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, consistent with the idea that concurrent implementation of monetary policy is largely anticipated, we find that target shocks only have a limited effect on yields, while communication shocks have a large and economically significant impact on swap rates and sovereign yields, especially at intermediate maturities. Second, we document that around the European debt crisis communication had the effect of driving a wedge between yields on core versus peripheral countries. We show that neither the revelation of the ECB's private information about macro indicators nor credit risk can explain this yield spread effect on their own. Instead, we consider an alternative explanation whereby monetary policy induces demand shocks for bonds, and we show that in combination with agents' home bias results in risk premia that help to rationalize our findings.

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

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The effectiveness of monetary policy does not solely depend on the control of short-term interest rates but also on central banks' ability to shape market expectations.[1] Indeed, recent evidence from the U.S shows that monetary policy shocks have significant effects on asset prices and that much of this effect arises from information about future interest rates. In addition to an information channel monetary policy potentially affects asset prices through a risk premium channel.[2] However, direct identification of these channels are plagued with difficulties since (i) monetary policy shocks are not strictly exogenous; and (ii) the conduct of U.S monetary policy does not allow for a clean separation between target rate versus communication effects.

In this paper, we focus on monetary policy announcements by the European Central Bank (ECB). While most central banks inform the public about their monetary policy decisions on the day they are taken, the ECB not only releases a press statement with the current policy decision, but also holds a press conference on the day of Governing Council meetings, including a question and answer session 45 minutes after the rate decision has been publicised.[3] 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 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. 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.

We exploit this feature using high-frequency data on money market rates that allows a clean identification of target rate versus communication shocks, and study their impact on yields of sovereign bonds in the cross-section of Eurozone sovereign yields. We document a number of novel results.

First, target rate shocks have an impact on bond yields mostly at short maturities consistent with the idea that the physical implementation of monetary policy is largely anticipated.

[1]Some monetary economists argue that the management of expectations is *the* task of monetary policy. For example, Svensson (2004) writes: "monetary policy is to a large extent the management of expectations," and, according to Woodford (2003), "not only do expectations about policy matter, but ... very little else matters."

[2]Using high frequency data, Fleming and Piazzesi (2005) show that the effect of target rate surprises on yields depends on the slope of the yield curve, a proxy for risk compensation. Hanson and Stein (2015) show that long maturity real rates react strongly to surprise announcements and argue instead that this effect must be due to premia.

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

Second, shocks during communication windows have both economically large and highly statistically significant effects on bond yields, especially at intermediate maturities. For example, we find that two-year German bond yields move 80bps as a response to a 100bp change in the communication shock; hence, communication matters.

Third, 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, monetary policy has a significantly different effect on core countries, defined as Germany, France, Netherlands, and Belgium, versus peripheral countries, defined as Italy, Spain, Ireland, and Portugal.[4] We find that target rate shocks have no effect on yields of peripheral countries, while core countries' yields are increased. Communication shocks, on the other hand, significantly increase yields in both peripheral and core countries, but more so for the latter than for the former. For example, for any 100bp communication shock, there is on average a 40bp change in bond yields of peripheral countries – half the size of the effect in core countries. Since we find cumulative target (communication) shocks to be positive (negative) in the post-crisis period, this implies that target rate shocks brought core and peripheral yields closer to each other, but at the same time the ECB's communication shocks increased the spread between them.

We try to rationalize these findings with three potential explanations. A literature in macroeconomics studies whether central banks possess private information about the state of the economy and whether monetary policy conveys this information to the public. In case of the ECB, one could imagine that negative communication shocks provide a signal that the health of the Eurozone is deteriorating and that the periphery is deteriorating more than the core. Using survey data on future output and inflation, we find no evidence that expectations are reacting to monetary policy shocks. We conclude that the release of information to the public is not responsible for our main result. Another dimension along which core and peripheral countries differ is credit risk. Studying the reaction of sovereign CDS around ECB meetings, we do not find that monetary policy affects credit risk in a significant way in the pre-2009 period. More importantly, in the post-2009 period, there is little statistical difference in the reaction between core and peripheral countries' response in credit risk to either target or communication shocks. Thus, we reject the hypothesis that credit risk, on its own, is the driver of our results.

Finally, motivated by a growing empirical and theoretical literature that documents an

[4]Our sample of countries accounts for about 85% of the total GDP of the Eurozone.

increase in home bias of large European banks during the crisis, we rationalize our empirical findings in a dynamic equilibrium term structure model. We consider an economy with two countries. 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 the monetary policy beyond its direct impact on interest rates. In particular, we assume that institutional investors interpret positive (negative) 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 either the current target rate or 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 portfolio exhibits 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 while Section II describes our data and monetary policy shock estimates. We summarize our main empirical findings in Section III and provide a theoretical model in Section IV. Section V concludes.

Related literature: This paper contributes to three strands of the literature. First, a large empirical literature extracts monetary policy shocks from money market rates.[5] However, measuring the actions of monetary policy remains a challenging task. One source of difficulty is related to the fact that policy actions reflect an endogenous response to the macro-economy. To address the 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 (2015)), 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 (2005a) propose extracting latent factors using high-frequency yield changes in a narrow window around FOMC announcements but must impose identifying assumptions in order to understand the role of target rate shocks versus 'path' shocks. 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.[6]

Second, 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

[5]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).

[6]The ECB publishes a press release announcing its policy rate, i.e., the minimum bid rate for the main refinancing operations of the Eurosystem, decision at 13:45 CET. The press release normally only contains information about the ECB's policy rates. At 14:30 CET, the ECB president and Vice-President hold a press conference, during which they discuss the future path of monetary policy (forward guidance on interest rates), as well as announcing any additional non-standard measures.

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. The authors show that trading volumes are up to seven times higher during target rate announcements and the press conference than during Thursday when no announcement takes place. Moreover, the unexpected component of ECB explanations has a significant and sizeable impact on Euribor futures prices. 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. 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. They find that a more positive tone leads to higher stock returns. 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. Moreover, stock returns are significantly higher whereas option implied volatility is lower on announcement days which feature a press conference than days when there is no press conference. 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.[7]

Third, 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. In these papers risk premia are driven solely by shocks

[7]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."

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 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 shortcut 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, 2015), Gennaioli, Martin, and Rossi (2014), and Barbu, Fricke, and Moench (2016), among others, study home bias in sovereign bond markets. In contrast to the above literature, our contribution is about 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) Fed funds 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 changes in the Fed funds rate are fully expected (see, e.g., Gürkaynak, Sack, and Swanson (2005a)). 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 $F = \Delta Y \Omega$.

Like us, Gürkaynak, Sack, and Swanson (2005a) 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. However, in their setup, these 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.

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 in different time windows at the ECB. Hence, our approach does not rely on imposing any restrictions and we estimate latent factors F from equation (1) separately during the target rate announcement and the press conference. We explain details of the procedure and some institutional details in the next section.

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. There is one scheduled ECB meeting per month, except for the years 2001 and 2008 when there were 20 and 13 meetings, respectively. This leaves us with 177 announcement days from which we exclude 15 announcements that were either not followed by a press conference or were unscheduled. The exclusion dates are summarized in Table I. Our final sample thus consists of 162 announcement days: there are 19 days when the main refinancing rate was

raised, 11 days when the interest rate was decreased, and 132 meetings with no change.

[Insert table I here]

A. Market reaction around target rate announcement and press conference

The ECB publishes a press release announcing its policy rate decision at 13:45 CET. The press release normally only contains information about the ECB's policy rates. At 14:30 CET, the ECB President and Vice-President hold a press conference, during which they discuss the future path of monetary policy (forward guidance on interest rates), as well as announcing any additional non-standard measures. The press conference consists of an introductory statement and the Question and Answer session. The structure of the introductory statements has remained the same since the very beginning: (i) the first part reports 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) the second part discusses both real and monetary developments in the Euro area, and since May 2003 it is followed by a "sum-up and cross-check" paragraph, which repeats the initial synthetic assessment; (iii) finally, the ECB President concludes with some considerations on fiscal policy and structural reforms.

[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).

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 3.48% within 30 minutes. Market participants did not expect any change in interest rates for the April meeting but expected an interest rate hike later in the year. However, when at the press conference 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." The first question at the Q&A was what "heightened alertness" means compared to "strong vigilance," an expression that the ECB had used previously to signal upcoming hikes. Trichet then went on to say that "we could decide to move our rates by a small amount in our next meeting." As can be seen from the lower panel, 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 in the next meeting, on July 3, 2008.

November 3, 2011: The ECB unexpectedly cut interest rates by 25bps for the first time in two years at Mario Draghi's first meeting as new chairman. Consequently, we see that the two-year swap rate drops from 1.46% to 1.37% within 10 minutes and then stabilizes 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 Mario Draghi 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 "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 maturity two years. We choose as a cutoff two years for the following reason. The primary objective of the ECB is price stability over the medium term and they do not specify any specific horizon. However, the ECB believes "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". That being said, the ECB implicitly hinted to have a horizon of two to three years, by publishing forecasts (including interest rates) with a projection horizon of two years (extended to three years as of December 2016).[8]

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.[9]

[Insert figure 2 here]

Our procedure to back out target and communication shocks follows in two steps. First, we need to establish in the data how many factors are present in each window. Then we can back out the shocks by calculating principal components from changes in the 13 interest rates. To establish the number of factors, we use principal components analysis on the 162 (number of announcements) $\times$ 13 (maturities) matrix of swap changes.

[Insert table II here]

Table II 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 80%, and the first two PCs explain around 90% of the variation. To assess the statistical significance of these factors, we regress swap rate changes on the first and second PC of both the target and communication window; regression coefficients and corresponding t-statistics for each maturity are presented in Table III. Panel A contains our results for PCs constructed during the target rate window. For PC1, we find that the t-statistics are highly

[8] See here http://www.ecb.europa.eu/pub/projections/html/index.en.html.

[9] We can shrink the target and communication windows and we can also introduce a gap of 10 minutes between the target rate and communication windows. All our results remain quantitatively and qualitatively the same.

significant from the shortest maturity swap rate (one month) out to two years, and adjusted R^2s range between 42% for the shortest maturity to 10% for the longest one. The second row in Panel A reports regression results for PC2; notice the significant drop in the explanatory power as well as the low t-statistics. For intermediate maturities, between ten months and one years, the second PC is insignificant, and then becomes negative and again significant going out to two years.

[Insert table III 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 only significant at the short end, and estimated coefficients are negative and insignificant at the long end. Different from Panel A, however, coefficients for the first PC are mostly significant around the one year maturity, with a corresponding R^2 over 70%. 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 mostly insignificant. Second, target rate and communication shocks have a differential effect along interest rate maturities. While policy shocks during the communication window mainly affect interest rates at intermediate maturities, shocks in the target rate window mainly have an impact on the short end of the curve.

In the following, we label PC1 from the target rate window as our target rate shock, $Z_{r,t}$ and PC1 from the communication window as communication shock, $Z_{\theta,t}$. We present summary statistics of the target rate and communication shocks in Table IV.

