EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

Stefano Corradin and
Maria Rodriguez-Moreno

Violating the law of one price: the role of non-conventional monetary policy

No 1927 / July 2016

Abstract

We document that a large yield spread, a basis, developed between USD- and EUR-denominated comparable bonds issued by the same euro area country over the $2008-2013$ period. We find evidence that the basis varies over time, depending on liquidity withdrawn by strongly-constrained banks from the ECB and haircuts applied in the repo market, on the one hand, and the collateral policy and the liquidity supply conditions determined by the ECB, on the other. Overall, ECB collateral and liquidity factors explain a relevant share of the total variation in the basis and help to explain cross country dispersion in the basis.

JEL classification: G01, G12

Non-technical summary

The absence of arbitrage opportunities is a central tenet of asset pricing theory: assets that generate identical cash flows must command the same market price, so that there is no opportunity for profitable arbitrage trading ("The Law of One Price" - LoOP). Nevertheless, there are instances in which the LoOP breaks down for non-negligible periods of time. Recent theory stresses the role of haircut requirements, the difference between the market value of an asset used as loan collateral and the amount of the loan, and funding constraints in propagating mis-pricing in financial markets. Garleanu and Pedersen (2011) highlight that the limited ability of financial institutions to borrow against their securities due to funding constraints can have significant asset pricing effects. In such circumstances, non-conventional monetary policy measures can increase asset prices by lowering haircut requirements and offering loans, relaxing funding constraints in the financial sector (Ashcraft, Garleanu, and Pedersen (2011)). However, haircut differences for securities with (nearly) identical cash flows may lead to a basis violating the LoOP during a liquidity crisis.

We investigate the role of the European Central Bank (ECB) non-conventional monetary policy and lending facility in affecting bond yields during the financial and euro area sovereign debt crisis. We use the relative pricing of comparable pairs of USD- and EUR-denominated bonds issued by the same euro area country and define a basis as the difference between the yield-to-maturity of an USD-denominated bond, after hedging the foreign exchange rate risk, and the yield-to-maturity of a comparable EUR-denominated bond. We document that the basis is striking and persistent: USD-denominated bonds traded at a cheaper level (lower price or higher yield) than EUR-denominated bonds. Thus, we provide evidence that the basis strongly co-moves with measures of the ECB non-conventional monetary policy, using ECB proprietary data on haircuts applied to bonds, liquidity drawn and collateral pledged by individual banks.

We expect the ECB liquidity facility to affect the basis through three main channels. First, the ECB introduced the fixed-rate full allotment in all liquidity operations in October 2008, allowing banks to access unlimited liquidity at a fixed rate in return for collateral. As a result, the ECB's balance sheet expands and contracts flexibly depending on the funding needs of the banks. Second, the ECB changed the haircuts of the USD-denominated bonds at different points in time, while keeping the haircuts of the EUR-denominated bonds stable and lower than in the private market. Third, the ECB offered loans at long maturities that were only available for some banks.

We provide three novel empirical results that firmly link the ECB non-conventional monetary policy to the basis and are consistent with Garleanu and Pedersen (2011) predictions. First, we find that the basis is sensitive to changes in the ECB haircuts applied on USD-denominated bonds. On 15 October 2008 the ECB announced that USD-denominated bonds were admitted as collateral, but subject to an additional haircut due

to the denomination in foreign currency. We find that the basis including eligible USD-denominated bonds was lower than the basis including non-eligible USD-denominated bonds during the eight weeks after the ECB collateral expansion. Our estimates suggest that the change in the ECB eligibility criteria lowered the yield-to-maturity of the eligible relative to the non-eligible USD-denominated bond, after hedging the currency risk, by 13 basis points. The impact is substantial and persistent when compared to the limited empirical evidence in the literature.

Second, we find that increases in haircuts by Central Counter-party Clearing Houses (CCPs) in the fall of 2011 lead to a larger basis for Italy and Spain in periods when the ECB kept haircuts substantially lower and stable but only for EUR-denominated bonds. Because differential of haircuts between the CPPs and the ECB proxies for the opportunity cost a bank faces with the choice of bidding for liquidity in the ECB refinancing operations and in the private repo markets, increases in the CCPs haircuts tend to reduce asset values, make refinancing more costly in the private repo markets and induce banks to rely more on collateralized central bank liquidity. Thus, the fact that only EUR-denominated bonds could be pledged in exchange for ECB liquidity in the fall of 2011 generates a stronger asymmetry between USD- and EUR-denominated bonds and leads to a larger basis.

Third, we find that the basis widens when strongly-constrained banks need central bank liquidity. We construct a liquidity and collateral measure, using ECB proprietary data at bank level. The liquidity measure tracks the evolution over time of the liquidity withdrawn by strongly-constrained banks. We find statistically and economically significant evidence that our liquidity measure strongly co-moves with the basis, especially during the euro area sovereign debt crisis period. The collateral measure tracks the share of collateral in a sovereign country debt pledged to the ECB by strongly-constrained banks. The size of the basis for a country is strongly positively related to the amount of sovereign bonds issued by the same country pledged to the ECB only for Italy and Spain, especially when the ECB implemented the 3−year Long Term Refinancing Operations (LTROs) consisting of 3−year collateralized loans of EUR 489 billion in the first allotment (21 December 2011) and more than EUR 500 billion in the second allotment (29 February 2012). We document that almost 50% of this liquidity is drawn by strongly-constrained banks who pledged almost 15% of their collateral in Italian and Spanish sovereign bonds. Our findings are partly consistent with Drechsler et al. (2014) who document that European banks, which borrowed heavily, also pledged increasingly risky collateral to the ECB. They argue that the ECB's liquidity facility was used for risk-shifting due to the lower haircuts, while our results highlight the role played by the ECB in alleviating the financial sector's funding crisis.

1 Introduction

Recent theory stresses the role of haircut requirements and funding constraints in propagating mis-pricing in financial markets. Garleanu and Pedersen (2011) highlight that the limited ability of financial institutions to borrow against their securities due to funding constraints can have significant asset pricing effects. In such circumstances, non-conventional monetary policy measures can increase asset prices by lowering haircut requirements and offering loans, relaxing funding constraints in the financial sector (Ashcraft, Garleanu, and Pedersen (2011)). However, haircut differences for securities with (nearly) identical cash flows may lead to a basis, violating the Law of One Price (LoOP) during a liquidity crisis.

So far there is limited empirical evidence on the impact of non-conventional monetary policy and lending facility on asset prices (BIS (2015)).[1] Ashcraft, Garleanu, and Pedersen (2011) present evidence regarding the effects of Fed lending under the Term Asset-Backed Securities Loan Facility (TALF). Their evidence indicates that TALF lending did affect the prices of assets that were eligible for use as collateral for borrowing under this programme looking at the differential effect on commercial mortgage-backed securities (CMBS) that were eligible for the TALF programme relative to the effect on similar securities that were not eligible. However, the impact is limited, accounting for the level of the CMBS yields when the TALF was introduced, and temporary. Campbell et al. (2011) find that TALF lowered interest rate spreads for some categories of asset-backed securities (ABS) but had little impact on the pricing of individual securities.

We investigate the role of the European Central Bank (ECB) non-conventional monetary policy and lending facility in affecting bond yields during the financial and euro area sovereign debt crisis. We use the relative pricing of comparable pairs of USD- and EUR-denominated bonds issued by the same euro area country and define a basis as the difference between the yield-to-maturity of an USD-denominated bond, after hedging the foreign exchange rate risk, and the yield-to-maturity of a comparable EUR-denominated bond. We document that the basis is striking and persistent. Thus, we provide evidence that the basis strongly co-moves with measures of the ECB non-conventional monetary policy, using ECB proprietary data on haircuts applied to bonds, liquidity drawn and collateral pledged by individual banks.

Before the beginning of the crisis in 2007 the size of the basis was negligible, representing an excellent example of the success of the LoOP. Over the period September 2008 - April 2010, the basis is large and persistently positive. The finding is consistent with Buraschi, Menguturk, and Sener (2015), who find that USD-denominated bonds issued by Turkey (Brazil and Mexico) traded at a cheaper (richer) level than EUR-denominated

[1] BIS (2015) discusses whether and how the design of central banks' operational frameworks influences private collateral markets, including collateral availability, pricing, related market practices, and market performance under stress.

bonds over the same time period. In May 2010 the intensification of the euro area sovereign debt crisis further impacted the size of the basis and significant differences emerged across the countries that cannot be entirely explained by the violation of covered interest rate parity (CIRP) over the same period. The basis for Austria reached 92 basis points, while the basis for Italy and Spain reached 135 and 220 basis points respectively. Interestingly, the basis of Turkey was negligible over the same period. Buraschi, Menguturk, and Sener (2015) document that the basis is country specific and find evidence that the banks' increased reliance on wholesale funding market and the geographical concentration in sovereign holdings play a key role in explaining the basis in emerging markets.

We focus, instead, on the role of non-conventional monetary policy and we expect the ECB liquidity facility to affect the basis through three main channels. First, the ECB introduced the fixed-rate full allotment in all liquidity operations in October 2008, allowing banks to access unlimited liquidity at a fixed rate in return for collateral. As a result, the ECB's balance sheet expands and contracts flexibly depending on the funding needs of the banks. Second, the ECB changed the haircuts of the USD-denominated bonds at different points in time, while keeping the haircuts of the EUR-denominated bonds stable and lower than in the private market. Third, the ECB offered loans at long maturities that were not available in the private market.

We provide four novel empirical results that firmly link the ECB non-conventional monetary policy to the basis and are consistent with Garleanu and Pedersen (2011) predictions. First, we find that the basis is sensitive to changes in the ECB haircuts applied on USD-denominated bonds. On 15 October 2008 the ECB announced that USD-denominated bonds were admitted as collateral, but subject to an additional haircut due to the denomination in foreign currency. We find that the basis including eligible USD-denominated bonds was lower than the basis including non-eligible USD-denominated bonds during the eight weeks after the ECB collateral expansion. Our estimates suggest that the change in the ECB eligibility criteria lowered the yield-to-maturity of the eligible relative to the non-eligible USD-denominated bond, after hedging the currency risk, by 13 basis points. The impact is substantial and persistent when compared to the temporary increase of 20 basis points in the first two weeks then reduced to 3 basis points over time in the yield spread for the non-eligible TALF super senior CMBS documented by Ashcraft, Garleanu, and Pedersen (2011) and when accounting for the higher level of yields of these securities.[2]

Second, we find that increases in haircuts by Central Counter-party Clearing Houses (CCPs) lead to a larger basis for Italy and Spain in periods when the ECB kept haircuts substantially lower and stable. This is consistent with Garleanu and Pedersen (2011) the-

[2]The average level of yields for super senior CMBS was of 5.72%, when the TALF programme was launched on 9 March 2009. The average level of yields of eligible USD-denominated bonds, after hedging the currency risk, is of 4.39% when the ECB collateral expansion programme was launched on 14 November 2008.

ory that predicts that the basis should be related to the difference in haircut requirements between the market and the central bank times the shadow cost of capital, proxied as the difference between the collateralized and un-collateralized borrowing rate. Sovereign bonds issued by Italy and Spain experienced a dramatic increase in CCPs haircuts in the fall of 2011. In response to the increase in sovereign spreads, the CCPs substantially increased the haircuts requirements for Italy and Spain, while ECB haircuts stayed fairly stable over the same period.[3] Instead, CCPs haircuts were flat for Austria, Belgium and Finland. Because differential of haircuts between the CPPs and the ECB proxies for the opportunity cost a bank faces with the choice of bidding for liquidity in the refinancing operations of the ECB and in the private repo markets, increases in the CCPs haircuts tend to reduce asset values, make refinancing more costly in the private repo markets, as also shown by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) and documented empirically by Gorton and Metrick (2012) and Krishnamurthy, Nagel, and Orlov (2014), and induce banks to rely more on collateralized central bank liquidity. In fact, we find that substantial cross-sectional variation in the basis between these two groups of countries can be mainly attributed to differences in haircuts.

Third, we provide evidence that the basis widens when strongly-constrained banks need central bank liquidity consistent with the Garleanu and Pedersen (2011) prediction that binding margin constraints play a key role in widening the basis. We construct a liquidity and collateral measure, using ECB proprietary data at bank level. The liquidity measure tracks the evolution over time of the liquidity withdrawn by strongly-constrained banks. We find statistically and economically significant evidence that our liquidity measure strongly co-moves with the basis, especially during the euro area sovereign debt crisis period. The collateral measure tracks the share of collateral in a sovereign country debt pledged to the ECB by strongly-constrained banks. The size of the basis for a country is strongly positively related to the amount of sovereign bonds issued by the same country pledged to the ECB only for Italy and Spain, especially when the ECB implemented the 3−year Long Term Refinancing Operations (LTROs) consisting of 3−year collateralized loans of EUR 489 billion in the first allotment (21 December 2011) and more than EUR 500 billion in the second allotment (29 February 2012). We document that almost 50% of this liquidity is drawn by strongly-constrained banks who pledged almost 15% of their collateral in Italian sovereign bonds. A similar development can be observed for Spain, while the reliance of sovereign bonds issued by Austria, Belgium and Finland is insignificant. Our findings are partly consistent with Drechsler et al. (2014) who document that European banks, which borrowed heavily, also pledged increasingly risky collateral to the ECB. They argue that the ECB's liquidity facility was used for risk-shifting due to the lower haircuts, while our results highlight the role played by the funding channel.

[3] Mancini, Ranaldo, and Wrampelmeyer (2015) and Boissel et al. (2014) analyze the functioning of the euro area repo market and the role of CCPs during the euro area sovereign debt crisis.

Fourth, we find that our liquidity and collateral measure is negatively correlated with the implied shadow cost of capital of Italy and Spain, consistent with the Garleanu and Pedersen (2011) prediction that a central bank policy characterized by lower haircuts than the market ones and a full allotment liquidity should relax the margin constraint of strongly-constrained banks and hence reduce their shadow cost of capital.

When examining the effects of monetary policy on the basis, we conduct panel regression analysis considering specific bond and market factors following Buraschi, Menguturk, and Sener (2015). These factors, proposed by several lines of research on limits to arbitrage that originate in the seminal paper by Shleifer and Vishny (1997), proxy for different sources of frictions that can lead to persistent deviations from the LoOP such as (i) short selling restrictions; (ii) funding costs; (iii) institutional and regulatory frictions; and (iv) trading liquidity.[4] Although these factors affect the basis, we observe that they play a limited role during the euro area sovereign debt crisis period. The R^2 of our regressions drops from 31.8% (financial crisis) to 6.3% (euro area sovereign debt crisis). When we include our monetary policy factors the explanatory power substantially improves. Our results are consistent with the idea that access to the central bank liquidity facility was priced by market participants as documented for Brazil and Mexico basis during the financial crisis by Buraschi, Menguturk, and Sener (2015) using an event study analysis. However, our monetary policy factors allow us to account for a great share of the basis and to explain the cross country dispersion in the basis we observe.

The basis we observe might be driven by the relative of scarcity of US dollars in Europe (Baba and Packer (2009), Coffey, Hrung, and Sarkar (2009) and Griffoli and Ranaldo (2009)), when wholesale funding sources came under extreme stress at the end of 2008 and 2011. To address this concern, we carry out two robustness exercises. First, we use the basis based on USD- and EUR- denominated bonds issued by Turkey to control for factors that affected all bond markets at the same time (Buraschi, Menguturk, and Sener (2015)), since Turkish bonds could not be pledged to the ECB in exchange of liquidity. Second, we detract the currency swap spread from the basis to account for this common risk factor. Our results are not affected by these exercises.

The paper is organized as follows. The next section presents and discusses the basis. Section 3 describes the data, while Section 4 briefly reviews the Garleanu and Pedersen (2011) model. Section 5 provides evidence that changes in the ECB haircuts affect bond yields, while Section 6 shows that the monetary policy factors play a key role in explaining the cross country dispersion in the basis. Section 7 concludes.

[4]Shleifer and Vishny (1997) and Duffie (2010) discuss how limited availability of risk capital by arbitrageurs leads to persistent deviations from the LoOP when an initial price shock occurs. Within this literature, there are several recent empirical papers to whom our paper is related. Bai and Collin-Dufresne (2013) investigate the cross-sectional variation in the CDS-bond basis. Fleckenstein, Longstaff, and Lustig (2014) document and study the US TIPS-Treasury bond puzzle. Mancini, Ranaldo, and Wrampelmeyer (2013) find significant variation in liquidity across exchange rates and strong commonality in liquidity across currencies providing evidence that FX market liquidity is crucial for arbitrage trading.

2 The Basis

We define the basis for the pair i of country j at time t as

$$Basis_{i,j,t} = \text{Ask } YTM^{USD->EUR}_{m,j,t} - \text{Bid } YTM^{EUR}_{n,j,t}, \tag{1}$$

where Ask $YTM^{USD->EUR}_{m,j,t}$ is the ask yield-to-maturity of a synthetic (from USD to EUR using currency swaps) bond m issued by country j and Bid $YTM^{EUR}_{n,j,t}$ is the bid yield-to-maturity of EUR-denominated bond n issued by the same country j. We explicitly account for transaction costs: in order to exploit a positive basis, a trader should buy the USD-denominated at the ask price and sell short the EUR-denominated bond at the bid price. We convert the USD-denominated bond into a synthetic EUR-denominated one by means of a cross-currency asset swap package. First, we exchange the fixed coupons of the USD-denominated bond at the Euribor rate plus a spread, the cross currency spread or cross currency basis, with a currency swap. Hence, we enter a floating-fixed interest rate swap to exchange the EUR-denominated stream of floating inflows into a fixed coupon rate. To illustrate this strategy, we provide a real 2-period example.

Example - On 1 October 2010 the USD-denominated bond trades for \$101.661 (ask price) and a comparable EUR-denominated bond costs €102.350 (bid price; Bid YTM^{EUR} = 1.624%). The two bonds are issued by Italy. The first one has coupon rate of 3.5%, while the latter one of 4.25% and both bonds pay coupons on semi-annual basis. The USD- and EUR-denominated bond expires on 15 July 2011 and 1 September 2011, respectively.[5] An investor buys a par cross currency asset swap package that consists of an USD-denominated bond and a fixed-for-floating swap. First, he exchanges the fixed coupons of the USD-denominated bond (fixed side) at the Euribor rate plus the currency swap spread (floating side). The present value of the fixed side is equal to $\$100.592 = -\$1.661 + \$1.039 + \$101.214$. The first component is the upfront payment because the USD-denominated bond does not trade at par ($-\$1.661 = \$100 - \$101.661$). The second component is the discounted value of the first cash flow $\$1.039 = \$3.5 \times 0.999 \times 0.297$, where 0.999 is the discount factor based on the Euribor rate over the period 18 January - 15 July 2011 and $0.297 = 107/360$ is the rescaled number of days in the same time period. The last component accounts for the coupon and principal payment $\$101.214 = \$1.712 + \$99.502$, where $\$1.712 = \$3.5 \times 0.995 \times 0.492$ and $\$99.502 = 0.995 \times \$100$. The cash flows of the floating leg are the following. On 18 January 2011, the investor exchanges the fixed payment \$3.5 with the floating payment $\$100 \times (1.184\% + css) \times 0.297$, where 1.184% is the annualized Euribor rate over the period 18 January - 15 July 2011 and css is the currency swap spread. On 15 July 2011, the floating payment is $\$100 \times (1.387\% + css) \times 0.492 + \$100$,

[5] Appendix A.3.1 provides a complete description of the bonds characteristics. The EUR-denominated bond has the ISIN code IT0004404973, while the USD-denominated has the ISIN code US46540BT47.

where 1.387% is the annualized forward Euribor rate over the period 18 January - 15 July 2011, 0.492 is the rescaled number of days in the same time period and \$100 is the principal payment. Both cash flows are discounted at 1 October 2010 taking the Euribor as the appropriate discount rate. The currency swap spread css is set such that the present value of the fixed and floating leg equal on 1 October 2010. The implied currency swap spread is 0.793%. Finally, the investor gets into a floating-fixed interest rate swap to exchange the EUR-denominated stream of floating inflows of the currency swap into a fixed coupon rate. In order to create the synthetic EUR-denominated bond, the payment dates corresponds to the ones in which the EUR-denominated bond pays the coupons. The fixed coupon rate is set such that the present value of the floating leg €72.934 = \$100.592/1.379, where 1.379 is the USD/EUR spot exchange rate on 1 October 2010, equals the present value of the fixed leg. The implied fixed rate coupon bond is 2.063%, which is equivalent to the yield-to-maturity of the synthetic EUR-denominated bond. Finally, the basis is $0.436\% = 2.063\% - 1.624\%$, defined as the difference between the yield-to-maturity of the synthetic bond and the yield-to-maturity of the EUR-denominated bond. Appendix A.1 describes the cash flows employed in the strategy.

For every single fixed-rate USD-denominated bond issued by an euro area country, we select a comparable fixed-rate EUR-denominated bond in terms of issuer and maturity. Then, we create a list of paired bonds and compute the basis as in Equation (1). Our sample covers bonds issued by Austria, Belgium, Finland, Italy, and Spain. USD-denominated bonds were issued by other euro area countries, such as Germany, Greece, Portugal and the Netherlands, but there are not EUR-denominated bonds issued by these countries that can be matched with the first ones according to our criteria. Section 3.1 describes the pair matching process.

Each panel of Figure 1 depicts the average basis across the bond pairs at a country level from January 2006 to February 2013 on a weekly frequency. At first glance, we observe a large and persistent positive basis that is common across all countries, where the yield-to-maturity of the synthetic EUR-denominated bonds is almost systematically higher than the yield-to-maturity of the EUR-denominated bonds. And hence, for most of the sample period we observe that the USD-denominated bonds trade cheaper than the comparable EUR-denominated bonds.

