Central Bank Communication and the Yield Curve

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Abstract

We decompose ECB monetary policy surprises into target and communication shocks and document a number of novel findings. First, on days when the ECB announces its monetary policy, virtually almost all of the variation of Euro area bond yields is driven by communication shocks and this effect is most pronounced at intermediate maturities. Second, while the effect of ECB monetary policy was homogeneous across countries before the European debt crisis, we document dramatic differences post crisis, and show that communication shocks drive a wedge between core and peripheral yields. We empirically link the core-periphery wedge to a Euro area breakup and credit risk premium. To explain these facts, we build a model in which central bank communication reveals information about the state of the economy. Monetary policy induces demand shocks for sovereign bonds leading to bond market fragmentation and risk premia, which offset accommodating monetary policy.

Keywords: interest rates, monetary policy, sovereign bonds, central bank communication, home bias

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Once upon a time, central banks were deliberately mysterious about their future policy. Since then, central banks have moved toward greater transparency not just by providing timely information about its monetary policy decision but also by publishing minutes of the meetings and forecasts about the intended future path of interest rates, among other things. Moreover, central bankers nowadays give many speeches, hold news conferences, and interact via social media. Shin (2017) recently pointedly asked: "Can central banks talk too much?."

There are good reasons for the increased importance of communication in recent years. With limited scope to manoeuvre interest rates, central banks embraced novel monetary policy tools after the financial crisis. Effective transmission of monetary policy in the pursuit of price stability starts with asset prices. In this paper, we focus on the effects of central bank communication on sovereign bond yields. The novelty of our results concerns the heterogeneous impact of communication in the cross-section of euro area countries' bond yields. More specifically, we document that communication as pursued by the European Central Bank (ECB) drove a wedge between peripheral and core countries' bond yields and we attribute this wedge to a redenomination and credit risk premium.

Evidence from the U.S. shows that monetary policy has significant impact on asset prices and that much of this effect arises from changes in risk premia rather than directly from changes in the short-rate.[1] We focus on announcements by the ECB for several reasons: First, the institutional features of the ECB allow us to separate two different dimensions of monetary policy conduct, namely the effects coming from target rate announcements and communication. Second, by studying the cross-section of euro area countries' yields allows us to more sharply disentangle the monetary policy effects arising from changes in the short-rate and risk premia.

While most central banks inform the public about their monetary policy decisions, on the day of Governing Council meetings the ECB releases a press statement with the current policy decision and 45 minutes later holds a separate press conference.[2] Hence, the institutional details of the ECB allow us to decompose intraday changes in the euro area money market yield curves into news related to the level of the ECB policy interest rate (target rate shocks) and news

[1]For example, Bernanke and Kuttner (2005) document that monetary policy shocks have large effects on stock returns mainly by altering the equity risk premium. Hanson and Stein (2015) and Gertler and Karadi (2015) show that long maturity interest rates react strongly to monetary surprise announcements, and emphasize the response of term premia.

[2]The U.S. Federal Reserve introduced press conferences on a quarterly frequency in April 2011.

related to the future path of monetary policy (communication shocks). Moreover, the ECB has conducted some form of 'forward guidance' since inception, so it is a policy tool that extends well before the zero lower bound period.[3]

With the two shocks at hand, we document a number of novel results. First, target rate shocks affect bond yields almost one-for-one at the short end of the yield curve but have little impact on long term yields. The magnitude of target rates shocks is in line with an earlier literature studying the effect of U.S. monetary surprises on bond yields. Information shocks during communication window, however, have large effects on bond yields, being most pronounced for intermediate maturities but also having significant impact at long term maturities. For example, we find that during the 2001 to 2014 period, in response to a hypothetical 100bp change in the communication shock, two-year German bond yields move 150bps while ten-year German yields move 60bps. Comparing their joint impact, we show that while target shocks can have a significant impacts on bond yields in the statistical sense, we find that virtually almost all explained variability in bond yields on ECB days is explained by communication.

Second, we obtain our main result by splitting the sample into the pre- and post-crisis periods. We find that before 2009, monetary policy shocks affect bond yields of all euro area countries uniformly. After 2009, however, we show a differential effect to communication shocks arises between core and peripheral yields which increased yield spreads at a time when unconventional measures were being implemented to reduce them.[4] Specifically, we show that peripheral yields' response to communication shocks were muted whereas core country reactions remained unchanged after the financial crisis. Using rolling regressions, we find that the effect of central bank communication on peripheral bond yields starts declining in 2011 and becomes insignificant in 2013. Combining this observation with the fact that communication shocks were mostly negative post 2009, because the market had expected higher future short rates than what the ECB then signalled, we show this drove down yields in core countries considerably whereas peripheral countries moved much less; thus, a significant spread was generated (at its peak, in May 2013, this wedge represented 22% of the total two-year yield spread).

[3]For example, former ECB president Jean-Claude Trichet was active in steering rates both with his 'traffic light' system of varying degrees of 'vigilance' to signal upcoming rate hikes and with his comments on the appropriateness of the prevailing yield curve.

[4]We define the core as Germany and France, and the periphery and Italy and Spain. These countries account for about 76% of the total GDP of the Eurozone.

One natural candidate to explain this wedge is a fear of a euro area breakup and sovereign default risk. Indeed, this is alluded to in ECB President Draghi's famous "whatever it takes" speech in which he relates peripheral countries' high borrowing costs to the emergence of liquidity, redenomination, and credit risk.[5] To test this hypothesis, we explore the effect of monetary policy shocks on credit default swap (CDS) quanto spreads. CDS quanto spreads are the difference between two otherwise same CDS denominated in different currencies. CDS quantos therefore not just measure the credit risk of a country but also the redenomination and possibly liquidity risk. In the case of the euro area, these are CDS in U.S. dollars and euros. A potential default of an euro area country would immediately trigger a devaluation of the euro vis-à-vis the dollar and hence euro area CDS denominated in dollars trade at a higher spread (and are in general also more liquid). We find that while communication shocks have no effect on core countries quanto spreads, peripheral quanto spreads significantly increase on ECB announcement days.

Finally, when we control for the CDS quanto spread in a regression from peripheral and core bond yields on monetary policy shocks, we find the estimated coefficients on the communication shocks to be aligned between core and peripheral countries. In other words, the CDS quanto spreads are the "missing risk premium" when studying the effect of communication shocks on sovereign bond yields. One last question remains: Why does central bank communication command a risk premium?

To shed light on this question we develop a dynamic equilibrium term structure model in which central bank communications, via a signalling channel, induces demand shocks in the fixed income market. We consider an economy with two countries, and we assume bond markets of these countries to be partially segmented, motivated by the large empirical and theoretical literature that studies the home bias in peripheral countries during the European debt crisis. Bond prices are determined through the interaction between banks that act as active traders across bond markets but are subject to transaction costs when purchasing foreign bonds, and institutional investors, such as pension funds and life insurance companies. We assume that these latter agents, instead of focusing (purely) on the risk-return trade-off, also care about

[5] The precise statements reads "Then there's another dimension to this that has to do with the premia that are being charged on sovereign states borrowings. These premia have to do, as I said, with default, with liquidity, but they also have to do more and more with convertibility, with the risk of convertibility". For a full transcript of the speech see http://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html.

the monetary policy beyond its direct impact on interest rates. In particular, we assume that institutional investors interpret positive (negative) communication shocks as good (bad) news, and respond by increasing (reducing) their demand for peripheral debt.

Within the model, when the central bank announces changes to the intended future path of monetary policy, yield curves can be affected via two channels. The direct impact of monetary policy operates through the expectation channel. A positive current target rate shock increases all future expected target rates, but due to mean reversion, its effect dies out over time. Thus, as a reaction, all yields go up, but current long yields are less sensitive to target rate shocks than short yields. At the same time, forward guidance provides information about intended future (medium-term) target rates, so a positive communication shock increases medium-term yields while leaving short and long yields intact, corresponding to a hump-shaped response across maturities.

The second, indirect effect works through the risk premium channel: by influencing the demand of institutional investors, monetary policy shocks alter the effective supply of bonds that banks have to hold in equilibrium. In particular, if a negative communication shock is realized, pension funds demand fewer long-term peripheral bonds. As these bonds are risky, banks, who have to hold more in equilibrium, demand higher risk prices for all debt. Hence, the risk premium channel goes in the opposite direction of the expectations channel, damping the overall effect of communication.

The risk premium channel, however, is asymmetric due to the partial segmentation of bond markets that we obtain via transaction costs. When institutional investors demand fewer peripheral bonds upon negative monetary policy shocks, most of the increase in the effective supply must be absorbed by the local peripheral banks, whose portfolios exhibit higher home bias, and who require a higher risk premium to compensate them for the larger amount of risk. Thus, the risk premium increase is larger for peripheral bonds than in the core country. Given that the expectation channel affects interest rates of the two countries to the same extent, and that the risk premium channel goes the opposite direction as the expectation channel, we obtain that core country bonds are more responsive to monetary policy shocks than peripheral bonds. Hence, our model provides an understanding of how monetary policy shocks can affect the term structure in equilibrium, both across maturities and across countries.

The rest of the paper is organized as follows. After the literature review, Section I outlines how we identify our monetary policy shocks, and Section II describes our data and monetary policy shock estimates. We present our main empirical findings in Section III, and provide a theoretical model in Section IV. Section V concludes.

Related literature:

This paper contributes to four strands of the literature. First, several papers have studied how central bank communication can affect asset prices. Ehrmann and Fratzscher (2005) compare the communication strategies of the Federal Reserve, the Bank of England, and the ECB. Their findings suggest that central bank communication is a key determinant of the market's ability to anticipate monetary policy decisions and the future path of interest rates. Rosa and Verga (2008) examine the effect of ECB communication on the price discovery process in the Euribor futures market using a tick-by-tick dataset. A number of studies have constructed wording indicators to classify the content of the statements of the ECB's or Fed's press conferences. Ehrmann and Fratzscher (2007) find that more hawkish statements lead to higher rates while a more dovish tone leads to lower interest rates. Lucca and Trebbi (2011) construct a hawkish/dovish indicator from statements of Federal Open Committee Members and find longer-dated yields react to changes in communication around announcements. Schmeling and Wagner (2016) explore the effect of central bank tone on asset prices, where the tone measures the number of "negative" words in the press statement following the target rate announcement. Boguth, Grégoire, and Martineau (2016) document a shift in attention away from FOMC announcements that are not followed by a press conference to those which do. Different from these papers, we can separately identify target rate versus communication shocks and show that communication about monetary policy is not only the dominant factor driving interest rate changes on announcement days but also has significantly different effects in the cross-section of Eurozone bond yields.[6]

Second, a large empirical literature extracts monetary policy shocks from money market rates.[7] However, measuring the actions of monetary policy remains a challenging task. One

[6]Indeed, the ECB explicitly acknowledges the importance of its monthly press conference. For example, in its Monthly Bulletin of November 2002 (p. 62), they write: "a correct interpretation by the market of the monetary policy decisions taken by the central bank reduces the volatility of interest rates," and hence "a good understanding of monetary policy allows private agents to better manage and hedge their risks, which may contribute to reducing market uncertainty and enhancing economic welfare."

[7]A seminal paper in this field is Kuttner (2001), who proposes measuring the unexpected change in the current policy rate with changes in the price of Federal Funds futures that settles in the month containing the meeting. For a recent survey article on this literature see Buraschi and Whelan (2016).

source of difficulty is related to the fact that policy actions reflect an endogenous response to the macro-economy. To address this endogeneity problem, the literature has proposed the use of structural vector autoregressions (Christiano, Eichenbaum, and Evans (1999)), using changes in interest rates orthogonal to the information contained in internal Fed forecasts (Romer and Romer (2004)), a heteroskedasticity approach on the variance-covariance matrix of daily yields (Boyarchenko, Haddad, and Plosser (2017)), and identification using high frequency changes to interest rates around announcements (Cochrane and Piazzesi (2002)). A second difficulty is separating the effect of target rate from communication shocks. For example, Gürkaynak, Sack, and Swanson (2005) propose extracting latent factors using high-frequency yield changes in a narrow window around FOMC announcements but need to impose identifying assumptions in order to disentangle the role of target rate shocks versus 'path' shocks. Swanson (2017) extends this approach to include a third "quantitative easing" related factor. We contribute to this literature by exploiting the fact that the ECB conducts the target rate announcement and the press conference at different points in time; thus, allowing a simple yet clean separation of these effects.

Fourth, our paper also contributes to the theoretical literature that explores the effect of monetary policy and bond supply on the term structure of interest rates. We build on the framework developed by Vayanos and Vila (2009), in which risk-averse arbitrageurs demand higher risk premiums on bonds if their exposure to interest-rate risk increases due to shifts in the net supply of bonds. Greenwood and Vayanos (2014) use this theoretical framework to study the implications of a change in the maturity structure of government debt supply, and Hanson (2014) and Malkhozov, Mueller, Vedolin, and Venter (2016) extend the model to include mortgage backed securities.[8] In these papers risk premia are driven solely by shocks to supply, and they cannot be extended trivially to account for news on future policy rates. In contrast, our framework incorporates forward guidance into the risk premium channel that works via demand shocks of institutional investors, and provides a multi-country setting that allows us to study cross-sectional differences between core and peripheral countries.

Finally, our paper is also related to the vast theoretical and empirical literature on home bias

[8]Greenwood, Hanson, and Vayanos (2016) study forward guidance in rates and bond supply to evaluate the impact of QE announcements in the US. Greenwood, Hanson, and Liao (2017) model asset price dynamics in segemented markets to assess the impact of recent large-scale asset purchases by central banks.

in portfolio choice dating back to Black (1974), Stulz (1981), Errunza and Losq (1985), French and Poterba (1991), Baxter and Jermann (1997), and Coval and Moskowitz (2001), among others. In our model home bias is a result of transaction costs on foreign bond investments, similar to Martin and Rey (2004), that can also be viewed as a reduced form way for modelling stricter international portfolio constraints (e.g., Bhamra, Coeurdacier, and Guibaud (2014)) or costlier information acquisition on foreign assets (e.g., Van Nieuwerburgh and Veldkamp (2009) and Valchev (2017)). Further, Becker and Ivashina (2014), Gennaioli, Martin, and Rossi (2014), and Barbu, Fricke, and Moench (2016), among others, study home bias in European sovereign bond markets. In contrast to the above literature, our focus is on how home bias affects the transmission of monetary policy shocks.

I. Identification of monetary policy shocks

In this section, we outline the identification strategy for monetary policy shocks around target rate announcements and the press conference. Many papers use (daily) changes in either the (unexpected change in the) target rate or other nominal interest rates with longer maturities. This approach is plagued by two issues. First, by using daily data, one cannot rule out that information other than monetary policy affects interest rates throughout the day. Second, ample empirical evidence shows that target rate changes are largely anticipated (see, e.g., Gürkaynak, Sack, and Swanson (2005)). In contrast, the policy shocks we extract are a composite measure of high-frequency changes in interest rates with different maturities which allows us to capture changes in monetary policy beyond the shortest maturity itself. Moreover, our identification is based on the premise that changes in the policy indicators in these tight windows are dominated by the information about monetary policy contained in the ECB target rate announcement and press conference.

Let ΔY denote a $T \times N$ matrix of yield changes described by the following dynamics:

$$\Delta Y = F\Omega' + \eta, \tag{1}$$

where T denotes the number of announcements and N the different maturities. F is a $T \times k$ matrix of latent factors, with $k < N$, that drive the variation of yield changes on these days. Ω

is a $k \times N$ matrix of factor loadings and η is a $T \times N$ matrix of idiosyncratic error terms. Matrix Ω contains the eigenvectors of the covariance matrix of ΔY and F is computed as $F = \Delta Y \Omega$.[9]

In a seminal paper, Gürkaynak, Sack, and Swanson (2005) identify policy shocks using principal component analysis on futures rates with maturities up to one year in a tight window bracketing FOMC target rate announcements. We follow these authors and extract principal components from money market rates with maturities up to two years. Moreover, our approach allows for a separate identification of target rate and communication shocks by making use of an institutional feature of ECB policy announcements, namely that the target rate announcement and press conference take place separately. Therefore, we estimate latent factors F from (1) separately around the target rate announcement and the press conference, and our approach does not rely on imposing any restrictions. We explain details of the procedure and some institutional details in the next section.[10]

II. Estimation of monetary policy shocks

We work with tick-by-tick high frequency data that runs from February 1, 2001, to December 31, 2014. During this period there is one ECB meeting per month, except for the years 2001 and 2008, when there were 20 and 13 meetings, respectively. Out of the 177 announcement days we exclude 16 that were either not followed by a press conference or were unscheduled. We also ignore other speeches done by the ECB President or Vice-President for identification issues, as our focus is on disentangling target rate from communication shocks and studying their effects.[11] Our final sample thus consists of 161 announcement days: there are 19 days when the main refinancing rate was raised, 10 days when the interest rate was decreased, and

[9]We normalize the eigenvectors such that the factor loadings sum to one and are therefore interpreted as weights. The first principal component is then a variance maximizing average.

[10]In the setup of Gürkaynak, Sack, and Swanson (2005), the principal components have no structural interpretation a priori since, for example, both factors are correlated with changes in the Fed funds rate. As rate announcements and other potential dimensions of monetary policy (e.g., forward guidance) happen at the same time in the U.S., the authors propose an identification strategy by restricting the second principal component to have no effect on the short-end of the yield curve after a factor rotation. In other words, their second principal component moves interest rates for the upcoming year without changing the current Fed funds rate. The Online Appendix presents a comparison between the approach in Gürkaynak, Sack, and Swanson (2005) and our identification strategy. Interestingly, we find that when using the Gürkaynak, Sack, and Swanson (2005) 'path' shocks, results are very similar to the ones obtained from the identification in this paper. This provides external validation for the rotation procedure in Gürkaynak, Sack, and Swanson (2005) to extract information about the future path.

[11]The exclusion dates are summarized in Table OA-1 of the Online Appendix.

132 meetings with no change.

There are two noteworthy points regarding our sample. First, since 2010, the ECB also announces so-called unconventional monetary policy such as the securities market program (SMP), long-term refinancing operations (LTROs), outright market transactions (OMT), or asset purchase programs (APP). These announcements have been the focus of an enormous literature. In our sample of 161 announcements, we identify six dates on which an unconventional measure was announced during the press conference. We verify in the Online Appendix that these six announcements do not significantly affect our results. Second, we end our sample in December 2014, as since January 2015, the press release refers to current and future unconventional policy measures, too. Our period of interest thus ends in December 2014 to keep our identification clean.[12]

A. *Market reaction around target rate announcement and press conference*

The ECB publishes a brief press release announcing its policy rate decision at 13:45 CET. In our sample, the press release only contains information about the ECB's policy rates. From 14:30 CET, the ECB President and Vice-President hold a press conference. The press conference starts with an introductory statement, whose structure has remained the same since the very beginning: it contains (i) a summary of the ECB's monetary policy decision and balance of risks to price stability, and since July 2013 it includes also an open-ended forward guidance; (ii) a discussion of both real and monetary developments in the Euro area, and, since May 2003, a "sum-up and cross-check" paragraph that repeats the initial synthetic assessment; and (iii) a conclusion with some considerations on fiscal policy and structural reforms. The press conference then continues with a Question and Answer session.