Both target rate and communication shocks are on average zero, i.e., there is no surprise on average, and the standard deviation is almost equally large for both shocks. However, we 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 IV here]

Figure 3 plots the time-series of the target rate and communication shocks. 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. The second event corresponds to June 5, 2008, when Trichet hinted at a rate hike at the following meeting discussed before. The third event corresponds to March 3, 2011, when Trichet hinted at a interest rate tightening at the next meeting by saying at the press conference that "strong vigilance is warranted." On August 4, 2011, the fourth event, rates were kept constant but the market expected an announcement about bond purchases for Italy and Spain (the first round which was announced on May 10, 2010, only included Greece, Ireland, and Portugal). On this day the Dow Jones fell to its lowest level since 2008 and the FTSE100 fell by more than 4%. In an unusual move, the ECB then announced the following Sunday that bond purchases would be extended to Spain and Italy. On November 3, 2011, Draghi surprised the market by a 25bp cut at his first meeting (fifth event). Finally, the sixth event highlighted on Figure 3: On July 5, 2012, the ECB cut interest rates by 25bps to an all-time low.

[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, Netherlands, France, Belgium, Italy, Ireland, Spain and Portugal, with maturities ranging between three months and 10 years, available from Bloomberg.
Credit risk: One major concern during the Eurozone crisis was the default risk of certain peripheral countries. To measure the credit risk of each country, we use euro-denominated five-year credit default swaps (CDS) available from Markit.[10] Since sovereign CDS data only commence to be traded frequently after 2002 and due to liquidity concerns in the early sample, we start our analysis involving CDS in January 2002.
Macroeconomic forecasts: Eurozone countries also differ across economic conditions. To capture these, we use GDP growth and inflation forecasts from Consensus Economics. We have four quarter forecasts on Germany, France, Netherlands, Spain, and Italy. Belgium, Portugal, and

[10]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 CDS data.

Ireland are not covered by Consensus Economics. These forecasts are released at the end of each month, about ten days before the ECB's monthly press conference.

We present a summary statistic of bond yields and CDS in Table V.

[Insert table V here]

On average, German bond yields are the lowest for most maturities, and Irish 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 16bps, while Spanish and Italian CDS are almost 1% on average, and Portuguese CDS are around 2%. We also note that the Portuguese CDS reached as high as 15%, while the maximum value for Germany is not even 1%.

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, long-term interest rates are sensitive to monetary policy shocks. Second, while before the 2009 crisis monetary policy had a uniform effect on bond yields of core and peripheral countries, since 2009, core countries react more to target and communication shocks than peripheral countries.

All regressions start in February 2001 and end in December 2014. Regressions that exclude the Eurozone crisis end in December 2008, and regressions that include CDS start in January 2002. All regression coefficients are standardized, meaning we de-mean and divide each variable by its standard deviation before running the regression. 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 effect 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.

Earlier literature 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 US, UK, Germany and Canada.

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 monetary policy shocks. The results for bond yield (forward) changes are gathered in the upper (lower) panel of Figure VI.

Target rate shocks have a highly significant effect on daily swap rate changes, especially at the short end and the effect dies out as the maturity prolongs. Similarly, estimated coefficients for communication shocks are highly statistically different from zero for all maturities. The effect is largest for the one and two year maturities and decreases with the maturity. Economically, we find that for any 100bps change in the target rate shock, there is 42bps change in the one-year maturity swap rate whereas communication shocks induce a 83bps increase. For the ten-year swap rate, the effect of both target and communication shocks is still economically large, as it is around 65bps. An effect which is similar in size to the one reported for U.S. Treasury yields.

Forward rate changes display a very similar pattern and we observe significant estimates up until a maturity of seven years both for target and communication shocks. For example, seven-year forward rate changes move by 32bps as a response to communication shocks and 12bps as a response to target rate shocks.

[Insert figure VI here]

To summarize, we find that changes in short-term interest rates have significant effects on long-term interest rates.

B. *Sovereign bond yields*

We now want to study the effect of monetary policy shocks on the cross-section of sovereign bond yields. To this end, we regress changes in bond yield changes onto the target rate and communication shocks jointly:

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

where $\Delta y_{i,t}^{\tau}$ is the daily yield change of country i with maturity τ. We summarize the results in Figures 5 (core countries) and 6 (peripheral countries).

[Insert figure 5 here]

There are two main findings. First, we note that the effect of target rate shocks is generally decreasing with maturity both for core and peripheral countries, however, the effect on peripheral countries is not statistically different from zero. 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 the maturity prolongs. Comparing core versus peripheral countries, we find the former to be affected more by monetary policy shocks than the latter. For example, for any 100bps increase in the communication shock, there is almost a 80bps increase in the two-year yield for Germany, Netherlands, and France and a 60bps increase in the corresponding Belgian yield. Effects on peripheral countries basically half as a 100bps increase in the communication shock increases two-year yields by around 40bps.

[Insert figure 6 here]

C. *Main result: The effect of monetary policy over time*

Against the backdrop of our previous result, we now want to focus on two different aspects of ECB monetary policy. First, we want to study whether monetary policy has affected bond yields differently over time, and second, whether the effect has changed between core and peripheral countries. In the following, we define core (peripheral) countries' yields to be the median yield for each maturity of core (peripheral) countries. We first run regression (2) for the pre-crisis (January 2001 to December 2008, 90 observations) and post-crisis period (January 2009 to

December 2014, 72 observations) separately. The results are reported in the upper two rows in Figure 7.

[Insert figure 7 here]

The upper two panels plot the effect of target rate (left panel) and communication shocks (right panel) when we end the sample in December 2008. We note two results: First, estimated coefficient for core and peripheral countries are virtually the same, indicating that monetary policy did not have a differential effect between these countries before the 2008-2009 global financial crisis. Second, coefficients for target rate shocks are now statistically different from zero also for peripheral countries, moreover, the size of the effect on peripheral countries for communication shocks is twice as large as in the full sample. For example, for any 100bps change in the communication shock, there is a 80bps change in bond yields of both core and peripheral countries.

The lower two panels present the results for the January 2009 to December 2014 period. Interestingly, now target rate shocks have a differential effect on core versus peripheral countries. While estimated coefficients are positive and significant out to seven years for core countries, peripheral countries' coefficients are negative and not significant at any maturity. The lower right panel depicts the effect of communication shocks during the crisis period. While we find virtually the same hump-shaped pattern as in the pre-2009 period for core countries, there is a large difference between core and peripheral countries with peripheral countries being affected less. For example, for any 100bp communication shock, there is a 80bps change in the two-year yield for core countries as in the pre-crisis period whereas the effect on a two-year peripheral country bond yield is only around 20bps.

Given the seemingly large difference post 2009, we explore the differential effect of monetary policy shocks onto core and peripheral countries in more detail by running a regression directly on the yield spread between peripheral and core countries:

$$\Delta\left(y^{\tau}_{\text{per},t} - y^{\tau}_{\text{core},t}\right) = \beta_r Z_{r,t} + \beta_\theta Z_{\theta,t} + \epsilon_t.$$

where $y^{\tau}_{\text{per},t}$ is the median yield for each maturity τ for peripheral countries, and $y^{\tau}_{\text{core},t}$ is the corresponding median yield of core countries at time t. We summarize the results in the lower two panels of Figure 7. We notice that estimated coefficients for both target rate (lower left

panel) and communication (lower right panel) are statistically significant for almost all the maturities except for the long-end for target rate shocks. Given the economically large effect of monetary policy shocks on yield spreads, in the following, we try to rationalize our findings.

Since the onset of the crisis in 2008, the ECB tried to ease money market distress and to reduce sovereign spreads mainly (i) by drastically lowering its target rate, (ii) by providing unprecedented amounts of liquidity support against a broader set of asset used as collateral, and more recently, (iii) by introducing quantitative easing in the form of the Asset Purchase Programme. Several studies have analyzed the impact of different unconventional monetary policy announcements for bond yields of peripheral countries and the consensus is that bond yields of the riskiest countries such as Italy and Spain have fallen significantly around these unconventional monetary policy announcements (see e.g., Krishnamurthy, Nagel, and Vissing-Jorgensen (2015)). Our results indicate that monetary policy also had an effect on core countries and more importantly, the effect is quantitative larger than on peripheral countries. We now want to understand in more detail the effects of both target and communication on yield spreads over time. To this end, we first plot in Figure 8 (upper panels) the cumulative target and communication shocks for the entire period and for the period between January 2009 to December 2014.

[Insert figure 8 here]

We notice that up until 2009, communication shocks cumulatively had a positive effect, while target rate shocks were negative. The sign switches at the beginning of 2009, when the target shocks become positive and communication shocks negative. The increase in the cumulative sum of target rate shocks implies that the target rate was set higher than what the market expected.[11] 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. If we combine this insight together 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. In Figure 8 (lower panels), we plot the cumulative effect of target (left lower

[11] The US 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 Fed.

panel) and communication (right lower panel) shocks onto the yield spread, where we multiply the cumulative shocks with the estimated coefficients for the two-year yield spread from the lower two panels in Figure 7. Interestingly, we find that target rate shocks until mid 2012 had cumulatively lowered the spread between peripheral and core countries, whereas since then the effect has reversed and is approaching zero. Communication shocks, on the other hand, have a positive effect on the yield spread which is increasing until 2011/2012 (the beginning of Draghi's tenure) and then slightly decreasing again but still positive until the end of 2014.

To summarize, we find that while since the onset of the 2009 crisis up until 2013, target rate shocks decreased the spread between the riskiest and safest countries in line with the ECB's goal, communication shocks increased the spread. Since the overall effect of communication shocks is larger than the corresponding target rate shocks, we conclude that the ECB's monetary policy and in particular its communication strategy had the unintended consequence of increasing interest rates of peripheral countries' bonds relative to core countries'. In the next section, we try to explain these findings using different competing explanations.

D. Possible explanations

Our empirical results highlight two interesting observations: First, communication shocks significantly move intermediate-term interest rates. Second, these shocks increase the spread between peripheral and core countries since 2009. In the following, we ask what characteristics of core and peripheral countries could explain these results. Two obvious dimensions along which core and peripheral countries differ are their credit risk and economic fundamentals, especially since 2009. Hence, one natural starting point is to ask whether monetary policy had any significant effect on peripheral countries' credit risk or whether monetary policy signalled (unintentionally) bad news to the market about peripheral countries.

D.1. Credit risk

An obvious channel through which monetary policy can affect bond yields is through credit risk. Right up until the Eurozone crisis, neither bond yields nor the CDS are significantly different between core and peripheral countries and yields only start to diverge after the eruption of the Global Financial Crisis in the summer of 2008. One natural driver between peripheral and core

countries could therefore be credit risk.[12]

To check our hypothesis, we run a regression from CDS changes onto target and communication shocks:

$$\Delta\text{cds}_{i,t} = \beta_r Z_{r,t} + \beta_\theta Z_{\theta,t} + \epsilon_{i,cds,t},$$

where $\Delta\text{cds}_{i,t}$ is the change in country-level CDS and the spread between peripheral and core countries CDS. Results of this regression are presented in Table VII.

[Insert table VII here]

We notice that in the pre-2009 period, almost none of the estimated coefficients for target or communication shocks are statistically significant indicating that there is no relationship between credit risk and monetary policy on days when the ECB makes an announcement. Post 2009, however, we notice a significant and negative effect from communication mainly on Belgium and France and to a lesser extent on changes in CDS of Spain and Italy. To check whether there are any significant effects on the spread between peripheral and core countries, we refer to the regression results regarding the spread (last column). We notice that neither the target rate nor the communication shock have a significant effect on the credit spread. Taken together our results show that credit risk cannot be a channel through which central bank communication increased the spread between peripheral and core countries' bond yields.