At the beginning of the sample period we observe that the basis is close to zero. Between the Lehman Brothers collapse and March 2009, the basis generally increases across the five european countries (from Panel (a) to (e)) and Turkey (Panel (f)). This finding is consistent with Buraschi, Menguturk, and Sener (2015), who find that USD-denominated bonds issued by Turkey traded at a cheaper level than the EUR-denominated bonds over the same time period. The basis across the bond pairs for Italy reached 140 basis points, while the basis for Austria, Belgium and Spain reached 71, 57 and 56 basis points, respectively.

After that period the basis drops but its level is still above that observed at the beginning of the sample period. In May 2010, the activation of the Security Market Programme (SMP) by the ECB is seen as the official start of the sovereign debt crisis in the euro area with the Greek debt crisis, which triggered the sovereign debt crisis for Ireland and Portugal and later for Italy and Spain in August 2011. This period is also characterized by the activation of a set of non-conventional measures by the ECB such as the first 3-year LTRO in December 2011 and the second one in February 2012, whose objective was to provide liquidity for a very long horizon that was not available in the private repo market. Over the period December 2011 - March 2012, the basis across the bond pairs for Austria reached 92 basis points, while the basis for Italy and Spain reached 135 and 220 basis points. The basis of Turkey remained unaffected by this turmoil.

The violation of the LoOP we document for euro area sovereigns is concomitant with the violation of the covered interest rate parity (CIRP) (Baba and Packer (2009), Coffey, Hrung, and Sarkar (2009) and Griffoli and Ranaldo (2009)). This parity failed due to a severe dollar shortage that banks, especially the European ones, faced because they had funding problems both in their local currency and in U.S. dollars (Ivashina, Scharfstein, and Stein (2015)). This prompted these banks to swap euro funding into dollar funding using cross currency swaps, which resulted in CIRP violations when there was limited capital to take the other side of the trade. Still, the violation of the CIRP in foreign exchange market cannot explain the cross country dispersion in the basis we observe. Figure 1 also depicts the average cross currency swap spread (long term CIRP deviation) between USD and Euro. For comparability reasons we report cross currency swap spreads with positive sign. For each pair, the cross currency swap spread between USD and Euro is matched using the cross currency swap spread tenor and the residual time-to-maturity of the pair. Then, we compute the average across the pairs for each country. We observe that the cross currency swap spread accounts almost for the entire basis of Finland. However, there is a sizable residual component that cannot be attributed to the violation of the CIRP condition for Italy. This empirical fact is also consistent with Buraschi, Menguturk, and Sener (2015) who document that the basis is country specific. Brazil and Mexico on average payed lower risk premia in USD than in EUR (negative basis), whereas the opposite holds for Turkey (positive basis). They provide evidence that geographical frictions operating at the country level play a key role in explaining their basis.

There are three main reasons why one might expect the basis to be positive and to become even more positive during strongly distressed periods in the euro area sovereign markets. Because the natural buyers of euro area sovereign bonds are European banks, we can expect that banks who relied more on funding using sovereign bonds faced an increasing cost of financing during the crisis. Figure 2 shows the evolution of European banks holdings for USD-denominated (top panel) and EUR-denominated (bottom panel) sovereign bonds for each country under analysis during the financial and euro area sovereign debt crisis.[6] The figure shows an interesting pattern. The European banks hold a small fraction of USD-denominated sovereign bonds with the exception of Italy and Spain. Starting from the euro area sovereign debt crisis in spring 2011, the share of USD-denominated sovereign bond holdings increases and reaches 39% (28%) for Italy (Spain). Because banks' holdings of EUR-denominated sovereign bonds do not increase during the same period, that rise makes funding of USD-denominated sovereign bonds increasingly expensive in comparison with EUR-denominated sovereign bonds. Second, under Basel rules, EUR-denominated domestic sovereign bonds have zero capital weightings for domestic banks, while the USD-denominated domestic sovereign bonds do not, so holding these bonds would incur capital charges (Acharya, Engle, and Pierret (2014)). Third, during the euro area debt sovereign crisis period, USD-denominated bonds were not accepted as eligible collateral for the ECB liquidity facility.

Our trading strategy to convert the USD-denominated bond into a synthetic EUR-denominated bond deserves further comments due to its undeniable importance in the calculation of the basis. If the basis is still positive even after considering the transaction costs of executing the trading strategy, it does not necessarily imply the existence of an arbitrage opportunity. In fact, arbitrage requires that the two bonds be identical in each state of uncertainty. Buraschi, Menguturk, and Sener (2015) discuss the conditions that have to be satisfied to expect a null basis. First, the two bonds have to be identical in terms of fungibility, collateral value and liquidity. Second, neither bond is subject to short selling constraints and the costs of short-selling the bonds have to be identical. Third, a trader who exploits the trading strategy previously discussed should not be subject to funding constraints. Fourth, the two bonds are subject to simultaneous default and the two recovery rates should be identical in expectation. Finally, either default occurs at bonds' maturity or, if default occurs earlier, the EUR/USD exchange rate is independent of the issuing country's default event, otherwise this would affect the recovery value of the bond. This latter condition is key for our trading strategy. In case of early default, even if the recovery rates of the two bonds are the same, the trader holds a currency swap that may gain or loose value depending on the correlation between the exchange rate and the default event making the hedging strategy incomplete and the arbitrage opportunity risky. To mitigate this risk, traders could use an extinguishing currency swap or hedge the residual risk with a Quanto CDS spread. The first one is an agreement that can be canceled when the reference entity defaults. The latter one is the difference between the CDS quotes in USD and EUR written on the same entity (Buraschi, Menguturk, and Sener (2015)). Hence, a positive or negative basis should be interpreted as evidence of

[6]The holdings are re-scaled by the total outstanding amount of USD-denominated bonds issued by each country. The figure is based on an ECB proprietary data on securities holdings on a security-by-security base.

frictions that prevent these conditions to be met.

These conditions apply when the bonds are issued by the same sovereign in different currencies. In our setting, we consider bonds issued by the same euro area sovereign in euros and dollars. An extensive literature on sovereign default risk including Duffie, Pedersen, and Singleton (2003), Pan and Singleton (2008), Longstaff et al. (2011), Du and Schreger (2013) and many others makes the key point that default risk for foreign currency-denominated sovereign bonds may differ from that for local currency-denominated bonds. The sovereign may "print money", deflate the debt and repay it but in a depreciated currency or may choose to selectively default on local versus foreign currency-denominated bonds or may re-denominate the local currency-denominated bonds. First, the euro can be viewed as foreign currency to its member states, because national authorities don't control the "printing press" (Corsetti and Dedola (2013) and De Grauwe (2013)). Second, our sample includes bonds issued by the same country in dollars under different laws, allowing us to control for the effect of different jurisdictions on the basis.

Finally, there are other three alternative ways to hedge for the currency risk. One can use the forward market to hedge each cash flow as in Buraschi, Menguturk, and Sener (2015). Another approach is to use cross currency swaps, subtracting par swap rates directly from yields of coupon bearing bonds (Krishnamurthy, Nagel, and Vissing-Jorgensen (2014) and Du and Schreger (2013) for two recent examples). Alternatively, Tuckman and Porfirio (2003) propose a strategy to create an adjusted-synthetic forward rate that takes into account violations of the CIRP in the long run on the basis of the spot exchange rate, the local and foreign Libor and the cross currency basis. Appendix A.2.1 documents that these alternatives have a substantial impact on the calculation of the basis affecting the level of the basis itself, but our empirical results are robust to the different approaches used to compute the basis.

3 Data and Variables

3.1 Basis and Bond Characteristics

We focus on all euro area countries that issue fixed-rate coupon bonds denominated in USD. Using information from the Dealogic database, we select all bonds issued in USD before 1999 and with a maturity date after 2008. For those bonds we find a comparable EUR-denominated bond in terms of the same issuer and similar maturity. We rule out those USD-denominated bonds for which (i) we do not find an EUR-denominated bond whose settlement date mismatch is less than 6 months; (ii) bid and ask prices are not available; and (iii) short selling activity information from Data Explorers is not available. Thus, our sample covers information for five countries: Austria, Belgium, Finland, Italy, and Spain. We have 36 fixed-rate coupon bonds of which 19 are USD- and 17 EUR-denominated. Appendix A.3.1 reports information about the 36 bonds.

Bond level information is gathered from Bloomberg. We retrieve daily bid, mid and ask prices and yields (Bloomberg BGN).[7] We calculate the basis as in Equation (1) using ask and bid prices and following the strategy described in Section 2 and in Appendix A.1. To compute the basis, we collect data on USD and EUR swap rates using matching end-of-day Bloomberg data.[8] In order to avoid systematic convergence in the basis around the maturity date due to the convergence of the price to the face value, we rule out the last year of the bond life.[9] In Appendix A.3.2 we carry out a duration gap analysis to test whether cash flow mismatch has significant impact on the basis dynamics.

We also consider specific bond factors. Belgium issues USD-denominated debt under local law, while Austria, Finland and Spain under English law. Italy is the only country issuing under different regimes in our sample. It issues most of the USD-denominated bonds under the New York legislation but some under local and English law. Instead, all EUR-denominated bonds are issued under the local law. Then, we consider other bond specific covenants such as negative pledge and cross default clauses which could potentially explain differences across comparable bonds by including a dummy variable, $Additional\ Clauses_{i,j}$, that takes the value of one when the USD-denominated bond is issued under those covenants.

Then, bond level information is complemented with information about lending activity provided by Data Explorers. Although security lending activity is not a direct measure of short selling activity, it is a proxy commonly used in the limits to arbitrage literature. In fact, to short a bond, an investor must first borrow the bond through a secured loan where the owner of the bond lends the bond to the investor at some market determined rate. We explore the effect of two variables: $No.\ of\ Transactions_{i,j,t}$ and $Indicative\ Fee_{i,j,t}$. The $No.\ of\ Transactions_{i,j,t}$ refers to the difference between the number of daily open lending transactions in the USD- and the EUR-denominated bonds of pair i issued by country j at day t. On average, we observe 21 and 14 daily open lending transactions on the EUR- and USD-denominated bonds respectively. The $Indicative\ Fee_{i,j,t}$ denotes the difference between the daily average fee for borrowing the USD- and the EUR-denominated bonds of pair i issued by country j at day t. We observe that the average fee is around 43 (48) basis points for EUR-denominated (USD-denominated) bonds during our sample.

Table 1 provides an overview of the main USD-denominated bonds characteristics, the pair characteristics and the average of the main variables just discussed at pair level.

As a robustness check we also construct two alternative bases. We first calculate the basis as in Equation (1) for sovereign bonds issued by Turkey denominated in Euros and in

[7]Bloomberg BGN is a weighted average of the quotes contributed to Bloomberg by a minimum of five brokers and dealers.

[8]Swaps rates are quoted in terms of the constant rate on the contracts floating leg. The traded maturities are $1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25$ and 30 years. To obtain swap rates for intermediate maturities, we use linear interpolation.

[9]For example, if the bond's maturity date is 31 May 2012, the bond is included in our sample upon 31 May 2011.

US dollars following the same criteria previously described. The final sample has 8 fixed-rate coupon bonds (4 USD- and 4 EUR-denominated bonds) and leads to a total of 4 pairs. Second, we construct a new basis using EUR-denominated government agency bonds that are eligible ECB collateral but are subject to higher haircuts than comparable EUR-denominated sovereign bonds. The government agency bond is explicitly or implicitly guaranteed by its own sovereign country. We compute the basis as the difference between the ask yield-to-maturity of the government agency bond and the bid yield-to-maturity of the comparable sovereign bond.[10] Our sample covers 51 pairs of bonds relative to 8 agencies that belong to 4 countries.[11]

3.2 Monetary Policy Factors

3.2.1 *Eurosystem Collateral Management and Liquidity Facility*

The Eurosystem engages in two types of market operations: main refinancing operations (MRO) and longer-term refinancing operations (LTRO). MROs are regular liquidity-providing transactions with a weekly frequency and a maturity that is one week. LTROs are liquidity-providing transactions offered every month and have a maturity of three months. During the crisis, the ECB decided to provide more LTROs with various maturities, adding three and six months, one year and three years. After October 2008, the ECB have conducted fixed-rate auctions with full allotment. In a fixed rate auction, the ECB sets an interest rate and banks can borrow an unlimited amount at the given interest rate. The ECB provides funds to banks against collateral via a lending arrangement that mirrors private repos. The ECB risk control framework establishes collateral eligibility criteria, based on type of assets, credit quality, place of issuance, type of issuer, currency, acceptable markets and other characteristics which are applied uniformly across the euro area. The ECB collateral management compiles a public list of eligible marketable assets on a daily basis.[12] The amount of funding provided equals the market price of the collateral multiplied by one minus the haircut on the loan.[13] This haircut depends by the combination of asset type, issuer, rating class and bond time-to-maturity.[14]

[10]We first select all eligible EUR-denominated agency bonds issued before 1999 and with a maturity date after 2008 (from ECB proprietary data). For those bonds we find a comparable sovereign EUR-denominated bond in terms of the same issuer-country and similar maturity.

[11]The agencies are: CADES (Caisse d'Amortissement de la Dette Sociale - France), SFEF (Caisse d'Amortissement de la Dette Sociale - France), KfW (Kreditanstalt fr Wiederaufbau - Germany), NRW (North Rhine-Westphalia Bank - Germany), CDP (Cassa Depositi and Prestiti - Italy), Ispa (Infrastrutture Spa Italy), ICO (Instituto de Credito Oficial - Spain) and FROB (Fondo de Reestructuracion Ordenada Bancaria - Spain).

[12]The list is available at `https://www.ecb.europa.eu/paym/coll/assets/html/index.en.html`.

[13]If the market price is not available or not reliable, the Eurosystem computes a theoretical price of the asset.

[14]Categories include government bonds, agency bonds, corporate bonds, asset-backed securities, covered bonds, and non-marketable collateral. See also `https://www.ecb.europa.eu/pub/pdf/other/financial_risk_management_of_eurosystem_monetary_policy_operations_201507.en.pdf`.

Our dataset contains bank-level information about total borrowing and collateral pledged with the ECB. The dataset covers the period from October 2008 until February 2013.[15] It contains weekly information about all of the collateral pledged by a bank. The data identify all banks which borrow from the ECB in each week. Collateral is identified at the asset level (ISIN code for marketable assets) and nominal values, pre- and post-haircut market values and haircut applied are recorded.[16] The total post-haircut market value of collateral represents the banks total borrowing capacity with the ECB.

A. Eligibility and Haircuts

The ECB treats USD- and EUR-denominated bonds from the same issuer differently. First, USD-denominated bonds are not accepted as collateral during the whole sample period of our study. The ECB admitted USD, pounds sterling or Japanese yen as eligible collateral subject to the fulfillment of the relevant eligibility criteria from 14 November 2008 to 31 December 2010 and from 9 November 2012 onwards. Second, USD-denominated bonds have to be deposited in the European Economic Area (EEA) to be eligible. Third, USD-denominated bonds are currently subject to an additional haircut of 16% due to currency risk when they are eligible.[17]

To measure the opportunity cost a bank faces with the choice of bidding for liquidity in the refinancing operations of the ECB and in the centrally cleared private repo markets, we collect data on haircuts applied by euro area CCPs.[18] CCPs apply haircuts to bonds on a daily basis to cover the potential costs of liquidation, which CCP would incur in the event of a member's default in order to close the open positions. For Italy, we collect the haircuts applied on repo transactions backed by Italian sovereign bonds by Cassa Compensazione e Garanzia (CC&G) and LCH Clearnet, who apply the same repo haircuts. For Spain, we collect the haircuts applied on cash and repo transactions backed by Spanish sovereign bonds by Bolsas y Mercados Espanoles (BME). Finally, we collect the haircuts applied on repo transactions by Eurex for all the countries. LCH Clearnet and Eurex are the two major CCPs in the euro area (Mancini, Ranaldo, and Wrampelmeyer (2015) and Boissel et al. (2014)). All the four CCPs have their own internal methodological approach to set the haircuts. However, one key difference is the following one. While the CC&G, BME and LCH Clearnet revise their own haircuts on a discretionary basis, Eurex has adopted a dynamic and rule-based approach to set the haircuts at bond level.[19]

[15] Prior to end of September 2008 the data are recorded intermittently.

[16] The ECB estimates market values for non-marketable collateral.

[17] During the first eligibility window (14 November 2008 - 31 December 2010) the additional haircut due to the denomination in the USD currency was of 8%.

[18] Generally, haircuts can be placed in cash or in EUR-denominated sovereign bonds. The bonds deposited as collateral are subject to haircuts based on the sovereign issuer and their duration.

[19] First, a yield shift of 1% is computed for every bond. Then, the haircut is calculated in two steps: (i) the actual yield of the bond is calculated based on the current market price and the yield is then shifted by using the yield shift factor; (ii) a theoretical bond price is calculated by using the shifted yield. The difference between the theoretical price and the current market price is set into relation to the

Our measure of opportunity cost is the difference between CCPs and ECB haircuts at bond level. For Italy and Spain, we compute two measures. For Italy, one based on the haircuts set by CC&G / LCH Clearnet and the second one by Eurex. For Spain, one based on the haircuts set by BME and the second one by Eurex. This difference is computed only for the EUR-denominated bonds because repo transactions on USD-denominated bonds are not cleared by the CCPs.

B. Liquidity and Collateral

Using the ECB collateral and liquidity data at the bank level, we identify strongly-constrained banks. At the bank level, we use the total post-haircut market value of collateral, that represents the banks total borrowing capacity with the ECB on the basis of the assets it has already mobilized as collateral, and the total borrowing with the ECB to compute the collateral coverage ratio, the total borrowing normalized by the total post-haircut market value of the collateral. At the end of each month we sort banks into three groups based on the 33^{th} and 66^{th} percentile of the collateral coverage ratio distribution. Banks that have a collateral coverage ratio higher than the 66^{th} percentile are identified as strongly-constrained banks. Our $Liquidity\ Measure_t$ tracks the total borrowing of this group, rescaled by the total post-haircut market value of collateral pledged to the ECB.

Then, we construct a collateral measure, $Collateral\ Measure_{j,t}$, that tracks the share of total collateral in the sovereign country j debt pledged to the ECB by the strongly-constrained banks previously identified. We use this measure to analyze whether strongly-constrained banks rely more on a specific sovereign debt.

3.3 Market Factors

In order to control for the potential impact of risk factors on the basis we include a set of global and country-specific market risk factors. First, we include the cross currency swap spread, $XCS_{i,j,t}$, in our baseline panel regression to control for a common risk factor. The cross currency swap spread between USD and Euro is matched with each pair using the cross currency swap spread tenor and the pair i time-to-maturity.

Second, we consider the Quanto Credit Default Swap, $Quanto\ CDS_{j,t}$, that refers to the differential of CDSs on the same underlying, but quoted in different currencies. Both EUR- and USD-denominated CDS use the full restructuring clause (CR) implying that any restructuring event qualifies as a credit event. According to Ehlers and Schönbucher (2006), the $Quanto\ CDS_{j,t}$ is defined as one minus the ratio between the average EUR-denominated CDS spread and the average USD-denominated CDS spread capturing the expected devaluation of the Euro relative to the USD conditional on the country's default.

market price in order to obtain a percentage. This percentage serves as the new haircut. The haircut so computed cannot fall under a defined minimum haircut set by Eurex.

We consider EUR- and USD-denominated CDS spreads with maturities of 6 month and $1, 2, 3, 4, 5, 7, 10, 20$ and 30 years to compute the $Quanto\ CDS_{j,t}$.

To assess money market conditions we look at the spread between unsecured inter-bank lending and secured inter-bank repos (repurchase agreements backed by sovereign or high quality bonds) of the same maturity. In the euro area, this spread is the difference between Euribor and Eurepo rate, where the latter one is defined as the rate at which one prime bank offers funds in euro to another prime bank if in exchange the former receives general collateral from a basket of (high quality) assets. Due to the increased riskiness of its sovereign collateral, the repo rates of Italian and Spanish collateral have been diverging from the ones of Germany and France since July 2011. Thus, we compute this spread at country level, $Euribor_t - Eurepo_{j,t}$, using the 3−month tenor.[20]

4 Margin-based Asset Pricing

Garleanu and Pedersen (2011) extend the classic CAPM framework introducing a margin constraint. A margin is an alternative to a haircut. A haircut is expressed as the percentage deduction from the market value of collateral (e.g. 2%), while an initial margin is the market value of collateral expressed as a percentage of the purchase price (e.g. 105%) or as a simple ratio (e.g. 105 : 100). In their framework, agents can borrow but subject to a margin requirement that has a direct non-risk-based effect on asset valuation: the more difficult to fund a bond is (i.e., the higher margins), the higher the required yield. Their model features a two agents economy with a risk averse and a less averse (i.e., natural buyer) agent. Both agents face exogenous margin requirements. This resembles the real world where investors are able to lever their portfolios but their maximum leverage is limited by a margin requirement. A margin requirement of $m \times 100\%$ means that the investors on capital must make up at least $m \times 100\%$ of her total investment in risky securities. For example, if the margin requirement is $m = 40\%$, an investor with €1 to invest can deposit the €1 as margin and borrow up to €2.5($= 1/0.4$).