[Insert Figure 1 here]

To get a first impression of how the target rate announcement and the press conference affect interest rates, we illustrate the market reaction in high frequency at three specific announcements. Figure 1 plots the two-year Euribor swap rate throughout the day from 09:00 to 17:30 CET for April 6, 2006 (upper panel), June 5, 2008 (middle panel), and November 3, 2011 (lower panel).

[12] The ECB also started to publish its monetary policy deliberations in January 2015.

April 6, 2006: The ECB decided to keep interest rates unchanged, following a 25bps increase after the previous meeting in March. Indeed, while we find no reaction in the swap rate at the target rate announcement, there is a sharp decrease right after the start of the press conference at 14:30, when the swap rate fell from 3.54% to 3.47% within 30 minutes. Market participants did not expect any change in interest rates at the April meeting but expected an interest rate hike later in the year. However, when at the press conference ECB President Jean-Claude Trichet told the press that "the current suggestions regarding the high probability of an increase of rates in our next meeting do not correspond to the present sentiment of the Governing Council," money market rates started to fall rapidly as the market revised its expectations about future interest rates downward.

June 5, 2008: The ECB decided to keep interest rates unchanged; Trichet, however, indicated that risks to price stability have increased, and that inflation has risen significantly. The press statement also included that the Governing Council was in a "state of heightened alertness" and struck a hawkish note by emphasizing that "risks to price stability over the medium term have increased further." During the Q&A, Trichet also said that "we could decide to move our rates by a small amount in our next meeting." As a result, the swap rate increased from 5% to 5.15% within the first 30 minutes of the press conference. Indeed, a rate hike was then decided by the Governing Council at their next meeting, on July 3, 2008.

November 3, 2011: At Mario Draghi's first meeting as new chairman, the ECB unexpectedly cut interest rates by 25bps, for the first time in two years. Consequently, the two-year swap rate dropped from 1.46% to 1.37% within 10 minutes, and then stabilized around this level with no reaction at the press conference. The fact that the market seemed surprised by the interest rate cut is manifested in a question that a journalist asked during the press conference: "President Draghi, welcome to Frankfurt. I have a few questions about today's rate decision, which came as a bit of a surprise. Was the decision unanimous? And can you explain the reasoning behind it, because if the economy needs it and there are very few upside risks to inflation left, why did you not cut by 50 basis points, or are you going to do that next month?"

These examples illustrate two noteworthy points: First, the importance of using high-frequency data instead of daily data, as most of the action happens within tight windows of several minutes, and second, the fact that central bank "communication" can move asset prices without any specific actions taken.

B. Estimation

The intra-day interest rate data that we employ consist of real time quotes from Reuters TickHistory. The data are unsmoothed, but we filter for mispriced quotes and sample the data at the one minute interval. To construct our monetary policy shocks, we rely on overnight index swap rates with maturities ranging between one and twelve months, and swap rates with a two-year maturity. While the primary objective of the ECB is price stability over the medium term, and they state that "it is not advisable to specify ex-ante a precise horizon for the conduct of monetary policy, since the transmission mechanism spans a variable, uncertain period of time," a two-year cutoff can be justified by the ECB implicitly hinting to have a horizon of two to three years by publishing forecasts (including interest rates) with a projection horizon of up to two years (extended to three years as of December 2016).[13]

The target rate window is defined as a 45 minute window bracketing the 13:45 CET announcement, starting at 13:40 and ending at 14:25 CET. The communication window starts at 14:25 CET, and ends at 15:30 CET, 40 minutes after the press conference is over. We illustrate this in Figure 2. We refer to the entire window, which encompasses both the target rate and communication windows, as the monetary policy window.[14]

[Insert Figure 2 and Table I here]

Our procedure to back out target and communication shocks follows in two steps. First, we use principal components analysis on the 161 (number of announcements) $\times$ 13 (maturities) matrix of swap rate changes for each of the two windows. Second, we determine how many important factors are present in each window, and construct the shocks from them.

Table I summarizes the results for the target and communication window, as well as the monetary policy window. We note that for each of the three windows the first PC explains more than 86%, and the first two PCs explain more than 93% of the variation. Thus, we restrict our attention to the first two principal components. To assess the economic significance of these factors, we regress swap rate changes on the first and second PC of both windows; regression coefficients, corresponding t-statistics, and adjusted R^2s for six maturities are presented in

[13] See, e.g., http://www.ecb.europa.eu/pub/projections/html/index.en.html.

[14] When we shrink the target and communication windows, or introduce a gap of 10 minutes between the target rate and communication windows, all our results remain the same, both quantitatively and qualitatively.

Table II. Panel A contains our results for PCs constructed during the target rate window. For PC1, we find that the t-statistics are highly significant from the shortest maturity swap rate (one month) out to five years, as adjusted R^2s decrease from 39% to 4%.[15] The second row in Panel A reports regression results for PC2; notice the significant drop in the explanatory power as well as the lower t-statistics compared to PC1. For intermediate maturities, between six and 24 months, the second PC is insignificant, then becomes negative and significant going out to ten years. The final row of panel A reports the change in the R^2, denoted as ΔR^2, when including PC2 in the regression, compared to the one that uses only PC1. Since the PCs are orthogonal, this number represents the marginal explanatory power of PC2, and shows that the second factor has little impact on yield changes during the target window.

[Insert Table II here]

A very similar picture emerges for the communication window in Panel B. While the first PC is highly significant throughout all maturities, the second PC is marginally significant at the short end, and estimated coefficients are negative and highly significant at the long end. Different from Panel A, however, coefficients for the first PC display a hump-shaped pattern around the one- and two-year maturity, with a corresponding R^2 of 80%, which then declines slowly to 57% at the ten-year maturity. Similar as for the target window, we find the marginal increase in R^2 from the second PC to be small, especially at the short-end.

Taken together, we make two noteworthy observations. First, one principal component seems to explain a significant fraction of the variation of interest rate changes during ECB announcement days, whereas the second PC is economically mostly insignificant. Second, target rate and communication shocks have a differential effect along interest rate maturities. While shocks in the target rate window mainly have an impact on the short end of the curve, policy shocks from the communication window mainly affect interest rates at intermediate maturities.

Based on our analysis, in the following, we label PC1 backed out from the target rate window as our target rate shock, and denote by $Z_{r,t}$ and PC1 from the communication window as communication shock, denoted by $Z_{\theta,t}$. We present summary statistics of the target rate and communication shocks in Table III. We find that both target rate and communication shocks have zero mean, i.e., there is no surprise on average. At the same time, the volatility of

[15] We compute zero-coupon bond yields by bootstrapping high-frequency swap rates.

communication shocks is almost twice as large as target shocks. We also note that while target rate shocks feature a negative skewness, the skewness for communication shocks is positive. Moreover, both shocks exhibit significant excess kurtosis.

[Insert Table III here]

Figure 3 plots the time-series of the target rate and communication shocks. The first salient observation is that target rate shocks are basically almost zero most of the time except for some large outliers. Communication shocks, however, display more variation, especially starting in mid 2008 when shocks are mostly negative.

The figure also contains brief annotations that help to explain some of the larger observations in the figure. The first one coincides with the May 10, 2001, meeting when the ECB surprisingly cut the refinancing rate by 25bps; reasons for the surprise easing were the disappointing unemployment and industrial production numbers from Germany, published on May 8 and 9, 2001, indicating a significant slowdown of the German economy. Our target shock on this day is measured at -18.55bps, implying that the rate cut on this day was largely unanticipated. The second event corresponds to June 5, 2008, when President Trichet hinted at a rate hike at the following meeting; the communication shock is 18.08bps. The third event corresponds to March 3, 2011, when Trichet hinted at a tightening at the next meeting by saying at the press conference that "strong vigilance is warranted." On November 3, 2011, President Draghi surprised the market by a 25bps cut at his first meeting, identified as a -10.65bps target rate shock. Finally, on July 5, 2012, the ECB cut interest rates by 25bps to an all-time low; our target shock is -8.16bps.

[Insert Figure 3 here]

C. Additional data

To explore the effect of monetary policy shocks onto asset prices, we need a host of other data. *Bond yields:* We use daily bond yields of Germany, France, Italy, and Spain, with maturities ranging between three months and 10 years, available from Bloomberg.[16] Core (peripheral)

[16]We focus on these four countries as both bond and CDS data coverage for these countries is reliable.

bond yields are calculated as the average of German and French (Italian and Spanish) bond yields.[17]

Credit risk: To measure the credit and redenomination risk of each country, we use U.S. Dollar and Euro-denominated five-year credit default swaps (CDS) available from Markit.[18]

[Insert Table IV here]

We present a summary statistic of bond yields and CDS in Table IV. On average, German bond yields are the lowest for all maturities, and Italian yields are the highest. In terms of credit risk, not very surprisingly, five-year CDS also increase from core to peripheral countries. For example, German € CDS are on average 21bps, while Spanish and Italian € CDS are more than 1% on average. We also note that both the Italian and Spanish CDS reached as high as 5%, while the maximum value for Germany is not even 1%. Most Eurozone CDS trading is, however, not in euros but in U.S. dollars.[19] U.S. dollar denominated CDS display higher spreads than euro denominated CDS. The difference between U.S. dollar and euro denominated CDS is called a CDS quanto.[20]

III. Empirical analysis

In this section we study the effect of target rate and communication shocks on bond yield changes for different maturities for days on which the ECB makes their monetary policy announcements. Our two main empirical findings are as follows: First, while before the 2009 crisis monetary policy had a uniform effect on bond yields of core and peripheral countries, peripheral countries' bond yield reaction to monetary policy becomes muted and even insignificant after 2009. As a consequence, ECB monetary policy drove a wedge between peripheral and core countries' yields in this period. Moreover, this is mainly due to communication shocks. Second,

[17]When we use GDP weighted averages, all our results remain qualitatively the same.

[18]Markit provides CDS data with different restructuring clauses, which define the credit events that trigger settlement. Since the 'complete restructuring' clause is the most standard and liquid class, we take these data.

[19]Imagine an investor bought an Italian CDS denominated in euros. Upon Italy's default, the euro would immediately depreciate vis-à-vis the U.S. dollar. U.S. dollar denominated CDS are hence a better hedge than an equivalent euro denominated CDS.

[20]On the occurrence of a default, the buyer of a CDS quanto gets (100 − recovery rate) × $\frac{\$}{€}$ % change. That implies that the buyer gets compensated for any depreciation of the euro against the U.S. dollar and the recovery value.

we link the wedge between core and peripheral bond yields to an emergence of a denomination and credit risk premium.

Our baseline regressions start in February 2001 and end in December 2014. Regressions that exclude the Eurozone crisis end in February 2009. With each estimated coefficient, we report t-statistics adjusted for Newey and West (1987) standard errors.

A. *Zero coupon yields and forwards*

Before moving to sovereign bond yields, we explore the impact of monetary policy shocks on zero coupon bond yield and forward rate changes. What we are mostly interested in is whether monetary policy shocks which are estimated from short-term yields have an effect on longer maturity yields. Standard expectations hypothesis tells us that movements in short rates should only have a minor impact on longer maturity interest rates, unless shocks to short rates are extremely persistent.

To examine the effect of target and communication shocks on zero-coupon yields and forwards, we run multivariate regressions from yield and forward changes on our two proxies of policy shocks. The results for bond yield (forward) changes are illustrated on the upper (lower) panel of Figure 4, while Table V collects the zero-coupon yield regression coefficients. Shaded areas present 95% confidence intervals.

[Insert Figure 4 and Table V here]

Target rate shocks have a highly significant effect on swap rate changes, especially at the short end, and the effect dies out as the maturity prolongs. Estimated coefficients for communication shocks are also highly statistically different from zero for all maturities, and the effect is largest for the one- and two-year maturities, and decreases with maturity afterwards. Economically, we find that for any 100bps change in the target rate shock, there is 56bps change in the two-year yield, whereas communication shocks of the same size induce changes of 120bps to the one-year yield and 104bps to the two-year yield. For the ten-year rate, the effect of target shocks declines close to 14bps, however, the effect of communication shocks is still both statistically and economically large, with a yield response of 47bps for any 100bps shock.

To evaluate the importance of central bank communication on zero-coupon yields, the penultimate row of Table V reports the adjusted R^2s of our regressions when we include both monetary policy shocks, while the last row reports the increase in the R^2s compared to a univariate regression that only uses the target rate shock as right-hand-side variable. Our findings suggest that, except for very short maturities, communication shocks are an order of magnitude more important than target rate shocks to explain the variation in yields: the change in the R^2s ranges between 16% at the ten-year maturity and 67% at the one-year maturity.

Our results are comparable to the earlier literature that documents a strong impact of U.S. monetary policy shocks on long-term nominal and real yields. For example, Cochrane and Piazzesi (2002) find that a 100bps increase in the one-month Eurodollar rate around FOMC announcements is associated with a 52bps increase in the ten-year nominal Treasury yield. Similarly, Hanson and Stein (2015) find that a 100bps change in the two-year nominal yield measured on FOMC announcement days leads to a 42bps change in ten-year forward real interest rates. Hanson, Lucca, and Wright (2017) document strong effects for ten-year bond yield changes in the U.S., United Kingdom, Germany, and Canada in response to monetary policy shocks.

We further study whether monetary policy shocks have a longer lasting effect on bond yields beyond the one-day horizon. To this end, we present the same regression results for two- and three-day changes in the middle and lower panel of Table V. We note that the results are virtually unchanged for these slightly longer horizons.

Zero-coupon bond yields are the average of one-year forward rates over the maturity of a bond, while forward rates are the risk-neutral expectation of future short rates, so it is interesting to translate our results to the space of forward rates. The lower panel of Figure 4 shows that the reaction of forward rate changes to both types of monetary policy shocks are significant up until a maturity of seven years. For example, the one-year forward rate five years ahead moves by 50bps as a response to 100bps monetary policy shocks. To summarize, we find that changes in short-term interest rates have significant effects on long-term interest rates.

B. Sovereign bond yields

Next we turn our attention to how ECB monetary policy affects bond yields in the cross-section of Euro area countries, a particularly topical question after the onset of the Euro area debt crisis in 2009. To this end, we regress changes in bond yields of country i onto the target rate and communication shocks jointly:

$$\Delta y_{i,t}^{\tau} = \alpha_i^{\tau} + \beta_{i,r}^{\tau} Z_{r,t} + \beta_{i,\theta}^{\tau} Z_{\theta,t} + \epsilon_{i,t}^{\tau}, \tag{2}$$

where $\Delta y_{i,t}^{\tau}$ is the daily yield change of country i with maturity τ. We summarize the results for Germany, France, Italy, and Spain in Figure 5.

[Insert Figure 5 here]

There are two main findings. First, we note that the effect of target rate shocks is generally decreasing with maturity for both core and peripheral countries, however, the effect on peripheral countries is not statistically different from zero, especially for longer maturities. Second, the effect of communication shocks is most pronounced for intermediate maturities and orders of magnitude larger than target shocks: coefficients are small at the short-end of the term structure, increasing until the two-year maturity, and then decreasing again as maturity lengthens. Comparing the reaction of core versus peripheral countries, we find the former to be affected more by both target and communication shocks than the latter. For example, for any 100bps increase in the communication shock, there is an approximately 140bps increase in the two-year yields of Germany and France, whereas for Italy and Spain the effect is less than 100bps. Moreover, comparing statistical significance, we find that point estimates are more precisely estimated for the core countries than peripheral countries: Visually, the standard error bounds are much larger for Italy and Spain. These observations are interesting since heterogeneous responses to policy shocks have important implications for both asset pricing and ECB policy making. In the following we study the cross-country differences in depth.

C. Main result: The heterogeneous impact of communication

Against the backdrop of our previous result, we focus on two different aspects of ECB monetary policy next. First, we want to study whether monetary policy has affected sovereign bond yields differently in the cross section, and second, whether the effect has changed over time. In the following, for each maturity we define core (peripheral) yields to be the average yield of Germany and France (Italy and Spain). We first run regression (2) for the pre-crisis (January

2001 to February 2009, 91 observations) and post-crisis (March 2009 to December 2014, 70 observations) periods separately, and report the results in Figure 6.[21]

[Insert Figure 6 here]

The upper two panels plot the effect of target rate (left panel) and communication shocks (right panel) when the sample ends in February 2009. We first note that before the 2008-2009 global financial crisis, estimated coefficients for core and peripheral countries are virtually the same, indicating that monetary policy did not have a differential effect on these countries. Moreover, coefficients for target rate shocks are statistically different from zero for both types of countries, and the point estimates for communication shocks on peripheral yields are significantly larger than those documented for the full sample. For example, for any 100bps change in the communication shock, there is a 144bp change in two-year bond yields for both core and peripheral countries.

The lower two panels present results for the March 2009 to December 2014 period. We find that target rate shocks have a differential effect on core versus peripheral countries: Estimated coefficients for core countries are similar for most maturities and even slightly larger at the long end of the yield curve than before, while peripheral countries' coefficients are now negative and significant out to three years. The lower right panel depicts the effect of communication shocks during the crisis period. While for core countries we find virtually the same hump-shaped pattern as in the pre-2009 period, peripheral countries are affected much less. For example, for a 100bp communication shock post 2009 there is a 142bp change in the two-year yield for core countries, just as in the pre-crisis period, whereas the effect on a two-year peripheral yield is only around 40bps. Moreover, peripheral point estimates of communication shocks are only borderline significant for maturities exceeding five years.

In order to understand in more detail this result, we next turn to rolling regressions. The left panel of Figure 7 plots adjusted R^2s from rolling-window regressions of two-year bond yield changes of core and peripheral countries on target and communication shocks (bold lines) and for communication shocks only (dashed lines).[22] We notice two interesting features. First, before the crisis, monetary policy shocks accounted for around 40% of the variation of bond

[21] We start our crisis sample in March 2009, as this was the time when yields of core and peripherals started to significantly diverge. All of our results also hold when we start the sample in January 2009, for example.

[22] We use a rolling window of 50 months. Results look qualitatively the same with different window lengths.

yield changes of both core and peripheral countries. Mid 2008, the adjusted R^2 doubles to 80% which coincides with the beginning of ECB's dovish monetary policy and several cuts in the target rate.[23] While the high R^2 persists throughout the crisis for core countries, there is a complete breakdown in the effect of monetary policy on peripheral bond yields starting in 2010: The adjusted R^2 drops from 80% back to 40% in the first half of 2010 and then subsequently reaches zero in 2012. Second, we find that almost all of the variation is explained by the communication shocks themselves. The difference between the total R^2 and the R^2 from using communication shocks only is virtually almost zero.

We further explore these events in the right panel of Figure 7, where we plot rolling estimated coefficients on communication shocks for core and peripheral countries' two-year bond yield changes. Indeed, we find the effect on core countries' bond yields to remain very stable throughout the 2008 to 2015 period. Peripheral countries' bond yields, however, become virtually insensitive to communication shocks starting in 2011 as the estimated coefficient starts to drift downwards and becomes insignificant at the end of 2012.