D.2. ECB information revelation

A large literature argues that monetary policy actions communicate information about the state of the economy to an imperfectly informed public. The idea is that the policy maker has more information about economic fundamentals and that the central bank's action taken in response to these fundamentals provide information to private agents.[13] Hence, one channel

[12] It is important to emphasize that we exclude announcements from our analysis that contain information about unconventional monetary policy tools such as the outright purchases of government debt of distressed countries aimed at lowering their bond yields. Krishnamurthy, Nagel, and Vissing-Jorgensen (2015) document that some but not all programs significantly reduced bond yields of distressed countries such as Greece, Italy and Spain through lowering their credit risk.

[13] For example, Romer and Romer (2000) document central bank informational advantage by showing that Greenbook forecasts produced by the Federal Reserve Board of Governors outperform some private forecasts. Nakamura and Steinsson (2015) find that FOMC forward guidance conveys the FOMC's private information to market participants and that this information transfer has large macroeconomic effects. Gürkaynak, Sack, and Swanson (2005b) show that one way to explain the large effects of monetary policy on long-term forward rates is to assume that the private agents' views of long-term inflation are not well-anchored. Tang (2015) shows that surprises in the Federal funds rate are empirically linked to inflation expectations.

through which monetary policy could increase bond spreads, is by signalling to the market bad economic fundamentals of peripheral countries.

In case of the ECB, information can be revealed either through interest rate setting or through communication and one prominent example for the latter is the use of the word 'vigilance' in their press communications to voice concerns regarding upward risks in price stability. In the following, we want to examine whether monetary policy shocks are linked to inflation, output, and short-term interest rate forecasts of core and peripheral countries and whether there are any cross-sectional differences between how core and peripheral countries load on monetary policy shocks. To estimate the effect of monetary policy on forecast revisions, we run panel regressions of the change from one month to the next on both the target and communication shock that occurs during this month both for the pre-2009 and post-2009 period. Table VIII summarizes the results.

[Insert table VIII here]

If surprise ECB policy announcements represent shocks to the stance of monetary policy unrelated to current macroeconomic circumstances, then a positive innovation to either target or communication should lower inflation and output. Our estimates indicate mixed results.[14] We summarize our findings as follows. First, private forecasters do not revise their expectations following a monetary policy shock neither pre- nor post-2009 in a significant way.[15] Second, we also do not see any significant difference between changes in expectation between core and peripheral countries. Overall, we find little evidence that private agents revise their expectations about economic fundamentals as a response to monetary policy.

D.3. Home Bias

Our last channel concerns home bias in sovereign bond holdings. Recent empirical evidence documents a strong home bias in peripheral government debt starting at the end of 2008: Portuguese banks increased their domestic bond holdings by almost 90%, Irish and Italian

[14] Campbell, Evans, Fisher, and Justiniano (2012) find that estimated signs are opposite to those predicted by the standard New Keynesian model using U.S. data: unanticipated increases in the Gürkaynak, Sack, and Swanson (2005a) path factor lead to decreases in expected unemployment and increases in expected inflation. From this the authors conclude that professional forecasters believe that FOMC policy surprises contain useful and otherwise unavailable macroeconomic information. These results hold pre- and post-crisis.

[15] Not surprisingly, R^2 are low since we do not expect monetary policy to account for the bulk of macroeconomic information. In unreported results, we control for realized macroeconomic outcomes and we find R^2 to be significantly higher.

banks by 20% and Spanish banks by 13% in 2009 alone and at the beginning of 2015, Italian and Spanish financial institutions still held 10% of their bank assets in local bonds.[16] This increase in domestic bonds coincides with the introduction of the ECBs unconventional Long-Term Refinancing Operations, which allows banks to use sovereign bonds as collateral for central bank liquidity.[17] We plot in Figure 9 a proxy of home bias, defined as the ratio of the amount of domestic bonds held and bonds issued by other Euro area countries for core and peripheral countries. Indeed, we see a steep increase in domestic bond holdings starting in 2009 for peripheral countries but virtually no change for core countries.

[Insert figure 9 here]

In the following, we want to explore whether and how an increase in sovereign bond home bias has affected bond yields post-2009. To this end, we run the following regression:

$$\Delta y_{i,t}^{\tau} = \beta_h \text{home bias}_{i,t} + \beta_r Z_t^r + \beta_\theta Z_t^\theta + \gamma_r \left(\text{home bias}_{i,t} \times Z_t^r\right) + \gamma_\theta \left(\text{home bias}_{i,t} \times Z_t^\theta\right) + \epsilon_t^\tau,$$

We are particularly interested in the sign (and significance) of the interaction term between the monetary policy shocks, target and communication, with the home bias proxy. In the upper panel, of Table IX, we present the results for the core countries, while results for peripheral countries are in the lower panel. We notice that for the core countries almost none of the estimated coefficients for the interaction terms, γ_r and γ_θ are statistically different from zero. For peripheral countries bond yields, however, we find significant coefficients for the interaction term with target shocks up to a five-year maturity, while the coefficients for the communication shock are significant at all maturities. Crucially, we find that the sign is negative, which implies that higher home bias, dampens the effect of both target and communication shocks.

[Insert table IX here]

Reverting back to our main result reported in Figure 7, we conclude that the increase in

[16] Home bias is not just a phenomenon which can be observed for banks but also more long-term investors. For example, Koijen, Koulischer, Nguyen, and Yogo (2016) report that banks, insurance companies, and pension funds in peripheral countries all hold more than 85% of their government bond portfolio in domestic government bonds.

[17] A large empirical and theoretical literature studies the so called doom loop, i.e. the strong linkages between sovereign and bank balance sheets during the 2009 Eurozone crisis and the re-nationalization of domestic sovereign debt by peripheral banks. Farhi and Tirole (2016) discuss different mechanisms underlying banks' home bias and the ensuing policy implications.

sovereign bond home bias in peripheral countries presents one potential channel through which the effect of monetary policy can be muted.

IV. Model

In this section we propose a dynamic equilibrium term structure model to rationalize our baseline empirical results about the impact of monetary policy on the yield curve. Interest rates are determined by the interaction between risk-averse banks and buy-and-hold institutional investors.

A. *Bond market*

Time is discrete and goes from zero to infinity. Agents, specified below, 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. We denote the time-t yield-to-maturity of a zero-coupon bond of country i paying one dollar at maturity $t+n$, $n = 1, ..., N$, by $y_{i,t}^{n}$, and the one-period holding return on this bond between t and $t+1$ by $R_{i,t+1}^{n} = ny_{i,t}^{n} - (n-1)\, y_{i,t+1}^{n-1}$. 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

$$r_{t+1} = r_t + \kappa_r \left(\theta_t - r_t\right) + \sigma_r \varepsilon_{r,t} \tag{3}$$

where

$$\theta_{t+1} = \theta_t + \kappa_\theta \left(\bar{\theta} - \theta_t\right) + \sigma_\theta \varepsilon_{\theta,t} \tag{4}$$

and $\varepsilon_{r,t}$ and $\varepsilon_{\theta,t}$ are independent random variables with mean zero and unit variance. According to (3) and (4), 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 $\varepsilon_{r,t}$ as changes to the target rate unexpected by investors, and $\varepsilon_{\theta,t}$ as the unexpected component of changes to the future path of interest rates, i.e., communication shocks.

At each date t and in each country i there exists a finite set of zero-coupon bonds in supply $S_{i,t} = \left(S_{i,t}^{1}, ..., S_{i,t}^{N}\right)^{T}$. 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 all the 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 the bond with maturity n in country i, expressed in time-t dollars, as $z^n_{i,t} = \gamma_i(n) z_t$, where $\gamma_i(n)$ is an exogenously given function and z_t is a demand factor that follows

$$z_{t+1} = z_t + \kappa_z(\bar{z} - z_t) + \eta_r \varepsilon_{r,t+1} + \eta_\theta \varepsilon_{\theta,t+1}. \tag{5}$$

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 demand for peripheral bonds as particularly risky assets: Upon the arrival of any negative shock to the target or the communication rate, which can be 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. To this end, we assume both $\gamma_p(n) > 0$ and $\gamma_p(n) > \gamma_c(n)$ for all n. 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 $\gamma_c(n) = 0$ and for peripheral bonds by taking $\gamma_p(n) = 1$ for all n; this significantly simplifies our analysis without affecting the main mechanism.[18]

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

[18] In fact, if investors consider core country bonds as safe havens, i.e., in the presence of flight-to-safety, we would also have $\gamma_c(n) < 0$. This would only amplify the risk premium difference between core and peripheral countries. Alternatively, we could specify the demand directly as an increasing function of r_t and/or θ_t. In that case our specified institutional demand would be similar to 'reaching-for-yield' behaviour; see, e.g., Hanson and Stein (2015) for a theoretical 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. Finally, we could also introduce independent movements to z_t via $\varepsilon_{z,t}$ shocks, but they would also 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 that they face quadratic transaction costs when buying or selling bonds of the other country: If bank a is born with wealth $w_{a,t}$ in period t and $x_{a,i,t} = \left(x^1_{a,i,t}, ..., x^N_{a,i,t}\right)^T$ denotes her position in country-i bonds, the budget constraint is written as

$$w_{a,t+1} = w_{a,t}\left(1 + r_t\right) + \sum_{i=c,p} x^T_{a,i,t}\left(R_{i,t+1} - 1_N r_t\right) - TC\left(x_{a,-a,t}\right), \tag{6}$$

where $R_{i,t} = \left(R^1_{i,t}, ..., R^N_{i,t}\right)^T$. The first two terms on the right-hand side of (6) capture the trading gains from the riskless money market account and the risky bonds of the core and peripheral countries, and the third term represents the transaction cost. For tractability, we specify the latter in terms of the variance of the portfolio of bonds of the other country $-a$:

$$TC\left(x_{a,-a,t}\right) = \frac{\phi}{2}\text{Var}_t\left(x^T_{a,i,t}R_{-a,t+1}\right). \tag{7}$$

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. This term 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.[19]

The optimization problem of banks is given by

$$\max_{\{x_{a,i,t}\}_{i=c,p}} \text{E}_t\left[w_{a,t+1}\right] - \frac{\alpha}{2}\text{Var}_t\left[w_{a,t+1}\right], \tag{8}$$

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

$$x_{c,i,t} + x_{p,i,t} + z_{i,t} = S_{i,t} \tag{9}$$

for all i and t.

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

B. Equilibrium

Let us write bond return processes in the form of

$$R_{i,t+1} = \mu_{i,t} + \Omega_{i,t}\varepsilon_t \tag{10}$$

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, $\varepsilon_t = (\varepsilon_{r,t}, \varepsilon_{\theta,t})^T$, and hence $\mathrm{Var}_t\left[R_{i,t+1}\right] = \Omega_{i,t}\Omega_{i,t}^T$ is an $N \times N$ positive definite matrix. Combining (6), (7) and (10) the optimization problem of, e.g., the core bank is equivalent to

$$\max_{\{x_{c,i,t}\}_{i=c,p}} \sum_{i=c,p} x_{c,i,t}^T \left(\mu_{i,t} - r_t 1_N\right) - \frac{\alpha}{2}\left(x_{c,c,t}^T\Omega_{c,t} + x_{c,p,t}^T\Omega_{p,t}\right)\left(x_{c,c,t}^T\Omega_{c,t} + x_{c,p,t}^T\Omega_{p,t}\right)^T \tag{11}$$
$$- \frac{\phi}{2} x_{c,p,t}^T \Omega_{p,t}\Omega_{p,t}^T x_{c,p,t},$$

which leads to the following first-order conditions:

$$\mu_{c,t} - r_t \mathbf{1}_N = \alpha\Omega_{c,t}\left(\Omega_{c,t}^T x_{c,c,t} + \Omega_{p,t}^T x_{c,p,t}\right) \tag{12}$$

and

$$\mu_{p,t} - r_t \mathbf{1}_N = \alpha\Omega_{p,t}\left(\Omega_{c,t}^T x_{c,c,t} + \Omega_{p,t}^T x_{c,p,t}\right) + \phi\Omega_{p,t}\Omega_{p,t}^T x_{c,p,t}. \tag{13}$$

Equations (12) and (13) highlight the importance of transaction costs that impede capital flows between the two countries. Equation (12) states that core-country bonds' expected excess returns, $\mu_{c,t} - r_t\mathbf{1}_N$, must compensate core banks for all the risk they bear when holding risky bonds of the two countries, but (13) shows that foreign bonds must also compensate banks for the transaction costs that makes investing abroad more expensive. Naturally, the relationship between bond returns and the positions of peripheral banks are exactly the opposite: they must pay transaction costs when investing in core bonds, which increases the required return. Equations (12) and (13) show that as long as $\phi \neq 0$, the market prices of risk in the two country might deviate from each other.