Intuitively, the margin requirement will affect asset pricing in the following manner. In an unconstrained CAPM world (where $m = 0$), an investor with low risk aversion borrows heavily in the risk-free asset and invests in the market portfolio of risky assets. However, in the constrained world, she is not able to do so as the maximum amount of leverage is limited by the margin requirement on each single asset. Thus, Garleanu and Pedersen (2011) show that for the asset in which the risk-tolerant investor holds a long

[20]Information about country specific general collateral repo is collected from RepoFund Rate (`www.repofundsrate.com`) which provides a series of daily country-specific repo indices. These indices are based on repo trades that use sovereign government bonds denominated in euro as collateral. Country-specific repo indices are available for Germany, France and Italy. We apply the German index to Finland, the French index to Austria and Belgium and the Italian index to Spain.

position in equilibrium, the required excess return $E(r^i)$ is

$$E(r^i) = r^{\text{risk-free}} + \beta^i \times \text{covariance risk premium} + m^i \times \text{margin premium}, \qquad (2)$$

where m^i is the margin requirement. The first two terms in the "margin" CAPM are the same as in the standard CAPM, namely the risk free rate and the covariance risk premium. If the margin requirements are zero, the "margin" CAPM nests the standard CAPM. With positive margin requirements ($m^i > 0$), the higher a security's margin requirement, the higher the required return. The margin premium depends on the product of ψ, the shadow price of the margin constraint in the risk-tolerant investor's optimization problem, and x, the relative importance of the risk-tolerant agent. Note that all quantitates might be time-varying. Garleanu and Pedersen (2011) quantify the cost of capital, ψ, with the interest rate differential between un-collateralized and collateralized loans, priced by Libor-OIS, where OIS is the overnight index swap.[21] Therefore, we should expect greater deviations from CAPM when: (i) the risk-tolerant agent's wealth is lower; (ii) margins are greater; and (iii) relative importance of risk-tolerant agents in risk sharing is high. Thus, conditions (i) and (ii) are likely to be stronger during a crisis.

The Garleanu and Pedersen (2011) framework based on CAPM offers an explanation of occurring of "bases", price gaps between securities with identical cash-flows but different haircuts, during a funding liquidity crisis. Consider two assets i and i' that have the same payoff but differing margins $m^{i'} < m^i$.[22] Applying the margin CAPM Equation (2), we get

$$\underbrace{E(r^i) - E(r^{i'})}_{\text{Basis}} = x \times \psi \times (m^i - m^{i'}) + (\beta^i - \beta^{i'}) \times \lambda = x \times \psi \times (m^i - m^{i'}), \qquad (3)$$

since returns are purely determined by cash flows which are identical ($\beta^i = \beta^{i'}$).[23] Thus, the key insight is that funding constraints affect yields and can generate departures from the LoOP making "arbitrage" no longer the best metric to describe "good deals".

As previously discussed, the ECB implemented non-standard lending policies during the financial and euro area debt sovereign crisis that are characterized by the common feature of lending against assets sat haircut requirements lower than available in the market. Let's suppose that the ECB lowers the haircut on asset i or keep it constant while the market haircut increases. The asset is held by the risk-tolerant agent. Thus, the main prediction would be that the ECB's policy lowers the required return (and lowers

[21] We will argue later that a better proxy for the collateral spread is the Euribor-Eurepo spread for the euro area. Indeed, Libor-OIS contains a pure bank-credit-term-spread component since Libor is a 3-month rate and OIS is based on overnight borrowing, which may somewhat muddle the pure collateral effect.

[22] We need also two additional assumptions: (i) the risk-averse agent cannot trade i'; and (ii) exogenous (institutional) demand to buy i'.

[23] This doesn't hold in a dynamic version of the model.

the yield or increases the price) of the asset itself (see also Equation (33) in Garleanu and Pedersen (2011)):

$$E(r^{i,\text{no ECB}}) - E(r^{i,\text{ECB}}) = x \times \psi \times (m^{i,\text{no ECB}} - m^{i,\text{ECB}}) > 0. \tag{4}$$

Ashcraft, Garleanu, and Pedersen (2011) extend the Garleanu and Pedersen (2011) framework to a production economy and discuss further model implications showing that the reduction in haircut (when asset i is not marginal) relaxes the margin constraint of the risk-tolerant agent. This policy has two effects: (i) it reduces the shadow cost of capital ψ (i.e. $\psi^{\text{ECB}} < \psi^{\text{no ECB}}$) of the risk-tolerant agent; and (ii) it flattens the haircut-return line reducing further the required return of asset i.

In the next sections we will test these model predictions providing evidence that the basis documented in Section 2 is highly sensitive to the ECB and market haircuts.

5 Do the ECB Haircuts Affect the Basis?

We examine how the basis reacted to changes in the ECB haircuts of the USD-denominated bonds. On 15 October 2008 the ECB announced that USD-denominated bonds were admitted as collateral by the ECB, but subject to an additional haircut due to the denomination in foreign currency. The change was implemented on 14 November 2008 and was in place until 31 December 2010. Subsequently, the ECB announced the reintroduction of this measure on 6 September 2012 with effect on 9 November 2012.

To establish a link between ECB haircuts and yields we use the following identification strategy. Some of the USD-denominated bonds of our sample did not benefit from the temporary expansion of the collateral, because they do not satisfy the depository requirement in the European Economic Area (EEA) making them ineligible for the ECB liquidity operations. Such feature of the programme allows us to assess if a reduction in the haircut of a bond increases its price (lowers its yield). Table 1 reports the pairs that become eligible after the collateral expansion.

We use a difference-in-differences approach to test for the effect of the change in the eligibility criteria over a window of 56 (8 weeks) days before and 56 after the intervention date. We conduct the following daily panel regression analysis:

$$\text{Basis}_{i,j,t} = \alpha + \delta_{i,j} + \gamma \text{Eligible}_{i,j} + \sum_{k=1}^{4} \nu_k \text{After}_k + \sum_{k=1}^{4} \beta_k \text{After}_k \times \text{Eligible}_{i,j} + \varepsilon_{i,j,t} \tag{5}$$

including pair fixed−effects, $\delta_{i,j}$. *Eligible* is a dummy variable that takes one for those pairs in which the USD-denominated bond fulfills the criteria to be eligible collateral before considering its currency and zero otherwise. The window after the event is divided in four groups of two weeks and $After_k$ is a dummy variable that takes one during the interval $(k-1) \times 2$ and $k \times 2$ weeks after the event. The first one takes one for a window of two weeks after the event and zero otherwise, the second one takes one from the third to the fourth week and zero otherwise and so on. This decomposition of the after event period allows us to evaluate the size and the persistence of the policy action on the basis.

Our data exhibit cross-sectional dependences as well as autocorrelation and heteroskedasticity. The error across different bases is correlated due to common shocks over time (cross-sectional dependences) and the error variance differs across pairs due to unique characteristics of each pair (heteroskedasticity). Ignoring these facts of the data could lead to potential bias in the inference. In order to address these problems we employ a Prais-Winsten regression with panel corrected standard errors (PCSE). The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process is common across panels. This procedure consists of estimating Equation (5) by OLS, using the residuals to estimate the correlation within panels (ρ) and transforming the observations by the well-known Prais-Winsten transformation to produce serially independent errors. Then, standard errors are corrected using the Beck and Katz (1995) methodology.

5.1 Results

Table 2 reports the results of estimating Equation (5) around the implementation dates (14 November 2008 and 9 November 2012) and the end of the first eligibility window (31 December 2010). Figure 3 shows the estimated response of the basis around the introduction of the changes in the eligibility criteria on 14 November 2008. This figure illustrates our difference-in-differences estimates by plotting the cross-sectional averages for the eligible USD-denominated pair group (grey line) and the non-eligible USD-denominated pair group (dark line). The dashed time-lines indicate the 2, 4, 6 and 8 weeks after the implementation date. We observe that before the announcement eligible and non-eligible pairs are characterized by similar levels of the basis, but after the implementation the eligible pairs have on average a lower basis of 13 basis points.[24]

To put these numbers in perspective, recall that the eligible USD-denominated bonds are subject to an additional haircut of 8%.[25] In our sample, the EUR-denominated bond is on average subject to a 3% haircut, while a comparable USD-denominated bond is subject to an overall haircut of $10.76\% = 1-(1-3\%)(1-8\%)$. As a result, our estimates suggest that the change in the ECB eligibility criteria lowered the yield-to-maturity of the eligible USD-denominated bond, after hedging the currency risk, by 13 basis points by decreasing haircuts from 100% to 10.76%.

The larger effect is registered after the second week, is persistent and significant at least

[24] 13 basis points is the average of the coefficients of the interaction between $After$ for the second, third and fourth window of two weeks and the *Eligible* dummy.

[25] During the first eligibility window the additional haircut is of 8%, while during the second one it is of 16%.

at 5%. The initial no-response could be due to slow price revision of the USD-denominated bonds by market participants who were generally confounded by which bonds were not eligible on 14 November 2008, the first date of implementation of the new eligibility criteria. Thus, because USD-denominated bonds tend to be traded less frequently than EUR-denominated bonds, prices reacted with a lag to the change in the eligibility criteria.

The overall impact on the yields is larger when compared with Ashcraft, Garleanu, and Pedersen (2011) who examine empirically the impact of the introduction of the TALF lending facility, studying the reaction of market prices by considering the price response to an unpredictable bond rejection from the TALF programme. They measure a temporary decrease of 5 basis points in the yield spread for the eligible TALF securities, but a statistically significant rise in the yield spread by over 20 basis points for the non-eligible assets. Thus, Figure 3 shows that the change in the ECB haircuts on USD-denominated bonds has a more persistent and lasting effect on the yields compared to Ashcraft, Garleanu, and Pedersen (2011) who find an impact of the TALF activation only in the early period. Finally, our results are consistent with Buraschi, Menguturk, and Sener (2015) who find that the basis for Brazil and Mexico decreased on 28 October 2008 when the Fed decided to extend the foreign currency swap facilities to these countries. However, our identification strategy is able to asses the causality of the ECB haircuts on USD-denominated bond yields and pin down the collateral premium of these bonds when becoming eligible.

Then, we conduct the difference-in-differences analysis around the expiration date (31 December 2010) of the changes in the eligibility criteria (Column (2)). We find that the basis of eligible pairs is not statistically distinguishable from that of non-eligible pairs after the termination of the first eligibility window. Finally, the impact of the second change in the collateral eligibility criteria (Column (3)) is still persistent and significant at least at 5%, although the overall impact is lower. After the implementation of the second extension the eligible pairs have on average a lower basis of 7 basis points.

Overall, our findings support the idea that the possibility of being pledged to the ECB in exchange for liquidity is priced in the eligible bonds. So, the fact that only EUR-denominated bonds can be pledged to the ECB in exchange for liquidity generates an asymmetry between EUR- and USD-bond represented in the basis. The asymmetry is partly reduced by the expansion of the list of eligible assets to some of the USD-denominated bonds, that are still subject to an additional and substantial haircut.

5.2 Robustness: ECB Agency Haircuts

To further establish a strong link between ECB haircuts and bond yields, we next construct a new basis using EUR-denominated government agency bonds that are eligible ECB collateral but are subject to higher haircuts than comparable EUR-denominated sovereign bonds. The government agency bond is explicitly or implicitly guaranteed by its own sovereign country. We compute the basis as the difference between the ask yield-to-maturity of the government agency bond and the bid yield-to-maturity of the comparable sovereign bond. Both bonds are EUR-denominated fixed-rate coupon bonds (see Subsection 3.1 for further details). Our sample covers 51 pairs of bonds relative to 8 agencies that belong to 4 countries: CADES (France), SFEF (France), KfW (Germany), NRW (Germany), CDP(Italy), ISPA (Italy), ICO (Spain) and FROB (Spain).

We study the impact of changes in the ECB haircuts policy on government agency bonds estimating variants of Equation (5). For every date in which we observe a change in the agency haircut (i.e., implementation date) we conduct a difference-in-differences analysis where we compare the evolution of those pairs whose haircuts have changed and those whose haircuts remain unchanged.[26] As already discussed, the ECB haircut depends on the combination of asset type, issuer group, rating and bond time-to-maturity. Then, the combination of asset type and issuer group determines the haircut category of an asset. In our sample, the increases in haircuts are due to: (i) changes in the issuer's group (e.g., an issuer is moved to a new category) and (ii) the revision of the haircuts schedule. Instead, decreases in haircuts are only due to changes in the issuer group.

We identify eight dates with changes in the ECB agency haircuts. Table 3 reports the results. Columns (1) − (5) report the impact of increases in the agency haircuts and Columns (6) − (8) report the impact of decreases in the agency haircuts. Column (1) refers to the revision of haircuts schedule on 1 February 2009 and affects the ICO and NRW pairs. Column (2) refers to the change of category of CDP on 4 March 2009. Column (3) refers to the revision of haircuts schedule on 1 January 2011 and affects the FROB, CDP and SFEF pairs. Columns (4) − (5) refers to the change of credit quality category suffered by FROB and ICO on 18 and 27 June 2012, respectively. Column (6) refers to the change of category of ISPA on 29 August 2008. Column (7) refers to the change of category of NRW and ICO on 17 February 2010. Finally, Column (8) refers to the change of category of FROB on 1 November 2012.

We document that increases in the difference between the agency and the sovereign haircuts applied by the ECB significantly increase the basis while decreases in the haircuts differences do not provide a conclusive impact on the basis. Thus, our evidence suggests that the market response is more sensitive to increases than decreases in the haircuts because the first ones might reduce the liquidity that banks can withdraw from the ECB. As a consequence, this would affect the collateral value of the asset.

[26] We focus on changes in the ECB haircuts policy and hence, we do not consider changes in the haircuts that are due to the bond residual maturity.

6 Does the ECB drive the Basis?

6.1 Time Series Determinants

The Garleanu and Pedersen (2011) model predicts that a larger deviation of LoOP occurs when (i) haircuts in private repo market are greater; (ii) financial institutions net worth is lower; and (iii) relative importance of risk-tolerant agents in risk sharing is high.

We test these predictions estimating different variants of the following specification at weekly frequency:

$$\begin{aligned}\text{Basis}_{i,j,t} = \alpha + \delta_j + \beta_1 \times \text{Bond Factors} + \beta_2 \times \text{Market Risk Factors} \\ + \beta_3 \times \text{Monetary Policy Factors} + \varepsilon_{i,j,t},\end{aligned} \tag{6}$$

where the dependent variable is the basis for each pair of bonds i and j refers to the issuer country. First, we account for specific bond and market factors proposed by the limits to arbitrage literature that originate in the seminal paper by Shleifer and Vishny (1997), as proxy for different sources of frictions that can lead to persistent deviations from the LoOP. *Bond Factors* contains pair−specific information about the bond liquidity, lending activity and bond covenants. Following the definition of the basis, we construct pair-specific information as the difference between the USD- and the EUR-related variables. *Market Risk Factors* contains country and global market risk factors.

Then, we include a set of novel *Monetary Policy Factors* based on ECB proprietary data: (i) haircuts differential between the CCPs and the ECB at country level; (ii) amount of liquidity drawn from the ECB liquidity facility by strongly-constrained banks; and (iii) amount of sovereign pledged to the ECB by strongly constrained banks at country level.

We employ a Prais-Winsten regression with country fixed−effects δ_j and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process is common to all the panels. Alternatively, we also estimate Equation (6) in first differences for our main results of Table 6 reporting the results in Table A-6. Our main results are not affected by this exercise.

We divide the period October 2008 - February 2013 into three subsamples: (i) financial crisis period starting on 1 October 2008 and ending on 9 May 2010; (ii) euro area sovereign debt crisis period starting on 10 May 2010 and ending on 28 February 2012; and (iii) post euro area sovereign debt crisis period starting on 1 March 2012 and ending on 15 February 2013. The beginning of the second period coincides with the activation of the SMP, while the beginning the third period starts immediately after the implementation of the second 3−year LTRO operation. While our definition of subsamples is motivated by two important ECB non-conventionally monetary policy interventions, we run statistical tests to identify the potential structural break points. Figure 4 depicts a box plot showing the mean and the percentiles 10, 25, 50, 75 and 90 of the basis for the three sub periods.

We perform a mean test (t-test) and a median test (Wilcoxon rank-sum test), testing the null hypothesis that there is no significant difference in mean and median deviation across the subsamples. Both tests confirm the existence of the turning points (Table 4).

6.1.1 Bond and Market Factors

Table 5 reports the estimates of Equation (6). Column (1) contains the results for the whole sample period, while Columns (2) − (4) report the results for the financial crisis period, euro area sovereign debt crisis period and post euro area sovereign debt crisis period, respectively.

We study the role of the lending activities by means of the $No.\ Transactions_{i,j,t}$ and $Indicative\ Fees_{i,j,t}$ variables. Regarding the latter one, we systematically observe that EUR-denominated bonds are more expensive than comparable USD-denominated bonds, which is consistent with the findings of Buraschi, Menguturk, and Sener (2015). In order to exploit the basis, we expect traders to buy cheap (USD-denominated) and short-sell expensive (EUR-denominated) bonds in such a way that relative increases in the number of transactions or of the lending cost of the EUR-denominated bonds should decrease the basis. However, the empirical results do not support this possible explanation. On the contrary, we find that an increase in the relative number of transactions of the EUR-denominated bonds (i.e., $No.\ Transactions_{i,j,t}$ becomes more negative) significantly widens the basis. Additionally, we observe that this effect is only significant during the euro area sovereign debt crisis period.

We control for the potential price impact of the "legal safety premium" according to which bonds governed by a foreign law trade at premium because of the stronger protection they offer to investors. We distinguish between USD-denominated bonds governed under New York law, $D.\ NY\ Law_{i,j}$, and English Law, $D.\ England\ Law_{i,j}$. Traditionally, those jurisdictions mainly diverge in the presence of collective action clauses (CAC) because the New York law did not include them. However, by late 2003 the vast majority of new sovereign bonds issued under the New York law used CAC (Weidemaier and Gulati (2013)) and hence it is likely that these bonds receive the same treatment of the bonds we have in our sample. We document that pairs in which the USD-denominated bond is governed under the New York law have a significant lower basis than the one issued under the local law. This result suggests the existence of a legal safety premium in the USD-denominated bond that is priced in the market.[27] On the contrary, we do not find a significant difference between the pairs in which the USD-denominated bond is governed under the England and the local law. Interestingly, we find evidence that $D.\ Additional\ Clauses_{i,j}$ is statistically significant in explaining variations in basis during

[27]Choi, Gulati, and Posner (2011) document that the yield premium of the Greek sovereign debt governed by local law versus foreign law was discernible before November 2009 but then increased, reaching a peak of 400 basis points, as the news about Greece's financial state emerged and the probability of a restructuring increased.

the post euro area sovereign debt crisis with a negative slope coefficient, suggesting that USD-denominated bonds with such features were more attractive. A possible explanation rests on the potential existence of premia related to the risk of a euro area country simultaneously or consequently withdrawing from the euro in the event of default. The risk would not affect investors holding sovereign bonds issued in USD under New York law with these two covenants (Krishnamurthy, Nagel, and Vissing-Jorgensen (2014)). In the summer of 2012, the ECB President Draghi labelled this risk the re-denomination risk. It is possible that increased re-denomination risk contributed to the values of the basis when concerns about Italy debt sustainability mounted again in the summer of 2012.

We also control for the differential of the outstanding amount of the two bonds, *Ratio* $Outstanding_{i,j,t}$, to control for time-variation in the relative size of the bonds which can be interpreted as a proxy of relative liquidity. In fact, both EUR- or USD-denominated bonds in each pair can be re-issued (or tapped) after the issuance, positively affecting the liquidity of the bond itself. As expected, we find that an increase in the relative amount outstanding of USD-denominated bonds significantly decreases the basis.[28]

We, then, address the impact of the country and global market factors. The Quanto CDS has been used as a proxy of the expected devaluation of the Euro relative to the USD, conditional on the default of a euro area country (Ehlers and Schönbucher (2006)). Buying EUR-denominated CDS is a less attractive hedge, as the value of that protection is likely to diminish as the referenced sovereign approaches default. Buraschi, Menguturk, and Sener (2015) argue that the Quanto CDS contracts gained great popularity during the euro area sovereign debt crisis period, as market participants feared a substantial devaluation of the Euro as a consequence of the default of one of its member countries. Before 2010, however, expected devaluation values were close to zero and the Quanto CDS prices were then trading at only a few basis points. According to the *Quanto* $CDS_{j,t}$ definition $(1 - CDS^{€}_{j,t}/CDS^{\$}_{j,t})$, we expect that the *Quanto* $CDS_{j,t}$ has a positive and significant impact on the basis. As *Quanto* $CDS_{j,t}$ increases, $CDS^{€}_{j,t}/CDS^{\$}_{j,t}$ ratio decreases and, as a consequence, credit risk premium in USD increases more than in EUR terms. Thus, yield-to-maturity of USD-denominated bond increases relative to yield-to-maturity of EUR-denominated bond, leading to an increase in basis. In fact, we do find empirical support for this intuition. *Quanto* $CDS_{j,t}$ is statistically significant in explaining variations in the basis with the expected positive slope coefficient.

Euribor - $Eurepo_{j,t}$ has a statistically significant and expected positive coefficient during the post euro area sovereign debt crisis (Column (4)): an increase in the spread implies tighter credit standards, reflecting more binding margin constraints, and is associated with a widening of the basis as documented by Garleanu and Pedersen (2011).

[28] We also estimate Equation (6) explicitly accounting for bid-ask spreads of both bonds and computing a basis based on mid yields-to-maturity. The bid-ask spread variable is not statistically significant for all the three sub-periods. The results are available on request.

Finally, we find a negative and significant impact of the $XCS_{i,j,t}$ on the basis in the first and second sub-period, suggesting that tensions in the global market made USD-denominated bonds relatively more attractive. However, the coefficient becomes positive and statistically significant in the post euro area sovereign debt crisis sub-period.

Overall, the bond and market factors affect the basis, but they play a limited role during the euro area sovereign debt crisis period, when the size of the basis on average widens and significant differences emerge across the countries. In fact, the R^2 of our regressions drops from 31.8% (financial crisis) to 6.3% (euro area sovereign debt crisis).

6.1.2 Monetary Policy Factors

Table 6 reports the results for the two groups of countries, (Italy and Spain vs Austria, Belgium and Finland) and for the three sub-periods. We report in brackets the economic impact of variables measured as the product between the estimated coefficient and the difference between the 90^{th} and 10^{th} percentile of the independent variable. We control for the market and bond factors and the country fixed-effects throughout, but we do not report the coefficients in this table for brevity.