[Insert Figure 7 here]

One particularly large drop happened on August 4, 2011. On that day, the Governing Council decided to keep interest rates unchanged, however, market participants expected an announcement about purchases of Italian and Spanish bonds which did not materialize.[24] On the same day, José Manuel Barroso, the President of the European Commission, warned of contagion from peripheral to core countries, and he called for Europe's leaders to re-assess the financial stability mechanisms designed to hold the Eurozone together.[25]

D. Communication and its effect on yield spreads

Since the onset of the crisis in 2008, the ECB has tried to easy distress in financial markets and to reduce sovereign spreads by (i) drastically lowering its target rate, (ii) providing un-

[23] We plot the EONIA rate for illustration purposes on the right axis of the left panel in Figure 7.

[24] This is best reflected in the Q&A session, when several questions are directly related to bond purchases of Italy and Spain.

[25] This weekend was particularly eventful for the Eurozone. On August 5, ECB President Trichet, together with Mario Draghi, wrote a secret letter to the Italian government in which they pushed for structural reforms "to be implemented as soon as possible," thereby implicitly tying the ECB's support to the implementation of these measures (the letter was leaked in September). On the same day, the Italian Prime Minister announced new measures to reduce the deficit and hasten economic reform. Finally, on August 7, a Sunday, the ECB announced that the Securities Markets Programme would also include Spain and Italy.

precedented amounts of liquidity support against a broader set of asset used as collateral, and since January 2015, by (iii) introducing quantitative easing in the form of the Asset Purchase Programme. Our results so far suggest that conventional monetary policy in the form of central bank communication is also a driver of the yield spread, as its impact is quantitatively larger on core countries than on peripheral countries.

[Insert Figure 8 here]

To evaluate the exact effect and economic significance of this channel, we calculate the size and direction of the spread implied by monetary policy shocks, and compare it to the time-series of the yield spread between core and peripheral countries. The top panel of Figure 8 plots the cumulative target and communication shocks for the entire period and for the period between March 2009 to December 2014. There are two noteworthy observations. First, target rate shocks are quantitatively much smaller than communication shocks. This is inline with our observations from Figure 3. Second, until 2009, communication shocks cumulatively had a positive effect, while target rate shocks were negative. The sign switches in the beginning of 2009, when target shocks become positive and communication shocks turn negative. The increase in the cumulative effect of target rate shocks implies that the target rate was set higher than what the market expected.[26] For the communication shock, however, we find the opposite: Communication about the future path of interest rates was lower than what was expected since 2009. Combining this insight with the estimated effect of target and communication shocks on the average peripheral-core yield spread, we can derive the cumulative effect of target and communication shocks during the crisis period.

The bottom panel of Figure 8 shows the cumulative impact of communication shocks on the two-year yield spread. We calculate this implied spread by multiplying realized shocks with the real-time policy loadings displayed in Figure 7, and add them up over time. Strikingly, we find that communication shocks had a positive effect on the yield spread; it increases between January 2011 (the beginning of president Draghi's tenure) and May 2013, peaking at 32bps,

[26] The U.S. Federal Reserve lowered its policy interest rate from 5.25% in September 2007 to 0-0.25% in December 2008 and at the same time also initiated quantitative easing. The ECB's first reaction was in July 2008, and it was to *raise* the main refinancing rate. After the Lehman bankruptcy in September 2008, the ECB joined an internationally coordinated rate reduction on 8 October. But then the ECB's slow pace of rate cuts was interrupted by two more hikes - in April and July 2011. The policy rate was brought to near-zero only in November 2013, five years after the U.S. Federal Reserve.

and then decreases but remains positive until the end of 2014. Economically, this effect is large: in May 2013, the two-year core-periphery yield spread was 147bps, and so at its peak the spread due to communication represented 22% of the total yield spread.[27]

[Insert Figure 9 here]

The "regime switch" in terms of central bank communication can also be illustrated in Figure 9, where we plot the number of mentions of core and peripheral countries (upper panel), as well as the number of mentions of "default" and "crisis" during the ECB press conference.[28] We notice that starting 2010 and in particular in the summer of 2011, peripheral countries are mentioned a multiple times more often than core countries. Moreover, we observe a large spike in default or crisis related mentions in the summer of 2011 as well.

E. *Possible risk premium channels*

One question that naturally arises is whether our findings are due to changes in expected short rates or to movements in risk premia. If changes in expected short rates were the only source, then core and peripheral countries' bond yields would move by the same amount in response to monetary policy shocks, since short rates for these Eurozone countries are identical. For this reason, Eurozone bond markets provide a unique opportunity to test whether and how monetary policy communication affects risk premia, since observing a cross-section of euro area yields one can difference out the expectation components. Hence, the above question becomes: what drives the difference in risk premia between peripheral and core countries?

Possible channels can be deduced from ECB President Mario Draghi's famous speech at an investor conference in London on July 26, 2012. He says: "Within our mandate, the ECB is

[27] At the May 2013 announcements, the main refinancing rate was lowered to 25bps, the first rate cut in 10 months. During the press conference, President Draghi mentioned that the ECB was "technically ready" to cope with negative interest rates (the deposit rate was at 0% at the time) indicating that banks could be charged for holding money overnight and thereby incentivising banks to lend out rather than keep the money at the central bank. Moreover, President Draghi also mentioned that "the ECB monitors very closely" all incoming evidence, a phrase which in the past suggested further policy action to come. In the press, this was widely interpreted as a harbinger for a quantitative easing program to start soon (see, e.g., http://www.reuters.com/article/us-ecb-rates/ecb-cuts-interest-rates-open-to-further-action-idUSBRE94100520130502.)

[28] We use a web-scraping algorithm to download transcripts of ECB press conferences and we use basic text analysis tools to count words. 'Peripheral' words include: *Italy, Spain, Greece, Portugal, Ireland* and *periphery.* 'Core' words include: *Belgium, France, Germany, Netherlands* and *core.* 'Crisis' words include: *crisis* and *default.*

ready to do whatever it takes to preserve the euro." Moreover, more importantly in our context, he also specifically mentions the divergence of peripheral and core bond yields and ascribes the resulting risk premia to the following three drivers: "Then there's another dimension to this that has to do with the premia that are being charged on sovereign states borrowings. These premia have to do, as I said, with default, with liquidity, but they also have to do more and more with convertibility, with the risk of convertibility."[29]

We conclude that the ECB was worried about large risk premia which are due to i) credit, ii) liquidity, and iii) redenomination risk. To capture these effects, in the following, we explore the impact of monetary policy shocks on CDS quantos. CDS quantos are defined as the difference between spreads on CDS denominated in different currencies and therefore provide an ideal vehicle to study the risk premium associated to not only credit but also denomination (and potentially liquidity) risk.

In order to show that risk premia are unlikely to just reflect credit risk, we plot in Figure 10 (upper panel) the CDS spreads of core and peripheral countries. We notice the divergence of the two time-series in the beginning of 2009, whereas, recall, the divergence of the sensitivity of core and peripheral bond yields with respect to communication shocks happens in late 2010 (see Figure 7).

Interestingly, this coincides with the divergence of the core and peripheral CDS quantos, depicted in the lower panel of Figure 10. Before August 2010, there is no difference between CDS spreads denominated in USD and EUR and hence the quanto is zero. Spreads then start to increase and peak at around 100bps for peripherals and 75bps for core countries mid 2012.

To test more formally the link between CDS quantos and monetary policy, we run regressions from two-day changes in CDS quantos on the monetary policy shocks:[30]

$$\Delta \text{CDS quanto}_{i,t} = \alpha_i + \beta_{i,r} Z_{r,t} + \beta_{i,\theta} Z_{\theta,t} + \epsilon_{i,t},$$

where i refers to core and peripheral. The results are reported in Table VI. We notice that target rate shocks neither affect quantos on core nor peripheral countries. Similar, we find no significant effect from communication shocks on quantos of core countries. Communication

[29] For a full transcript of the speech see http://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html.

[30] In line with the literature, we use two-day changes in CDS (see, e.g., Krishnamurthy, Nagel, and Vissing-Jorgensen (2017)).

shocks, however, load significantly negatively on the peripheral quanto spreads. Since communication shocks tend to be positive in the post-crisis period, we find that communication shocks increased the credit and breakup risk premium of peripheral countries while it did not affect the risk premium on core countries.

[Insert Figure 10 and Table VI here]

F. The missing risk premium and QE disappointment

One possible channel through which the ECB can generate a wedge in risk premia between core and peripheral countries is by what we call "QE disappointment". A plethora of literature studies the effects of asset purchases for the U.S. and England whereas evidence for the euro area is more scarce. One reason is that the ECB asset purchase program was announced with much delay when compared to the rest of the world. For example, the Federal Reserve announced its first asset purchase program (QE1) in November 2008 with further announcements in August 2010 (QE2) and September 2012 (QE3). Similarly, it was announced in January 2009, that the Bank of England would setup an asset purchase fund, followed by an official QE announcement by the Bank of England in March 2009. The ECB, however, announced only in January 2015 its asset purchase program which consists of combined monthly purchases of €60 billion of investment-grade public and private securities (the intended purchases constitute more than 10% of euro area GDP).[31]

What we argue is that central bank communication signalled bad news to the market not necessarily by what they said but rather what they did *not* say, hence, QE disappointment. Two main reasons why the market was expecting QE were the high borrowing costs for peripheral countries but also the fact that euro area inflation has been falling constantly since late 2011

[31] In the past the ECB launched other much smaller purchase programmes: two small purchase programmes targeting covered bonds issued by euro area banks (the so-called CBPP1 of €60 billion in 2009, and CBPP2 of intended €40 billion when announced in 2011 while nominally amounting to around €16 billion purchases when ended in 2012); a programme of outright purchases of public sector securities from distressed euro area countries (so-called SMP) during the euro area sovereign debt crisis of 2010-2011, amounting to around €210 billion at its peak; a programme of outright purchases of sovereign bonds (so-called OMT) in summer 2012 which was however never triggered; a programme of outright purchases of covered bonds and ABS (so-called CBPP3 and ABSPP) in September 2014, which has been subsumed in the expanded programme announced in January 2015. These announcements are the subject of Krishnamurthy, Nagel, and Vissing-Jorgensen (2017). Notice, however, that it is not the size of the program per se which determines whether it constitutes QE or not but the modalities with which the program is executed as outlined by ECB President Mario Draghi himself in a press conference: See, e.g., http://www.ecb.europa.eu/press/pressconf/2014/html/is140904.en.html.

and has been below 1% since October 2013, substantially short of the 2% target of the ECB. We can illustrate the markets disappointment using two concrete examples. At the August 4, 2011 meeting mentioned earlier, the market was expecting an announcement about possible bond purchases for Italy and Spain. When there was no such announcement during the press conference, spreads on peripheral bonds immediately increased. Another example is the October 2, 2014 meeting when outright purchases of covered bonds were announced during the press conference without specifying the size of the program. Several questions during the Q&A session concerned the size and the Financial Times wrote the next day "Draghi's lack of detail on measures disappoints".[32]

QE disappointment or bad news could potentially give rise to a risk premium which is the omitted variable when studying the effect of central bank communication on sovereign bond yields. In the following, we therefore re-run our baseline regression (2), but now control for CDS quanto spreads:

$$\Delta y^{\tau}_{\mathrm{i},t} = \alpha^{\tau}_{i} + \beta^{\tau}_{\mathrm{i},r} Z_{r,t} + \beta^{\tau}_{\mathrm{i},\theta} Z_{\theta,t} + \beta^{\tau}_{\mathrm{i,quanto}} \Delta \text{CDS Quanto}_{i,t} + \epsilon^{\tau}_{\mathrm{i},t}, \tag{3}$$

where i refers to core or periphery, and ΔCDS Quanto$_{i,t}$ is the two-day change in the average core or peripheral five-year CDS quanto. In particular, we are interested if coefficients $\beta_{\mathrm{core},\theta}$ and $\beta_{\mathrm{periphery},\theta}$ are still different in the post-crisis period as in Figure 6, or more aligned once we condition on the risk premia. Table VII reports regression results. We find that the estimated coefficients for communication shocks, $\beta_{\mathrm{per},\theta}$ and $\beta_{\mathrm{core},\theta}$, are closer to each other when conditioning for CDS quantos. In fact, the estimated coefficients are now much more aligned. Interestingly, we find the estimated coefficients of the CDS quantos to be not significant for core countries (with an exception at the three-month maturity) whereas coefficients for the peripheral CDS quantos are all highly statistically significant. Moreover, the change in the R^2 from adding the CDS quantos is very significant for peripheral bond yields, especially at longer maturities, where the change in R^2 is up to 40%.

To test more formally whether the estimated coefficients on the communication shocks are the same (or whether their difference is statistically different from zero), we run regressions from

[32] A Bloomberg survey held after the press conference indicated that 67% of all responded were disappointed with the information provided.

changes in yield spreads, defined as the difference between peripheral and core countries' yields, on target and communication shocks, as well as the quantos. We plot the estimated coefficients together with the 90% confidence bounds in Figure 11. The bold line presents estimated coefficient when only controlling for the monetary policy shocks. In line with our findings from Figure 6 and our earlier discussion, we notice that communication shocks significantly increased the spread almost for all maturities. Once we control for the quanto spreads, however, estimated coefficients (dashed line) are not significantly different from zero, except at the two-year maturity and at the very long end.

We hence conclude that once we control for the "missing risk premium", the effect of central bank communication on yields of core and peripheral countries is not that different anymore.

[Insert Table VII here]

One last question remains: If the market was expecting QE, why did the ECB wait for so long? There are many possible reasons, ranging from legal legitimacy of QE, to the reluctance of the Deutsche Bundesbank president Jens Weidmann to implement a full blown QE, to large uncertainty about the health of the European banking system to be able to actually expand credit. The market only started to price in a possible QE starting in September 2014 and this can be linked to two particular events. The first was an (unscripted) off-the-cuff comment by ECB President Mario Draghi in his Jackson Hole speech in August 22, 2014 (echoing the "whatever it takes" speech of July 2012). More specifically, when talking about deteriorating inflation expectations signalling potential deflation, he mentioned that "The Governing Council will acknowledge these developments and within its mandate will use all the available instruments needed to ensure price stability over the medium term." The words "all available instruments" were subsequently interpreted as QE. Moreover, it was also announced on August 27, 2014, that the ECB had appointed BlackRock to advise the central bank on a bond purchasing program. The second QE harbinger was at the September 2014 meeting, when during the Q&A session a journalist asked whether QE was discussed. ECB president Mario Draghi's response was: "Yes, it was discussed. QE was discussed. Some of our Governing Council members were in favour of doing more than I have just presented, and some were in favour of doing less. [...] A broad asset purchase programme was discussed, and some Governors made clear that they would like to do more." Interestingly, euro area sovereign bond yields started to fall in September 2014.

IV. Model

We proposes a dynamic equilibrium term structure model, in the spirit of Vayanos and Vila (2009), Greenwood and Vayanos (2014), and Malkhozov, Mueller, Vedolin, and Venter (2016), to rationalize our baseline empirical results.

A. Bond market

Time is discrete, and is indexed by $t = ..., -1, 0, 1, ...$ Agents can buy zero-coupon bonds of two countries referred to as core and peripheral and indexed by $i = c, p$, or put their money into an instantaneously riskless money market account that pays net return r_t. At each date t and in each country i there exists a finite set of zero-coupon bonds. The yield-to-maturity of bond of country i paying one dollar at maturity $t+n$, $n = 1, ..., N$, is denoted by $y^n_{i,t}$, and the one-period return on this bond between t and $t+1$ by $R^n_{i,t+1} = ny^n_{i,t} - (n-1)\, y^{n-1}_{i,t+1}$. The short rate r_t paid on the money market account is assumed to be exogenously given and its dynamics under the physical probability measure follows

$$r_{t+1} = r_t + \kappa_r (\theta_t - r_t) + Z_{r,t+1} \tag{4}$$

where

$$\theta_{t+1} = \theta_t + \kappa_\theta \left(\bar{\theta} - \theta_t\right) + Z_{\theta,t+1} \tag{5}$$

and $Z_{r,t+1}$ and $Z_{\theta,t+1}$ are independent random variables with mean zero and variances σ^2_r and σ^2_θ, respectively. According to (4) and (5), r_t mean-reverts to θ_t, which is itself time-varying; κ_r and κ_θ denote the speed of mean reversion of the short rate and its mean, respectively, σ_r and σ_θ are the instantaneous volatilities, and $\bar{\theta}$ is the true long-run mean of θ_t and hence of r_t. We think about r_t as being the target rate set by the central bank, and interpret $Z_{r,t}$ as changes to the target rate unexpected by investors, and $Z_{\theta,t}$ as the unexpected component of changes to the future path of interest rates, i.e., communication shocks.

At date t, bonds of country i are supplied in value $S_{i,t} = \left(S^1_{i,t}, ..., S^N_{i,t}\right)^\top$. As our focus is on the effect of target and communication shocks on asset prices, for simplicity, we assume constant bond supply, i.e., $S_{i,t} = S_i$. Further, we assume away credit risk: sovereign bonds supplied by the countries are not subject to default, and the only difference between core and peripheral countries is captured by the investor pool. While it would be straightforward to introduce time-varying supply and/or credit risk into the model (see, e.g., Greenwood and Vayanos (2014) for the former), they would increase the technical complexity without any significant additional insight.