Let us introduce the notation $s_{i,t} = S_{i,t} - z_{i,t}$ for the net supply of bonds that in equilibrium must be held by banks. The market-clearing condition (9) then becomes

$$x_{c,i,t} + x_{p,i,t} = s_{i,t} \tag{14}$$

for all i and t. Combining (14) with (12), (13), and the first-order conditions of the peripheral banks we obtain the following results:

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

$$\left(\Omega_{p,t}^T \Omega_{p,t}\right)^{-1} \Omega_{p,t}^T \left(\mu_{p,t} - r_t \mathbf{1}_N\right) = \alpha \left[\frac{2\alpha + \phi}{4\alpha + \phi} \Omega_{p,t}^T s_{p,t} + \frac{2\alpha}{4\alpha + \phi} \Omega_{c,t}^T s_{c,t}\right] \tag{15}$$

and

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

Moreover, bank positions satisfy

$$\Omega_{p,t}^T x_{p,p,t} = \frac{3\alpha + \phi}{4\alpha + \phi} \Omega_{p,t}^T s_{p,t} + \frac{\alpha}{4\alpha + \phi} \Omega_{c,t}^T s_{c,t} \text{ and } \Omega_{c,t}^T x_{p,c,t} = -\frac{\alpha}{4\alpha + \phi} \left[\Omega_{p,t}^T s_{p,t} - \Omega_{c,t}^T s_{c,t}\right] \tag{17}$$

for the peripheral bank and

$$\Omega_{p,t}^T x_{c,p,t} = \frac{\alpha}{4\alpha + \phi} \left[\Omega_{p,t}^T s_{p,t} - \Omega_{c,t}^T s_{c,t}\right] \text{ and } \Omega_c^T x_{c,c,t} = \frac{\alpha}{4\alpha + \phi} \Omega_{p,t}^T s_{p,t} + \frac{3\alpha + \phi}{4\alpha + \phi} \Omega_{c,t}^T s_{c,t} \tag{18}$$

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 $z_{p,t}^\tau$ 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 doubled their sovereign bond holdings between January 2009 to end of 2012 from 3% of total bank assets to 6%. 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 Farhi and Tirole (2016)) and financial repression theories (see, e.g., Becker and Ivashina (2014) and Chari, Dovis, and Kehoe (2016)). 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:

$$y_{i,t}^{n} = \frac{A_i(n)}{n} + \frac{B_i(n)}{n} r_t + \frac{C_i(n)}{n} \theta_t + \frac{D_i(n)}{n} z_t. \tag{19}$$

As the one-period holding return satisfies $R_{i,t+1}^{n} = n y_{i,t}^{n} - (n-1)\, y_{i,t+1}^{n-1}$, (19), together with (3), (4), and (5), implies that returns are indeed in the form (10). Substituting them into (15) and (16), 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 (19), with the following functions:*

$$B_c(n) = B_p(n) = \frac{1 - (1-\kappa_r)^n}{\kappa_r}, \tag{20}$$

and

$$C_c(n) = C_p(n) = \frac{1 - (1-\kappa_\theta)^{n-1}}{\kappa_\theta} + (1-\kappa_r)\frac{(1-\kappa_r)^{n-1} - (1-\kappa_\theta)^{n-1}}{\kappa_r - \kappa_\theta}, \tag{21}$$

while $D_c(n) = 0$ *and*

$$D_p(n) = -\frac{1 - (1-\kappa_z)^{n-1}}{\kappa_z} + \frac{k_B}{\kappa_z - \kappa_r}\left(\frac{1 - (1-\kappa_z)^{n-1}}{\kappa_z} - \frac{1 - (1-\kappa_r)^{n-1}}{\kappa_r}\right) \tag{22}$$
$$+ \frac{k_C}{\kappa_z - \kappa_\theta}\left(\frac{1 - (1-\kappa_z)^{n-1}}{\kappa_z} - \frac{1 - (1-\kappa_\theta)^{n-1}}{\kappa_\theta}\right)$$

with $k_B, k_C > 0$ constants. The functional form 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 two 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,[20,21]

$$\Delta y^n_{i,t} = \alpha^n_i + \beta^n_{i,r}\varepsilon_{r,t} + \beta^n_{i,\theta}\varepsilon_{\theta,t} + \nu_{i,t}. \tag{23}$$

From (5) and (19), it is imminent that $\beta^n_{i,r} = \left(\frac{B_i(n)}{n} + \frac{D_i(n)}{n}\eta_r\right)\sigma_r$ and $\beta^n_{i,\theta} = \left(\frac{C_i(n)}{n} + \frac{D_i(n)}{n}\eta_\theta\right)\sigma_\theta$. Thus, we obtain the following results:

Proposition 1. *The impact of target rate shocks on bond yields, measured by $\beta^n_{i,r}$, $i = c, p$, is positive and decreasing across maturities in both univariate and multivariate regressions.*

The impact of communication shocks, $\beta^n_{i,\theta}$, $i = c, p$, is positive and hump-shaped across maturities in both univariate and multivariate regressions.

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 directly through the expectation channel, and indirectly through risk premia.

A positive current target rate shock increases all future expected target rates, but due to mean reversion, its effect dies out over time. Thus, current long yields are less sensitive to target rate shocks than short yields: $\beta^n_{i,r}$ is positive and decreases with maturity. At the same time, a shock to θ_t provides information about intended future (medium-term) target rates, but does not affect the current rate r_t, and long-term yields are expected to mean-revert to the

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

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

long-term mean $\bar{\theta}$ eventually. Hence, a positive communication shock increases medium-term yields while leaving short and long yields intact, corresponding to a hump-shaped response $\beta^n_{i,\theta}$ across maturities.

Both types of shocks also have an indirect effect that works through the risk premium channel: by influencing the demand of buy-and-hold institutional investors, they effectively manifest as shocks to the relative net supply of bonds that risk-averse banks have to hold in equilibrium. A negative target rate or communication shock with which the central bank decreases yields are interpreted as bad news, and make pension funds 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, including those of the core country, too. Hence, the risk premium channel counteracts the direct (expectation) effect of shocks for all maturities in all countries.

Proposition 1 is in line with predictions originating just from the expectation hypothesis, but the risk premium channel is needed to explain cross-sectional differences between countries when studying the effect of the two types of shocks. For this end we compare regression coefficients from (23) for peripheral vs core countries.

Regarding the loading on target and communication shocks, we obtain the following predictions:

Proposition 2. *We have $\beta^n_{c,r} > \beta^n_{p,r}$ and $\beta^n_{c,\theta} > \beta^n_{p,\theta}$ for all $n = 1, ..., N$. Thus, monetary policy shocks have higher impact on bond yields in core countries than in peripheral countries.*

The heterogeneity across countries is driven by the friction that leads to partial segmentation of bond markets and prevents market prices of risk to equate across countries. Due to transaction costs banks exhibit home bias, so when on bad news buy-and-hold investors 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, the risk premium required on peripheral bonds is more prominent than in the core country, as suggested by (15) and (16). Given that the expectation channel is identical for bonds of the two countries, 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 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 excercise regarding the effect of transaction costs on the cross-country difference of bond holdings and regression coefficients.

Proposition 3. *We have* $d\left(\beta^n_{c,r} - \beta^n_{p,r}\right)/d\phi > 0$ *and* $d\left(\beta^n_{c,\theta} - \beta^n_{p,\theta}\right)/d\phi > 0$ *for all* $n = 1, ..., N$. *Thus, monetary policy 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 monetary policy shocks translate into positive supply shocks of peripheral bonds, home bias becomes more prominent in peripheral banks' portfolios but not (or just 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, (20)-(21) show that higher ϕ leads to a higher difference in the D_p and D_c functions, and hence increases both $\beta^n_{c,r} - \beta^n_{p,r}$ and $\beta^n_{c,\theta} - \beta^n_{p,\theta}$. Therefore, our model not only provides an explanation of the differential effect of monetary policy shocks across countries, but also shows that this effect is more prominent when banks tend to exhibit higher home bias in their bond portfolios.

V. Conclusion

Central bank communication has taken centre stage in both popular and academic literature since the advent of the 2008 financial crisis. However, measurement and understanding of central bank communication is problematic since identification is hampered by the mixing of conventional policy tools (such as target rate announcements) with communication about future policy. We provide a resolution of this problem by exploiting high-frequency data on

Eurozone money market rates to identify separately monetary policy actions from monetary policy communication.

To this end, we document the following findings. In the Eurozone, 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 financial crisis. We show that post 2009, target rate shocks significantly lowered the yield spread between peripheral and core countries but communication shocks increased the yield spread. This finding shows that communication shocks dampened some of the effects of the ECB's unconventional monetary policy tools aiming at lowering the yield spread.

We consider a set of standard explanations for this finding and reject them empirically. However, considering an alternative we rationalize this result in a model whereby the trade between risk-averse banks and pension funds generates a price of risk for monetary policy shocks in equilibrium. When the central bank announces changes to the current target rate or 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 pensions funds, which in turn alters 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. For the peripheral agent, similarly to (11), we have

$$\max x_c^T(\mu_c - r\mathbf{1}_N) + x_p^T(\mu_p - r\mathbf{1}_N) - \frac{\alpha}{2}\left(x_c^T\Omega_c + x_p^T\Omega_p\right)\left(x_c^T\Omega_c + x_p^T\Omega_p\right)^T - \frac{\phi}{2}x_c^T\Omega_c\Omega_c^T x_c \quad (24)$$

FOCs then become

$$0 = (\mu_c - r\mathbf{1}_T) - \alpha\Omega_c\left(\Omega_c^T x_c + \Omega_p^T x_p\right) - \phi\Omega_c\Omega_c^T x_c \quad (25)$$

and

$$0 = (\mu_p - r\mathbf{1}_T) - \alpha\Omega_p\left(\Omega_c^T x_c + \Omega_p^T x_p\right) \quad (26)$$

Combining (25) and (26), we write

$$\Omega_c^T x_c = \frac{1}{\phi}\left[\left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T(\mu_c - r\mathbf{1}_T) - \left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T(\mu_p - r\mathbf{1}_T)\right] \quad (27)$$

and

$$\Omega_p^T y_p = \frac{1}{\phi}\left[\left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T(\mu_p - r\mathbf{1}_T) - \left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T(\mu_c - r\mathbf{1}_T)\right] \quad (28)$$

and substituting these back into (26) and (12), respectively, we obtain

$$\Omega_p^T x_p = \frac{1}{\phi}\left[\frac{\alpha+\phi}{\alpha}\left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T(\mu_p - r\mathbf{1}_T) - \left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T(\mu_c - r\mathbf{1}_T)\right] \quad (29)$$

and

$$\Omega_c^T y_c = \frac{1}{\phi}\left[\frac{\alpha+\phi}{\alpha}\left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T(\mu_c - r\mathbf{1}_T) - \left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T(\mu_p - r\mathbf{1}_T)\right] \quad (30)$$