For the changes in the collateral eligibility criteria (Panel A), we introduce a dummy variable which is equal to one during the first and the second eligibility window of USD-denominated bonds ($Eligibility\ Window_t$), that is from 14 November 2008 to the 31 December 2010 and from 9 November 2012 onward. The beginning of each period is determined by the implementation rather than the announcement dates because the ECB published the list of eligible bonds on the implementation dates. Additionally, we interact these variables with a dummy that is equal to one for those pairs where the USD-denominated bonds fulfill all the eligibility criteria and therefore could be pledged to the ECB. We find that the basis of those eligible pairs is statistically lower than the ones of non-eligible pairs by 36 basis points for Italy and Spain during the euro area sovereign debt crisis period (Column (2)) and 17 basis points for Austria, Belgium and Finland during the post-euro sovereign debt crisis (Column (6)), confirming the results of Section 5. Eligibility of an USD-denominated bond has a negative impact on the basis increasing the collateral value of the USD-denominated bond and thus reducing the differential between USD- and EUR-denominated bond yields.

We next investigate how haircut differences between private repo market and the ECB has an impact on the basis. The Garleanu and Pedersen (2011) model predicts that a larger deviation of LoOP, a basis, occurs when haircuts in private repo market are greater. Panel B and C of Table 6 confirm such prediction reporting the coefficients from estimating Equation (6) including the two haircut differences measures. In Panel B we use the CCPs haircuts of CC&G - LCH Clearnet for Italy and of BME for Spain respectively, while in Panel C we use the Eurex haircuts for all countries. Haircut differences have a positive and significant impact on the basis in the euro area sovereign debt crisis period only for

Italy and Spain. According to the economic impact analysis, a change from the 10^{th} percentile to the 90^{th} percentile of the distribution of the haircut differential increases the basis of Italy and Spain by more than 58 (21) basis points in Panel B (C).

The 90^{th} percentile coincides with the dramatic increase in haircuts for Italian sovereign bonds on November 2011. With the intensification of the euro debt sovereign crisis the spread on the 10-year Italian (Spanish) government bonds vis-a-vis the 10-year German bunds rose from around 185 (250) to about 525 (458) basis points from end June until end-December 2011. In response to the increase in spreads, the CCPs, such as LCH Clearnet SA, CC&G and BME Clearing, substantially increased the haircuts requirements for the two sovereigns, while ECB haircuts stayed fairly stable over the same period. For example, the haircut requirements applied by LCH Clearnet SA on a 5-year maturity Italian sovereign bond increased from 8% in June 2011 to 16.8% in January 2012, while the ECB haircut did not exceed 2%. Similarly, the haircut requirements applied for a $5-$year maturity Spanish bond increased from 3% in June 2011 to 4% in January 2012, reaching the 8% at their peak in autumn 2012.[29] Figure 5 illustrates these developments showing the average haircut on EUR-denominated bonds when we apply the CC&G, BME Clearing, Eurex and ECB haircuts respectively. A similar and more dramatic increase in haircuts pattern for Italy and Spain can be seen for the Eurex haircuts, while the Eurex haircuts were quite stable and flat for Austria, Belgium and Finland.

Because differential of haircuts between the CPPs and the ECB proxies for the opportunity cost a bank faces with the choice of bidding for liquidity in the refinancing operations of the ECB and in the centrally cleared private repo markets, increases in the CCPs haircuts tend to reduce asset values, make refinancing more costly in the private repo markets, as also shown by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) and documented empirically by Gorton and Metrick (2012) and Krishnamurthy, Nagel, and Orlov (2014), and induce banks to rely more on central bank liquidity. In such circumstances, the wealth of some agents in the economy is decreasing and borrowing constraints are more likely to bind inducing a widening of the basis as predicted by Garleanu and Pedersen (2011). Panel D of Table 6 empirically supports these predictions. We use our $Liquidity\ Measure_t$ that tracks the evolution of the ECB liquidity drawn by strongly-constrained banks. Our results show that increases in our liquidity measure are associated with a larger basis. The coefficient is consistently positive and statistically significant at least at the 1% level for both groups of countries in the financial and the euro area sovereign debt crisis period. Consistent with the previous findings, we find that

[29] According to their internal rules, the LCH Clearnet raised haircut requirements once the spread of the 10-year bond relative to core sovereign issuers, such as Austria, Finland and the Netherlands, were above 450 basis points. In November 2011 Italian sovereign bond yields hit this threshold. The increase in the haircuts for the Italian government bonds substantially penalized the shorter maturities: the $1-3$ month class haircut increased from 1% to 4.5%, while the $7-10$ year class haircut went up from 6.65% to 11.65%.

the coefficient is larger for Italy and Spain, than for the other countries, with an economic impact of more than 16 basis points on the basis.

Figure 6 depicts the average opportunity cost of the EUR-denominated bonds for Italy and Spain, as the difference between the CCPs and ECB haircuts using bonds in sample and the CC&G and BME haircuts, and our liquidity measure $Liquidity\ Measure_t$.[30] The plot shows that the liquidity measure strongly co-moves with the average haircut differences suggesting that higher levels of CCPs haircuts are associated with a larger reliance on ECB funding. The liquidity measure reaches the highest levels when the ECB decided to provide a three-year LTRO (December 2011 and February 2012), while after these operations the CCPs decreased their haircut requirements on Italian sovereign bonds and kept these levels of haircuts in the post euro area sovereign debt crisis period. Our liquidity measure is mirroring the increase in haircuts for Italian and Spanish sovereign bonds in the private market. The overall effect was to induce banks to rely more on ECB funding pledging EUR-denominated bonds.

Our previous measure is not country-specific and mainly captures a common component across all the pairs. Therefore, we use our country-specific collateral measure, $Collateral\ Measure_{j,t}$, that tracks the share (of total collateral) in the sovereign country j debt pledged to the ECB by the strongly-constrained banks. Increases in $Collateral\ Measure_{j,t}$ are associated with a larger basis in the euro area sovereign debt crisis period (Panel E of Table 6). The size of the basis for a country is strongly positively related to the amount of sovereign bonds issued by the same country pledged to the ECB by strongly-constrained banks. The effect is statistically and economically sizable only for Italy and Spain with an economic impact of more than 37 basis points during the euro area debt sovereign crisis.

Figure 7 depicts our collateral measure showing that strongly-constrained banks relied more on Italian and Spanish sovereign debt reaching the highest levels when the ECB decided to provide the $3-$year LTROs. For Italy, the chart shows that the share of Italian sovereign collateral over the total collateral pledged by strongly-constrained bank has substantially increased starting in summer 2011, reaching the peak of 15% during the $3-$year LTROs. A similar development can be also observed for Spain, while the reliance of sovereign bonds issued by Austria, Belgium and Finland is insignificant (less than 1%).

Our results underpin further that the ECB liquidity facility access was priced, widening in particular the basis for these countries in times of increased sovereign credit spreads, such as Italy and Spain. Because only EUR-denominated bonds could be pledged to the ECB over this period of stress, the relative cost of holding USD-denominated bonds increased leading to a larger basis for Italy and Spain. Our findings are partly consistent with Drechsler et al. (2014) who document that European banks, which borrowed heavily,

[30] The average opportunity cost is computed as the average of the difference between the CCP and ECB haircut across all the Italian and Spanish pairs of our sample.

also pledged increasingly risky collateral to the ECB. They suggest that the ECB's liquidity facility was used for risk-shifting due to the lower haircuts, while our results highlight the role played by the funding channel.

6.1.3 Monetary Policy Factors vs Bond and Market Factors

The objective is to assess the relative importance of monetary policy factors relative to the bond and market factors in explaining the basis. We use a Shapley-Owen decomposition to examine how much of the variation in the basis is explained by the right-hand side explanatory variables and what is the relative contribution of each. This method takes into account of the interplay of regressor variables in sub-models and is calculated on the basis of information on the same type of goodness-of-fit measure, the R^2 in our case, in these sub-models.[31] A generalization of the Shapley value, the Owen value, allows for decomposition in the context of exogenously grouped regressors.[32] Thus, we report the Shapley-Owen decomposition for the main drivers of the basis for the three sub-samples and for the two groups of countries in Table 7. For the monetary policy factors, we separately focus on haircut differences and liquidity and collateral measure controlling for the eligibility component throughout.[33]

In the financial crisis sub-period, the predicted basis explains around 32% (19%) of the variation observed in the data for Italy and Spain (Austria, Belgium and Finland). The largest contributor to the overall variation in the predicted basis of Italy and Spain is bond factors (above 43%) looking through all the monetary policy channels (from Panel A to D of Column (1)). Monetary policy factors is the second largest contributor with around 18% when we use our country-specific collateral measure (Panel D), while its contribution is lower than 10% when we consider the other channels. Interestingly, the monetary policy factors account for more than 15% of the variation of Austria, Belgium and Finland sub-sample (Column (4)). The results are mainly driven by pairs issued by Austria due to the large balance exposure of Austrian banks to USD funding, which caused a corresponding increase in demand of USD liquidity provided by the ECB through the USD swap lines

[31] Calculating the Shapley value for a particular regressor j requires the computation of all 2^p possible models, where p is the total number of regressors, one each for each k combinations of models with k regressors. The Shapley value adds the marginal contribution to the R^2 from adding independent variable k to the model, weighted by the number of permutations represented by this sub-model. The R_j^2 for regressor j is given by $R_j^2 = \sum_{T \subseteq Z \ \{x_j\}} \frac{k!(p-k-1)!}{p!} \left[R^2(T \cup \{x_j\}) - R^2(T)\right]$, where T is model with k regressors but without regressor x_j, and $T \cup \{x_j\}$ is the same model but with x_j included. The set Z contains all models with combinations of regressors. Once a vector of these values is available, the Shapley values can be computed by iterating over each regressor and summing the weighted marginal contributions.

[32] The Owen value is an extension of the Shapley value for so-called "cooperative games" with coalitions. The key property is that the Owen value works the same way as the Shapley value, but for groups of regressors. Such groups may arise, e.g., if the model includes polynomial terms of a variable, dummy variables that recode a categorical variable, or variables that are conceptually related for other reasons.

[33] The decomposition is computed on the OLS estimates of Equation (6) on the transformed variables using the Prais-Wisten estimate of ρ (for example $\widetilde{Basis}_{i,j,t} = Basis_{i,j,t} - \rho Basis_{i,j,t-1}$).

established with the Fed.

In the euro area debt sovereign crisis period, the magnitudes and contributions change across the two groups of countries. The monetary policy factors are the main driver in explaining the basis variation for Italy and Spain. These factors are the largest contributors with collectively around 47% when we look at the difference in haircuts between CCPs and the ECB (Panel A of Column (2)), while our liquidity and collateral measure account for more than 34% (Panel C and D of Column (2)). Differently, the bond factors mainly account for more than 44% for Austria, Belgium and Finland (Panel B and D of Column (5)). This set of results provides further supporting evidence of joint role played by raising funding costs against Italian and Spanish collateral and the larger reliance on ECB liquidity by strongly-constrained banks documented in the previous section 6.1.2. As would be expected, the ECB funding factors contribute less after the implementation of the 3−year LTRO operations. The bond and market factors play a dominant role in the last sub-sample period for both groups of countries (Column (3) and (6)).

The decomposition suggests that factors related to the ECB interventions play a key role in explaining the overall variation in the predicted basis relative to the bond and market factors proposed by several lines of research on limits to arbitrage literature. The effect of these factors is state-contingent depending on the sample period and the country under analysis and they help to explain the cross country dispersion in the basis.

6.1.4 Robustness

The basis we observe might be driven by the relative of scarcity of US dollars in Europe and the activation of special swaps lines between the ECB and the Federal Reserve activated during 2008 and into 2009, when wholesale funding sources came under extreme stress. To address this concern we carry out two robustness exercises.

First, we follow Buraschi, Menguturk, and Sener (2015) and we estimate Equation (6) using as dependent variable the difference between the estimated basis of each pair and the average basis of Turkey, $Basis_{i,j,t} - \overline{Basis}_{\text{Turkey},t}$, to assess the impact of the ECB funding on the basis. Since sovereign bonds issued by Turkey cannot be pledged to the ECB in exchange of liquidity, this difference allows us to control for factors that affected all bonds at the same time. Table 8 reports the results that are consistent with the ones previously discussed of Table 6.

Second, we estimate Equation (6) using as dependent variable the difference between the estimated basis of each pair and the cross currency swap spread, $Basis_{i,j,t} - XCS_{i,t}$, matching the time-to-maturity of the basis with the tenor of the cross currency swap spread. In doing so, we directly account for cross currency swap as a common risk factor instead of using it as an explanatory variable. Table 9 reports the results, confirming that other frictions operating at country-level had an impact on the basis.

6.2 Monetary Policy Funding

The previous subsection provides evidence that the ECB keeping the haircuts constant while the market ones have been increasing for Italy and Spain during the euro area sovereign debt crisis had an impact on the basis of these countries. As predicted by Garleanu and Pedersen (2011) and Ashcraft, Garleanu, and Pedersen (2011), such policy accompanied by a full allotment liquidity, where a bank's liquidity is unlimited as far as collateral is pledged, should relax the margin constraint of strongly-constrained banks and hence reduce the shadow cost of capital ψ (i.e. $\psi^{\text{ECB}} < \psi^{\text{no ECB}}$).

We test this prediction following Garleanu and Pedersen (2011) who compare the CDS basis of investment-grade bonds with the CDS basis for high-yield bonds and find that they move closely together and that the margin return slope, the shadow cost of capital ψ, is linked to the Libor-OIS spread, credit tightness conditions and risk premia. One key difference between our paper and Garleanu and Pedersen (2011) is that their CDS haircuts do not change over time, while this is not the case for Italy and Spain.

Thus, we regress our daily basis on the daily haircut difference between the CCPs and the ECB every month

$$\text{Basis}_{i,j,t} = \text{slope}_{j,t} \times (\text{CCP Haircut}_{i,j,t} - \text{ECB Haircut}_{i,j,t}) + \epsilon_{i,j,t}. \tag{7}$$

This produces a time series of slopes that captures the shadow cost of capital ψ of Garleanu and Pedersen (2011). We regress the estimated slope on the Euribor-Eurepo spread because it is a better proxy for the collateral spread than the Euribor-OIS spread. The latter one contains a pure bank-credit-term-spread component, since Euribor is a 3−month rate and OIS is based on overnight borrowing, which may somewhat muddle the pure collateral effect. In addition, we test whether the ECB policy reduced the shadow cost of capital, using our liquidity and collateral measure and the spread between the ECB deposit rate, the rate at which the banks borrow from the ECB, and the Eurepo rate.

6.2.1 Results

Table 10 reports the results for Italy and Spain (Panel A) and for Austria, Belgium and Finland (Panel B). Consistent with Garleanu and Pedersen (2011), we find that the $\text{slope}_{j,t}$ capturing the shadow cost of capital positively co-moves with the collateral borrowing spread as proxied by the Euribor and Eurepo spread but the coefficient is not significant (Column (1)). When we regress the slope with the spread between the ECB deposit rate and the Eurepo rate, we find a positive and statistically significant coefficient for both groups of countries (Column (2)). This spread is country-specific and captures an additional opportunity cost that a bank faces with the choice of bidding for liquidity in the refinancing operations of the ECB and in the centrally cleared private repo markets. The first one is the haircut difference between the CPPs and the ECB that we discussed.

As expected our liquidity measure is negatively correlated with the shadow cost of capital for Italy and Spain and statistically significant (Column (3) - Panel A), consistent with the prediction that a central bank policy characterized by lower haircuts than the market ones and full allotment liquidity should relax the margin constraint of strongly-constrained banks and hence reduce their shadow cost of capital. However, we find that the same coefficient is positive and statistically significant for Austria, Belgium and Finland (Column (3) - Panel B). One possible explanation is the following one. Garleanu and Pedersen (2011) theory predicts that the basis should be related to the difference in haircut requirements between the repo market and the central bank times the shadow cost of capital, proxied by the difference between the collateralized and un-collateralized borrowing rate. The difference in haircut requirements for Austria, Belgium and Finland is stable over time (Figure 5) but the basis for these countries is still positive and persistent, suggesting that the variation of the basis has to be captured by the slope. While our liquidity measure is indeed an important determinant of the basis, it captures a common liquidity risk factor. In fact, when we regress the slope on our country-specific collateral measure (Column (4)), we find a negative and statistically significant coefficient only for Italy and Spain supporting our prediction that the ECB alleviated the banking funding crisis decreasing the shadow cost of capital of the banks holding sovereign bonds issued by these two countries.

7 Conclusions

In this paper, we document a large deviation from the LoOP in the euro area sovereign bond market between 2008−2013. A basis developed between EUR- and USD-denominated comparable bonds issued by the same country. USD-denominated bonds became substantially cheaper (higher yield-to-maturity) than those denominated in Euro, once the foreign exchange rate risk is hedged in the USD-EUR currency swap market.

The existence of these large and persistent deviations is not fully explained by the traditional channels used in the limits to arbitrage literature such as time-varying funding costs affecting capital, short selling constraints and liquidity risk. Apart from these factors, we find that the ECB non-conventional monetary policy measures play a key role in explaining the basis and help to explain cross country differences in the basis.

Overall, our results suggest that a monetary funding premium is embedded in the EUR-denominated bonds yields, because these bonds could be used as collateral for liquidity operations with the ECB at lower haircuts. This funding premium might also vary over time, depending on funding needs of strongly-constrained banks and haircuts applied in the repo market, on the one hand, and the collateral policy and the liquidity supply conditions determined by the ECB policy stance, on the other.

References

Acharya, Viral, Robert Engle, and Diane Pierret. 2014. "Testing macroprudential stress tests: The risk of regulatory risk weights." *Journal of Monetary Economics* 65:36–53.

Ashcraft, Adam, Nicolae Garleanu, and Lasse Heje Pedersen. 2011. "Two monetary tools: Interest rates and haircuts." In *NBER Macroeconomics Annual 2010, Volume 25*, 143–180. University of Chicago Press.

Baba, Naohiko, and Frank Packer. 2009. "Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08." *Journal of Banking & Finance* 33 (11): 1953–1962.

Bai, Jennie, and Pierre Collin-Dufresne. 2013. "The CDS-bond basis." *AFA 2013 San Diego Meetings Paper.*

Beck, Nathaniel, and Jonathan N Katz. 1995. "What to do (and not to do) with time-series cross-section data." *American Political Science Review* 89 (3): 634–647.

BIS. 2015. "Central bank operating frameworks and collateral markets." *CGFS Publications, Committee on the Global Financial System and the Markets Committee*, no. 53.

Boissel, Charles, François Derrien, Evren Ors, and David Thesmar. 2014. "Sovereign crises and bank financing: Evidence from the european repo market." *Available at SSRN 2506677.*

Brunnermeier, Markus K., and Lasse Heje Pedersen. 2009. "Market liquidity and funding liquidity." *Review of Financial studies* 22 (6): 2201–2238.

Buraschi, Andrea, Murat Menguturk, and Emrah Sener. 2015. "The geography of funding markets and limits to arbitrage." *Review of Financial Studies* 28 (4): 1103–1152.

Campbell, Sean, Daniel Covitz, William Nelson, and Karen Pence. 2011. "Securitization markets and central banking: An evaluation of the term asset-backed securities loan facility." *Journal of Monetary Economics* 58 (5): 518–531.

Choi, Stephen J., Mitu Gulati, and Eric A. Posner. 2011. "Pricing terms in sovereign debt contracts: a Greek case study with implications for the European crisis resolution mechanism." *Capital Markets Law Journal* 6:167–183.

Coffey, Niall, Warren B. Hrung, and Asani Sarkar. 2009. "Capital constraints, counterparty risk, and deviations from covered interest rate parity." *FRB of New York Staff Report*, no. 393.

Corsetti, Giancarlo, and Luca Dedola. 2013. "The mystery of the printing press: Self-fulfilling debt crises and monetary sovereignty." *CEPR Discussion Paper No. DP9358.*

De Grauwe, Paul. 2013. "The European Central Bank as lender of last resort in the government bond markets." *CESifo economic studies* 59 (3): 520–535.

Drechsler, Itamar, Thomas Drechsel, David Marques-Ibanez, and Philipp Schnabl. 2014. "Who borrows from the lender of last resort?" *Journal of Finance, forthcoming.*

Du, Wenxin, and Jesse Schreger. 2013. "Local currency sovereign risk." *FRB International Finance Discussion Paper*, no. 1094.

Duffie, Darrell. 2010. "Presidential address: Asset price dynamics with slow-moving capital." *Journal of Finance* 65 (4): 1237–1267.

Duffie, Darrell, Lasse Heje Pedersen, and Kenneth J. Singleton. 2003. "Modeling sovereign yield spreads: A case study of Russian debt." *Journal of Finance* 58 (1): 119–159.

Ehlers, Philippe, and Philipp Schönbucher. 2006. "The influence of FX risk on credit spreads." *Defaultrisk. com.*

Fleckenstein, Matthias, Francis A. Longstaff, and Hanno Lustig. 2014. "The TIPS-Treasury bond puzzle." *Journal of Finance* 69 (5): 2151–2197.

Garleanu, Nicolae, and Lasse Heje Pedersen. 2011. "Margin-based asset pricing and deviations from the law of one price." *Review of Financial Studies* 24 (6): 1980–2022.

Gorton, Gary, and Andrew Metrick. 2012. "Securitized banking and the run on repo." *Journal of Financial Economics* 104 (3): 425–451.

Griffoli, Tommaso M., and Angelo Ranaldo. 2009. "Deviations from covered interest rate parity during the crisis: a story of funding liquidity constraints." Technical Report, Working Paper, The Swiss National Bank.

Gromb, Denis, and Dimitri Vayanos. 2002. "Equilibrium and welfare in markets with financially constrained arbitrageurs." *Journal of Financial Economics* 66 (2): 361–407.