Bonds are held by competitive traders who can be of two types. Agents in the first class are referred to as buy-and-hold institutional investors, and they comprise pension funds, life insurance companies, and other unmodelled buy-and-hold market participants. We write their aggregate demand for bonds in country i as $U_{i,t} = \Gamma_i u_t$, where $\Gamma_i = \left(\Gamma_i^1, ..., \Gamma_i^N\right)^\top$ is an exogenously given $N \times 1$ vector and u_t is a one-dimensional demand factor that follows

$$u_{t+1} = u_t + \kappa_u \left(\bar{u} - u_t\right) + \eta_\theta Z_{\theta,t+1}, \tag{6}$$

with $\eta_\theta > 0$ constant. The key difference between the two countries is the sensitivity of the demand of buy-and-hold agents with respect to the monetary policy shocks. We think about peripheral bonds as particularly information-sensitive assets: Upon the arrival of any negative communication shock, understood as bad news about the economy and, in particular, as worse news for peripheral countries compared to core countries, the demand of institutional investors for peripheral bonds should decrease, and more so than the demand for core bonds. To this end, we assume both $\Gamma_p > 0$ and $\Gamma_p > \Gamma_c$. Because our results only depend on the difference in reaction between peripheral and core countries, for tractability, we normalize the institutional investors demand for core bonds to zero by assuming $\Gamma_c = 0$; this significantly simplifies our analysis without affecting the main mechanism.[33]

The second class of investors that we label banks can be based in either the core or the peripheral country; we assume there is a representative bank of each indexed by $a = c, p$. They

[33]In fact, if investors consider core-country bonds as safe havens, i.e., in the presence of flight-to-safety, we would also have $\Gamma_c < 0$. This would only amplify the risk premium difference between core and peripheral countries. Alternatively, we could specify the demand of buy-and-hold investors as an increasing function of θ_t. In that case our specified institutional demand would correspond to a downward-sloping demand curve, written as a linear function of yields instead of prices, and would also resemble 'reaching-for-yield' behaviour; see, e.g., Hanson and Stein (2015) for a modelling approach. Acharya and Steffen (2015) find evidence of reaching-for-yield behaviour by documenting that European banks were pursuing risky investments in high-yielding long-term sovereign debt, and financed them with low-yielding short-term wholesale funds. We could also introduce independent random shocks to u_t, but they would not change our main results.

live for one period and choose optimal bonds holdings to trade off the mean and variance of wealth change over the next period. Banks can trade all core and peripheral bonds, however, we assume they face quadratic transaction costs when buying or selling bonds of the other country: If bank a of period t is born with wealth $w_{a,t}$ and $x_{a,i,t} = \left(x^1_{a,i,t}, ..., x^N_{a,i,t}\right)^\top$ denotes her position in country-i bonds, the budget constraint is written as

$$w_{a,t+1} = w_{a,t}\left(1 + r_t\right) + \sum_{i=c,p} x^\top_{a,i,t}\left(R_{i,t+1} - r_t \mathbb{1}_N\right) - TC\left(x_{a,-a,t}\right), \tag{7}$$

where $-a = \{c, p\}\backslash\{a\}$ denotes the foreign country from the viewpoint of agent a. The first two terms on the right-hand side of (7) capture the portfolio return, and the third term represents the transaction costs that depend solely on the foreign investment. For tractability, we specify the latter in terms of the variance of the portfolio of foreign bonds:

$$TC\left(x_{a,-a,t}\right) = \frac{\phi}{2}\mathrm{Var}_t\left[x^\top_{a,i,t} R_{-a,t+1}\right]. \tag{8}$$

If bank a forms a riskless portfolio of country $-a$ bonds, e.g. by not holding any of those bonds, the transaction costs are zero, but otherwise they are strictly positive for both long and short positions.[34] This is a stylized way of capturing all kinds of constraints related to cross-country investment, and in the Online Appendix we show that assuming banks being subject to VaR or margin constraints, for example, would lead to similar first-order conditions and hence to equilibrium asset prices.[35]

The optimization problem of banks is given by

$$\max_{\{x_{a,i,t}\}_{i=c,p}} \mathrm{E}_t\left[w_{a,t+1}\right] - \frac{\alpha}{2}\mathrm{Var}_t\left[w_{a,t+1}\right], \tag{9}$$

where α is the coefficient of risk aversion. Finally, the market clearing condition is

$$x_{c,i,t} + x_{p,i,t} + U_{i,t} = S_{i,t} \tag{10}$$

[34]In the Appendix we solve the model allowing for heterogeneous transaction costs across countries, denoted by ϕ_a for bank a when investing in country $-a$ for both $a = c$ and p. As long as $\phi_c, \phi_p > 0$, all our results go through, but if at least one of them is zero, risk premia are the same across countries and bond yields react in a uniform way. Setting $\phi_c = \phi_p = \phi > 0$ hence only simplifies the algebra.

[35]In a recent paper, Gabaix and Maggiori (2015) study the effect of financial constraints of financial institutions who intermediate sovereign bonds in segmented markets.

for all i and t.

B. Equilibrium

Let us write bond return processes in the form of

$$R_{i,t+1} = \mu_{i,t} - \Omega_{i,t} Z_{t+1} \tag{11}$$

for $i = c, p$, where $\mu_{i,t} = \mathrm{E}_t\left[R_{i,t+1}\right]$ is the $N \times 1$ vector of one-period expected returns, $Z_{t+1} = \left(Z_{r,t+1}, Z_{\theta,t+1}\right)^\top$, and hence $\mathrm{Var}_t\left[R_{i,t+1}\right] = \Omega_{i,t}\Omega_{i,t}^\top$ is an $N \times N$ positive definite matrix. Combining (7), (8) and (11), the optimization problem of bank a is equivalent to

$$\begin{aligned}\max_{\{x_{a,i,t}\}_{i=c,p}} & \sum_{i=c,p} x_{a,i,t}^\top\left(\mu_{i,t} - r_t \mathbb{1}_N\right) - \frac{\alpha}{2}\left(x_{a,c,t}^\top \Omega_{c,t} + x_{a,p,t}^\top \Omega_{p,t}\right)\left(x_{a,c,t}^\top \Omega_{c,t} + x_{a,p,t}^\top \Omega_{p,t}\right)^\top \\ & - \frac{\phi}{2} x_{a,-a,t}^\top \Omega_{-a,t}\Omega_{-a,t}^\top x_{a,-a,t},\end{aligned} \tag{12}$$

which has the first-order conditions

$$\mu_{a,t} - r_t \mathbb{1}_N = \alpha \Omega_{a,t}\left(\Omega_{a,t}^\top x_{a,a,t} + \Omega_{-a,t}^\top x_{a,-a,t}\right) \text{ and} \tag{13}$$

$$\mu_{-a,t} - r_t \mathbb{1}_N = \alpha \Omega_{-a,t}\left(\Omega_{a,t}^\top x_{a,a,t} + \Omega_{-a,t}^\top x_{a,-a,t}\right) + \phi \Omega_{-a,t}\Omega_{-a,t}^\top x_{a,-a,t}, \tag{14}$$

where $\mathbb{1}_N$ denotes the $N \times 1$ vector with all elements being one. Equations (13) and (14) highlight the importance of transaction costs that impede capital flows between the two countries. Equation (13) states that local bonds' expected excess returns, $\mu_{a,t} - r_t \mathbb{1}_N$, must compensate banks for all the risk they bear when holding risky bonds of the two countries, but (14) shows that foreign bonds must also compensate banks for the transaction costs that makes investing abroad more expensive. In fact, as long as $\phi \neq 0$ and foreign investments $x_{a,-a,t}$ are non-zero in equilibrium, the market prices of risk in the two country might deviate from each other.

Let us introduce the notation $s_{i,t} = S_{i,t} - U_{i,t}$ for the effective net supply of bonds that in equilibrium must be held by banks. The market-clearing condition (10) then becomes

$$x_{c,i,t} + x_{p,i,t} = s_{i,t} \tag{15}$$

for all i and t. Combining (15) with (13) and (14), after some algebra we obtain the following results:

Lemma 1. *When $\phi \neq 0$, the equilibrium risk premia expressed as a function of the net supplies $s_{i,t}$ satisfy*

$$\mu_{p,t} - r_t \mathbb{1}_N = \alpha \Omega_{p,t} \left(\frac{2\alpha + \phi}{4\alpha + \phi} \Omega_{p,t}^\top s_{p,t} + \frac{2\alpha}{4\alpha + \phi} \Omega_{c,t}^\top s_{c,t} \right) \tag{16}$$

and

$$\mu_{c,t} - r_t \mathbb{1}_N = \alpha \Omega_{c,t} \left(\frac{2\alpha + \phi}{4\alpha + \phi} \Omega_{c,t}^\top s_{c,t} + \frac{2\alpha}{4\alpha + \phi} \Omega_{p,t}^\top s_{p,t} \right) \tag{17}$$

Moreover, bank positions solve

$$\Omega_{p,t}^\top x_{p,p,t} = \frac{3\alpha + \phi}{4\alpha + \phi} \Omega_{p,t}^\top s_{p,t} + \frac{\alpha}{4\alpha + \phi} \Omega_{c,t}^\top s_{c,t} \text{ and } \Omega_{c,t}^\top x_{p,c,t} = -\frac{\alpha}{4\alpha + \phi} \left(\Omega_{p,t}^\top s_{p,t} - \Omega_{c,t}^\top s_{c,t} \right) \tag{18}$$

for the peripheral bank, and

$$\Omega_{p,t}^\top x_{c,p,t} = \frac{\alpha}{4\alpha + \phi} \left(\Omega_{p,t}^\top s_{p,t} - \Omega_{c,t}^\top s_{c,t} \right) \text{ and } \Omega_c^\top x_{c,c,t} = \frac{\alpha}{4\alpha + \phi} \Omega_{p,t}^\top s_{p,t} + \frac{3\alpha + \phi}{4\alpha + \phi} \Omega_{c,t}^\top s_{c,t} \tag{19}$$

for the core bank.

Lemma 1 shows that in the presence of transaction costs banks exhibit home bias: it is more expensive for core agents to purchase peripheral bonds and vice versa, so core agents end up holding more of core bonds and peripheral agents are the main investors of peripheral bonds. This home bias, in turn, gets reflected in the risk premia too, because transaction costs prevent market prices of risk to equalize across countries. Holding everything else equal, if a lower demand $u_{p,t}^\tau$ of buy-and-hold investors leads to a higher effective supply of peripheral bonds, $s_{p,t}^\tau$, this raises the aggregate risk banks must bear, and thus pushes up the required premia on all assets. However, this increase is asymmetric: most of these bonds end up being held by peripheral banks, who in turn mainly hold peripheral bonds, and thus peripheral risk premia must rise more in equilibrium. Notice that in the limit $\phi \to \infty$ we get complete segmentation of markets: a positive shock to $s_{p,t}^\tau$ must be fully absorbed by peripheral banks, which in turn only increases peripheral bond risk premia.

Our results on banks' home bias in response to supply shocks is consistent with the large empirical literature that documents a home bias in sovereign bond holdings of Eurozone countries starting in 2009. In particular, banks in peripheral countries acquired only domestic government bonds while selling those from other Euro area sovereigns. During this period, peripheral countries' banks increased their sovereign bond holdings between January 2009 to end of 2014 from 5% of total bank assets to 13% (see Figure **??**). Theories aiming to explain the increase in home bias by peripheral countries include risk-shifting theories (see, e.g., Gennaioli, Martin, and Rossi (2014)) and financial repression theories (see, e.g., Becker and Ivashina (2014) and Chari, Dovis, and Kehoe (2016)), see e.g., Farhi and Tirole (2017) for a literature review. Our approach is consistent with these as the transaction costs paid on foreign investments makes banks act as if they were more risk-tolerant towards risks of the home country bonds (the effective risk aversion parameter is α versus $\alpha + \phi$ on foreign bonds).

Next we solve for equilibrium bond prices. We conjecture that bond yields are affine in the state variables:

$$y_{i,t}^{n} = \frac{A_i(n)}{n} + \frac{B_i(n)}{n} r_t + \frac{C_i(n)}{n}\theta_t + \frac{D_i(n)}{n} u_t. \tag{20}$$

From here, the definition of return $R_{i,t+1}^{n}$, together with (20) and (4)-(6), implies that returns are indeed in the form (11). Substituting them into (16) and (17), we obtain a set of difference equations. Imposing the initial conditions of $B_i(1) = 1$ and $A_i(1) = C_i(1) = D_i(1) = 0$, after some algebra, we obtain the following result:

Theorem 1. *In the term structure model described above, there exists an equilibrium in which yields are affine and given by (20), with the following functions:*

$$B_i(n) = \frac{1 - (1 - \kappa_r)^n}{\kappa_r}, \tag{21}$$

$$C_i(n) = \frac{\kappa_r}{\kappa_r - \kappa_\theta}\left[\frac{1 - (1 - \kappa_\theta)^n}{\kappa_\theta} - \frac{1 - (1 - \kappa_r)^n}{\kappa_r}\right], \tag{22}$$

and

$$\begin{aligned} D_i(n) = {} & \alpha k_B \frac{\frac{1-(1-\kappa_r)^n}{\kappa_r} - \frac{1-\left(1-k_{i,D}\right)^n}{k_{i,D}}}{\kappa_r - k_{i,D}} \\ & + \alpha k_{i,C} \frac{\kappa_r}{\kappa_r - \kappa_\theta}\left[\frac{\frac{1-(1-\kappa_\theta)^n}{\kappa_\theta} - \frac{1-\left(1-k_{i,D}\right)^n}{k_{i,D}}}{\kappa_\theta - k_{i,D}} - \frac{\frac{1-(1-\kappa_r)^n}{\kappa_r} - \frac{1-\left(1-k_{i,D}\right)^n}{k_{i,D}}}{\kappa_r - k_{i,D}}\right], \end{aligned} \tag{23}$$

where $k_B, k_{i,C} > 0$ and $0 < k_{i,D} < 1$ constants. The non-negative functions B and C are equivalent for core and peripheral countries, and the loadings on the institutional demand factor u_t satisfy $D_p(n) < D_c(n) < 0$ for all $n > 1$. The functional forms for $A_i(n)$, $i = c, p$, are given in the Appendix.

C. Model Predictions

Our model has a series of implications regarding the effect of target and communication shocks on bond yields, both across different maturities and across countries. We summarize them in three propositions that correspond to our baseline tests presented in the empirical analysis.

We consider the effect of target rate and communication shocks by running multivariate regressions of yield changes of country-i bonds with maturity n on both the target rate shock and the communication shock, that is,[36],[37]

$$\Delta y_{i,t}^n = \alpha_i^n + \beta_{i,r}^n Z_{r,t} + \beta_{i,\theta}^n Z_{\theta,t} + \varepsilon_{i,t}. \tag{24}$$

From (6) and (20), it is imminent that $\beta_{i,r}^n = \frac{B_i(n)}{n}$ and $\beta_{i,\theta}^n = \frac{C_i(n)}{n} + \frac{D_i(n)}{n}\eta_\theta$. Thus, we obtain the following results:

Proposition 1. *The impact of target rate shocks on bond yields is positive and decreasing across maturities in both univariate and multivariate regressions. Moreover, the impact is uniform across countries: $\beta_{c,r}^n = \beta_{p,r}^n$.*

Proposition 2. *The impact of communication shocks, $\beta_{i,\theta}^n$, $i = c, p$, is positive and hump-shaped across maturities in both univariate and multivariate regressions. Moreover, we have $\beta_{c,\theta}^n > \beta_{p,\theta}^n$ for all $n = 1, ..., N$. Thus, central bank communication has higher impact in core countries than in peripheral countries.*

Bond yields are the average expected returns earned through the lifetime of bonds, which in turn depend on current and expected future risk-free rates and risk premia. Therefore, when the central bank announces changes to either the current target rate or the intended future path of monetary policy, yield curves can be affected via two channels.

[36] Defining the target shock as r_t instead of the $Z_{r,t}$ shock would only change the level of the coefficients proportionally, because the volatility of r_t, σ_r, is constant.

[37] As the two types of shocks are uncorrelated in the model, univariate regressions of yield changes on either the target or the communication shocks would yield the same regression coefficients as the multivariate one.

A direct effect operates through the expectation channel, and it is uniform across all countries, because they share the same target rate process. A positive current target rate shock increases all future expected target rates, but due to mean reversion, its effect dies out over time. Thus, all yields go up, but current long yields are less sensitive to target rate shocks than short yields: $\beta_{i,r}^n$ is positive and decreases with maturity.

Similarly, the direct expectation channel is also present for monetary policy communication. A shock to θ_t provides information about intended future (medium-term) target rates: a positive communication shock implies that future target rates are to be higher than previously expected. On the other hand, it does not affect the current policy rate r_t, and long-term yields are expected to mean-revert to the long-term mean $\bar{\theta}$ eventually. Hence, a positive communication shock increases all medium-term yields while leaving short and long yields intact; captured by $C_i\left(n\right)/n$, the expectation channel implies a hump-shaped response across maturities.

The second, indirect effect, works through the risk premium channel: by influencing the demand of buy-and-hold institutional investors through the signalling (news) channel, monetary policy shocks can effectively manifest as shocks to the relative net supply of bonds that risk-averse banks have to hold in equilibrium. In our model, target rate shocks do not influence the relative demand for bonds, thus the risk premium channel is absent for them, leading to Proposition 1. However, a negative communication shock is interpreted as bad news, and pension funds become less willing to hold peripheral bonds. As these bonds are risky, banks, who have to hold more in equilibrium, demand a higher risk premium on all risky bonds. Vice versa, positive communication shocks are interpreted as good news for pension funds, who demand more bonds, and the equilibrium risk premium goes down. Overall, a positive communication shock raises rates via the expectation channel but lowers them via the risk premium channel: the direct and indirect effects go opposite directions, as captured by the negative sign of $D_i\left(n\right)$.

The heterogeneity of the risk premium effect across countries is driven by the friction that leads to partial segmentation of bond markets: transaction costs prevent banks to act as unconstrained arbirtageurs and equate market prices of risk across countries. Due to transaction costs banks exhibit home bias, so when on bad news buy-and-hold investors such as pension funds demand fewer peripheral bonds, peripheral banks must absorb most of this increase in the effective supply, and they require a higher risk premium to compensate them for the larger amount of risk. Thus, changes in the risk premium of peripheral bonds are more prominent than in the core country, as suggested by (16) and (17). Given that the expectation channel is identical for bonds of the two countries, and that the risk premium channel, only present for communication shocks, goes the opposite direction as the expectation channel, we obtain that core country bonds are more responsive to communication shocks than peripheral bonds. Hence, our model provides an understanding of how target and communication shocks can affect the term structure in equilibrium, both in the cross-section of maturities and across countries.

Finally, we study the effect of banks' home bias on the reaction of yield spreads to monetary policy shocks. Since our model is affine, we can only provide a comparative static exercise regarding the effect of transaction costs on the cross-country difference of bond holdings and regression coefficients.

Proposition 3. *We have* $\partial\left(\beta^n_{c,\theta} - \beta^n_{p,\theta}\right)/\partial\phi > 0$ *for all* $n = 1, ..., N$*. Thus, communication shocks have higher impact on bond yield spreads when investing abroad is costlier and market segmentation is larger.*

From Lemma 1 it is imminent that higher ϕ leads to higher home bias in banks' bond portfolios; e.g., in the limit $\phi \to \infty$ we get complete segmentation of markets as peripheral banks end up holding peripheral bonds only. For finite levels of ϕ, however, and keeping everything else equal, a positive shock to effective peripheral bond supply $s_{p,t}$ means peripheral banks increase their peripheral bond holdings while selling off core bonds for risk sharing purposes. In the meantime, core banks increase both core and peripheral bond holdings. Thus, as negative communication shocks translate into positive supply shocks of peripheral bonds, home bias becomes more prominent in peripheral banks' portfolios but not (or to a lesser extent) in core banks' portfolios. Thus, we can interpret higher ϕ as a proxy for higher home bias of peripheral banks.

At the same time, (21)-(22) show that higher ϕ leads to a higher difference in the D_p and D_c functions, and hence increases $\beta^n_{c,\theta} - \beta^n_{p,\theta}$. Therefore, our model not only provides an explanation of the differential effect of communication shocks across countries, but also highlights that this effect goes hand in hand with the home bias of bank sovereign portfolios, studied extensively by the recent macro and finance literature.

V. Conclusion

Central bank communication has taken centre stage in both popular and academic literature since the advent of the 2008 financial crisis. However, little is know about the effect of communication on asset prices, especially when compared to more traditional target rate shocks. We exploit high-frequency data on Eurozone money market rates to identify separately monetary policy actions from monetary policy communication and study its effect on the cross-section of sovereign bond yields in the Euro area.

We document the following findings. Target rate shocks affect short term interest rates more than long term interest rates, consistent with what has been documented in the U.S. However, there is an additional affect of central bank communication that has a strong effect at intermediate maturities bond yields and which is hump shaped in maturity. Dissecting the time series, our main result concerns the effect of monetary policy pre- and post European debt crisis. While monetary policy had a uniform effect on core and peripheral bond yields pre-crisis, we document significant differences post-2009. In particular, while communication shocks significantly lowered yields of core countries, peripheral countries' bond yields were immune against communication which led to a significant increase in the core-periphery wedge. This finding shows that communication shocks offset some of the effects of the ECB's monetary policy tools aiming at easing the funding squeeze of peripheral countries.