Imposing the market-clearing conditions $x_c + y_c = s_c$ and $x_p + y_p = s_p$ we get

$$\frac{2\alpha+\phi}{\alpha}\left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T(\mu_c - r\mathbf{1}_T) - 2\left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T(\mu_p - r\mathbf{1}_T) = \phi\Omega_c^T s_c$$

and

$$\frac{2\alpha+\phi}{\alpha}\left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T(\mu_p - r\mathbf{1}_T) - 2\left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T(\mu_c - r\mathbf{1}_T) = \phi\Omega_p^T s_p$$

Solving for $\left(\Omega_p^T\Omega_p\right)^{-1}\Omega_p^T\left(\mu_p - r\mathbf{1}_T\right)$ and $\left(\Omega_c^T\Omega_c\right)^{-1}\Omega_c^T\left(\mu_c - r\mathbf{1}_T\right)$ we obtain (15) and (16). Substituting those back into the first-order conditions yields (17) and (18). $\square$

Proof of Theorem 1. To be added. $\square$

Proof of Propositions 1-3. To be added. $\square$

Figures

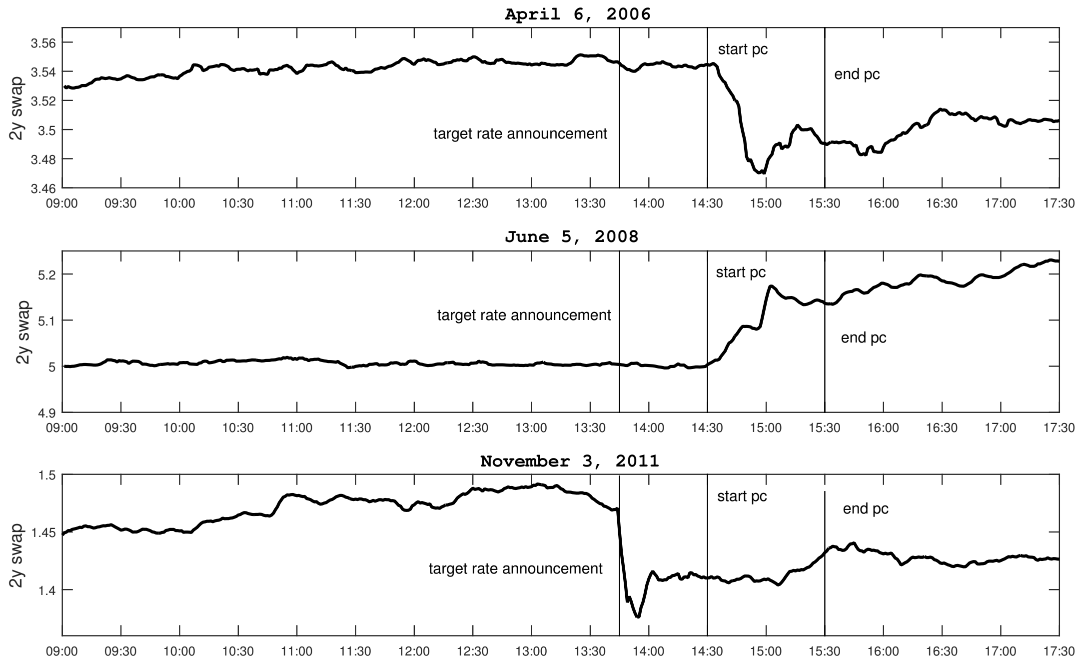

Figure 1. The two-year swap rate on three ECB announcement days
The figure plots the two-year swap rate on April 6, 2006 (upper panel), June 5, 2008 (middle panel) and November 3, 2011 between 09:00 and 17:30. Vertical lines represent the target rate announcement (13:45), the start of the press conference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

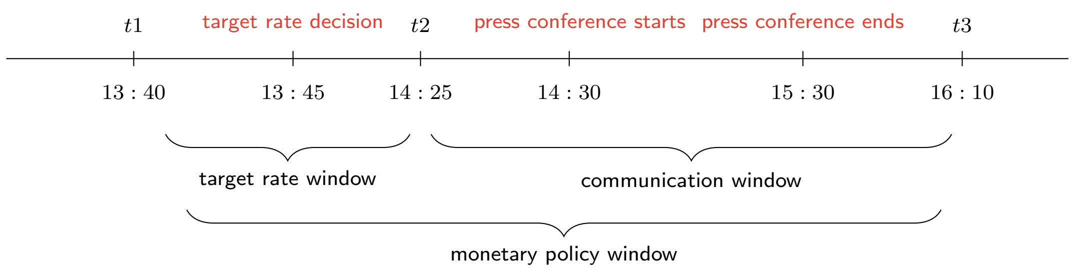

Figure 2. Monetary policy decision window
The figure illustrates the time line of ECB announcements. All times are in Central European Times (CET).

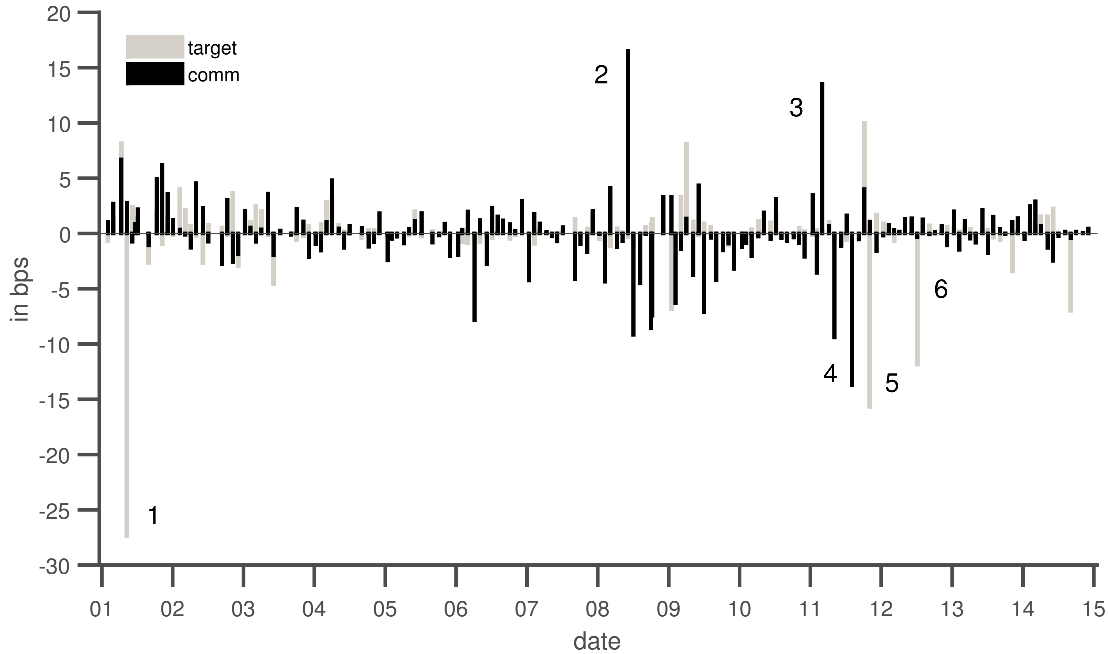

Figure 3. Time series of target and communication shocks
This figure plots target and communication shocks between 2001 and 2014. 1) May 10, 2001: surprise 25bps cut after dismal industrial production and unemployment numbers from Germany. 2) June 5, 2008: Trichet announces rate hike for next meeting. 3) March 3, 2011: 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 Draghi's first meeting. 6) July 5, 2012: 25bp cut to an all-time low to 0.75%.

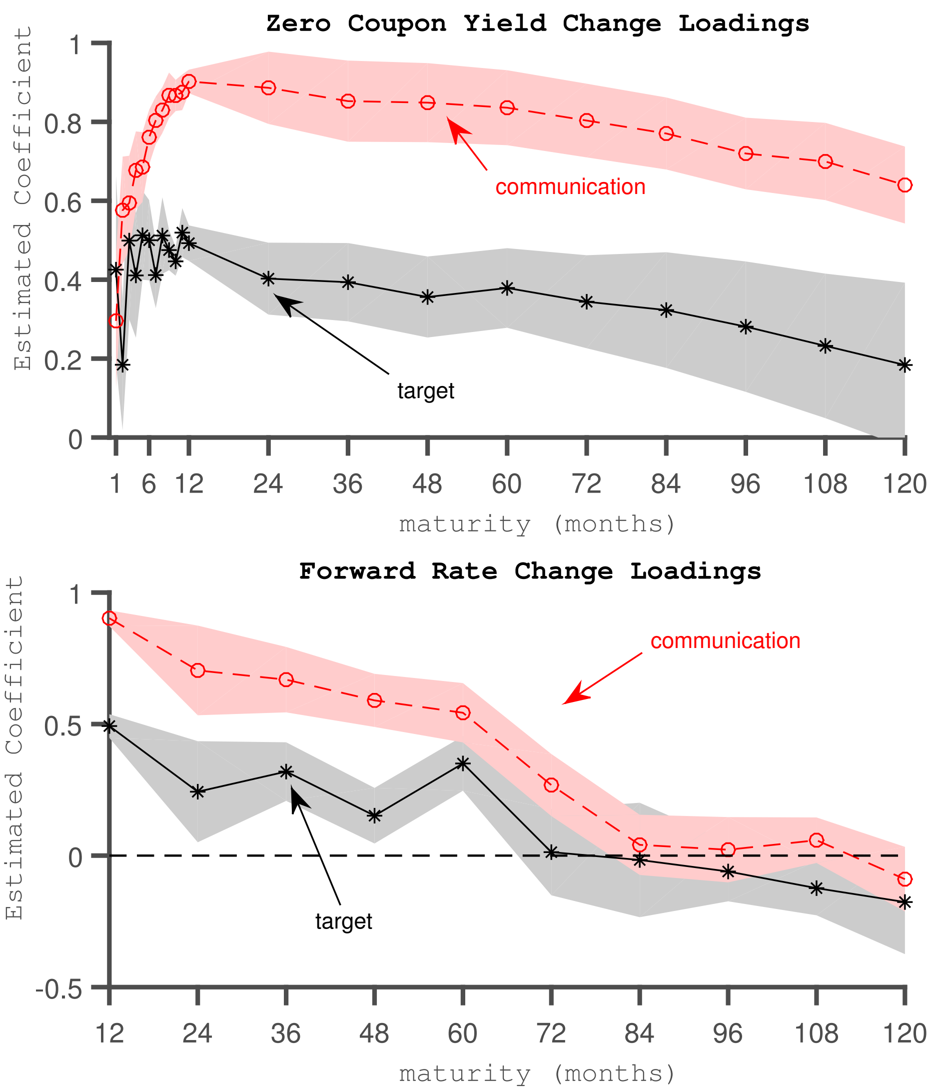

Figure 4. Yield and forward rate loadings on target and communication shocks
This figure plots estimated coefficients from a multivariate regression from changes in bond yields and one-year forwards on target and communication shocks:

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

where Δy_t^τ (Δf_t^τ) are zero coupon yield (forward) changes between 13:40 CET and 16:10 CET with maturities $\tau = 1, \ldots, 120$ months. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to December 2014.