Ivashina, Victoria, David S. Scharfstein, and Jeremy C. Stein. 2015. "Dollar funding and the lending behavior of global banks." *Quarterly Journal of Economics* 130 (3): 1241–1281.

Krishnamurthy, Arvind, Stefan Nagel, and Dmitry Orlov. 2014. "Sizing up repo." *The Journal of Finance* 69 (6): 2381–2417.

Krishnamurthy, Arvind, Stefan Nagel, and Annette Vissing-Jorgensen. 2014. "ECB policies involving government bond purchases: Impact and channels." Technical

Report, Stanford University, University of Michigan, and University of California Berkeley.

Longstaff, Francis A., Jun Pan, Lasse Heje Pedersen, and Kenneth J. Singleton. 2011. “How sovereign is sovereign credit risk?” *American Economic Journal: Macroeconomics* 3:75–103.

Mancini, Loriano, Angelo Ranaldo, and Jan Wrampelmeyer. 2013. “Liquidity in the foreign exchange market: Measurement, commonality, and risk premiums.” *Journal of Finance* 68 (5): 1805–1841.

———. 2015. “The Euro interbank repo market.” *Forthcoming Review of Financial Studies.*

Pan, Jun, and Kenneth J. Singleton. 2008. “Default and recovery implicit in the term structure of sovereign CDS spreads.” *Journal of Finance* 63 (5): 2345–2384.

Shleifer, Andrei, and Robert W. Vishny. 1997. “The limits of arbitrage.” *Journal of Finance* 52 (1): 35–55.

Tuckman, Bruce, and Pedro Porfirio. 2003. “Interest rate parity, money market basis swaps, and cross-currency basis swaps.” *Fixed income liquid markets research, Lehman Brothers*, vol. 1.

Weidemaier, W Mark C, and Mitu Gulati. 2013. “People’s history of collective action clauses.” *Virginia Journal of International Law* 54:51.

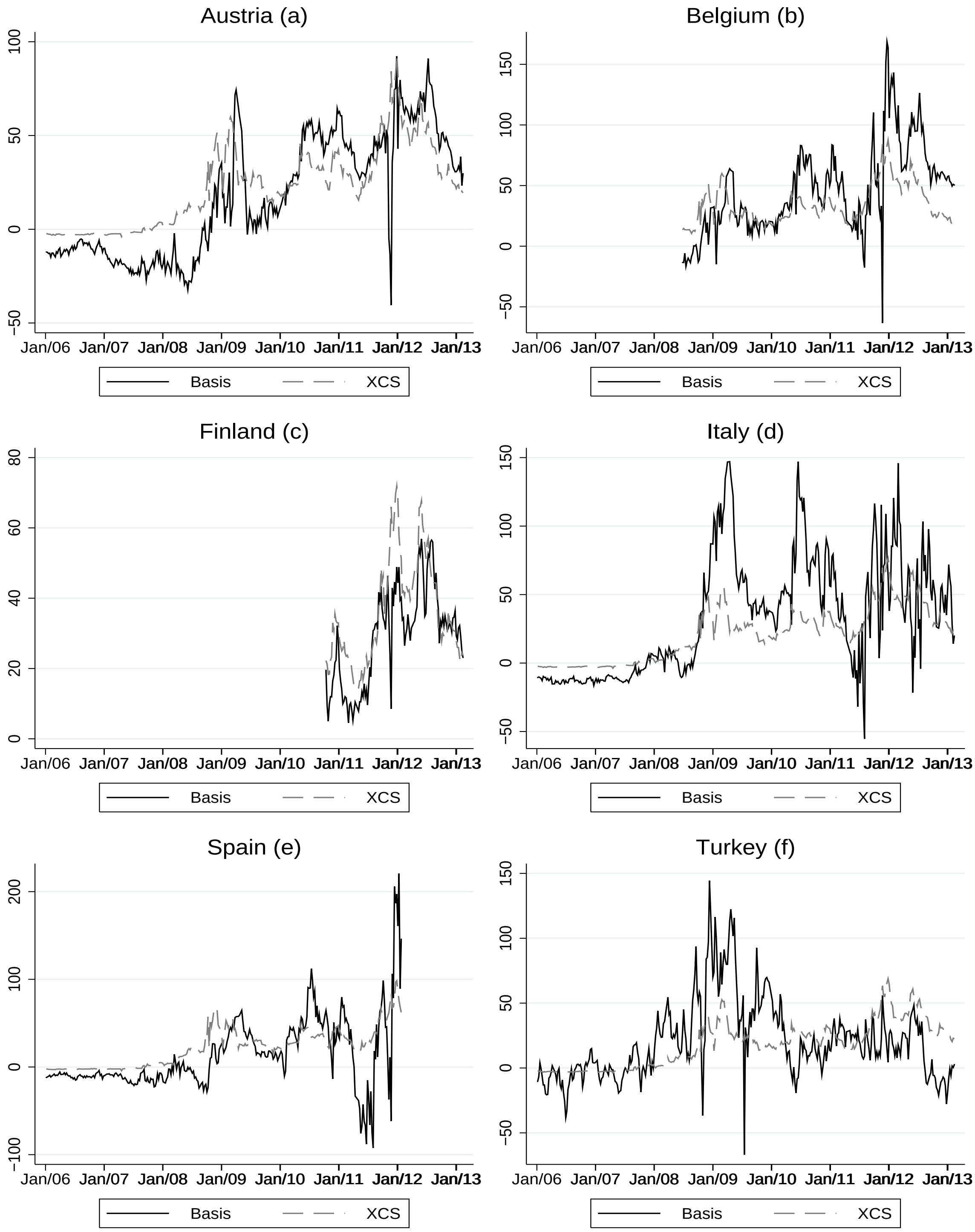

Figure 1: This figure depicts the average basis across pairs for Austria (a), Belgium (b), Finland (c), Italy (d), Spain (e) and Turkey (f). For every pair, the basis is defined as the difference between the ask yield-to-maturity of the USD-denominated bond after the conversion of the bond cash flows from USD to Euro ($\widehat{Y}_{i,t}^{USD->EUR}$) and the bid yield-to-maturity of the EUR-denominated bond ($Y_{i,t}^{EUR}$). The sample spans from January 2006 to February 2013. Bases are reported on a weekly basis and measured in basis points. The figure also depicts the weekly average cross currency swap spread XCS between USD and Euro. For each pair, the cross currency swap spread between USD and Euro is matched with each pair using the cross currency swap spread tenor and the residual time-to-maturity of the pair. The average across the pairs is computed for each country every week.

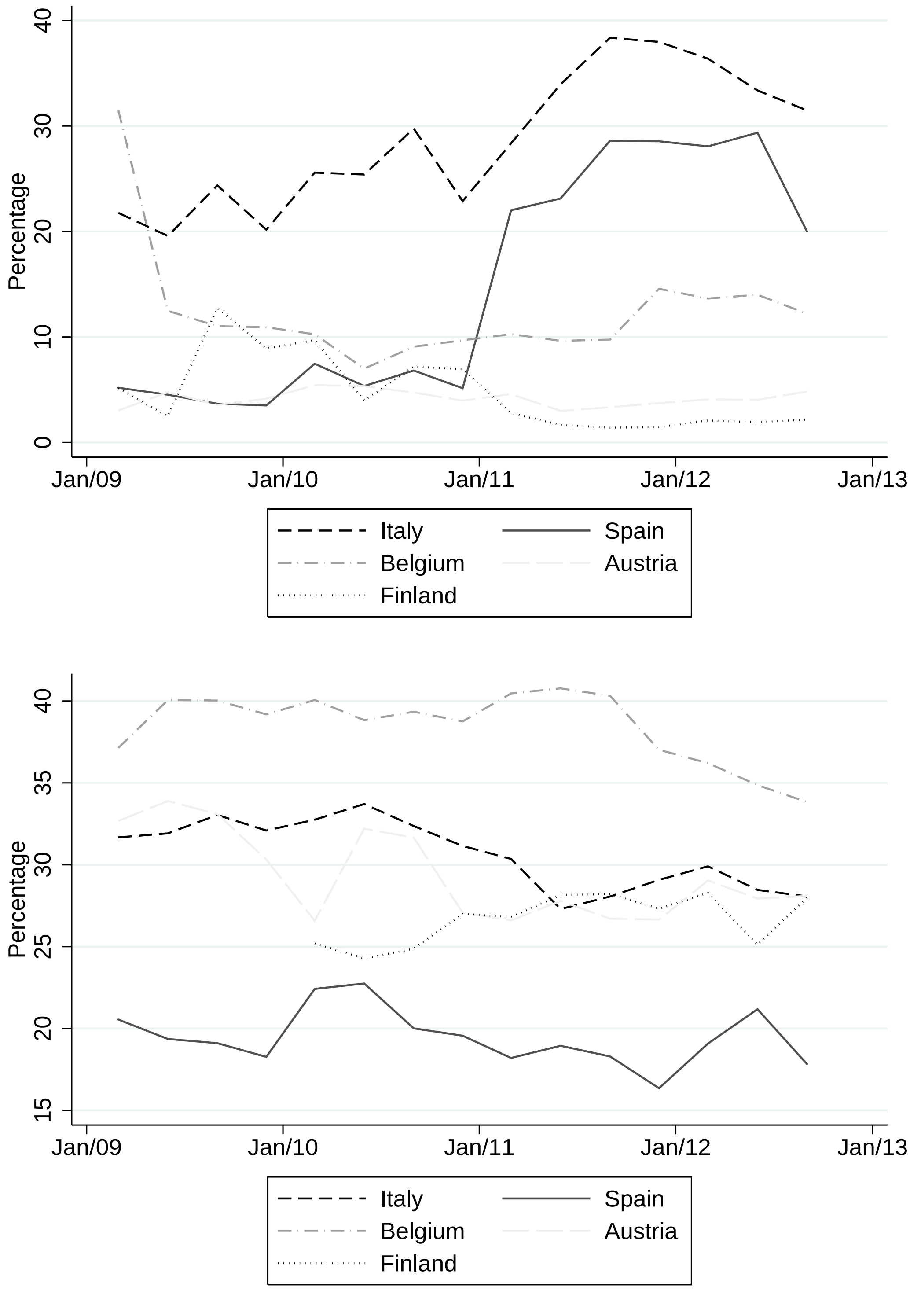

Figure 2: This figure depicts the evolution of bank holdings for USD-denominated (top panel) and EUR-denominated (bottom panel) sovereign bonds for each country during the financial and euro area sovereign debt crisis. The holdings are re-scaled by the total outstanding amount of USD- and EUR-denominated bonds issued by each country. The figure is based on ECB proprietary data on securities holdings on a security-by-security base.

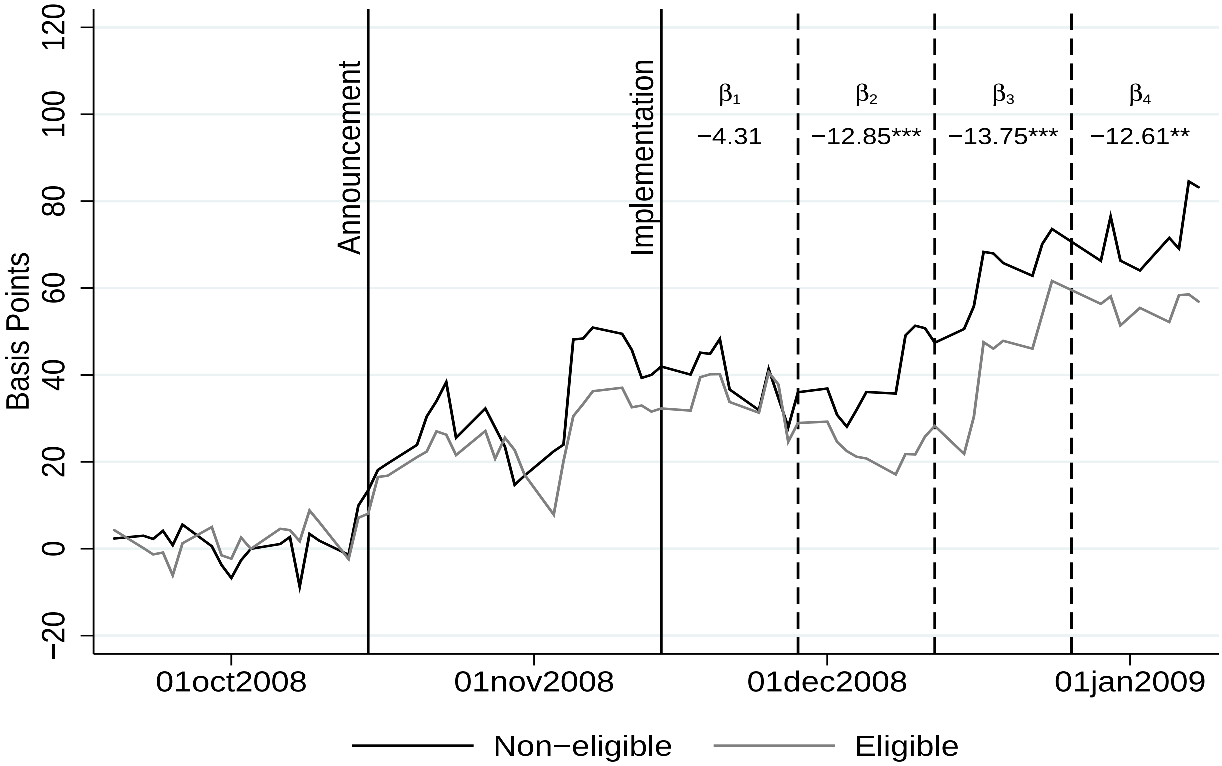

Figure 3: This figure illustrates the difference-in-difference analysis by plotting the cross-sectional averages for the eligible USD-denominated pair group (grey line) and the non-eligible USD-denominated pair group (dark line). The dashed lines refer to the 2, 4, 6 and 8 weeks after the implementation date. We report the β_k coefficient of Equation (5) that corresponds to the cross product of the dummies $After_k$ and the dummy $Eligible_{i,j}$.

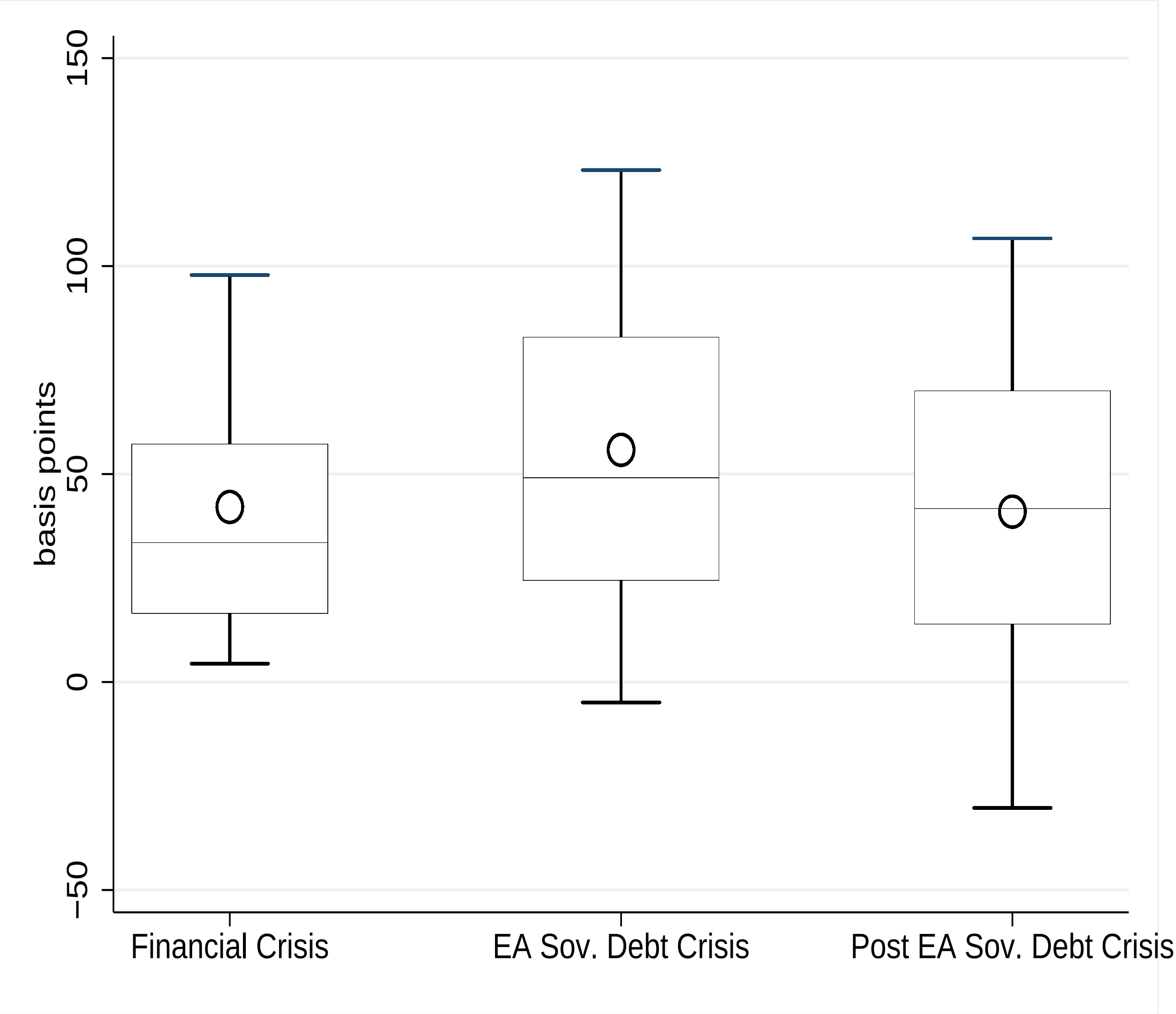

Figure 4: The figure depicts a box plot showing the 10, 25, 50, 75 and 90 percentiles of the basis distribution for three sub periods. The circle depicts the mean. The financial crisis period starts on 1 October 2008 and ends on 9 May 2010; the euro area sovereign debt crisis period starts on 10 May 2010 and ends on 28 February 2012; and the post euro area sovereign debt crisis period starts on 1 March 2012 and ends on 15 February 2013.

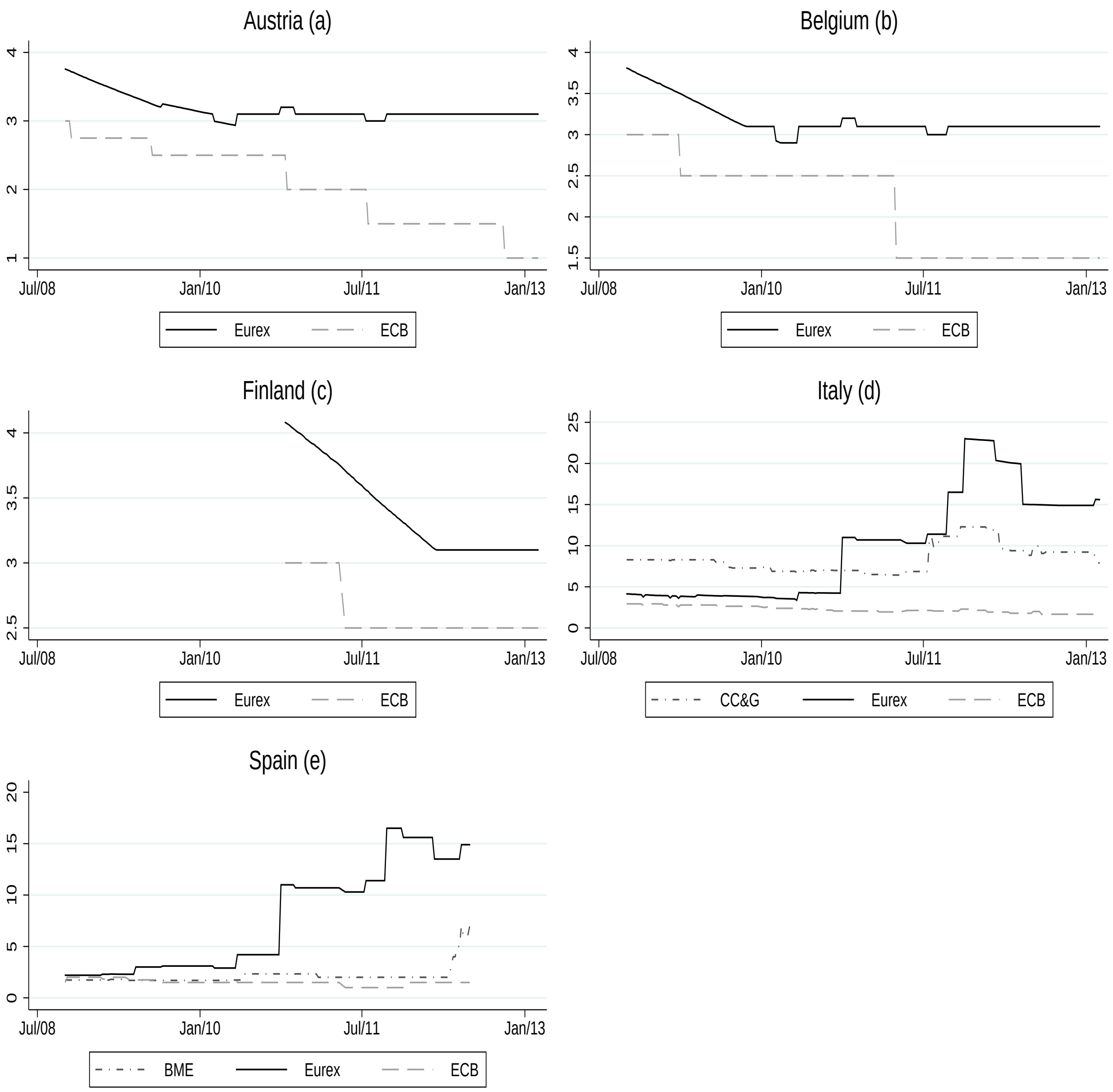

Figure 5: The figure depicts average haircuts applied by the ECB and different CCPs to EUR-denominated sovereign bonds issued by Austria, Belgium, Finland, Italy and Spain from October 2008 to February 2013. The black solid line refers to the haircuts applied on repo transactions by Eurex. The light grey dashed line refers to the haircuts applied by the ECB. For Italy and Spain haircuts applied by the CC&G and BME are reported (grey dash-dot line). Horizontal axes are measured on percentage points.