We empirically link the core-periphery wedge to an emergence of an euro area breakup and credit risk premium which offset the dovish monetary policy since 2009. We rationalize our empirical findings in a setting where central bank communication has an information effect. Surprise tightenings or loosening provide information to the market about the expected health of the economy and in particular, the peripheral countries. In the data, we find that once we control for the "missing risk premium", central bank communication affects core and peripheral bond yields in virtually the same way.

In our model, the trade between risk-averse local banks and global investors generates a price of risk for monetary policy shocks in equilibrium. When the central bank announces changes to the intended future path of monetary policy, it has a direct effect on the yield curve through a expectation channel, but also an indirect one, by influencing the demand of global investors, which in turn alters local banks' portfolios and the required risk premia of bonds.

We show that such an economy is capable of rationalizing our findings, and thus provides a potentially new transmission channel through which monetary policy operates.

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Appendix: Proofs

Proof of Lemma 1. We solve the model in the general case when ϕ varies across countries, so suppose that $\phi_c, \phi_p > 0$ but not necessarily identical. From (13) and (14), applied to $a = c$ and $a = p$, we obtain the four FOCs

$$\mu_{c,t} - r_t \mathbb{1}_N = \alpha\Omega_{c,t}\left(\Omega_{c,t}^\top x_{c,c,t} + \Omega_{p,t}^\top x_{c,p,t}\right), \tag{25}$$

$$\mu_{p,t} - r_t \mathbb{1}_N = \alpha\Omega_{p,t}\left(\Omega_{c,t}^\top x_{c,c,t} + \Omega_{p,t}^\top x_{c,p,t}\right) + \phi_c \Omega_{p,t}\Omega_{p,t}^\top x_{c,p,t}, \tag{26}$$

$$\mu_{p,t} - r_t \mathbb{1}_N = \alpha\Omega_{p,t}\left(\Omega_{p,t}^\top x_{p,p,t} + \Omega_{c,t}^\top x_{p,c,t}\right), \text{ and} \tag{27}$$

$$\mu_{c,t} - r_t \mathbb{1}_N = \alpha\Omega_{c,t}\left(\Omega_{p,t}^\top x_{p,p,t} + \Omega_{c,t}^\top x_{p,c,t}\right) + \phi_p \Omega_{c,t}\Omega_{c,t}^\top x_{p,c,t}. \tag{28}$$

From (25) and (26), after some algebra, we obtain

$$\Omega_{p,t}^\top x_{c,p,t} = \frac{1}{\phi_c}\left[\left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right) - \left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right)\right], \tag{29}$$

and similarly, from and of (27) and (28), we obtain

$$\Omega_{c,t}^\top x_{p,c,t} = \frac{1}{\phi_p}\left[\left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right) - \left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right)\right]. \tag{30}$$

Substituting these back into (25) and (27), respectively, we obtain

$$\Omega_{c,t}^\top x_{c,c,t} = \frac{1}{\phi_c}\left[\frac{\alpha + \phi_c}{\alpha}\left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right) - \left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right)\right] \tag{31}$$

and

$$\Omega_{p,t}^\top x_{p,p,t} = \frac{1}{\phi_p}\left[\frac{\alpha + \phi_p}{\alpha}\left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right) - \left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right)\right]. \tag{32}$$

Imposing the market-clearing conditions $x_{c,i,t} + x_{p,i,t} = s_{i,t}$, we get

$$\Omega_{c,t}^\top s_{c,t} = \left(\frac{1}{\phi_c} + \frac{1}{\phi_p} + \frac{1}{\alpha}\right)\left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right) - \left(\frac{1}{\phi_c} + \frac{1}{\phi_p}\right)\left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right)$$

and

$$\Omega_{p,t}^\top s_{p,t} = \left(\frac{1}{\phi_c} + \frac{1}{\phi_p} + \frac{1}{\alpha}\right)\left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right) - \left(\frac{1}{\phi_c} + \frac{1}{\phi_p}\right)\left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right).$$

From here

$$\left(\Omega_{c,t}^\top \Omega_{c,t}\right)^{-1}\Omega_{c,t}^\top\left(\mu_{c,t} - r_t \mathbb{1}_N\right) = \alpha\left[\xi\Omega_{c,t}^\top s_{c,t} + (1-\xi)\,\Omega_{p,t}^\top s_{p,t}\right] \text{ and} \tag{33}$$

$$\left(\Omega_{p,t}^\top \Omega_{p,t}\right)^{-1}\Omega_{p,t}^\top\left(\mu_{p,t} - r_t \mathbb{1}_N\right) = \alpha\left[\xi\Omega_{p,t}^\top s_{p,t} + (1-\xi)\,\Omega_{c,t}^\top s_{c,t}\right], \tag{34}$$

where

$$\xi = \frac{\frac{1}{\phi_c} + \frac{1}{\phi_p} + \frac{1}{\alpha}}{2\left(\frac{1}{\phi_c} + \frac{1}{\phi_p}\right) + \frac{1}{\alpha}} \geq \frac{1}{2}.$$

Substituting (33) and (34) into (29)-(32), we obtain the equilibrium holdings

$$\Omega_{p,t}^{\top} x_{p,p,t} = \Omega_{p,t}^{\top} s_{p,t} + \left[\frac{\alpha(1-2\xi)}{\phi_p} + (1-\xi)\right]\left(\Omega_{c,t}^{\top} s_{c,t} - \Omega_{p,t}^{\top} s_{p,t}\right), \; \Omega_{c,t}^{\top} x_{p,c,t} = \frac{\alpha(1-2\xi)}{\phi_p}\left(\Omega_{p,t}^{\top} s_{p,t} - \Omega_{c,t}^{\top} s_{c,t}\right),$$

$$\Omega_{p,t}^{\top} x_{c,p,t} = \frac{\alpha(1-2\xi)}{\phi_c}\left(\Omega_{c,t}^{\top} s_{c,t} - \Omega_{p,t}^{\top} s_{p,t}\right) \text{ and } \Omega_{c,t}^{\top} x_{c,c,t} = \Omega_{c,t}^{\top} s_{c,t} + \left[\frac{\alpha(1-2\xi)}{\phi_c} + (1-\xi)\right]\left(\Omega_{p,t}^{\top} s_{p,t} - \Omega_{c,t}^{\top} s_{c,t}\right),$$

that, in the special case of $\phi_c = \phi_p = \phi$, give (18) and (19). Finally, plugging those back into (25) and (27) we end up with

$$\mu_{c,t} - r_t \mathbb{1}_N = \alpha\Omega_{c,t}\left[\xi\Omega_{c,t}^{\top} s_{c,t} + (1-\xi)\,\Omega_{p,t}^{\top} s_{p,t}\right] \text{ and } \mu_{p,t} - r_t \mathbb{1}_N = \alpha\Omega_{p,t}\left[\xi\Omega_{p,t}^{\top} s_{p,t} + (1-\xi)\,\Omega_{c,t}^{\top} s_{c,t}\right]. \quad (35)$$

In the special case of $\phi_c = \phi_p = \phi$, these are equivalent to (16) and (17). We also obtain the following result:
Remark. Taking limits when, e.g., $\phi_p \to 0$, that is, the peripheral agent does not have to pay transaction costs on core bonds, we obtain

$$\mu_{p,t} - r_t \mathbb{1}_N = \frac{\alpha}{2}\Omega_{p,t}\left(\Omega_{p,t}^{\top} s_{p,t} + \Omega_{c,t}^{\top} s_{c,t}\right) \quad \text{and} \quad \mu_{c,t} - r_t \mathbb{1}_N = \frac{\alpha}{2}\Omega_{c,t}\left(\Omega_{p,t}^{\top} s_{p,t} + \Omega_{c,t}^{\top} s_{c,t}\right).$$

Therefore, if at least one of ϕ_c and ϕ_p is zero, there is no cross-sectional difference in bond Sharpe ratios, and bond yields are identical across countries. □

Proofs of Theorem 1 and Propositions 1-3. The definition of $R_{i,t+1}^n$, together with (4)-(6) and the conjectured (20) implies that returns are indeed in the form (11) with

$$\mu_{i,t} = \Psi_{i,0} + \Psi_{i,r} r_t + \Psi_{i,\theta}\theta_t + \Psi_{i,u} u_t \quad \text{and} \quad \Omega_{i,t} = \begin{pmatrix} B_i(0) & C_i(0) + D_i(0)\,\eta_\theta \\ \vdots & \vdots \\ B_i(N-1) & C_i(N-1) + D_i(N-1)\,\eta_\theta \end{pmatrix}, \quad (36)$$

where $\Psi_{i,0} = \left(\Psi_{i,0}^1, ..., \Psi_{i,0}^N\right)^{\top}$, $\Psi_{i,r} = \left(\Psi_{i,r}^1, ..., \Psi_{i,r}^N\right)^{\top}$, $\Psi_{i,\theta} = \left(\Psi_{i,\theta}^1, ..., \Psi_{i,\theta}^N\right)^{\top}$, and $\Psi_{i,u} = \left(\Psi_{i,u}^1, ..., \Psi_{i,u}^N\right)^{\top}$ are $N \times 1$ vectors with

$$\begin{aligned}
\Psi_{i,0}^n &= A_i(n) - A_i(n-1) - \kappa_\theta C_i(n-1)\,\bar{\theta} - \kappa_u D_i(n-1)\,\bar{u}, \\
\Psi_{i,r}^n &= B_i(n) - (1-\kappa_r)\,B_i(n-1), \\
\Psi_{i,\theta}^n &= C_i(n) - (1-\kappa_\theta)\,C_i(n-1) - \kappa_r B_i(n-1), \text{ and} \\
\Psi_{i,u}^n &= D_i(n) - (1-\kappa_u)\,D_i(n-1).
\end{aligned}$$

Combining these with (16) and (17), using $s_{i,t} = S_i - U_{i,t}$ and $U_{i,t} = \Gamma_i u_t$, and collecting constant, r_t, θ_t, and

u_t terms, we obtain the difference equations

$$\Psi_{i,0} = \alpha\Omega_{i,t}\left[\xi\Omega_{i,t}^{\top}S_i + (1-\xi)\,\Omega_{-i,t}^{\top}S_{-i}\right], \tag{37}$$

$$\Psi_{i,r} = \mathbb{1}_N, \quad \Psi_{i,\theta} = 0, \text{ and} \tag{38}$$

$$\Psi_{i,u} = -\alpha\Omega_{i,t}\left[\xi\Omega_{i,t}^{\top}\Gamma_i + (1-\xi)\,\Omega_{-i,t}^{\top}\Gamma_{-i}\right]. \tag{39}$$

Equations (38), together with $B_i(0) = C_i(0) = C(1) = 0$ and $B_i(1) = 1$, imply (21) and (22). Further, (39) is identical to

$$D_i(n) - (1-k_D)\,D_i(n-1) + \alpha k_{i,B}B_i(n-1) + \alpha k_{i,C}C_i(n-1) = 0$$

for all $n = 1, ..., N$, where $k_{i,D} = \kappa_u + \alpha\eta_\theta k_{i,C}$,

$$k_{i,B} = \xi\sum_{k=1}^{N} B_i(k-1)\,\Gamma_i^k + (1-\xi)\sum_{k=1}^{N} B_{-i}(k-1)\,\Gamma_{-i}^k, \text{ and}$$
$$k_{i,C} = \xi\sum_{k=1}^{N}\left[C_i(k-1) + D_i(k-1)\,\eta_\theta\right]\Gamma_i^k + (1-\xi)\sum_{k=1}^{N}\left[C_{-i}(k-1) + D_{-i}(k-1)\,\eta_\theta\right]\Gamma_{-i}^k.$$

In particular, in the special case considered in the main text, with $\Gamma_c^k = 0$ and $\Gamma_p^k > 0$, we have

$$k_{p,B} = \xi\sum_{k=1}^{N} B_p(k-1)\,\Gamma_p^k > \frac{1-\xi}{\xi}k_{p,B} = k_{c,B}, \text{ and}$$
$$k_{p,C} = \xi\sum_{k=1}^{N}\left[C_p(k-1) + D_p(k-1)\,\eta_\theta\right]\Gamma_p^k > \frac{1-\xi}{\xi}k_{p,C} = k_{c,C}.$$

As $B_c(.) = B_p(.) = B(.)$, $k_{i,B}$ can be rewritten as

$$k_{i,B} = \sum_{k=1}^{N}\left[\xi\Gamma_i^k + (1-\xi)\,\Gamma_{-i}^k\right]B(k-1),$$

so $k_{i,B}$ always exists and is positive. Moreover, $\xi > 1/2$ and $\Gamma_i^p > \Gamma_i^c$ implies $k_{p,B} > k_{c,B} > 0$. From here, we obtain (23).

Before we continue with our results, we present two Lemmas that will help us complete the Proofs of Propositions 1-3.

Lemma 2. *For any $0 < \kappa < 1$ and $n \geq 1$, the function*

$$F(\kappa, n) \equiv \frac{1-(1-\kappa)^n}{\kappa n}$$

is between zero and one, has limits $F(\kappa, 1) = 1$ and $\lim_{n\to\infty} F(\kappa, n) = 0$, and decreasing in both κ and n.

Proof. We rewrite F as

$$F(\kappa, n) = \frac{1}{n}\left[1 + (1-\kappa) + ... + (1-\kappa)^{n-1}\right].$$

Inside the bracket each expression is between zero and one, therefore their average must be between zero and one, too. Further, it is easy to see that when κ increases, every single term inside the bracket decreases, and so is F. Moreover, $(1-\kappa)^s$ decreases in s, so increasing n means the average of the terms inside the bracket must go down. □

Lemma 3. *For any* $0 < \kappa_1, \kappa_2 < 1$ *and* $n \geq 1$*, the function*

$$G(\kappa_1, \kappa_2, n) \equiv \frac{F(\kappa_1, n) - F(\kappa_2, n)}{\kappa_1 - \kappa_2} = \frac{\frac{1-(1-\kappa)^{\kappa_1}}{\kappa_1 n} - \frac{1-(1-\kappa)^{\kappa_2}}{\kappa_2 n}}{\kappa_1 - \kappa_2}$$

is negative, and increasing in κ_1 *and* κ_2*. Further,* $G(\kappa_1, \kappa_2, 1) = \lim_{n\to\infty} G(\kappa_1, \kappa_2, n) = 0$*, and U-shaped in between.*

Proof. As $F(\kappa, n)$ is decreasing in κ, we have that $F(\kappa_1, n) > F(\kappa_2, n)$ if and only if $\kappa_1 < \kappa_2$. Therefore, $G(\kappa_1, \kappa_2, n) < 0$ always. For the second half, we write

$$G(\kappa_1, \kappa_2, n) = \frac{F(\kappa_1, n) - F(\kappa_2, n)}{\kappa_1 - \kappa_2} = \frac{1}{(\kappa_1 - \kappa_2)\, n}\left[\sum_{s=0}^{n-1}(1-\kappa_1)^s - \sum_{s=0}^{n-1}(1-\kappa_2)^s\right] \tag{40}$$

$$= -\frac{1}{n}\sum_{s=0}^{n-1}\frac{(1-\kappa_1)^s - (1-\kappa_2)^s}{(1-\kappa_1) - (1-\kappa_2)} = -\frac{1}{n}\sum_{s=0}^{n-2}\sum_{t=0}^{s}(1-\kappa_1)^t (1-\kappa_2)^{s-t},$$

where in the last step we used

$$(1-\kappa_1)^s - (1-\kappa_2)^s = [(1-\kappa_1) - (1-\kappa_2)]\left[(1-\kappa_1)^{s-1} + (1-\kappa_1)^{s-2}(1-\kappa_2) + ... + (1-\kappa_1)(1-\kappa_2)^{s-2} + (1-\kappa_2)^{s-1}\right].$$

Therefore, if κ_2 increases, $(1-\kappa_2)$ decreases, and every single term in the double sum decreases. That means $G(\kappa_1, \kappa_2, n)$, which is negative, increases in κ_2. From symmetry, it also increases in κ_1. Regarding its shape across maturities, from (40) we can write G in the recursive form

$$G(\kappa_1, \kappa_2, n) = \frac{n-1}{n} G(\kappa_1, \kappa_2, n-1) - \frac{1}{n}\sum_{t=0}^{n-2}(1-\kappa_1)^t (1-\kappa_2)^{(n-2)-t}.$$

Therefore, the shape across maturities depends on the shape of the last term when n increases. But it is easy to see that

$$\frac{n-1}{n}\left(1 - \max\{\kappa_1, \kappa_2\}\right)^{n-2} < \frac{1}{n}\sum_{t=0}^{n-2}(1-\kappa_1)^t (1-\kappa_2)^{(n-2)-t} < \frac{n-1}{n}\left(1 - \min\{\kappa_1, \kappa_2\}\right)^{n-2},$$

where both the LHS and the RHS are hump shaped in n, due to $\frac{n-1}{n}$ being monotone increasing while the exponential term is decreasing. Taking the average of a hump-shaped function across maturities then also leads to a hump-shaped function. Since G is negative, the sign then flips: G is U-shaped. □

Proofs of Propositions 1-3. As we have $\beta_{i,r}^{n} = \frac{B_i(n)}{n} = F(\kappa_r, n)$, all parts of Proposition 1 follow simply from Lemma 2 applied to $\kappa = \kappa_r$.

Next, we write

$$\frac{C_i(n)}{n} = -\kappa_r \frac{F(\kappa_r, n) - F(\kappa_\theta, n)}{\kappa_r - \kappa_\theta} = -\kappa_r G(\kappa_r, \kappa_\theta, n).$$

From Lemma 3, it follows that $C_i(n)/n$ is positive for all n, it takes a zero value when $n = 1$ or $n \to \infty$, and hump-shaped in between.

We also rewrite $D_i(n)/n$ as

$$\frac{D_i(n)}{n} = \alpha k_{i,B} G(\kappa_r, k_D, n) + \alpha k_{i,C} \kappa_r \frac{G(\kappa_\theta, k_D, n) - G(\kappa_r, k_D, n)}{\kappa_r - \kappa_\theta},$$

From Lemma 3, it follows that $G(\kappa_r, k_D, n)$ is negative, moreover, $G(\kappa_\theta, k_D, n) > G(\kappa_r, k_D, n)$ if and only if $\kappa_\theta > \kappa_r$. Hence, due to $k_{i,B}, k_{i,C} > 0$, we obtain that D is always negative. Due to the limits of G when $n = 1$ and $n \to \infty$, $D_i(n)/n$ takes the value of zero at both extremes.

Finally, for $0 < \beta_{p,\theta}^{n} < \beta_{c,\theta}^{n}$ we need to show that $D_i(n)/n$ increases in k_D. But this again follows directly from Lemma 3. This concludes our proofs.