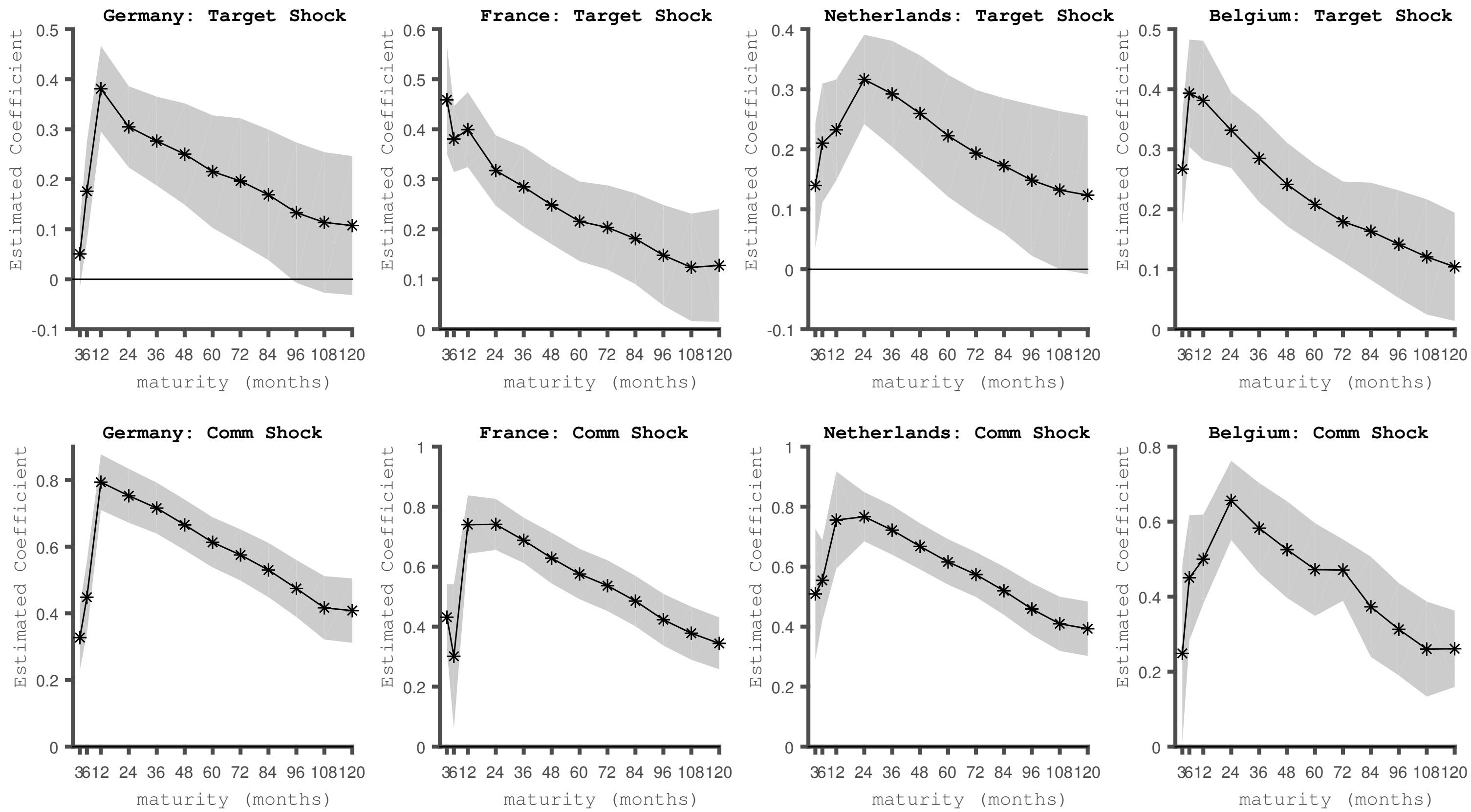

Figure 5. Core yield response to target and communication shocks

This figure plots the response of core countries' bond yields at different maturities for a target rate (upper panels) and communication (lower panels) shock on ECB announcement days. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to December 2014.

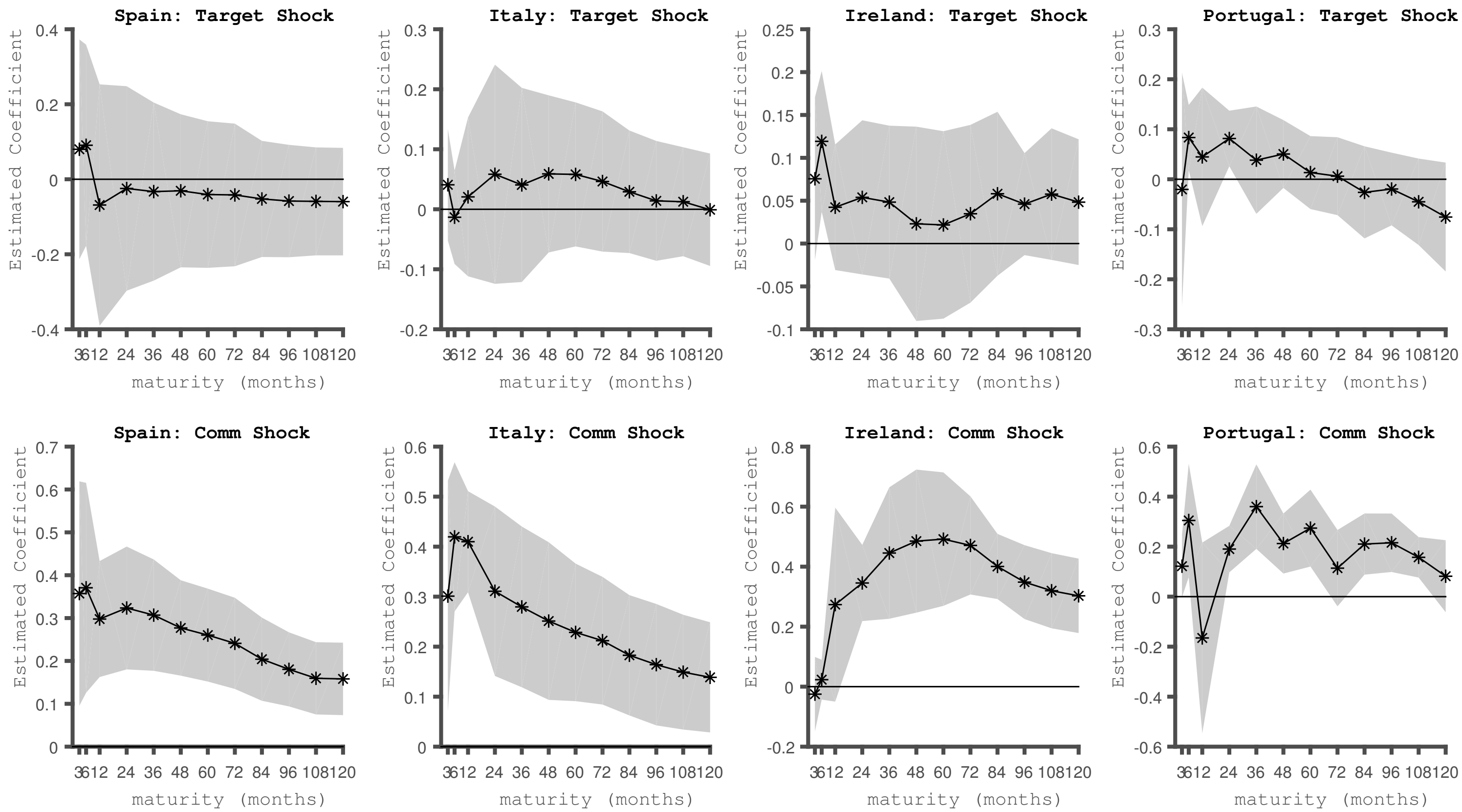

Figure 6. Peripheral yield response to target and communication shocks

This figure plots the response of peripheral countries' bond yields at different maturities for a target rate (upper panels) and communication (lower panels) shock on ECB announcement days. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to December 2014.

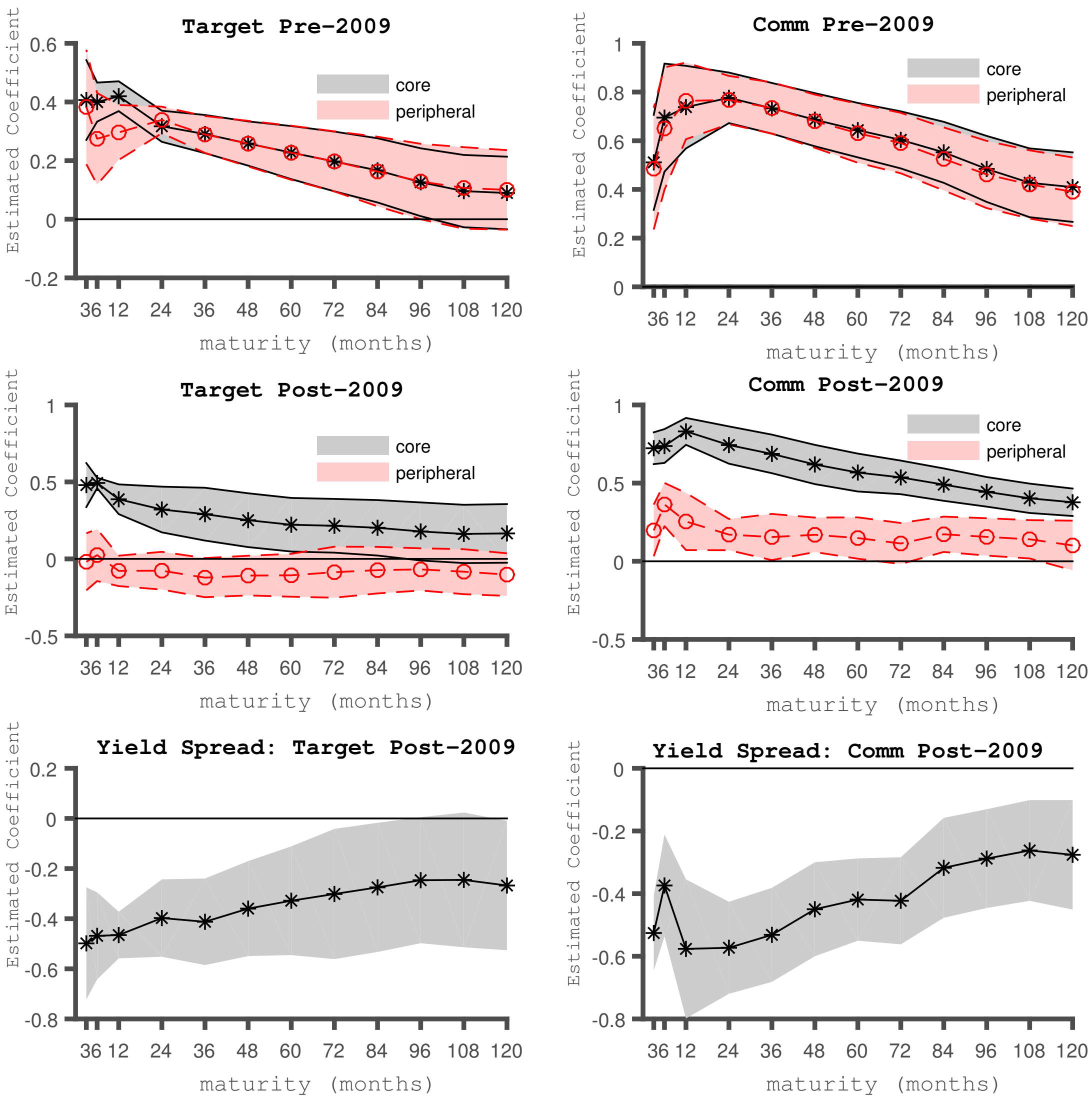

Figure 7. Sovereign yield reaction to shocks

This figure plots the response of core (solid line) and peripheral (dashed line) countries' bond yields, and the corresponding spread, for target rate (left) and communication (right) shocks on ECB announcement days, for different maturities:

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

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 December 2008 for the upper two panels and from January 2009 to December 2014 for the middle two panels. In the lower two panels, we plot estimated coefficients from regression the yield spread, that is the difference between peripheral and core country bond yield changes, onto target (lower left) and communication (lower right) shocks in the January 2009 to December 2014 period.