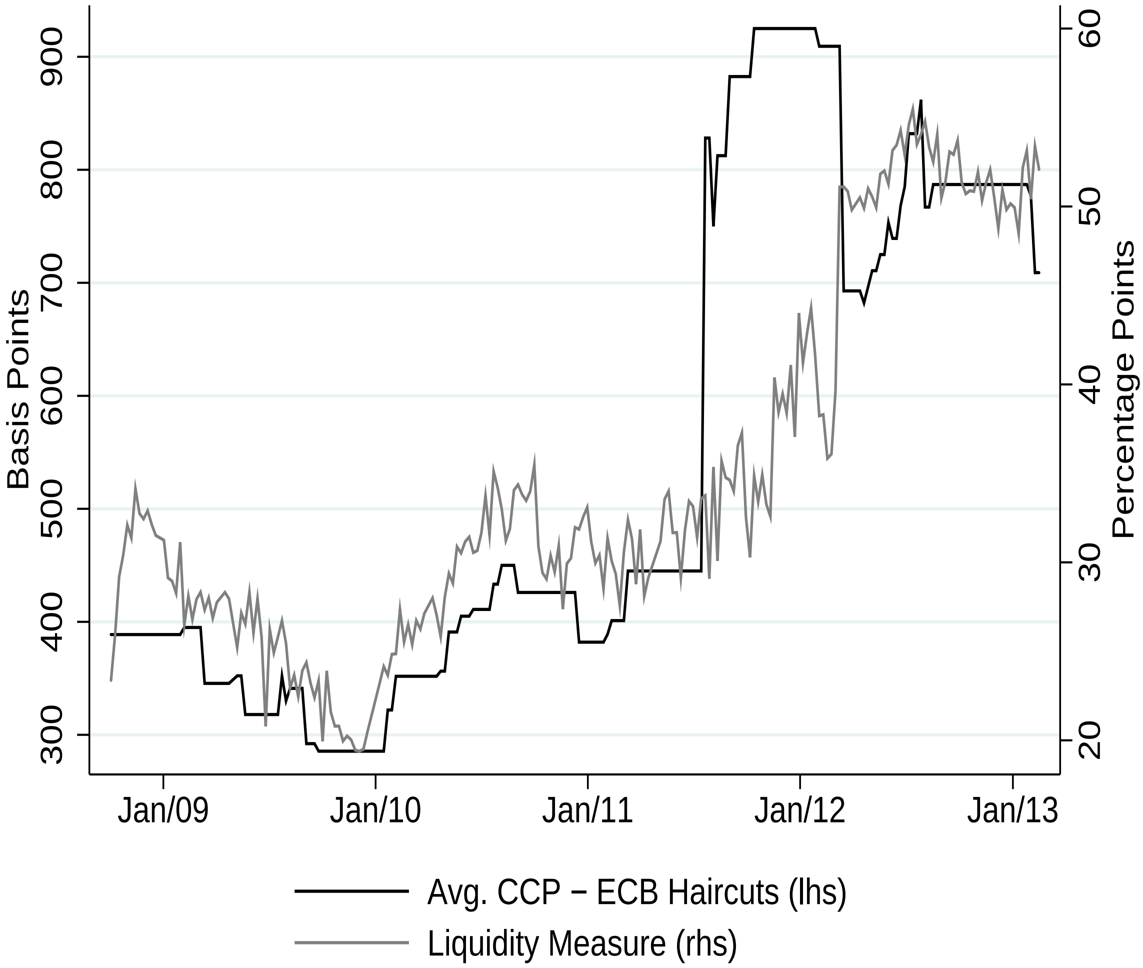

Figure 6: The figure depicts the average opportunity cost of the EUR-denominated bonds issued by Italy and Spain used in our sample (dark line), defined as the haircut difference between the CCPs and the ECB at bond level (CC&G and BME for Italy and Spain respectively), and the $Liquidity\ Measure_t$ that tracks the evolution over time of the liquidity withdrawn by strongly-constrained banks from ECB refinancing operations (grey line). Strongly-constrained banks are identified in the following way. At the bank level, we use the total post-haircut market value of collateral, that represents the banks total borrowing capacity with the ECB, and the total borrowing with the ECB to compute the collateral coverage ratio, the total borrowing normalized by the total post-haircut market value of the collateral. At the end of each month banks are sorted into three groups based on the 33^{th} and 66^{th} percentile of the collateral coverage ratio distribution. Banks that have a collateral coverage ratio higher than the 66^{th} percentile are identified as strongly-constrained banks.

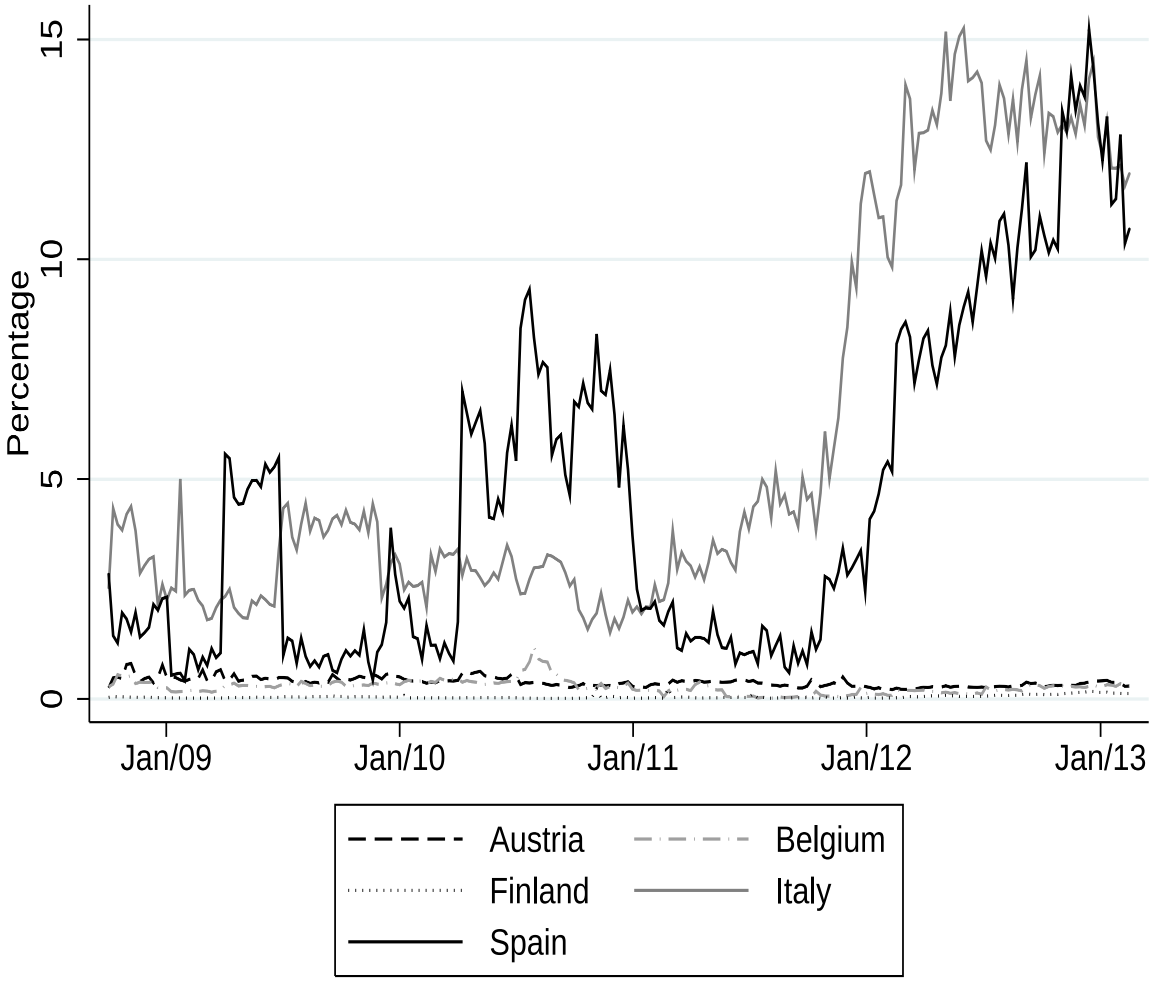

Figure 7: This figure depicts the $Collateral\ Measure_{j,t}$ defined as the share of total collateral in the sovereign country j debt pledged to the ECB by strongly-constrained banks. We report the collateral measure for Austria, Belgium, Finland, Italy and Spain. The sample spans from January 2008 to February 2013. Horizontal axes are measured on percentage points.

Table 1: **Descriptive Statistics - Bond Pair -** This table reports the main descriptive statistics at pair level: the starting (Column (2)) and ending (Column (3)) date in sample, country (Column (4)), the governing law of the USD-denominated bond (Column (5)), whether the USD-denominated bond is eligible for the ECB liquidity operations during those periods when USD-denominated bonds could be pledged to the ECB (Column (6)), the average basis (in basis points) (Column (7)), the average difference between the bid-ask yield spread of the synthetic EUR-denominated bond and the EUR-denominated bond (in basis points) (Column (8)), the average difference between the indicative lending fee of the USD-denominated bond and the EUR-denominated bond (in basis points) (Column (9)), the average difference between the number of transactions on loan of the USD-denominated bond and the EUR-denominated bond (Column (10)) and the average ratio of the amount outstanding of the USD- and EUR-denominated bonds. USD amounts are converted into Euro using the daily spot price (Column (11)).

(1) Pair	(2) Starting	(3) End	(4) Country	(5) Governing Law USD	(6) Eligible USD	(7) Basis	(8) Bid-Ask	(9) Lend. Fee	(10) No. Lend. Transactions	(11) Ratio Out. Amount
1	3/Oct/08	31/Aug/12	Belgium	Belgium	Yes	26.62	-4.60	5.29	-0.39	0.14
2	18/Sep/09	15/Feb/13	Belgium	Belgium	Yes	78.05	-5.41	7.95	-1.68	0.06
3	3/Oct/08	17/Jul/09	Spain	England	Yes	13.28	-3.22	10.80	2.73	0.05
4	3/Oct/08	29/Jun/12	Spain	England	No	23.52	-5.93	1.27	1.93	0.16
5	22/May/09	30/Apr/10	Spain	England	No	34.69	-4.25	8.24	7.64	0.09
6	13/Mar/09	4/Mar/11	Spain	England	No	47.43	-4.59	10.10	-13.45	0.07
7	3/Oct/08	22/Jun/12	Austria	England	Yes	19.77	-7.02	3.31	-32.91	0.17
8	3/Oct/08	15/Feb/13	Austria	England	Yes	25.11	-6.35	7.17	-19.12	0.10
9	22/Oct/10	15/Feb/13	Finland	England	No	28.46	-2.77	5.46	-8.19	0.25
10	18/Mar/11	15/Feb/13	Finland	England	No	34.09	-3.09	-1.91	-16.01	0.23
11	3/Sep/10	4/Feb/11	Italy	New York	Yes	91.67	-6.30	10.33	-15.30	0.08
12	3/Oct/08	15/Jun/12	Italy	New York	No	15.34	-3.99	7.76	-8.63	0.06
13	3/Oct/08	15/Feb/13	Italy	New York	No	35.97	-3.15	15.51	1.43	0.14
14	3/Oct/08	15/Feb/13	Italy	New York	No	72.79	-2.91	7.04	-19.38	0.06
15	3/Oct/08	15/Feb/13	Italy	Italy	No	59.98	-2.70	-5.93	-27.80	0.08
16	3/Oct/08	15/Feb/13	Italy	England	No	65.66	-2.63	1.05	-6.74	0.06
17	3/Oct/08	16/Jul/10	Italy	New York	No	31.25	-3.98	-0.41	3.59	0.12
18	22/Jan/10	7/Oct/11	Italy	New York	No	24.70	-3.37	-3.30	5.94	0.12
19	5/Feb/10	15/Feb/13	Italy	New York	No	14.06	-4.33	3.87	11.75	0.10

Table 2: **Changes in Eligibility Criteria -** This table reports the estimates of the difference-in-difference analysis around the changes in the eligibility criteria. Columns (1) and (3) report the estimates of Equation (5) around the first and second implementation dates of the changes in the eligibility criteria respectively. Column (2) reports the estimates of Equation (5) around the expiration date of the first implementation of the changes in the eligibility criteria. The regression is estimated over a time-window of 8 weeks before and after the date under analysis. The 8 weeks after the implementation are split in groups of two weeks by means of four dummy variables that take 1 during the corresponding window of two weeks and zero otherwise (i.e., D. 1-2w_t takes 1 during the first two weeks after the implementation date). The regression is conducted at the daily frequency. A Prais-Winsten regression is estimated with pair fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. In all the regressions, the correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	(1) 14-Nov-08 Implementation	(2) 1-Jan-11 End of Implementation	(3) 9-Nov-12 Implementation
D. 1-2w_t	14.742***	6.066	-6.167***
	(2.977)	(4.651)	(2.023)
D. 3-4w_t	27.016***	18.010***	2.344
	(3.333)	(4.610)	(2.175)
D. 5-6w_t	36.306***	6.454	0.921
	(3.622)	(4.610)	(2.202)
D. 7-8w_t	52.745***	-7.468	1.538
	(4.111)	(4.610)	(2.147)
$\text{Eligible}_{i,j}$	-14.662***	4.592	-0.820
	(4.703)	(5.823)	(2.387)
D. 1-2w_t x $\text{Eligible}_{i,j}$	-4.313	7.332	2.951
	(4.014)	(7.145)	(2.404)
D. 3-4w_t x $\text{Eligible}_{i,j}$	-12.852***	-1.639	-6.228**
	(4.499)	(7.082)	(2.584)
D. 5-6w_t x $\text{Eligible}_{i,j}$	-13.749***	0.977	-6.840***
	(4.918)	(6.820)	(2.617)
D. 7-8w_t x $\text{Eligible}_{i,j}$	-12.607**	4.705	-10.808***
	(5.570)	(6.264)	(2.568)
Constant	Yes	Yes	Yes
Pair FE	Yes	Yes	Yes
Num. Obs.	985	1140	692
R^2	0.320	0.064	0.052

Table 3: **Changes in ECB Agency Haircuts -** This tables reports the estimates of the difference-in-differences analysis around changes in ECB agency haircuts. Columns (1) – (5) report the impact of increases in agency haircuts and columns (6) – (8) report the impact of decreases in agency haircuts. The regression is estimated over a time-window of 8 weeks before and after the implementation date under study. The 8 weeks after the implementation are split in groups of two weeks by means of four dummy variables that take 1 during the corresponding window of two weeks and zero otherwise (i.e., D. 1-2w$_t$ takes 1 during the first two weeks after the implementation date). The regression is conducted at the daily frequency. A Prais-Winsten regression is estimated with pair fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	(1) 4-Feb-09	(2) 4-Mach-09	(3) 3-Jan-11	(4) 18-Jun-12	(5) 27-Jun-12	(6) 29-Aug-08	(7) 17-Feb-10	(8) 1-Nov-12
D. 1-2w$_t$	0.951	-0.400	0.790	-7.787***	-4.055***	5.063***	-0.519	-2.367***
	(1.306)	(1.315)	(0.720)	(0.613)	(0.484)	(0.638)	(0.649)	(0.483)
D. 3-4w$_t$	4.071***	2.520	-2.792***	-6.652***	-8.154***	12.075***	-1.412*	-4.473***
	(1.491)	(1.577)	(0.721)	(0.613)	(0.528)	(0.685)	(0.743)	(0.553)
D. 5-6w$_t$	1.900	2.012	-3.801***	-12.215***	-12.505***	14.715***	-3.476***	-6.538***
	(1.583)	(1.711)	(0.722)	(0.613)	(0.540)	(0.697)	(0.755)	(0.584)
D. 7-8w$_t$	4.402**	0.516	-3.151***	-16.794***	-15.689***	12.599***	-5.732***	-10.302***
	(1.727)	(1.887)	(0.724)	(0.613)	(0.573)	(0.731)	(0.812)	(0.648)
D. $\uparrow$ Haircut$_{i,j}$	11.015***	2.302	1.618	-5.788***	-0.344			
	(3.069)	(4.599)	(3.184)	(1.561)	(1.611)			
D. $\downarrow$ Haircut$_{i,j}$						-0.768	3.687***	1.587
						(2.029)	(1.087)	(1.360)
D. 1-2w$_t$ x D. $\uparrow$ Haircut$_{i,j}$	7.981***	17.283***	1.315	14.596***	6.274***			
	(2.491)	(5.566)	(3.281)	(2.349)	(1.149)			
D. 3-4w$_t$ x D. $\uparrow$ Haircut$_{i,j}$	6.774**	27.510***	8.979***	11.885***	11.015***			
	(2.909)	(6.646)	(3.281)	(2.349)	(1.253)			
D. 5-6w$_t$ x D. $\uparrow$ Haircut$_{i,j}$	8.880***	29.379***	9.969***	14.694***	19.518***			
	(3.102)	(7.209)	(3.281)	(2.349)	(1.284)			
D. 7-8w$_t$ x D. $\uparrow$ Haircut$_{i,j}$	6.704**	35.863***	4.189	23.117***	23.730***			
	(3.375)	(7.976)	(3.282)	(2.349)	(1.361)			
D. 1-2w$_t$ x D. $\downarrow$ Haircut$_{i,j}$						-5.785**	2.826***	-1.244
						(2.373)	(0.921)	(1.992)
D. 3-4w$_t$ x D. $\downarrow$ Haircut$_{i,j}$						-13.354***	4.649***	-2.083
						(2.548)	(1.048)	(2.278)
D. 5-6w$_t$ x D. $\downarrow$ Haircut$_{i,j}$						-19.837***	5.391***	-6.418***
						(2.594)	(1.078)	(2.398)
D. 7-8w$_t$ x D. $\downarrow$ Haircut$_{i,j}$						-18.201***	4.935***	-3.340
						(2.699)	(1.164)	(2.609)
Constant	YES	YES	YES	YES	YES	YES	YES	YES
Pair FE	YES	YES	YES	YES	YES	YES	YES	YES
Num. Obs.	1185	1164	2921	2640	2960	1037	2338	3328
R^2	0.070	0.150	0.068	0.309	0.325	0.428	0.174	0.121

Table 4: **Breakpoint Tests -** This table reports the test of significant differences in the mean and median levels of the basis across different three sub-samples periods: financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). Panel A reports the mean test. It contains the average basis across sub-periods and the p-value of the t-test analysis under the null hypothesis of equality of means across different sub-periods. Panel B reports the median test. It contains the median basis across sub-periods and the p-value of the Wilcoxon rank-sum test analysis under the null hypothesis of equality of medians across different sub-periods.

