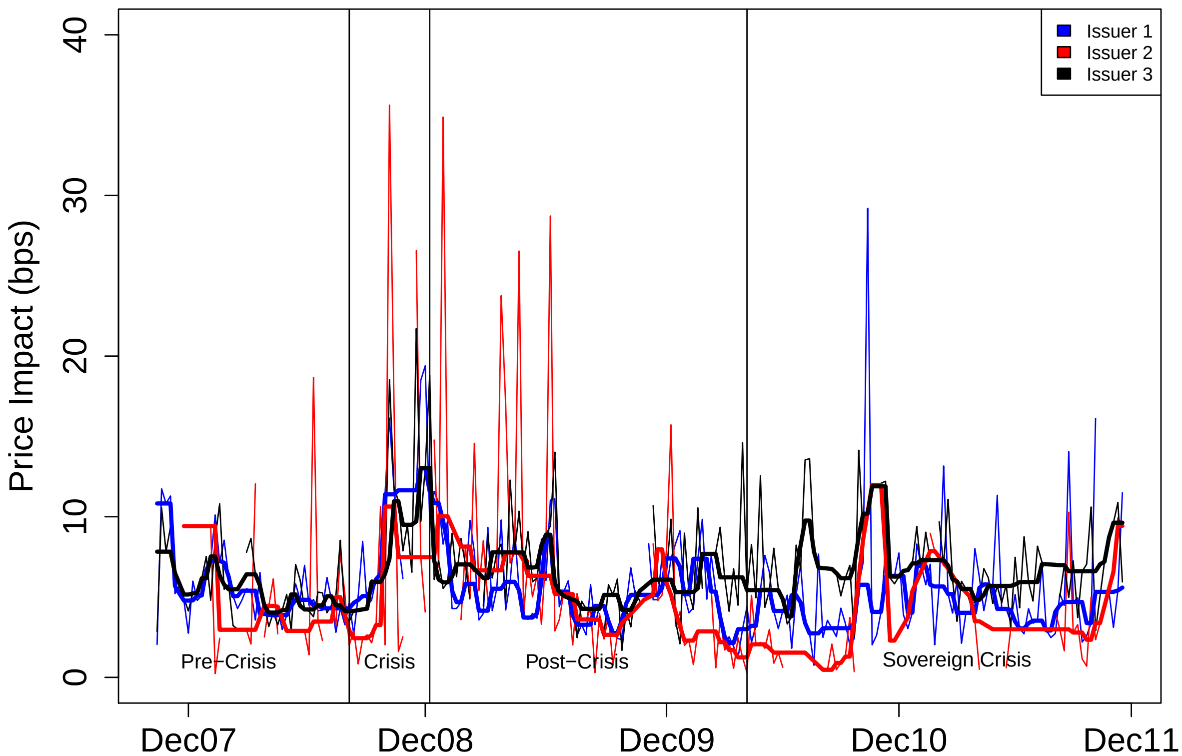

Figure IX:
Weekly price impact for different short term covered bonds issuers.
The figure shows weekly average price impact for short term covered bonds. The sample is split according to bond issuer. The thick lines are smoothed versions of the raw weekly series. The smoothing is done by a running median (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.