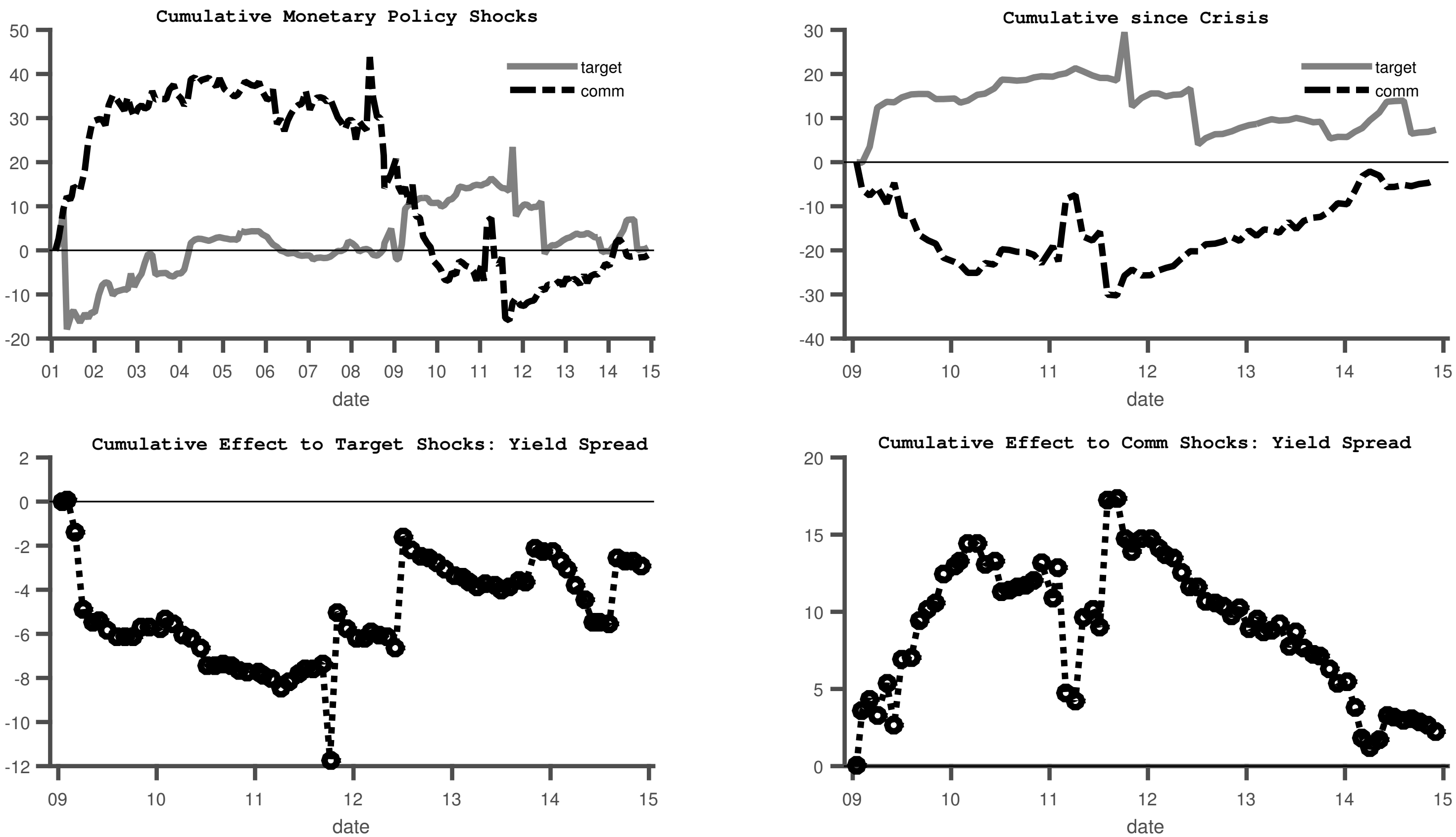

Figure 8. Cumulative target and communication shocks

This figure plots the cumulative sum of target (dashed line) and communication shocks (solid line) for the whole sample (upper left panel) and the crisis period (upper right panel). The lower left (right) panel plots the cumulative effect of target rate (communication) shocks on the two-year yield spread between peripheral and core countries.

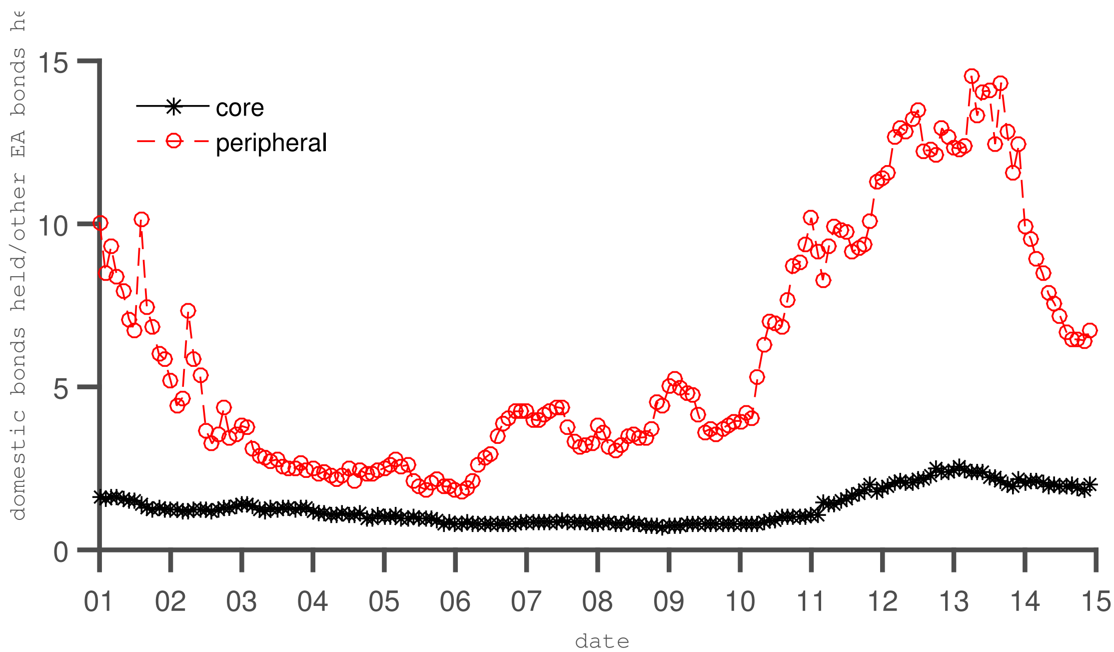

Figure 9. Home bias in core and peripheral countries

This figure plots home bias defined as the ratio between the amount of domestic bonds held and the amount of bonds held issued by other Euroarea countries. Data is monthly and running from January 2001 to December 2014.

Tables

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
November 6, 2008	Rate cut of 50bps with other central banks

Table I. 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.

	PC1	PC2	PC3
Monetary Policy	85.35	8.37	2.61
Target	80.74	11.62	1.47
Communication	83.65	6.76	4.89

Table II. 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.

	1m	2m	5m	10m	12m	24m
			Target Window			
PC1	0.65	0.52	0.59	0.47	0.46	0.32
t-stat	(5.25)	(3.88)	(9.89)	(8.09)	(9.70)	(4.79)
R^2	41.66%	26.90%	34.55%	21.83%	21.23%	10.08%
PC2	0.48	0.44	0.20	0.05	0.04	-0.16
t-stat	(6.99)	(6.05)	(3.67)	(0.90)	(0.74)	(-3.10)
R^2	22.78%	19.45%	4.10%	0.23%	0.17%	2.54%
			Communication Window			
PC1	0.34	0.67	0.77	0.86	0.86	0.78
t-stat	(2.72)	(8.93)	(15.81)	(22.52)	(19.83)	(9.52)
R^2	11.77%	44.28%	58.81%	73.99%	73.66%	60.59%
PC2	0.48	-0.04	0.09	-0.01	-0.03	-0.04
t-stat	(2.57)	(-0.32)	(0.48)	(-0.06)	(-0.16)	(-0.25)
R^2	23.20%	0.20%	0.85%	0.01%	0.10%	0.17%

Table III. 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:

$$\Delta y_t^\tau = \beta_1 \times \mathrm{PC}_t + \epsilon_t^\tau,$$

where PC_t is either the first or second PC from the target and communication window, respectively, and τ is the maturity. t-statistics are calculated using Newey and West (1987) allowing for serial correlation. Data runs from 2001 to 2014.

	Z_r	Z_θ
mean	0.000	0.000
stdev	3.240	3.298
min	-27.407	-13.746
max	9.997	16.544
skewness	-4.495	0.270
kurtosis	37.993	9.820

Table IV. Summary statistics of target and communication shocks

This table presents summary statistics for the target and communication shocks. Target (communication) 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.

	5y CDS	3m	6m	1y	2y	5y	10y	5y CDS	3m	6m	1y	2y	5y	10y
	Germany							Spain						
mean	0.163	1.870	1.897	1.984	2.124	2.687	3.373	0.912	2.110	2.257	2.454	2.901	3.732	4.590
stdev	0.167	1.542	1.539	1.530	1.488	1.394	1.175	1.114	1.367	1.307	1.247	1.173	0.990	0.796
max	0.914	4.914	4.835	4.731	4.703	4.995	5.355	5.042	6.185	8.063	8.394	7.850	7.895	7.492
min	0.013	-0.139	-0.625	-0.097	-0.104	0.021	0.574	0.023	-0.007	0.118	0.199	0.319	0.994	1.960
	France							Italy						
mean	0.313	1.881	1.909	2.007	2.207	2.845	3.577	0.957	2.246	2.385	2.980	3.440	4.168	4.899
stdev	0.354	1.541	1.541	1.521	1.472	1.311	1.101	1.127	1.482	1.500	1.955	2.428	2.032	1.714
max	1.987	4.855	4.834	4.750	4.815	5.062	5.465	5.015	5.466	9.807	18.171	24.265	16.690	12.098
min	0.015	-0.135	-0.523	-0.075	-0.040	0.095	0.718	0.053	0.048	-0.007	-0.012	0.017	0.483	1.358
	Netherlands							Ireland						
mean	0.295	1.923	1.937	2.013	2.227	2.895	3.672	1.526	2.108	2.245	2.454	2.865	3.672	4.479
stdev	0.265	1.521	1.503	1.488	1.424	1.232	0.965	2.172	1.341	1.283	1.219	1.096	0.968	0.890
max	1.299	4.740	4.682	4.660	4.831	4.919	5.432	11.940	5.770	6.027	6.070	6.854	7.690	7.692
min	0.011	-0.058	-0.068	-0.051	-0.048	0.183	0.851	0.017	0.016	0.046	0.114	0.192	0.776	1.678
	Belgium							Portugal						
mean	0.446	1.902	1.956	2.084	2.381	3.105	3.880	2.041	2.627	2.828	3.320	4.202	4.999	5.406
stdev	0.592	1.485	1.470	1.443	1.385	1.206	0.961	3.091	1.563	1.739	2.574	3.432	3.183	2.087
max	3.393	4.735	4.695	4.682	5.172	5.566	5.943	15.540	8.689	11.703	19.667	23.559	23.425	14.073
min	0.019	-0.116	-0.065	-0.055	-0.040	0.171	0.896	0.039	0.068	0.127	0.227	0.431	1.602	2.916

Table V. Summary statistics of CDS and bond yields

This table presents summary statistics for five-year CDS (first column) and bond yields (columns 2 to 7). Data is in percent and is sampled between 2002 (2001) and 2014 for CDS (bond yields).