		(1) Financial Crisis	(2) Euro Area Sov. Debt Crisis	(3) Post Euro Area Sov. Debt Crisis
Panel A: Mean Test				
Mean		42.109	55.841	40.979
	t-test			
	Ho: $Basis_{PreCrisis} = Basis_{SovCrisis}$		p-value=0.000	
	Ho: $Basis_{SovCrisis} = Basis_{PostSovCrisis}$		p-value=0.000	
	Ho: $Basis_{PreCrisis} = Basis_{PostSovCrisis}$		p-value=0.634	
Panel B: Median Test				
Median		33.523	49.156	41.716
	Wilcoxon rank-sum test			
	Ho: $Basis_{PreCrisis} = Basis_{SovCrisis}$		p-value=0.000	
	Ho: $Basis_{SovCrisis} = Basis_{PostSovCrisis}$		p-value=0.000	
	Ho: $Basis_{PreCrisis} = Basis_{PostSovCrisis}$		p-value=0.053	

Table 5: **Bond and Market Factors -** This table reports the estimates of Equation (6) for bond and market factors. Column (1) contains the estimates for the whole sample period, while Columns (2) – (4) report the results for the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). A Prais-Winsten regression is estimated with country fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. The regression is conducted at the weekly frequency. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	(1) Full Sample	(2) Financial Crisis	(3) Sovereign Debt Crisis	(4) Post Sovereign Debt Crisis
Bond Factors				
Indicative Fee$_{i,j,t}$	-123.557	86.759	-132.372	113.228
	(139.700)	(145.333)	(271.916)	(609.649)
No. Transactions$_{i,j,t}$	-0.274***	-0.109	-0.304***	-0.187
	(0.071)	(0.092)	(0.106)	(0.174)
D. England Law$_{i,j}$	12.566	9.584	14.332	2.691
	(9.603)	(11.145)	(14.894)	(15.424)
D. NY Law$_{i,j}$	-22.477***	-26.432***	-23.057*	-26.776*
	(8.246)	(9.049)	(12.441)	(15.068)
D. Additional Clauses$_{i,j}$	-7.496	1.887	-7.467	-36.155**
	(7.278)	(6.495)	(10.339)	(18.287)
Ratio Outstanding$_{i,j,t}$	-125.087***	-122.347***	-147.454**	-235.077
	(34.685)	(16.743)	(67.654)	(145.267)
Market Factors				
Quanto CDS$_{j,t}$	64.872***	43.757***	103.564***	10.689
	(8.056)	(13.074)	(16.669)	(11.647)
Euribor-Eurepo$_{j,t}$	-0.009	-0.018	-0.036	0.468***
	(0.022)	(0.029)	(0.034)	(0.166)
Cross Currency Swap$_{i,j,t}$	0.101	-0.132*	-0.243*	0.557**
	(0.072)	(0.071)	(0.136)	(0.227)
Country Fixed Effects				
$\delta_{j=\text{Belgium}}$	28.875**	16.964	36.821**	12.884
	(11.486)	(12.405)	(18.281)	(19.685)
$\delta_{j=\text{Finland}}$	5.752		11.937	7.090
	(5.143)		(9.169)	(16.632)
$\delta_{j=\text{Italy}}$	53.268***	64.934***	51.970***	21.394
	(7.820)	(9.121)	(12.690)	(15.098)
$\delta_{j=\text{Spain}}$	15.081	6.705	16.755	25.169
	(9.533)	(8.529)	(16.067)	(35.803)
Constant	Yes	Yes	Yes	Yes
Num. Obs.	2775	976	1288	511
R^2	0.091	0.318	0.063	0.191

Table 6: **Monetary Policy Factors: Eligibility, Haircut Differences, Liquidity and Collateral -** This table reports the estimates of Equation (6) including the eligibility (Panel A), haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel B), haircut differences between the Eurex CCP and the ECB haircuts (Panel C), the liquidity measure (Panel D) and the collateral measure (Panel E). Other control variables include bond and market factors and country fixed-effects. Columns (1) – (3) report the estimates for the pairs issued by Italy and Spain, while Columns (4) – (6) report the estimates for the pairs issued by Austria, Belgium and Finland. The sample is split in three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). Figures in brackets correspond to the economic impact of the continuous variables measured as the product between the estimated coefficient and the difference between the 90^{th} percentile and the 10^{th} percentile of the independent variable. A Prais-Winsten regression is estimated with country fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. The regression is conducted at the weekly frequency. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial Crisis	(2) Sovereign Debt Crisis	(3) Post Sovereign Debt Crisis	(4) Financial Crisis	(5) Sovereign Debt Crisis	(6) Post Sovereign Debt Crisis
Panel A - Eligibility						
Eligibility Window$_t$	1.769	24.628***	-5.056	11.226*	21.305***	0.044
Eligible Pair$_{i,j}$	13.166	54.164***			-13.201	-47.492***
Eligibility Window$_t$xEligible Pair$_{i,j}$	13.756	-36.615**			-14.321	-17.160***
R^2	0.315	0.110	0.275	0.161	0.072	0.581
Panel B - Haircuts (CC&G, BME)						
CCP -ECB Haircut$_{i,j,t}$	0.008	6.136***	4.888*			
	[0.048]	[58.906]	[25.662]			
R^2	0.311	0.115	0.283			
Panel C - Haircuts (Eurex)						
Eurex -ECB Haircut$_{i,j,t}$	-0.024	1.216*	2.189	0.956	-3.566	44.359***
	[-0.029]	[21.360]	[10.120]	[0.436]	[3.600]	[44.400]
R^2	0.311	0.094	0.279	0.150	0.061	0.564
Panel D - Liquidity						
Liquidity$_t$	0.908***	1.803***	1.036	1.224***	1.444***	1.030**
	[9.681]	[16.522]	[10.701]	[13.47]	[14.916]	[10.639]
R^2	0.321	0.109	0.276	0.188	0.089	0.584
Panel E - Collateral						
Collateral$_{j,t}$	-2.341***	4.987***	6.150***	-2.138	-12.156	-57.040*
	[-8.109]	[37.449]	[15.116]	[-0.576]	[-4.845]	[-14.408]
R^2	0.318	0.111	0.293	0.151	0.065	0.573
Num. Obs.	711	797	275	265	491	236
Bond Factors	YES	YES	YES	YES	YES	YES
Market Factors	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES

Table 7: **ECB factors vs bond and market factors - R^2 decomposition -** This table reports the contribution to the R^2 of Equation (6) including the haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel A), the haircut differences between the Eurex and the ECB haircuts (Panel B), the liquidity measure (Panel C) and the collateral measure (Panel D). The eligibility factor is included in all specifications. Other control variables include bond and market factors and country fixed-effects. Columns (1) − (3) report the estimates for Italy and Spain, while Columns (4) − (6) for Austria, Belgium and Finland for the three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). The decomposition is computed on the OLS estimates of Equation (6) based on the transformed variables using the Prais-Wisten estimate of ρ. We report the R^2 for the OLS and Prais-Wisten estimates.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial	(2) Sovereign Debt	(3) Post Sovereign Debt	(4) Financial	(5) Sovereign Debt	(6) Post Sovereign Debt
Panel A: Differences in Haircuts (CC&G & BME) & Eligibility						
Mon. Policy	7.00	47.17	14.10			
Bond	47.25	18.92	55.75			
Market	15.54	30.44	29.26			
Country FE	30.21	3.48	0.89			
R^2						
OLS	0.109	0.150	0.217			
Prais-Winsten	0.315	0.164	0.285			
Panel B: Differences in Haircuts (Eurex) & Eligibility						
Mon. Policy	8.74	35.56	3.94	15.38	16.01	15.82
Bond	46.50	23.77	64.88	18.53	46.47	40.57
Market	15.50	38.24	30.24	56.94	22.25	35.47
Country FE	29.26	2.43	0.94	9.15	15.27	8.14
R^2						
OLS	0.110	0.113	0.215	0.032	0.088	0.558
Prais-Winsten	0.315	0.126	0.280	0.163	0.071	0.581
Panel C: Liquidity Measure & Eligibility						
Mon. Policy	7.29	34.33	0.19	43.72	36.91	14.22
Bond	48.78	25.3	66.3	17.17	33.2	40.75
Market	15.33	37.37	32.17	30.68	18.82	36.35
Country FE	28.61	3.00	1.34	8.43	11.07	8.69
R^2						
OLS	0.118	0.111	0.210	0.051	0.114	0.550
Prais-Winsten	0.322	0.132	0.277	0.197	0.096	0.597
Panel D: Collateral & Eligibility						
Mon. Policy	18.04	34.78	8.21	21.98	18.28	19.77
Bond	43.59	23.16	60.15	19.77	44.83	39.03
Market	13.55	39.55	31.02	48.99	22.17	33.39
Country FE	24.81	2.51	0.61	9.27	14.72	7.81
R^2						
OLS	0.131	0.117	0.231	0.033	0.093	0.535
Prais-Winsten	0.322	0.139	0.294	0.165	0.076	0.586

Table 8: **Robustness: Net of Average Turkish Basis -** This table reports the estimates of Equation (6) on an alternative basis defined as the difference between the estimated basis of each pair and the average basis of Turkey including the eligibility (Panel A), haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel B), haircut differences between the Eurex CCP and the ECB haircuts (Panel C), the liquidity measure (Panel D) and the collateral measure (Panel E). Other control variables include bond and market factors and country fixed effects. Columns (1) – (3) report the estimates for the pairs issued by Italy and Spain while Columns (4) – (6) report the estimates for the pairs issued by Austria, Belgium and Finland. We split the sample in three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). A Prais-Winsten regression is estimated with country fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. The regression is conducted at the weekly frequency. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial Crisis	(2) Sovereign Debt Crisis	(3) Post Sovereign Debt Crisis	(4) Financial Crisis	(5) Sovereign Debt Crisis	(6) Post Sovereign Debt Crisis
Panel A - Eligibility						
Eligibility Window$_t$	-17.131*	37.547***	6.183	-34.419***	32.897***	0.420
	(9.708)	(6.308)	(10.048)	(12.377)	(11.871)	(4.888)
Eligible Pair$_{i,j}$	-2.147	57.464***			-13.361	110.951***
	(27.210)	(19.493)			(10.095)	(15.079)
Eligibility Window$_t$xEligible Pair$_{i,j}$	9.635	-41.528**			-12.359	-15.402**
	(26.661)	(17.968)			(13.485)	(7.834)
R^2	0.131	0.111	0.318	0.132	0.093	0.355
Panel B - Haircuts (CC&G, BME)						
CCP -ECB Haircut$_{i,j,t}$	-0.119	6.052***	2.479			
	(0.277)	(1.315)	(2.764)			
R^2	0.123	0.096	0.320			
Panel C - Haircuts (Eurex)						
Eurex -ECB Haircut$_{i,j,t}$	-0.107	0.679	1.561	-43.144**	-9.278	56.764***
	(0.277)	(0.665)	(1.464)	(20.121)	(7.148)	(7.295)
R^2	0.123	0.072	0.319	0.116	0.060	0.343
Panel D - Liquidity						
Liquidity$_t$	2.676***	1.892***	0.355	2.662***	1.698***	0.133
	(0.561)	(0.477)	(1.182)	(0.804)	(0.433)	(0.618)
R^2	0.159	0.093	0.316	0.137	0.084	0.341
Panel E - Collateral						
Collateral$_{j,t}$	-0.496	4.023***	4.316**	72.615***	-4.480	-37.029
	(1.328)	(1.271)	(2.146)	(21.010)	(18.168)	(39.946)
R^2	0.124	0.086	0.326	0.147	0.059	0.342
Num. Obs.	711	797	275	265	491	236
Bond Factors	YES	YES	YES	YES	YES	YES
Market Factors	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES

Table 9: **Robustness: Net of the Cross Currency Swap -** This table reports the estimates of Equation (6) on an alternative basis defined as the difference between the estimated basis of each pair and the corresponding cross currency swap including the eligibility (Panel A), haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel B), haircut differences between the Eurex CCP and the ECB haircuts (Panel C), the liquidity measure (Panel D) and the collateral measure (Panel E). Other control variables include bond and market factors and country fixed effects. Columns $(1)-(3)$ report the estimates for the pairs issued by Italy and Spain while Columns $(4)-(6)$ report the estimates for the pairs issued by Austria, Belgium and Finland. We split the sample in three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). A Prais-Winsten regression is estimated with country fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. The regression is conducted at the weekly frequency. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial Crisis	(2) Sovereign Debt Crisis	(3) Post Sovereign Debt Crisis	(4) Financial Crisis	(5) Sovereign Debt Crisis	(6) Post Sovereign Debt Crisis
Panel A - Eligibility						
Eligibility Window$_t$	8.220	19.067***	-2.968	12.709*	22.696**	-3.679
	(6.408)	(7.137)	(9.205)	(6.667)	(10.183)	(5.147)
Eligible Pair$_{i,j}$	24.995	52.903**			0.054	130.556***
	(17.552)	(21.160)			(8.926)	(13.851)
Eligibility Window$_t$xEligible Pair$_{i,j}$	13.609	-25.539			-18.099	-19.404**
	(15.961)	(17.426)			(11.818)	(8.760)
R^2	0.352	0.070	0.305	0.236	0.110	0.558
Panel B - Haircuts (CC&G, BME)						
CCP - ECB Haircut$_{i,j,t}$	0.157	7.726***	4.652			
	(0.126)	(1.338)	(2.839)			
R^2	0.327	0.102	0.312			
Panel C - Haircuts (Eurex)						
Eurex - ECB Haircut$_{i,j,t}$	0.144	3.313***	2.240	25.978**	3.066	70.464***
	(0.126)	(0.659)	(1.440)	(11.148)	(6.388)	(8.540)
R^2	0.123	0.072	0.319	0.116	0.060	0.343
Panel D - Liquidity						
Liquidity$_t$	1.471***	2.468***	0.984	2.027***	2.087***	1.499**
	(0.358)	(0.454)	(1.247)	(0.406)	(0.354)	(0.639)
R^2	0.356	0.096	0.306	0.302	0.124	0.544
Panel E - Collateral						
Collateral$_{j,t}$	-2.271***	7.001***	5.442**	-15.432	-18.957	-38.742
	(0.785)	(1.225)	(2.178)	(10.162)	(17.051)	(38.632)
R^2	0.331	0.106	0.319	0.216	0.085	0.538
Num. Obs.	711	797	275	265	491	236
Bond Factors	YES	YES	YES	YES	YES	YES
Market Factors	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES

Table 10: **Shadow Cost of Capital -** This table reports the sensitivity of the shadow cost of capital estimated in Equation (7). Column (1) reports the sensitivity to the Euribor-Eurepo spread and Column (2) reports the sensitivity to the ECB deposit rate - Eurepo spread. Column (3) reports the sensitivity to the monthly average liquidity withdrawn by strongly-constrained banks from the ECB. Column (4) reports the sensitivity to the monthly average share of the sovereign debt that is pledged to the ECB by strongly-constrained banks. An OLS regression is estimated with pair fixed-effects and robust standard errors. The regression is conducted at monthly frequency. j denoted country specific variable and i denotes pair specific variable. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	(1)	(2)	(3)	(4)
Panel A - Italy & Spain				
Euribor-Eurepo$_{j,t}$	2.396			
	(1.592)			
ECB Rate-Eurepo$_{j,t}$		7.369***		
		(1.731)		
Liquidity$_t$			-0.304***	
			(0.032)	
Collateral$_{j,t}$				-0.800***
				(0.077)
Pair FE	YES	YES	YES	YES
Num. Obs.	396	396	396	396
R^2	0.229	0.264	0.152	0.178
Panel B - Austria, Belgium & Finland				
Euribor-Eurepo$_{j,t}$	1.008			
	(3.462)			
ECB Rate-Eurepo$_{j,t}$		18.585***		
		(2.510)		
Liquidity$_t$			0.525***	
			(0.056)	
Collateral$_{j,t}$				-17.821
				(13.821)
Pair FE	YES	YES	YES	YES
Num. Obs.	135	135	135	135
R^2	0.606	0.469	0.461	0.598

Appendix

A.1 - Cash Flows from the USD-denominated to the Synthetic EUR-denominated Bond

In order to create a synthetic EUR-denominated bond we consider the following strategy (Table A-1). At date T_0 the trader buys a par cross currency asset swap package that consists of an USD-denominated bond (notional $N^{\$}$ that pays a coupon rate of $c_{\$}^{A}$ per semi-annual period and expires at date T_n) and a fixed-for-floating swap. The price of the complete package and the notional are fixed at par (i.e., $N_{\$}/S_0$ where S_0 is the Euro/US Dollar spot rate at time T_0). The buyer has to pay ($P_i^{\$} < \$N_{\$}$) or receive ($P_i^{\$} > \$N_{\$}$) an upfront payment to compensate for any premium or discount paid for the USD-denominated bond at date T_0. This upfront payment ensures that the net position created by the cross currency asset swap package is the same as an USD-denominated bond issued at par. Every payment date the buyer pays the fixed payment $C_{\$}^{A} = c_{\$}^{A} \times N^{\$} \times dacc$ where $dacc$ is the ratio of the accruals dates over the count date convention and receives the floating rate payment $(r_{€} + css) \times N^{\$}/S_0 \times dacc$ where $r_{€}$ is the annualized 3-month Euribor rate and css is the par asset-swap spread. We calculate the spread css as the value that makes the value of the contract zero at date T_0, accounting for the mismatch in coupon rates and payment dates (semi-annual vs quarterly) between the bond and the swap due to the Euribor interest rate swap convention. Note that the cross-currency swap at time T_0 involves: (i) an exchange of the USD-denominated bond in exchange of the notional amount in euros ($N^{\$}/S_0$) at the initiation date, (ii) a series of floating interest payments in euros associated with the principal $N^{\$}/S_0$ in exchange of a series of fixed interest payment in dollars associated with the principal $N^{\$}$, (iii) an exchange of the USD-denominated bond against the notional amount in Euros ($N^{\$}/S_0$). To create a synthetic fixed-rate coupon EUR-denominated bond, the investor gets into a floating-for-fixed interest rate swap to exchange the EUR-denominated stream of floating inflows into a fixed coupon rate. The floating-for-fixed interest rate swap is initiated at date T_0 and consists of the exchange of the floating inflows $(r_{€} + css) \times (N^{\$} \ / \ \mathrm{S}_0) \times dacc$ against a fixed swap rate $C_{€}^{B} = c_{€}^{B} \times (N^{\$}/S_0) \times dacc$, where $c_{€}^{B}$ is the coupon rate of the synthetic EUR-denominated bond. For comparability reasons, the dates of the fixed-leg are matched with the EUR-denominated comparable bond at pair level. We finally estimate the yield-to-maturity $\widehat{Y}^{USD->EUR}$ based on the EUR-denominated cash flows.

A.2 - Understanding the Basis

A.2.1 - Alternative Methods to Create a Synthetic EUR-denominated bond

We estimate the basis under three different methods to convert the USD-denominated cash flows in Euro. We report the results for Italy (Figure A-1), but all the results are available on request. The grey solid line depicts the trading strategy considered in the paper (Appendix A.1). The black solid line depicts the basis using the approach developed by Tuckman and Porfirio (2003) who derive an adjusted-synthetic forward rate that takes into account violations of the CIRP in the long run. The grey dashed line depicts the trading strategy that involves the use of forward contracts to convert the USD-denominated cash flows. The sample spans from January 2006 to February 2013. We observe sizable differences across the three approaches in terms of the level of the basis. However, our main results (Table 6) are not affected when we use the standard forward contracts (Table A-2) and the adjusted forward rate approach of Tuckman and Porfirio (2003) (Table A-3) to compute the basis.

A.2.2 - Breaking Down the Basis: Beyond the CIRP

CIRP requires the return of a risk-less investment on domestic currency to be equal to the fully hedged return of a risk-less investment in a foreign currency. It is well known that CIRP condition did not hold during the financial crisis comparing investments in USD and Euros. Following Buraschi, Menguturk, and Sener (2015) we estimate the basis that is purely due to the frictions in the foreign exchange market (Basis CIRP) and compare it with the basis estimated from Equation (1). We report the average results for Italy (Figure A-2). We observe that the violation of the CIRP condition explains a constant part of the basis during the financial and euro area sovereign debt crisis periods. Nevertheless, there is a sizable residual component that cannot be attributed to the violation of the CIRP condition.

A.3 - Basis

A.3.1 - Bond Characteristics

Table A-4 reports the main characteristics of the bonds used in our analysis, such as the ISIN code, settlement date, maturity date, coupon, currency denomination and outstanding amount.

A.3.2 - Duration Gap

Section 3.1 explains how pairs of bonds are selected. Nevertheless, the duration of the two comparable bonds forming a pair could differ across bonds, exposing an investor to a potential cash flow risk. We estimate the potential exposure of long-short strategy as implemented in the construction of the basis (Equation 1) (Table A-5). We compute the average duration of all bonds in our sample (Column (2) and (3)) and the average duration gap of the trading strategy for every pair (Column (4)). We find a positive duration gap in most of the pairs meaning in general the synthetic EUR-denominated bond is more price sensitive than the comparable EUR-denominated bond. In addition, we report the impact on the basis of a shift in both yield curves of 1 and 2.32 standard deviation (Column(5) and (6)). We document that an increase of 1 (2.32) standard deviation decreases the basis by 12.66 (-29.37) basis points in the most extreme case.

A.4 - Additional Results

Table A-6 reports the estimates of Equation (6) in first differences. Our main results (Table 6) are not affected by this exercise.

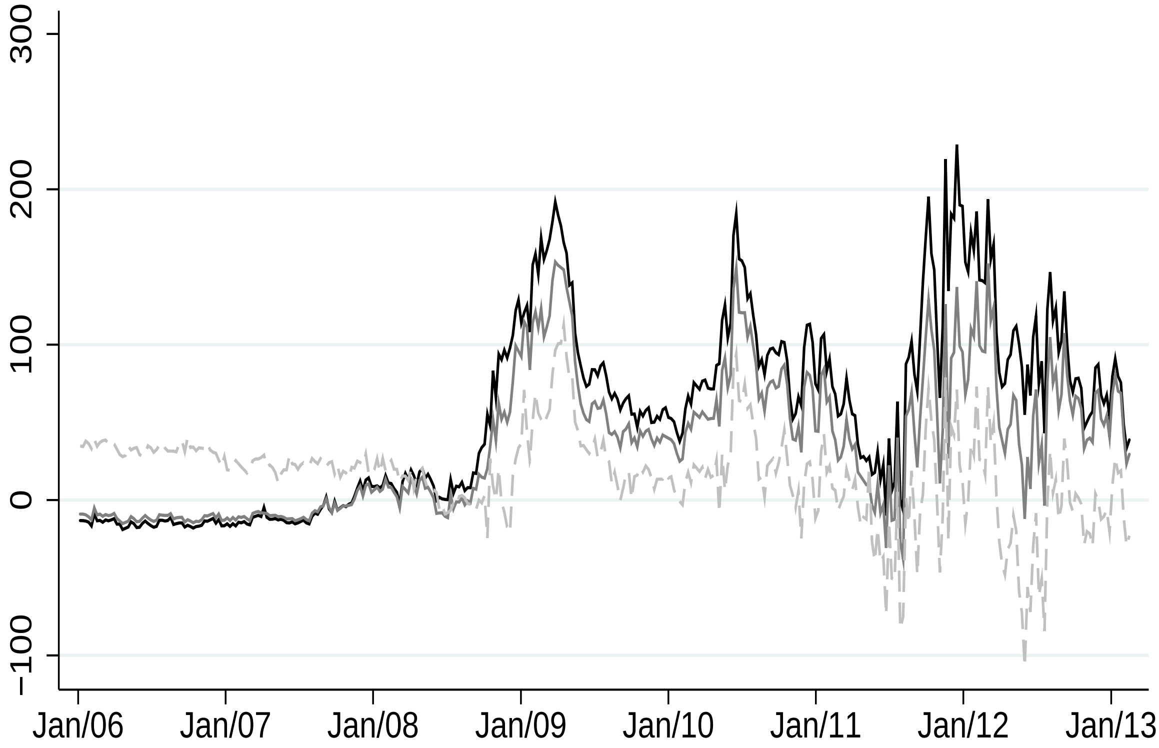

Figure A-1: The figure depicts the average basis for Italy under three different methods for hedging the currency risk. The grey solid line corresponds to the trading strategy discussed in Appendix A.1. The black solid line corresponds to the Tuckman and Porfirio (2003) strategy based on adjusted forward rates. The grey dashed line corresponds to the trading strategy based on forward contracts. The sample spans from January 2006 to February 2013 and the y-axis is measured in basis points.