□

Figures

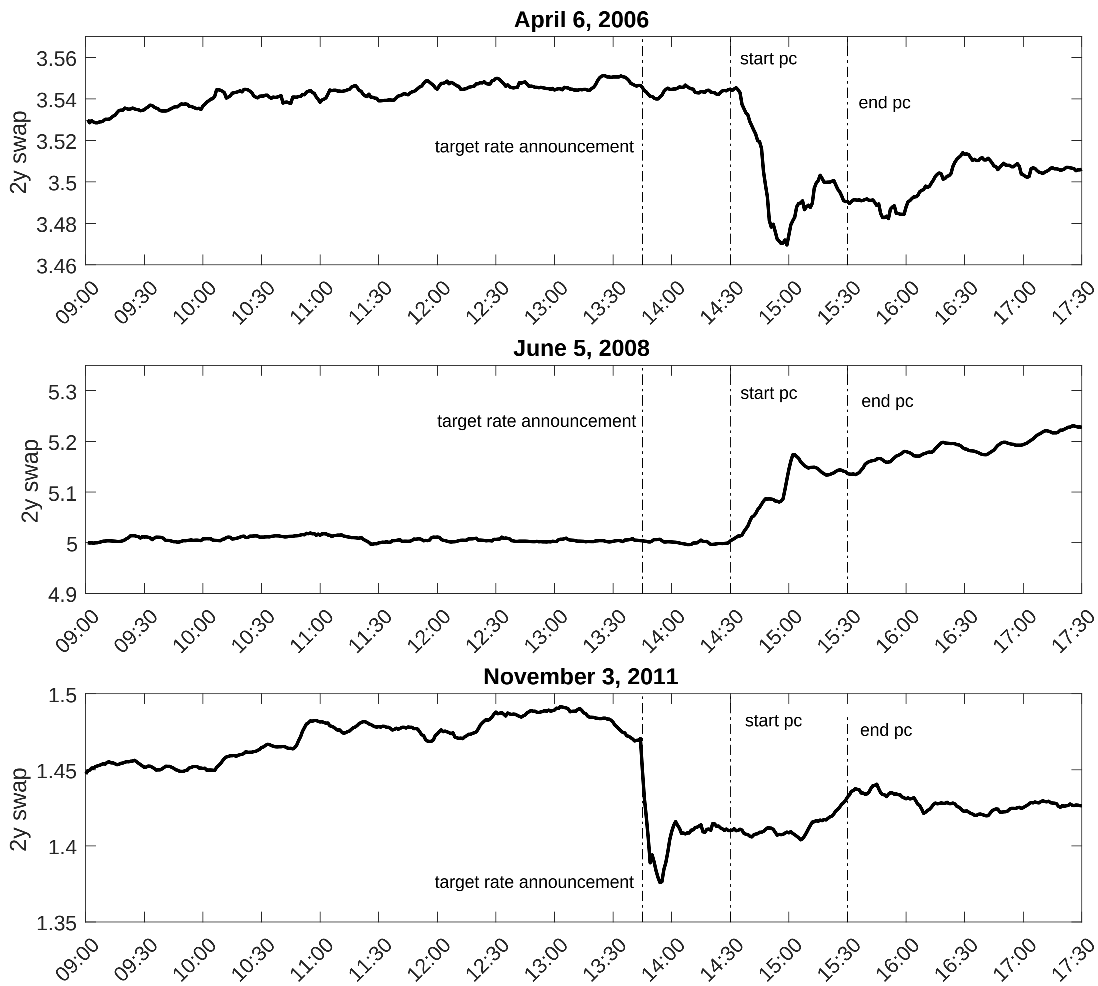


Figure 1. The two-year swap rate on three ECB announcement days
The figure plots the two-year swap rate on April 6, 2006 (upper panel), June 5, 2008 (middle panel) and November 3, 2011 between 09:00 and 17:30. Vertical lines represent the target rate announcement (13:45), the start of the press conference (14:30), and the end of the press conference (15:30). All times are in CET.

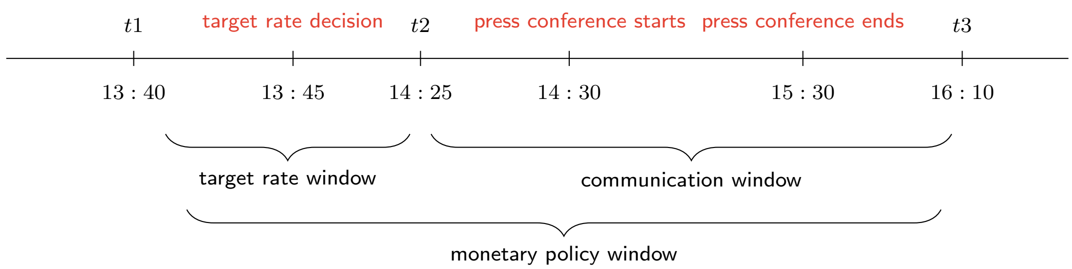


Figure 2. Monetary policy decision window

The figure illustrates the time line of ECB announcements. All times are in Central European Times (CET).

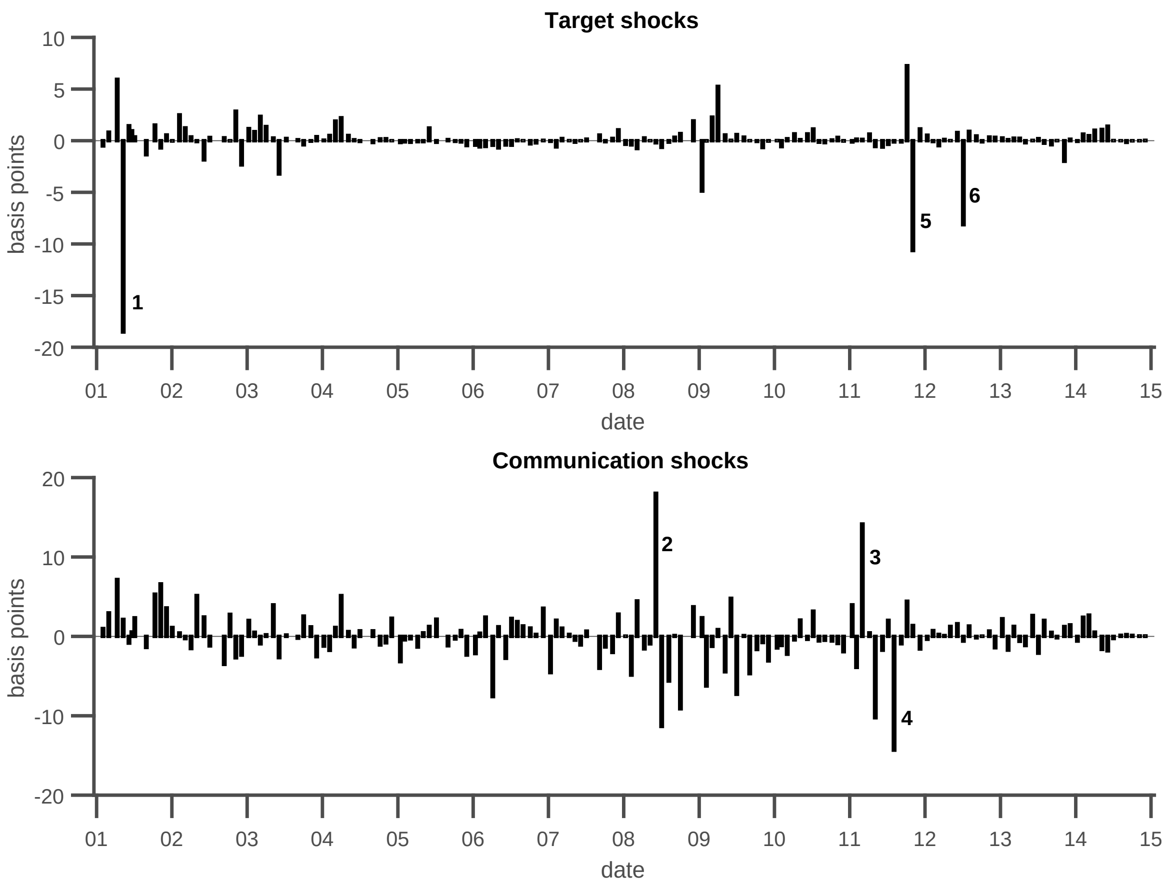
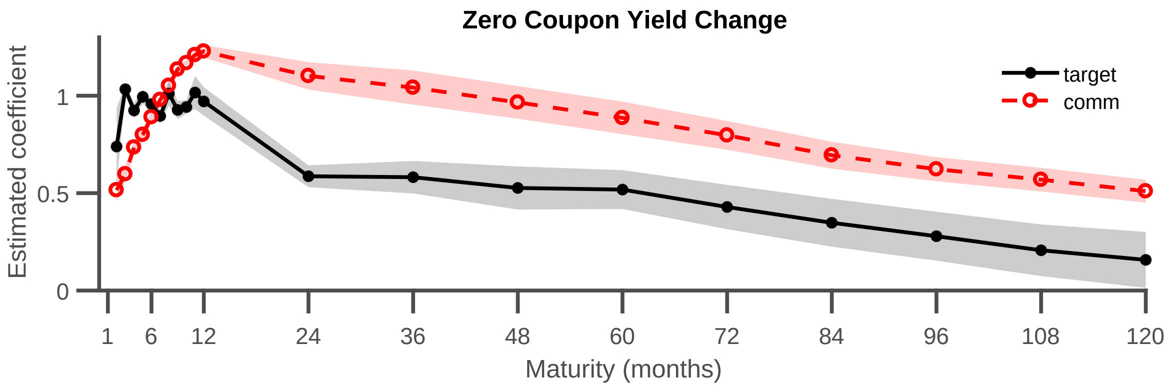


Figure 3. Time series of target and communication shocks

This figure plots target (upper panel) and communication (lower panel) shocks between 2001 and 2014. 1) May 10, 2001: surprise 25bps cut after dismal industrial production and unemployment numbers from Germany. 2) June 5, 2008: President Trichet announces rate hike for next meeting. 3) March 3, 2011: President Trichet announces interest rate hike at next meeting. 4) August 4, 2011: Rates were kept constant but market expected announcement of bond purchases for Italy and Spain. 5) November 3, 2011: Surprise 25bps cut at President Draghi's first meeting. 6) July 5, 2012: 25bps cut to an all-time low to 0.75%.



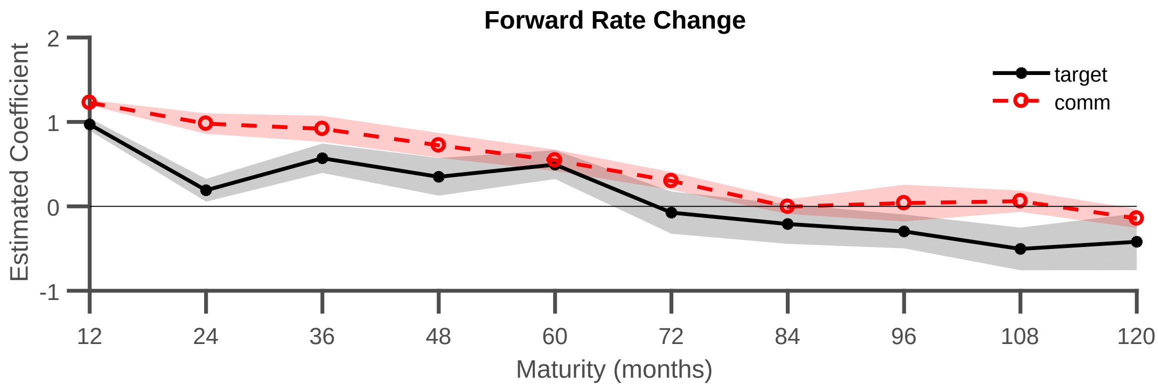


Figure 4. Yield and forward rate loadings on target and communication shocks
This figure plots estimated coefficients from a multivariate regression from changes in bond yields and one-year forwards on target and communication shocks:

$$\begin{aligned} \Delta y_t^\tau &= \beta_r Z_{r,t} + \beta_\theta Z_{\theta,t} + \epsilon_t^\tau, \\ \Delta f_t^\tau &= \beta_r Z_{r,t} + \beta_\theta Z_{\theta,t} + \epsilon_t^\tau, \end{aligned}$$

where Δy_t^τ (Δf_t^τ) are zero coupon yield (forward) changes between 13:40 CET and 16:10 CET with maturities $\tau = 1, \dots, 120$ months. Confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to December 2014.

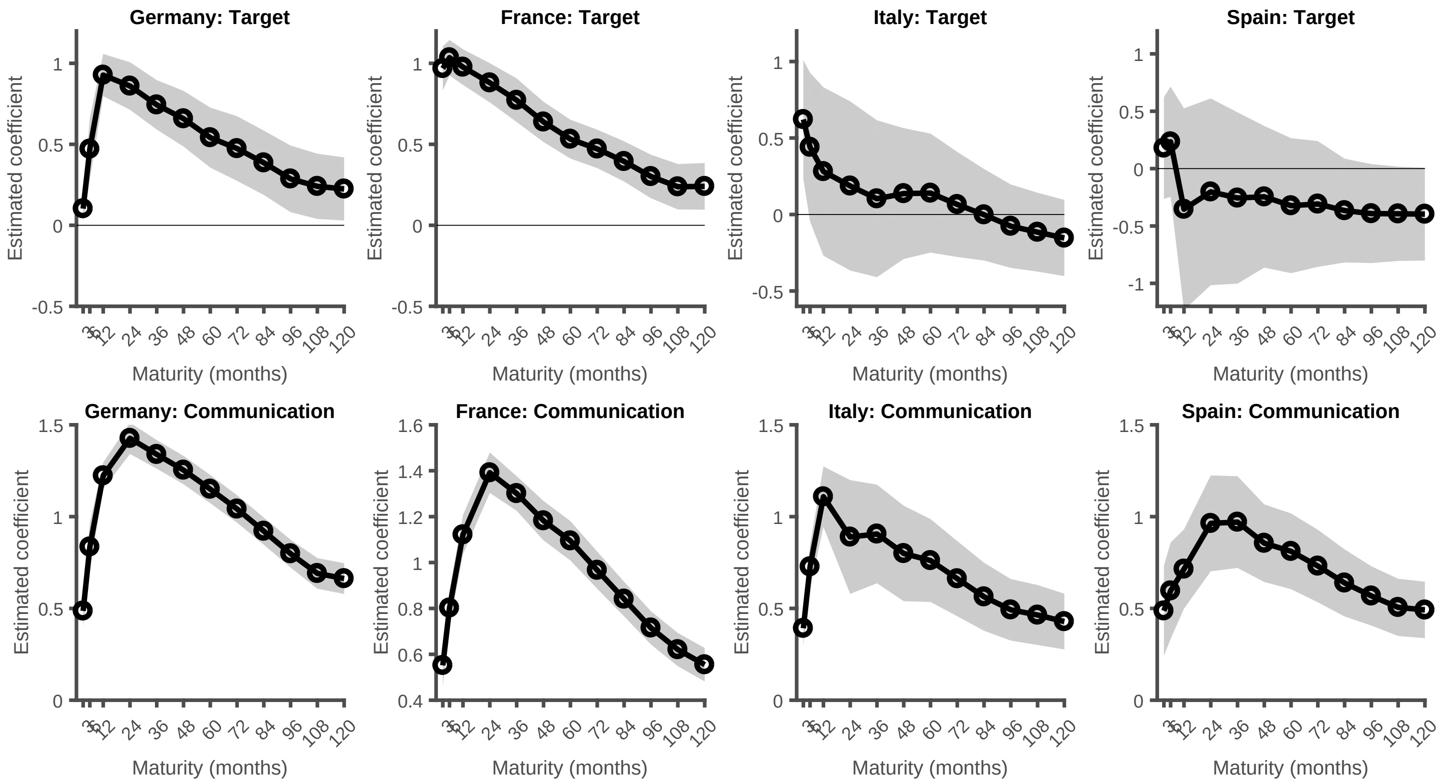


Figure 5. Core and peripheral yield response to target and communication shocks

This figure plots the response of core (= Germany and France) and peripheral (= Italy and Spain) countries' bond yields at different maturities for a target rate (upper panels) and communication (lower panels) shock on ECB announcement days. Confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to December 2014.

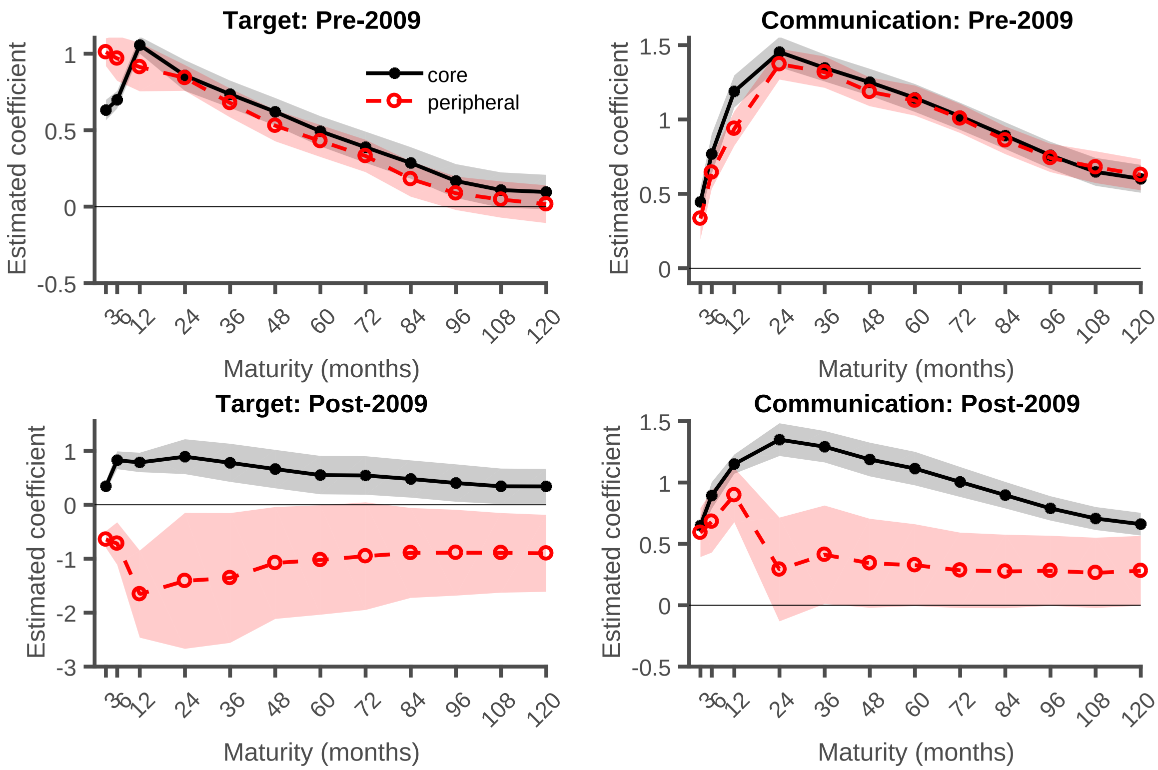


Figure 6. Core and peripheral yield response before and after the onset of the crisis
This figure plots the response of core (solid line) and peripheral (dashed line) countries' bond yields at different maturities for a target rate (left) and communication (right) shock on ECB announcement days:

$$\Delta y^{\tau}_{i,t} = \beta^{\tau}_{i,r} Z_{r,t} + \beta^{\tau}_{i,c} Z_{\theta,t} + \epsilon^{\tau}_{i,c,t},$$

where $\tau = 3m, \ldots, 10y$. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to February 2009 for the upper two panels and from March 2009 to December 2014 for the lower two panels.