	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y
Z_r	0.327	0.272	0.256	0.211	0.194	0.156	0.135	0.110	0.076	0.089
	(5.42)	(7.41)	(6.40)	(4.73)	(4.06)	(2.84)	(2.36)	(1.91)	(1.42)	(1.39)
Z_θ	0.770	0.735	0.660	0.656	0.607	0.573	0.515	0.460	0.411	0.397
	(16.51)	(13.39)	(12.83)	(8.66)	(8.39)	(7.81)	(9.41)	(7.83)	(7.31)	(6.38)
R^2	70.51%	61.71%	50.41%	47.74%	40.77%	35.45%	28.44%	22.44%	17.53%	16.58%

Table VI. Daily swap response to target and communication shocks

This table reports the results of multivariate regressions of daily changes in swap rates across different maturities on target ($Z_{r,t}$) and communication ($Z_{\theta,t}$) shocks. t-statistics are calculated using Newey and West (1987). Data runs from January 2001 to December 2014.

	Pre-2009								
		core				peripheral			spread
	GER	FRA	NED	BEL	SPA	ITA	IRE	POR	
Z^r	-0.070	-0.218	-0.337	-0.161	-0.171	-0.236	-0.281	-0.145	-0.047
	(-0.68)	(-1.36)	(-5.06)	(-0.89)	(-1.20)	(-1.16)	(-2.13)	(-1.39)	(-0.92)
Z^θ	0.047	0.063	-0.034	0.096	0.139	0.077	0.043	0.028	-0.012
	(0.59)	(1.14)	(-0.41)	(0.87)	(0.97)	(0.77)	(0.75)	(0.67)	(-0.18)
R^2	-0.41%	4.14%	10.18%	2.50%	3.89%	5.20%	6.99%	1.10%	-0.03%
	Post-2009								
		core				peripheral			spread
	GER	FRA	NED	BEL	SPA	ITA	IRE	POR	
Z^r	-0.280	-0.226	0.270	0.051	-0.104	-0.047	0.119	-0.109	-0.815
	(-1.85)	(-1.65)	(2.67)	(0.38)	(-0.71)	(-0.32)	(0.72)	(-0.53)	(-1.06)
Z^θ	-0.199	-0.218	0.108	-0.315	-0.139	-0.147	-0.012	0.115	0.057
	(-1.66)	(-4.43)	(0.76)	(-3.78)	(-2.41)	(-1.82)	(-0.13)	(1.72)	(1.21)
R^2	11.13%	9.22%	6.40%	8.82%	1.98%	1.25%	-0.01%	1.05%	7.41%

Table VII. Credit risk regressions

This table reports the results of multivariate regressions of daily changes in country level CDS as well as the spread between the median peripheral and median core country CDS on target ($Z_{r,t}$) and communication ($Z_{\theta,t}$) shocks:

$$\Delta \text{cds}_{i,t} = \beta_r Z_t^r + \beta_\theta Z_t^\theta + \epsilon_{i,cds,t}.$$

t-statistics are calculated using Newey and West (1987). Data runs from January 2002 to December 2008 (pre-crisis) and from January 2009 to December 2014 (post-crisis).

	Pre-2009		Post-2009	
	GDP	Infl	GDP	Infl
		Germany		
Z^r	-0.017	0.004	0.197	0.290
	(-0.24)	(0.04)	(1.23)	(2.84)
Z^θ	-0.029	0.140	0.209	0.064
	(-0.25)	(0.95)	(0.77)	(0.48)
R^2	0.11%	1.95%	8.79%	9.07%
		France		
Z^r	0.101	-0.055	0.325	-0.024
	(2.43)	(-0.45)	(1.68)	(-0.35)
Z^θ	-0.011	0.037	0.095	0.114
	(-0.09)	(0.34)	(0.43)	(0.97)
R^2	1.03%	0.44%	11.86%	1.32%
		Netherlands		
Z^r	0.099	-0.159	-0.066	0.100
	(1.56)	(-2.01)	(-0.27)	(1.03)
Z^θ	-0.021	0.159	0.151	-0.091
	(-0.17)	(1.01)	(0.89)	(-1.05)
R^2	1.02%	5.13%	2.59%	1.71%
		Italy		
Z^r	0.046	-0.024	0.315	0.188
	(0.46)	(-0.19)	(1.30)	(1.05)
Z^θ	-0.076	0.097	0.175	0.115
	(-0.69)	(0.78)	(1.32)	(1.36)
R^2	0.81%	1.01%	13.79%	5.17%
		Spain		
Z^r	-0.019	0.009	0.304	-0.134
	(-0.51)	(0.07)	(1.79)	(-0.59)
Z^θ	0.060	0.152	0.056	0.098
	(0.32)	(1.24)	(0.59)	(1.21)
R^2	0.41%	2.30%	9.77%	2.58%

Table VIII. Economic forecast revision regressions

This table reports the results of multivariate regressions of economic forecast revisions (short-term interest rate, inflation, output) for Germany, France, Netherlands, Spain and Italy on the target and communication shocks,

$$\Delta E[y^{3m}/\text{infl}/\text{output}]_{i,t} = \beta_r Z_{r,t} + \beta_\theta Z_{\theta,t} + \epsilon_{i,t}^{\text{forecast}}.$$

t-statistics are calculated using Newey and West (1987). Data runs from January 2001 to December 2008 (pre-crisis) and from January 2009 to December 2014 (post-crisis).

	3m	6m	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y
							Core					
home bias	0.005	-0.072	-0.141	-0.179	-0.167	-0.162	-0.143	-0.149	-0.149	-0.139	-0.117	-0.104
	(0.09)	(-1.34)	(-2.66)	(-1.96)	(-1.74)	(-1.62)	(-1.42)	(-1.53)	(-1.53)	(-1.45)	(-1.26)	(-1.11)
Z^r	1.443	0.711	1.126	1.162	1.264	1.170	0.948	0.904	0.947	0.994	0.996	0.993
	(2.99)	(4.38)	(5.81)	(2.25)	(2.41)	(2.45)	(2.20)	(2.08)	(1.95)	(1.86)	(1.85)	(1.78)
Z^θ	1.378	1.205	1.005	0.885	0.447	0.253	0.019	-0.148	-0.223	-0.314	-0.490	-0.556
	(2.58)	(3.20)	(2.44)	(1.42)	(0.61)	(0.32)	(0.02)	(-0.19)	(-0.30)	(-0.45)	(-0.75)	(-0.88)
interaction Z^r	-0.965	-0.222	-0.761	-0.869	-1.007	-0.952	-0.758	-0.723	-0.780	-0.851	-0.869	-0.861
	(-1.93)	(-1.41)	(-4.09)	(-1.76)	(-1.98)	(-2.01)	(-1.69)	(-1.59)	(-1.56)	(-1.56)	(-1.57)	(-1.50)
interaction Z^θ	-0.652	-0.457	-0.141	-0.100	0.284	0.409	0.588	0.727	0.756	0.800	0.932	0.970
	(-1.27)	(-1.13)	(-0.36)	(-0.17)	(0.41)	(0.53)	(0.75)	(0.94)	(1.02)	(1.15)	(1.41)	(1.52)
R^2	78.94%	80.81%	88.45%	71.29%	61.76%	50.45%	41.83%	38.50%	33.46%	28.32%	24.15%	22.07%
							Peripheral					
home bias	-0.136	-0.190	-0.130	-0.138	-0.198	-0.140	-0.146	-0.162	-0.150	-0.120	-0.068	-0.065
	(-1.16)	(-1.92)	(-1.56)	(-2.21)	(-2.55)	(-1.97)	(-2.09)	(-2.31)	(-1.99)	(-1.60)	(-0.87)	(-0.86)
Z^r	3.925	4.528	2.548	2.968	3.187	2.558	2.816	3.170	2.561	2.429	2.418	2.478
	(1.20)	(2.19)	(2.44)	(2.30)	(2.32)	(1.67)	(1.66)	(1.64)	(1.35)	(1.40)	(1.31)	(1.36)
Z^θ	4.332	4.615	3.635	2.748	4.676	3.520	3.811	4.103	3.129	3.267	2.906	3.383
	(2.61)	(3.38)	(1.86)	(2.31)	(2.85)	(2.61)	(2.72)	(2.97)	(2.17)	(2.26)	(2.09)	(2.25)
interaction Z^r	-3.947	-4.512	-2.631	-3.052	-3.317	-2.672	-2.928	-3.263	-2.642	-2.501	-2.501	-2.579
	(-1.23)	(-2.21)	(-2.54)	(-2.31)	(-2.38)	(-1.72)	(-1.70)	(-1.65)	(-1.37)	(-1.42)	(-1.34)	(-1.42)
interaction Z^θ	-4.107	-4.214	-3.356	-2.550	-4.485	-3.325	-3.636	-3.959	-2.929	-3.089	-2.751	-3.268
	(-2.49)	(-3.01)	(-1.66)	(-2.11)	(-2.73)	(-2.45)	(-2.57)	(-2.84)	(-2.02)	(-2.13)	(-1.97)	(-2.14)
R^2	10.34%	21.67%	11.01%	7.22%	11.30%	8.13%	8.13%	7.88%	7.38%	6.31%	5.23%	5.29%
ΔR^2	6.42%	8.39%	4.00%	3.77%	7.47%	4.15%	4.84%	5.87%	3.91%	3.45%	2.60%	3.26%

Table IX. Home bias regressions post-2009

This table reports the results of regressions of changes in yields of core countries (Germany, France, Netherlands, and Belgium) and peripheral countries (Italy, Portugal, Spain and Ireland) onto home bias of corresponding (core and peripheral) banks, target and communication shocks and the target and communication shocks interacted with the home bias proxy,

$$\Delta y_{i,t}^{\tau} = \beta_h \text{home bias}_{i,t} + \beta_r Z_t^r + \beta_\theta Z_t^\theta + \gamma_r \left(\text{home bias}_{i,t} \times Z_t^r\right) + \gamma_\theta \left(\text{home bias}_{i,t} \times Z_t^\theta\right) + \epsilon_t^\tau.$$

Home bias for each country is defined as the ratio between the amount of domestic bonds held and the total amount of bond held in each country. To construct a core and peripheral home bias, we take the average of all core and peripheral countries, respectively. t-statistics are calculated using robust standard errors clustered at the country level. ΔR^2 indicates the change in the adjusted R^2 relative to a multivariate regression, where we only control for target and communication shocks. Data runs from January 2009 to December 2014.