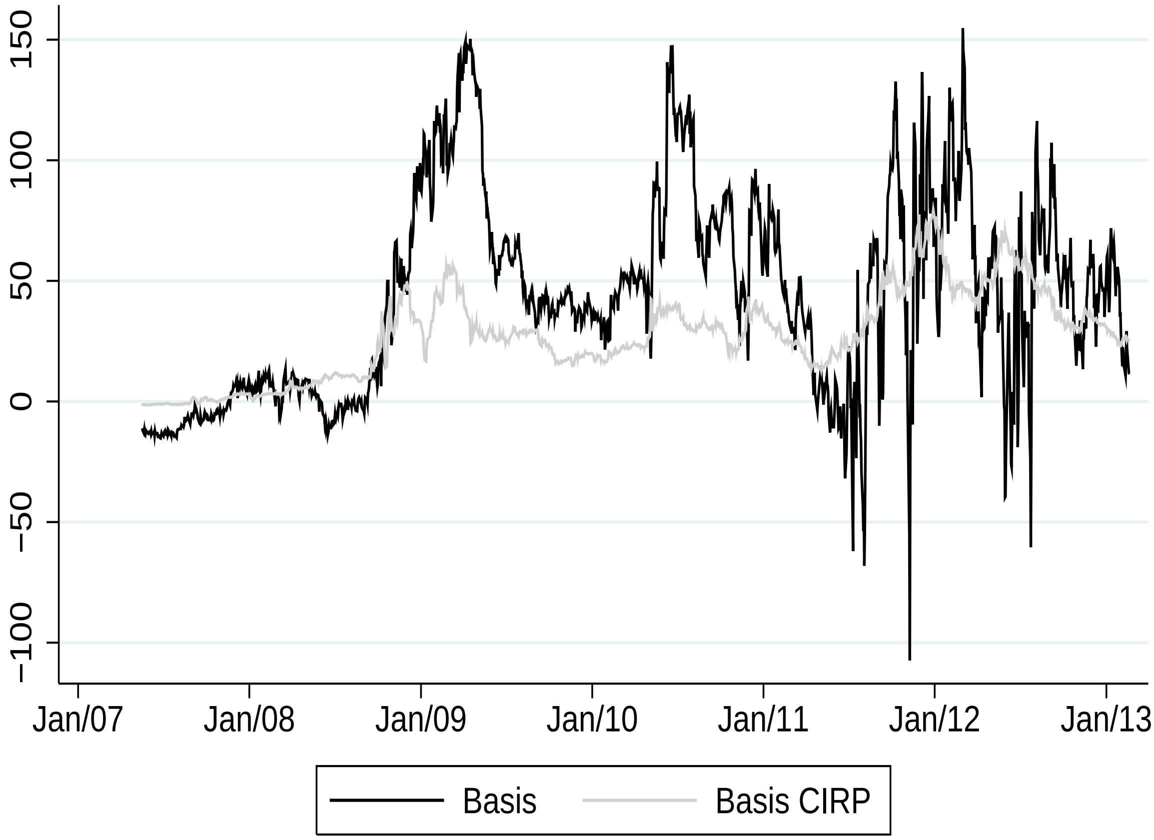

Figure A-2: The figure shows the average basis for Italy (black line) and the basis that is purely due to the violation of the CIRP (grey line). The sample spans from May 2007 to February 2013 and the y-axis is measured in basis points.

Table A-1: **Cash flows from the USD-denominated to the synthetic EUR-denominated bond -** This table reports the cash flows of the trading strategy. Panel A reports the strategy to convert the USD-denominated bond into a synthetic EUR-denominated bond. Panel B reports the cash flows of the comparable EUR-denominated bond.

Panel A: Cash Flows of Synthetic EUR-denominated Bond				
Time	T_0	T_1	...	T_n
Cross Currency	$-N_\$/S_0$	$C^A_\$$	$C^A_\$$	$C^A_\$ + N_\$/S_0$
Asset Swap		$(r_€ + css) \times (N_\$/S_0)) \times dacc$	$(r_€ + css) \times (N_\$/S_0) \times dacc$	$(r_€ + css) \times (N_\$/S_0) \times dacc$
		$-C^A_\$$	$-C^A_\$$	$-C^A_\$$
Interest Rate Swap		$(r_€ + css) \times (N_\$/S_0) \times dacc$	$(r_€ + css) \times (N_\$/S_0) \times dacc$	$(r_€ + css) \times (N_\$/S_0)) \times dacc$
		$C^B_€$	$C^B_€$	$C^B_€$
Final Cash Flows	$-N_\$/S_0$	$C^B_€$	$C^B_€$	$C^B_€$+ N$_\$/S_0$
Yield-to-maturity			$N_\$/S_0 = \sum_{i=1}^{T_n} \frac{C^B_€}{\left(1+y^{\$\rightarrow€}\right)^i} + \frac{N_\$/S_0}{\left(1+y^{\$\rightarrow€}\right)^{T_n}}$	
Panel B: Cash Flows of EUR-denominated Bond				
Time	T_0	T_1	...	T_n
Buy Euro-denominated bond	$-P_€$	$C^A_€$	$C^A_€$	$C^A_€ + N_€$
Final Cash Flows	$-P_€$	$C^A_€$	$C^A_€$	$C^A_€ + N_€$
Yield-to-maturity	$P_€ = \sum_{i=1}^{T_n} \frac{C^A_€}{\left(1+y^€\right)^i} + \frac{N_€}{\left(1+y^€\right)^{T_n}}$			

Table A-2: **Robustness: Forwards -** This table reports the estimates of Equation 6 on an alternative basis defined using forward rates including the eligibility (Panel A), haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel B), haircut differences between the Eurex CCP and the ECB haircuts (Panel C), the liquidity measure (Panel D) and the collateral measure (Panel E). Other control variables include bond and market factors and country fixed effects. Columns $(1)-(3)$ report the estimates for the pairs issued by Italy and Spain while Columns $(4)-(6)$ reports the estimates for the pairs issued by Austria, Belgium and Finland. We split the sample in three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). A Prais-Winsten regression is estimated with country fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. The regression is conducted at the weekly frequency. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial Crisis	(2) Sovereign Debt Crisis	(3) Post Sovereign Debt Crisis	(4) Financial Crisis	(5) Sovereign Debt Crisis	(6) Post Sovereign Debt Crisis
Panel A - Eligibility						
Eligibility Window$_t$	-0.236	22.221***	-2.127		16.057*	3.893
	(6.257)	(4.970)	(8.471)		(8.845)	(3.291)
Eligible Pair$_{i,j}$	0.722	35.537**			-6.078	-17.959**
	(18.376)	(14.450)			(9.117)	(8.468)
Eligibility Window$_t$xEligible Pair$_{i,j}$	9.114	-44.429***		-1.525	-19.590*	-18.976***
	(16.032)	(14.941)		(6.280)	(10.879)	(5.248)
R^2	0.335	0.147	0.331	0.113	0.139	0.550
Panel B - Haircuts (CC&G, BME)						
CCP - ECB Haircut$_{i,j,t}$	1.977	4.038***	8.065***			
	(2.224)	(0.971)	(2.471)			
R^2	0.335	0.132	0.358	0.113	0.133	0.529
Panel C - Haircuts (Eurex)						
Eurex -ECB Haircut$_{i,j,t}$	-0.905	0.252	1.060	14.815	4.336	35.343***
	(3.571)	(0.519)	(1.328)	(9.999)	(6.501)	(4.977)
R^2	0.334	0.114	0.329	0.118	0.135	0.529
Panel D - Liquidity						
Liquidity$_t$	0.822**	2.125***	1.443	1.064***	1.616***	1.168**
	(0.344)	(0.529)	(1.168)	(0.395)	(0.393)	(0.478)
R^2	0.340	0.131	0.332	0.137	0.158	0.570
Panel E - Collateral						
Collateral$_{j,t}$	-2.188***	3.373***	4.068*	1.511	-22.712	-36.271
	(0.845)	(1.029)	(2.283)	(10.275)	(16.976)	(31.092)
R^2	0.342	0.125	0.334	0.111	0.138	0.538
Num. Obs.	711	797	275	265	491	236
Bond Factors	YES	YES	YES	YES	YES	YES
Market Factors	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES

Table A-3: **Robustness: Adjusted Forwards -** This table reports the estimates of Equation 6 on an alternative basis defined using the adjusted-synthetic forward proposed by Tuckman and Porfidio (2003) including the eligibility (Panel A), haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel B), haircut differences between the Eurex CCP and the ECB haircuts (Panel C), the liquidity measure (Panel D) and the collateral measure (Panel E). Other control variables include bond and market factors and country fixed effects. Columns (1) – (3) report the estimates for the pairs issued by Italy and Spain while Columns (4) – (6) reports the estimates for the pairs issued by Austria, Belgium and Finland. We split the sample in three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). A Prais-Winsten regression is estimated with country fixed-effects and with corrected standard errors (PCSEs) for contemporaneous correlation across panels and serial autocorrelation within panels. The correlation within panels is treated as a first-order autocorrelation AR(1) and the coefficient of this process ρ is common to all the panels. j denotes country specific variable and i denotes pair specific variable. The regression is conducted at the weekly frequency. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial Crisis	(2) Sovereign Debt Crisis	(3) Post Sovereign Debt Crisis	(4) Financial Crisis	(5) Sovereign Debt Crisis	(6) Post Sovereign Debt Crisis
Panel A - Eligibility						
Eligibility Window_t	7.319	21.104***	-3.905		19.621**	0.456
	(6.065)	(4.953)	(8.353)		(8.022)	(3.344)
Eligible $\text{Pair}_{i,j}$	8.610	35.214**			4.184	10.892
	(12.956)	(15.485)			(8.752)	(8.867)
Eligibility Window_txEligible $\text{Pair}_{i,j}$	10.126	-41.528***		2.393	-23.068**	-15.365***
	(10.916)	(15.974)		(5.988)	(10.339)	(5.325)
R^2	0.450	0.293	0.380	0.517	0.259	0.864
Panel B - Haircuts (CC&G, BME)						
CCP - ECB $\text{Haircut}_{i,j,t}$	1.431	4.446***	7.483***			
	(1.961)	(0.954)	(2.468)			
R^2	0.445	0.263	0.398	0.517	0.228	0.860
Panel C - Haircuts (Eurex)						
Eurex -ECB $\text{Haircut}_{i,j,t}$	-2.539	0.655	0.967	15.000	7.123	45.035***
	(3.328)	(0.516)	(1.320)	(9.841)	(6.745)	(5.031)
R^2	0.445	0.251	0.378	0.523	0.230	0.860
Panel D - Liquidity						
Liquidity_t	1.132***	2.071***	1.073	1.022***	1.472***	0.780
	(0.328)	(0.514)	(1.165)	(0.377)	(0.364)	(0.487)
R^2	0.455	0.259	0.380	0.532	0.239	0.872
Panel E - Collateral						
$\text{Collateral}_{j,t}$	-2.891***	3.964***	4.293*	6.124	-31.363*	-33.389
	(0.784)	(1.016)	(2.271)	(9.447)	(16.666)	(31.744)
R^2	0.456	0.261	0.384	0.521	0.237	0.863
Num. Obs.	711	797	275	265	491	236
Bond Factors	YES	YES	YES	YES	YES	YES
Market Factors	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES

Table A-4: **Descriptive Statistics - Bond -** This table reports the main descriptive statistics at bond level. We report the ISIN, issuer country, settlement and maturity date, coupon (all bonds are fixed-rate coupon bonds), currency, and outstanding amount in EUR-millions at the settlement date (for those bonds USD-denominated we apply the spot exchange rate).

ISIN	Country	Settlement Date	Maturity Date	Coupon	Currency	Amount Out.
AT0000385992	Austria	28/May/03	20/Oct/13	3.8	EUR	5000
XS0170724479	Austria	25/Jun/03	25/Jun/13	3.25	USD	1297
AT0000386073	Austria	15/Jan/04	15/Jul/14	4.3	EUR	3000
XS0192781150	Austria	19/May/04	19/May/14	5	USD	831
BE0000314238	Belgium	24/Apr/08	28/Mar/14	4	EUR	5000
BE0934531337	Belgium	1/Jul/08	3/Sep/13	4.25	USD	1269
BE6000356335	Belgium	15/Sep/09	15/Sep/14	2.875	USD	685
FI4000018049	Finland	21/Sep/10	15/Apr/16	1.75	EUR	4000
XS0550739535	Finland	19/Oct/10	19/Oct/15	1.25	USD	1450
XS0605995561	Finland	17/Mar/11	17/Mar/16	2.25	USD	1426
IT0003190912	Italy	1/Feb/02	1/Feb/12	5	EUR	23468
XS0144129649	Italy	1/Mar/02	15/Jun/12	5.625	USD	3465
US465410BF43	Italy	27/Feb/03	15/Jun/13	4.375	USD	1861
IT0003472336	Italy	2/May/03	1/Aug/13	4.25	EUR	4962
IT0003719918	Italy	1/Sep/04	1/Feb/15	4.25	EUR	4500
US465410BN76	Italy	21/Jan/05	21/Jan/15	4.5	USD	3077
IT0003844534	Italy	2/May/05	1/Aug/15	3.75	EUR	4000
US465410BQ08	Italy	25/Jan/06	25/Jan/16	4.75	USD	1631
IT0004019581	Italy	1/Mar/06	1/Aug/16	3.75	EUR	5000
US465410BR80	Italy	20/Sep/06	20/Sep/16	5.25	USD	2362
IT0004164775	Italy	2/Jan/07	1/Feb/17	4	EUR	4000
US465410BS63	Italy	12/Jun/07	12/Jun/17	5.375	USD	1502
US465410BT47	Italy	4/Jun/08	15/Jul/11	3.5	USD	1618
IT0004404973	Italy	1/Sep/08	1/Sep/11	4.25	EUR	5000
US465410BU10	Italy	5/Oct/09	5/Oct/12	2.125	USD	1709
IT0004564636	Italy	4/Jan/10	15/Dec/12	2	EUR	4500
IT0004568272	Italy	15/Jan/10	15/Apr/15	3	EUR	5840
US465410BV92	Italy	26/Jan/10	26/Jan/15	3.125	USD	1778
ES00000120E9	Spain	12/Apr/05	30/Jul/10	3.25	EUR	3500
XS0225226710	Spain	20/Jul/05	20/Jul/10	4.125	USD	832
ES00000120Z4	Spain	15/Jan/08	30/Apr/11	4.1	EUR	3631
ES00000121H0	Spain	8/Apr/08	31/Jan/14	4.25	EUR	3171
XS0363874081	Spain	14/May/08	17/Jun/13	3.625	USD	1294
XS0376589288	Spain	16/Jul/08	18/Jul/11	3.375	USD	1264
ES00000121I8	Spain	13/Jan/09	30/Apr/12	2.75	EUR	3378
XS0416150950	Spain	5/Mar/09	5/Mar/12	2.75	USD	797
US900123AS92	Turkey	24/Sep/03	15/Jan/14	9.5	USD	1090
DE000A0AU933	Turkey	10/Feb/04	10/Feb/14	6.5	EUR	1000
XS0245387450	Turkey	1/Mar/06	1/Mar/16	5	EUR	750
US900123AZ36	Turkey	26/Sep/06	26/Sep/16	7	USD	1183
XS0285127329	Turkey	2/Feb/07	2/Apr/19	5.875	EUR	1250
US900123BA75	Turkey	3/Oct/07	3/Apr/18	6.75	USD	884
US900123BH29	Turkey	18/Mar/10	30/Mar/21	5.625	USD	735
XS0503454166	Turkey	22/Apr/10	18/May/20	5.125	EUR	1500

Table A-5: **Duration Analysis -** This table reports the duration analysis of the 19 bond pairs under study. Columns (2) – (3) report the average duration of the EUR- and synthetic EUR-denominated bond. Column (4) reports the average duration gap of the trading strategy. Columns (5) – (6) report the impact on the basis of a shift in both yield curves of 1 and 2.32 standard deviation.

(1) Pair	(2) Duration EUR Bond (years)	(3) Duration Synthetic EUR Bond (years)	(4) Duration Gap (years)	(5) Impact $\sigma = 1.57\%$ (bps)	(6) Impact $\sigma = 2.32\%$ (bps)
1	3.189	3.234	0.067	-4.561	-10.581
2	2.667	2.708	-0.067	4.499	10.438
3	1.427	1.424	0.038	-2.550	-5.915
4	2.281	2.358	-0.076	5.141	11.927
5	1.473	1.489	0.012	-0.837	-1.941
6	1.732	1.736	0.002	-0.106	-0.247
7	3.050	3.084	0.004	-0.302	-0.701
8	3.660	3.735	0.187	-12.660	-29.371
9	4.169	4.157	-0.042	2.819	6.539
10	3.980	3.981	0.105	-7.095	-16.460
11	2.064	2.092	0.082	-5.565	-12.910
12	2.831	2.852	0.043	-2.900	-6.729
13	4.115	4.117	0.020	-1.370	-3.178
14	4.573	4.488	0.047	-3.146	-7.300
15	5.383	5.255	0.179	-12.129	-28.140
16	5.727	5.592	0.156	-10.574	-24.532
17	1.627	1.755	0.006	-0.426	-0.988
18	1.676	1.783	-0.001	0.076	0.176
19	3.488	3.442	-0.033	2.234	5.183

Table A-6: **Robustness: First-Difference Specification -** This table reports the estimates of an alternative specification of Equation 6 in which all variables are consider in weekly changes. The dependent variable is the basis defined in Equation (1). It includes the haircut differences between the CCPs (LCH Clearnet SA, CC&G and BME) and the ECB haircuts (Panel A), the haircut differences between the Eurex CCP and the ECB haircuts (Panel B), the liquidity measure (Panel C) and the collateral measure (Panel D). The governing laws, additional clauses and the country fixed-effects are excluded. Columns (1) − (3) report the estimates for pairs issued by Italy and Spain, while Columns (4) − (6) report the estimates for pairs issued by Austria, Belgium and Finland for the three sub-periods: the financial crisis (October 2008 - May 2010), euro area sovereign debt crisis (May 2010 - February 2012) and post euro area sovereign debt crisis (March 2012 - February 2013). A panel regression with robust standard errors is estimated. The regression is conducted at the weekly frequency. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Italy & Spain			Austria, Belgium & Finland		
	(1) Financial Crisis	(2) Sovereign Debt Crisis	(3) Post Sovereign Debt Crisis	(4) Financial Crisis	(5) Sovereign Debt Crisis	(6) Post Sovereign Debt Crisis
Panel A - Haircuts (CC&G, BME)						
Δ CCP -ECB Haircut$_{i,j,t}$	-1.388	5.851***	0.985			
	(1.404)	(1.358)	(2.266)			
R^2	0.047	0.148	0.235	0.027	0.085	0.069
Panel B - Haircuts (Eurex)						
Δ Eurex -ECB Haircut$_{i,j,t}$	-10.202*	4.535***	3.276***	10.346	-10.073**	
	(6.116)	(1.510)	(1.046)	(7.713)	(4.844)	
R^2	0.058	0.165	0.253	0.030	0.087	0.066
Panel C - Liquidity						
Δ Liquidity$_t$	-0.084	1.533**	1.422	0.345	1.099***	0.026
	(0.272)	(0.655)	(1.013)	(0.334)	(0.336)	(0.271)
R^2	0.048	0.152	0.240	0.035	0.105	0.069
Panel D - Collateral						
Δ Collateral$_{j,t}$	-1.660**	4.099**	5.205***	-6.172	-24.326***	-7.114
	(0.736)	(1.961)	(1.819)	(9.767)	(9.084)	(35.136)
R^2	0.058	0.146	0.257	0.034	0.091	0.069
Num. Obs.	683	786	268	257	483	230
Bond Factors	YES	YES	YES	YES	YES	YES
Market Factors	YES	YES	YES	YES	YES	YES
Country FE	NO	NO	NO	NO	NO	NO

Acknowledgements
The views expressed herein are those of authors only and do not represent the position of the European Central Bank or the Eurosystem. We are grateful for comments from Geert Bekaert, Frederic Boissay, Sergio Mayordomo, Benjamin Sahel, Cristina Sommacampagna and Suresh Sundaresan; and James McAndrews, Philippe Mueller, Loriana Pelizzon, Yusho Kagraoka and Christian Schlag (our discussants). We benefited from discussions with Cristina Arellano, Alessandro Beber, Markus Brunnermeier, Andrea Buraschi, Jose Manuel Campa, John Campbell, Benoît Cœuré, Greg Duffee, Emmanuel Farhi, Alessandro Fontana, Marie Hoerova, Gur Huberman, Matteo Maggiori, Simone Manganelli, Michele Manna, Augustine Landier, David Lando, Manfred Kremer, Frank Smets, Jens Tapking, Andrea Tiseno, Oreste Tristani and Harald Uhlig, and participants in seminars at ECB, IESE, International Conference on Sovereign Bond Markets, Tokyo 2014, ECB-Bank of England workshop “Understanding the yield curve: what has changed with the crisis”, Frankfurt am Main September 2014, ECB workshop on “Non-standard monetary policy measures”, Frankfurt am Main October 2014, and Day Ahead Conference, San Francisco Federal Reserve, January 2016. Luca Baldo and Francesca Barbiero provided outstanding research assistance. Previous versions of this paper circulated under the title "Limits to Arbitrage: Empirical Evidence from the Euro Area Sovereign Market".

Stefano Corradin (corresponding author)
European Central Bank, Frankfurt am Main, Germany; email: stefano.corradin@ecb.int

Maria Rodriguez-Moreno
Universidad de Navarra, Spain

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

ISSN 1725-2806 (online)
ISBN 978-92-899-2175-6
DOI 10.2866/585712
EU catalogue No QB-AR-16-044-EN-N