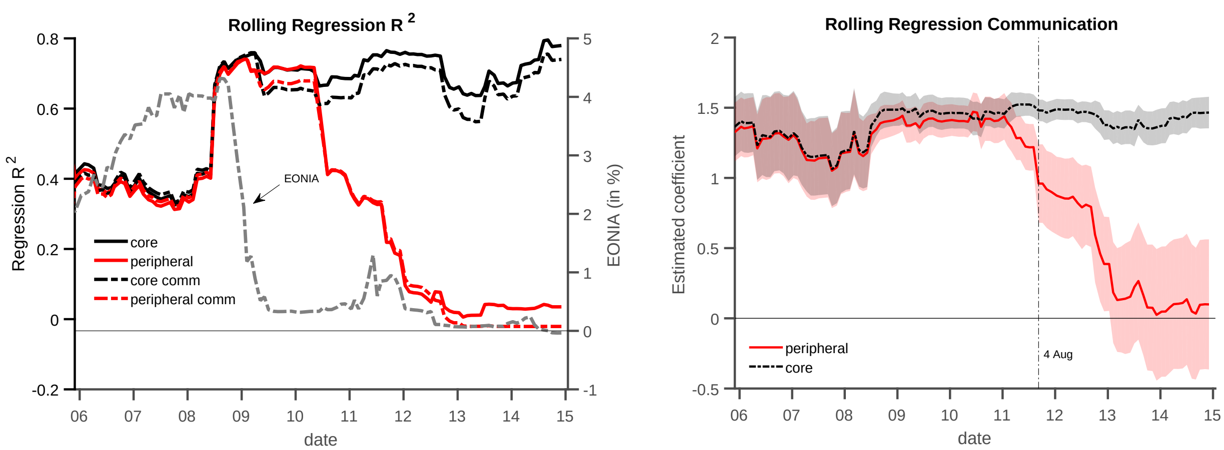


Figure 7. Rolling R^2 and regression coefficients

The left panel plots the rolling adjusted R^2 from regressing core and peripheral two-year bond yields on the target and communication shock (bold lines). The dashed lines present the adjusted R^2 when controlling only for communication shocks. The right axis depicts the EONIA rate (in percent). The right panel plots regression coefficients from rolling regressions of core and peripheral bond yields on the communication shock. The window size for the rolling window is set to 50 months.

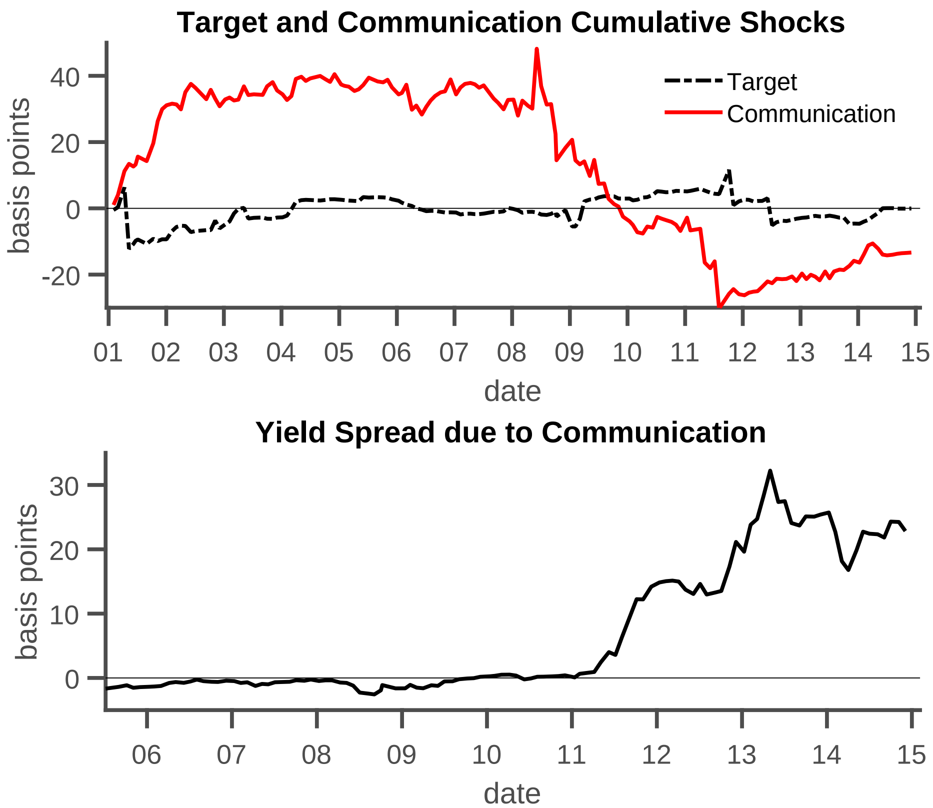


Figure 8. Cumulative monetary policy shocks and the effect on the yield spread

The upper figure plots cumulative target (dashed line) and communication (bold line) shocks from January 2001 to December 2014. The lower panel plots the difference between the product of the cumulative communication shock and the rolling regression coefficient for peripheral bond yield changes on communication shocks in Figure 7 and the product of the cumulative communication shock and the rolling regression coefficient for core bond yield changes on communication shocks in Figure 7.

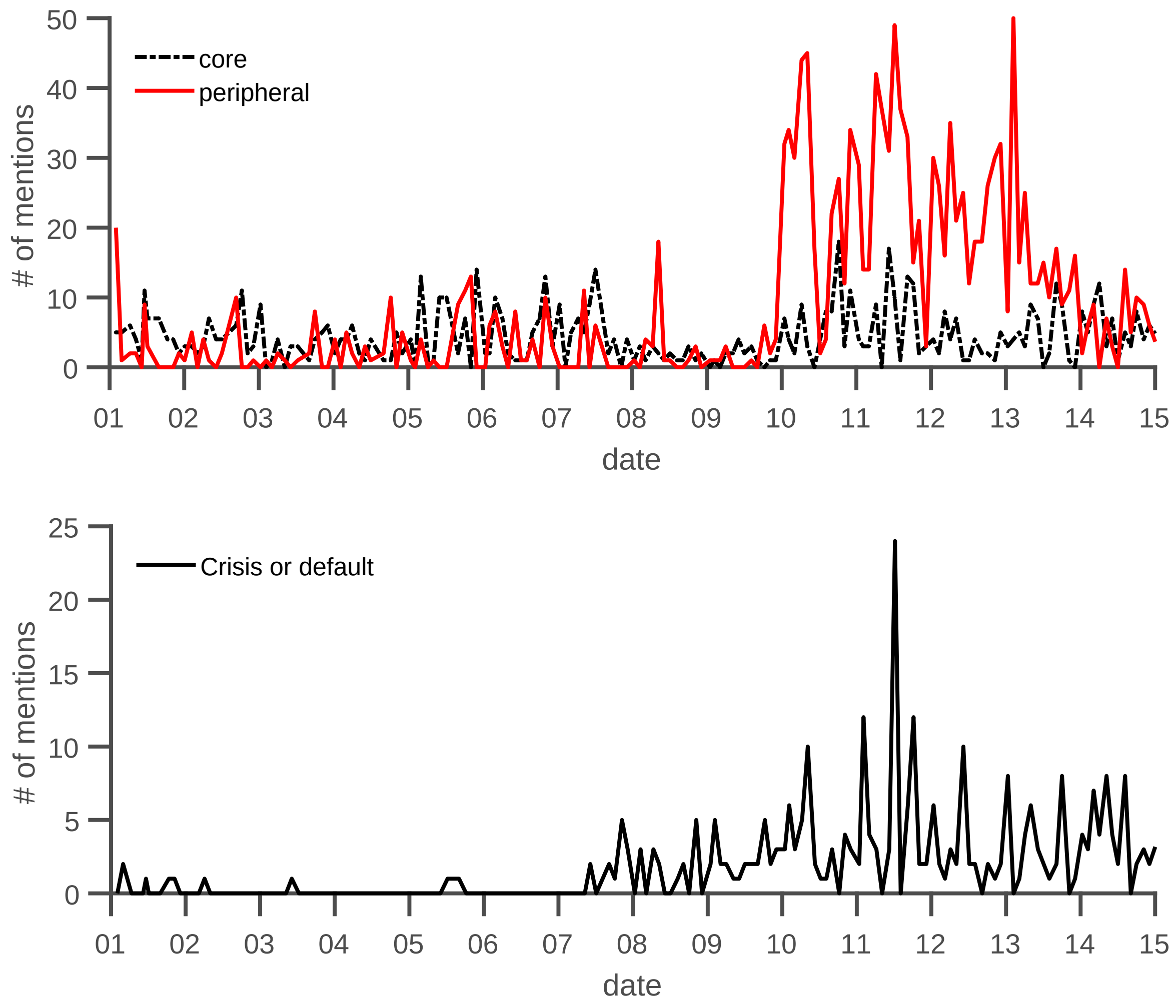


Figure 9. Textual Analysis

The upper panel plots the number of mentions of core versus peripheral countries during ECB press statements. The lower panel plots the number of mentions of “crisis” or “default”. ’Peripheral’ words include: *Italy, Spain, Greece, Portugal, Ireland* and *periphery*. ’Core’ words include: *Belgium, France, Germany, Netherlands* and *core*. ’Crisis’ words include: *crisis* and *default*.

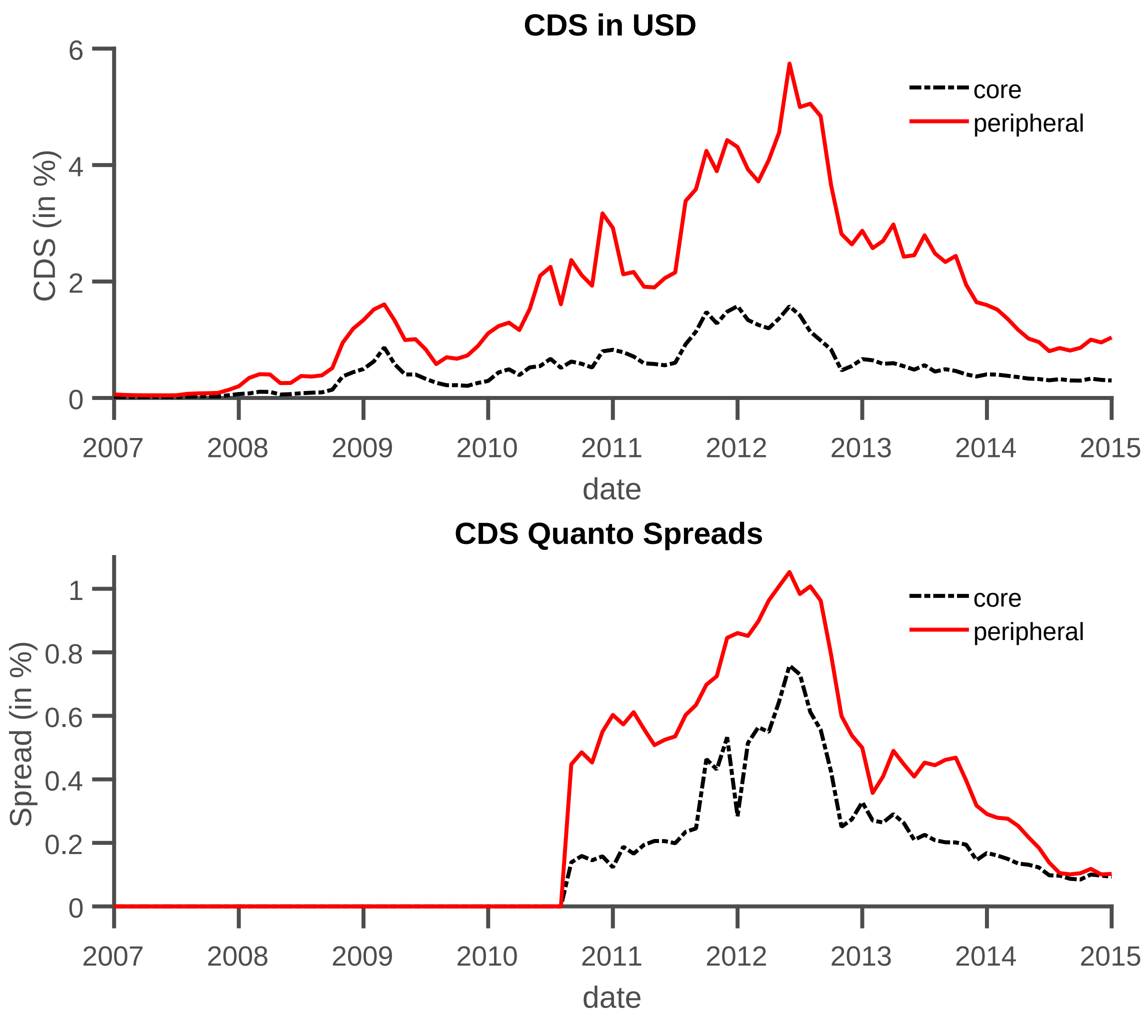


Figure 10. CDS in USD and CDS Quanto Spreads

The upper panel plots credit default swaps in USD for core and peripheral countries in percent. The lower panel plots CDS quanto spreads of core and peripheral countries in percent. Quanto spreads are defined as the difference in CDS contracts denominated in USD and EUR. Data is monthly.

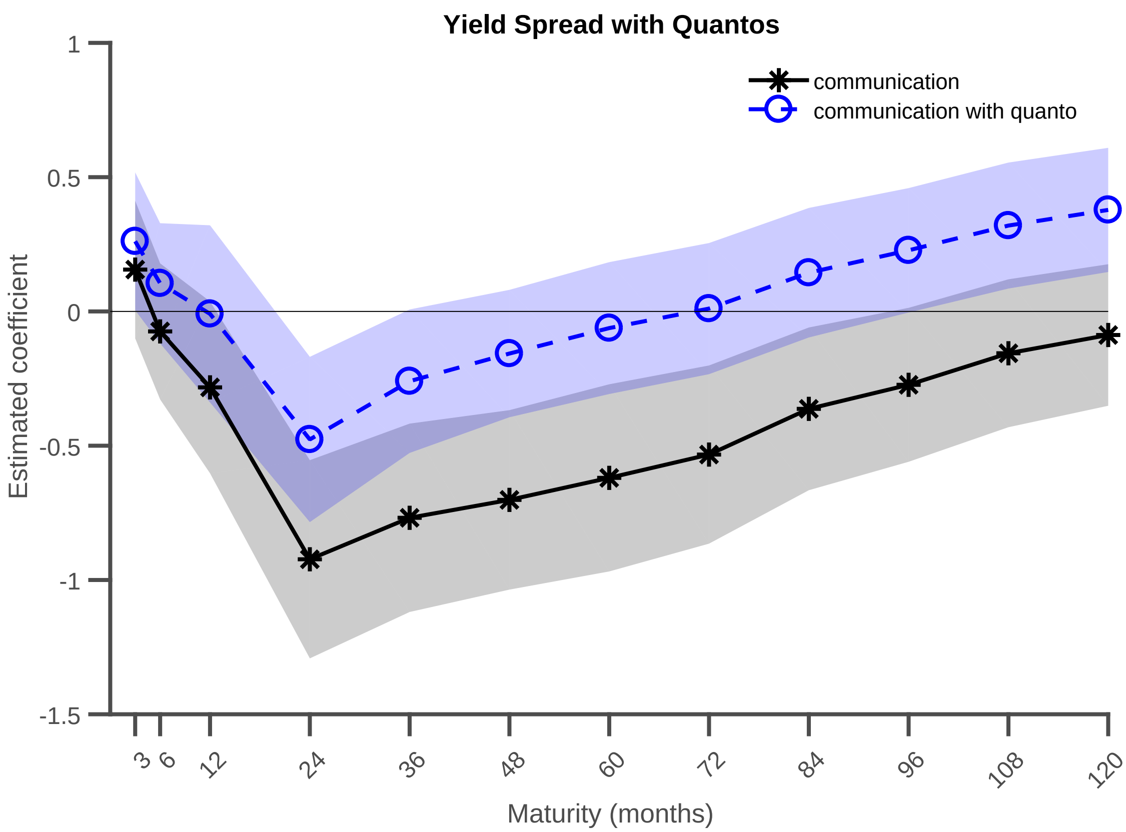


Figure 11. Yield spread response to communication shocks

This figure plots the estimated coefficients (circles and dashed line) on communication shocks, $\widehat{\beta_c^\tau}$, when regressing yield spreads defined as the difference between peripheral and core yields at different maturities on target and communication shocks, and CDS quantos on ECB announcement days:

$$\Delta y^\tau_{per,t} - y^\tau_{core,t} = \beta^\tau_r Z_{r,t} + \beta^\tau_c Z_{\theta,t} + \beta^\tau_{\text{quanto}} \Delta \text{quanto}_t + \epsilon^\tau_{i,c,t},$$

where $\tau = 3m, \ldots, 10y$. The bold line with star markers presents the estimated coefficient when only controlling for the monetary policy shocks. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from March 2009 to December 2014.

Tables

	PC1	PC2	PC3
Monetary Policy	87.68	6.56	2.48
Target	86.36	5.66	1.71
Communication	89.14	4.15	2.90

Table I. Principal components in different windows
An eigenvalue decomposition of a positive definite covariance matrix is $cov(dy_t^N) = Q\Lambda Q^\top$. The columns of Q contain eigenvectors and the diagonal elements of Λ contain eigenvalues. Principle components are formed by $PC_t = Qdy_t^N$. The fraction of explained variance of the k'th PC is given by $\Lambda(k,k)/\sum_k \Lambda(k,k)$. Target (Communication) captures change in yields between 13:40 and 14:25 CET (14:25 and 16:10 CET), while the monetary policy window measures yield changes between 13:40 and 16:10 CET.

	3	6	12	24	60	120
			Target Window			
PC1	0.77	1.05	1.09	1.05	0.59	0.24
t-stat	(4.26)	(18.75)	(16.30)	(15.91)	(3.90)	(1.55)
PC2	0.18	0.09	−0.06	−0.05	−0.17	−0.11
t-stat	(3.09)	(1.46)	(−0.78)	(−0.66)	(−2.23)	(−1.70)
R^2	38.92	36.79	22.87	20.84	9.65	3.91
ΔR^2	4.96	0.49	−0.27	−0.33	1.45	1.16
			Communication Window			
PC1	0.53	0.82	1.23	1.25	0.98	0.57
t-stat	(10.48)	(19.55)	(44.86)	(41.15)	(24.82)	(9.09)
PC2	0.15	0.02	−0.23	−0.29	−0.59	−0.42
t-stat	(1.95)	(0.23)	(−2.03)	(−2.86)	(−7.06)	(−7.20)
R^2	44.37	58.24	78.36	81.20	75.84	56.67
ΔR^2	2.33	−0.22	2.04	3.17	17.05	16.89

Table II. Swap rate loadings on PCs

This table reports estimated coefficients from univariate regressions from changes in swap rates during the monetary policy window (i.e., between 13:40 and 16:10 CET) onto the first (PC1) and second (PC2) principal components constructed from swap changes in the target or communication window around ECB monetary policy announcements:

$$\Delta y_t^\tau = \beta_1 \times \text{PC1}_t + \beta_1 \times \text{PC2}_t + \epsilon_t^\tau,$$

where PC1_t and PC2_t are either the first and second PC from the target (upper panel) or communication (lower panel) window, respectively, and τ is the maturity. ΔR^2 indicates the change in the adjusted R^2 when adding the second PC. t-statistics are calculated using Newey and West (1987) allowing for serial correlation.

	Z_r	Z_θ
Mean	-0.00	-0.00
Std Dev	2.18	3.51
Min	-18.53	-14.33
Max	7.26	18.02
Skew	-4.49	0.34
Kurtosis	39.13	10.12
AR(1)	-0.29	-0.16

Table III. Summary statistics of target and communication shocks

This table presents summary statistics for the target and communication shocks. Target (Z_r) (communication (Z_θ)) shocks are calculated from a principal component analysis applied to swap rate changes with maturities ranging between one-month and two years sampled between 13:40 and 14:25 CET (14:25 and 16:10 CET) on days that the ECB announces its monetary policy. Data is sampled between 2001 and 2014.

	CDS ($)	CDS (€)	3	6	12	24	60	120
				France				
mean	0.57	0.41	1.92	1.93	2.01	2.22	2.89	3.67
stdev	0.55	0.36	1.52	1.50	1.48	1.42	1.23	0.96
min	2.47	1.98	4.74	4.68	4.66	4.83	4.91	5.43
max	0.02	0.02	−0.06	−0.07	−0.05	−0.05	0.18	0.85
				Germany				
mean	0.30	0.21	1.86	1.89	1.98	2.12	2.68	3.37
stdev	0.27	0.18	1.54	1.53	1.53	1.48	1.39	1.17
min	1.15	0.91	4.91	4.83	4.73	4.70	4.99	5.35
max	0.01	0.01	−0.13	−0.62	−0.09	−0.10	0.02	0.57
				Italy				
mean	1.52	1.30	2.19	2.32	2.53	2.89	3.70	4.54
stdev	1.41	1.16	1.35	1.34	1.25	1.14	0.95	0.76
min	5.90	5.01	6.53	7.90	8.16	7.84	7.76	7.34
max	0.05	0.05	0.13	0.14	0.21	0.34	1.03	2.04
				Spain				
mean	1.53	1.26	2.10	2.24	2.45	2.86	3.67	4.47
stdev	1.48	1.14	1.34	1.28	1.22	1.09	0.97	0.89
min	6.33	5.04	5.77	6.02	6.07	6.85	7.69	7.69
max	0.02	0.02	0.01	0.04	0.11	0.19	0.77	1.67

Table IV. Summary statistics of CDS and bond yields

This table presents summary statistics for five-year CDS denominated in US Dollars (first column), Euros (second column) and bond yields for maturities ranging between three to 120 months (columns 2 to 7). Data is in percent. CDS are sampled between October 2005 and 2014. Bond yields are sampled between 2001 and 2014.

	3	6	12	24	60	120
			One-day change			
Z_r	1.07	1.01	1.01	0.71	0.46	0.13
t-stat	(17.33)	(15.77)	(8.67)	(5.70)	(3.16)	(0.72)
Z_θ	0.62	0.96	1.43	1.40	1.19	0.65
t-stat	(8.25)	(13.37)	(20.22)	(15.82)	(10.34)	(4.68)
R^2	71.81	80.65	80.92	62.70	42.81	15.91
ΔR^2	31.00	54.70	66.28	56.20	40.23	16.11
			Two-day change			
Z_r	1.11	1.06	1.10	0.87	0.42	0.07
t-stat	(12.50)	(10.61)	(6.71)	(3.70)	(1.68)	(0.23)
Z_θ	0.66	1.07	1.58	1.77	1.23	0.58
t-stat	(7.31)	(10.81)	(12.43)	(9.23)	(5.52)	(2.44)
R^2	62.46	65.40	60.56	45.07	22.43	5.09
ΔR^2	28.74	46.13	49.98	40.79	21.65	5.63
			Three-day change			
Z_r	1.10	1.05	1.09	0.88	0.42	0.08
t-stat	(12.36)	(10.35)	(6.70)	(3.69)	(1.69)	(0.25)
Z_θ	0.65	1.06	1.58	1.77	1.23	0.58
t-stat	(7.24)	(10.52)	(12.42)	(9.22)	(5.53)	(2.44)
R^2	61.43	63.33	60.43	45.13	22.36	5.16
ΔR^2	28.31	44.67	49.90	40.78	21.58	5.69

Table V. Swap rate response to target and communication shocks
This table reports the results of multivariate regressions of zero-coupon one-, two- and three-day changes in swap rates across different maturities on target ($Z_{r,t}$) and communication ($Z_{\theta,t}$) shocks on days when the ECB announces their monetary policy. t-statistics are calculated using Newey and West (1987). ΔR^2 indicates the change in the adjusted R^2 when we add communication shocks, Z_θ, to the regression. Data runs between 2001 and 2014.

	core	peripheral
Z_r	-0.107	-0.224
t-stat	(-0.74)	(-1.60)
Z_θ	-0.047	-0.112
t-stat	(-1.55)	(-2.00)
R^2	-0.96%	7.23%

Table VI. CDS Quantos

This table reports estimated coefficients from regressing changes of core and peripheral countries CDS quanto spreads onto monetary policy shocks. Quantos are defined as the difference in average CDS spreads on core and peripheral countries denoted in USD and EUR. t-statistics are calculated using Newey and West (1987). The sample runs from September 2010 to December 2014.

	3	6	12	24	60	120
			Core			
Z_r	0.51	1.03	0.91	1.19	1.30	1.10
t-stat	(5.16)	(6.81)	(3.41)	(2.03)	(2.20)	(2.46)
Z_θ	0.61	0.97	1.32	1.66	1.15	0.54
t-stat	(5.28)	(6.83)	(9.18)	(10.55)	(6.84)	(4.09)
quanto	0.61	−1.13	0.25	0.25	0.14	0.27
t-stat	(3.20)	(−1.40)	(0.92)	(0.90)	(0.30)	(0.48)
R^2	45.48	37.30	58.63	47.97	24.12	8.28
ΔR^2	6.00	4.51	−0.28	−0.60	−1.08	−1.14
			Peripheral			
Z_r	−1.11	−2.07	−2.35	−2.58	−1.68	−1.12
t-stat	(−8.95)	(−5.37)	(−3.10)	(−2.03)	(−2.20)	(−2.41)
Z_θ	0.88	1.12	1.32	1.17	1.06	0.87
t-stat	(3.46)	(3.13)	(3.85)	(3.90)	(5.14)	(3.37)
quanto	1.36	1.72	2.88	4.42	5.34	4.29
t-stat	(3.45)	(3.13)	(3.79)	(5.28)	(7.91)	(5.42)
R^2	41.48	42.98	27.18	31.84	48.95	40.50
ΔR^2	15.30	11.88	12.71	20.57	40.12	35.35

Table VII. Bond yield response with quanto

This table reports estimated coefficients from regressing daily bond yield changes of core and peripheral countries onto monetary policy shocks and changes in five-year CDS quantos for core and peripheral countries. t-statistics are calculated using Newey and West (1987). ΔR^2 reports the change in the adjusted R^2 when adding the CDS quanto as a control variable. The sample runs from March 2009 to December 2014.

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OA-1. Comparison with other shocks

OA-2. Additional Tables and Results

date	Type of announcement
February 15, 2001	No press conference
March 15, 2001	No press conference
March 29, 2001	No press conference
April 26, 2001	No press conference
May 23, 2001	No press conference
August 2, 2001	No press conference
September 17, 2001	Unscheduled, no press conference
September 27, 2001	No press conference
October 25, 2001	No press conference
August 1, 2002	No press conference
July 31, 2003	No press conference
August 5, 2004	No press conference
August 4, 2005	No press conference
August 2, 2007	No press conference
October 8, 2008	Coordinated rate cut of 50bps with other central banks
November 6, 2008	BoE shocked market by 150bps cut

Table OA-1. Excluded ECB announcement days
This table lists ECB announcement dates which are excluded from our analysis. Excluded dates either include announcements which were not followed by a press conference, unscheduled meetings or days when unconventional monetary policy decisions were taken.

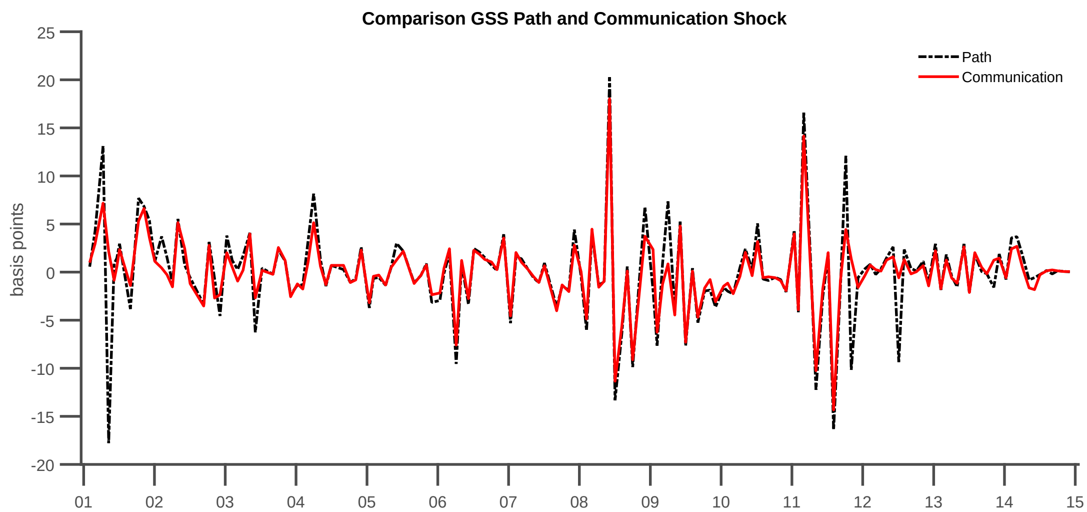

Figure OA-1. Time-Series GSS Path Shock

This figure plots the time-series of Gürkaynak, Sack, and Swanson (2005) path shocks and our communication shocks between January 2001 and December 2014.

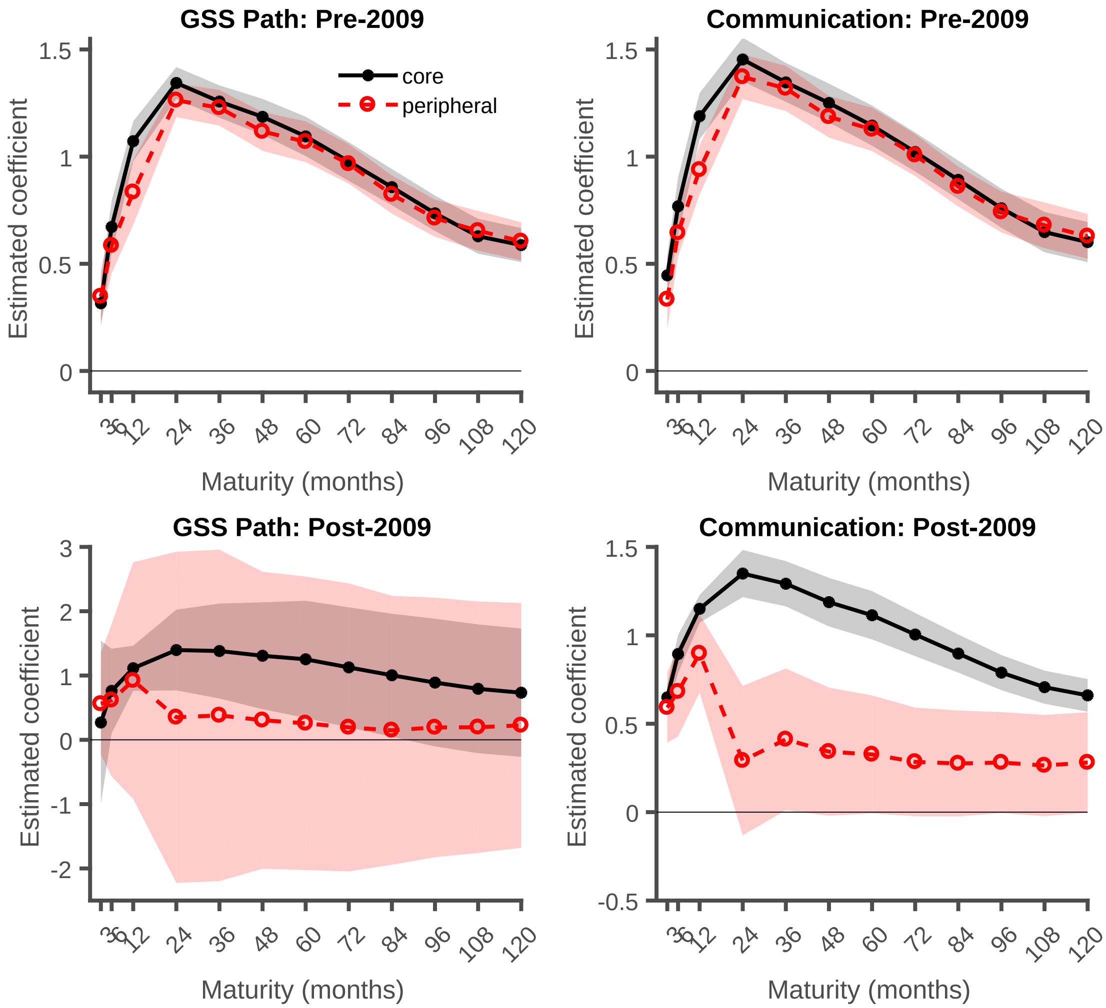

Figure OA-2. Core and peripheral yield response before and after the onset of the crisis This figure plots the response of core (solid line) and peripheral (dashed line) countries' bond yields at different maturities for a Gürkaynak, Sack, and Swanson (2005) path shock (left panels) and communication shock (right panels) on ECB announcement days:

$$\Delta y_{i,t}^{\tau} = \beta_{i,c}^{\tau} \text{path}_t \text{ or } Z_{\theta,t} + \epsilon_{i,c,t}^{\tau},$$

where $\tau = 3m, \ldots, 10y$. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to February 2009 for the upper two panels and from March 2009 to December 2014 for the lower two panels.

OA-3. Unconventional Monetary Policy

Our paper focusses on standard monetary policy announcements. In the following, we explore the effect of so-called unconventional monetary policy on our results. Unconventional measures include the securities markets program (SMP), Outright Monetary Transactions (OMT), Asset Purchase Programmes (APP), and Long-Term Refinancing Operations (LTROs). Table OA-2 summarizes a list of these announcement dates from Dewachter, Iania, and Wijnandts (2016). Bold dates coincide with "normal" ECB announcement days.

Date	Program	What
May 5, 2010	SMP	Government debt purchase of distressed countries (Greece, Ireland, and Portugal)
August 8, 2011	SMP	Extension of first round of SMP to include Italy and Spain
December 1, 2011	LTRO	Draghi's speech at European parliament
December 8, 2011	**LTRO**	**Announcement of 3-year loan scheme for European banks.**
July 26, 2012	OMT	Draghi's "whatever it takes" and "believe me, it will be enough" speech at investors' conference
August 2, 2012	**OMT**	**OMT mentioned at press conference**
September 6, 2012	**OMT**	**Official announcement**
June 5, 2014	LTRO	Operations that provide financing to credit institutions for periods of up to four years.
August 22, 2014	APP	Draghi's speech at Jackson Hole
September 4, 2014	**APP**	**Asset-backed securities purchase programme (ABSPP) and third covered bond purchase programme (CBPP3)**
October 2, 2014	**APP**	**ABSPP and third covered bond purchase programme (CBPP3)**
November 6, 2014	**APP**	**Draghi expresses commitment to using additional unconventional instruments within its mandate.**
November 21, 2014	APP	President Draghi's speech at the Frankfurt European Banking Congress "ECB will do what it must"

Table OA-2. Unconventional Monetary Policy Announcements
This table lists ECB announcement dates which contained unconventional monetary policy news. Bold dates are dates which coincide with "normal" ECB announcement dates.

We notice that six dates coincide with "normal" announcement days. One obvious question now is whether either target and especially communication shocks displayed any special feature during these days. We report in Table OA-3 the size of target and communication shocks and find them to be virtually zero.

		Z_r	Z_θ
LTRO	December 8, 2011	0.01	-0.02
OMT	August 2, 2012	0.01	0.01
OMT	August 2, 2012	0.01	0.01
APP	September 4, 2014	0.00	0.00
APP	October 2, 2014	0.00	0.00
APP	November 6, 2014	0.00	0.00

Table OA-3. Target and Communication Shocks on UMP Dates

This table target (Z_r) and communication (Z_θ) shocks on ECB announcement days where unconventional measures were announced during the statement.

To check the effect of these six dates on our results, we re-estimate the shocks by excluding the six dates. We then re-run our regressions using these new shocks and core and peripheral bond yields. The results are reported in Table OA-4. The upper two panels report our baseline results, i.e., these are the regressions using our shocks consisting of all announcements and the lower two panels report the same regressions but when we exclude the unconventional monetary policy dates. We notice that the two sets of results are literally the same.

	3	6	12	24	60	120
	Core: 2009 - 2015					
Z^r	0.343	0.824	0.781	0.886	0.546	0.337
t-stat	(3.79)	(5.00)	(4.35)	(2.76)	(1.55)	(1.05)
Z^θ	0.649	0.893	1.149	1.349	1.113	0.660
t-stat	(9.29)	(8.26)	(14.70)	(10.12)	(8.15)	(7.15)
R^2	25.27%	39.70%	77.24%	61.70%	34.80%	16.19%
	Peripheral 2009 - 2015					
Z^r	-0.643	-0.718	-1.654	-1.408	-1.021	-0.898
t-stat	(-4.20)	(-1.83)	(-2.05)	(-1.12)	(-1.01)	(-1.26)
Z^θ	0.592	0.682	0.898	0.292	0.327	0.281
t-stat	(2.98)	(2.69)	(4.06)	(0.69)	(0.98)	(0.99)
R^2	30.86%	24.10%	15.77%	2.09%	-0.09%	0.39%
	Core: 2009 - 2015 without 6 UMP dates					
Z^r	0.343	0.824	0.781	0.886	0.546	0.337
t-stat	(3.79)	(5.00)	(4.35)	(2.76)	(1.55)	(1.05)
Z^θ	0.649	0.893	1.149	1.349	1.113	0.660
t-stat	(9.29)	(8.26)	(14.70)	(10.12)	(8.15)	(7.15)
R^2	25.27%	39.70%	77.24%	61.70%	34.80%	16.19%
	Peripheral 2009 - 2015 without 6 UMP dates					
Z^r	-0.643	-0.718	-1.654	-1.408	-1.021	-0.898
t-stat	(-4.20)	(-1.83)	(-2.05)	(-1.12)	(-1.01)	(-1.26)
Z^θ	0.592	0.682	0.898	0.292	0.327	0.281
t-stat	(2.98)	(2.69)	(4.06)	(0.69)	(0.98)	(0.99)
R^2	30.86%	24.10%	15.77%	2.09%	-0.09%	0.39%

Table OA-4. Baseline Regression with and without UMP

The upper two panels report regression coefficients when regressing changes in bond yields of core and peripheral countries on the target and communication shock in the March 2009 to December 2014 sample. The lower two panels run the same regression but we exclude the six announcement dates when unconventional monetary policy was included in the statement.