

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. However, we show that communication shocks have a large and economically significant impact on sovereign yields, displaying a hump-shaped pattern across maturity. 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 study two explanations for this finding, revelation of the ECB's private information and credit risk, and argue that neither channel can explain the effect on yield spreads. Motivated by this, we consider an alternative explanation in which central bank communication affects the aggregate demand due to the presence of reaching-for-yield investors. We show that a resulting risk premium channel helps to rationalize our findings.

Keywords: interest rates, monetary policy, sovereign bonds, reaching for yield

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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. One potential channel through which guidance can work is via its effect on risk premia.² However, direct identification of this channel is 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/or 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 only at short maturities consistent with the idea that the physical implementation of monetary policy is largely anticipated. 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

¹Some 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."

²Using 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 affect must be due to premia.

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

the communication shock; hence, communication matters.

Third, splitting our sample into the pre- and post-crisis periods, we find that before 2009 monetary policy shocks affect bond yields of all countries uniformly, while after 2009, 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 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 the ECB's communication shocks increased the spread between peripheral and core countries.

We try to rationalize these findings with three potential explanations: A large literature in macroeconomics studies whether the central bank's monetary policy signals information about the central bank's views about macroeconomic dynamics to private investors. In case of the ECB, one could think that lower expectations about the future path of interest rates could either lead to an anticipation of exogenous easing of future monetary policy (good news) or an anticipated endogenous policy response to a weaker economy (bad news). Using survey data on future output, unemployment, and inflation of core and peripheral countries, we find that private agents' forecast revisions as a response to communication shocks are only statistically relevant in the pre-2009 period. Moreover, we do not find any difference between forecast revisions about peripheral or core countries. We conclude from these findings that release of information to the public cannot drive the spread between peripheral and core countries. Another natural dimension along which core and peripheral countries differ is credit risk. Using panel regressions, we find that communication shocks actually lowered the credit spread between peripheral and core countries. Thus, we reject the hypothesis that credit risk is a likely driver of our results.

Finally, motivated by a growing empirical literature that explores the effect of reaching-for-yield investors, we rationalize our empirical findings in a parsimonious international dynamic equilibrium term structure model in which interest rates are determined through the interaction between risk-averse arbitrageurs and yield-oriented investors. Our focus on reaching-for-yield investors is motivated by recent empirical evidence that documents a tilt towards risky assets as interest rates reached a zero lower bound (see, e.g., Di Maggio and Kacperczyk (2016) for

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

the U.S. and Barbu, Fricke, and Moench (2016) for the Eurozone). These investors, instead of focusing purely on the risk-return tradeoff when investing in bonds, also care about the shape of the current yield curve: in effect, if the yield (or forward) curve is upward sloping, reaching-for-yield investors want to buy more long-maturity bonds for each unit of interest rate risk the bond bears.⁵ Because bond yields are the average expected returns earned through the lifetime of bonds, which depend on expected future risk-free rates and risk premia, 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.

A direct impact 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, 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: shocks, by influencing the demand of yield-oriented investors, effectively manifest as changes to the relative net supply of bonds that risk-averse arbitrageurs have to hold in equilibrium. For example, a positive communication shock that lifts all yields, especially medium-term ones, via the expectation channel also increases the relative demand of yield-oriented investors for all bonds. In turn, this change in relative net supplies translates to a decreasing equilibrium risk premium on all bonds that risk-averse arbitrageurs demand. Therefore, the risk premium channel dampens the direct effect of a communication shocks on yields, especially for medium-term yields: the hump shifts down and towards longer maturities. The difference in the proportion of yield-oriented investors across countries implies that the indirect effect is more prominent in peripheral countries than in core countries. Hence, our model provides an understanding of how target rate and communication shocks affect the term structure in equilibrium, both in the cross-section of 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

⁵For empirical evidence on investors “reaching for yield” in the Eurozone see, e.g., Acharya and Steffen (2015). In their paper, the authors show that some of the European commercial banks pursued high economic risk and return investing by high-yielding long-term government debt financed with low-yielding short-term wholesale funds. Barbu, Fricke, and Moench (2016) empirically document a strong link between expectations about future short-rates and reaching for yield behavior of German investment funds since 2009.

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.⁶ 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 most 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 target rate announcement and press conference at different points in time; thus, allowing a simple yet clean separation of these effects.⁷

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 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

⁶A 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.

⁷The 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.

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 the dominant factor driving interest rate changes on announcement days.⁸

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 net 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, while also providing a multi-country setting that can allow for additional dimensions of heterogeneity, including the amount of government debt and credit risk. Moreover, the existence of reaching-for-yield investors gives rise to a risk premium channel absent in a model where there are only risk-averse arbitrageurs, which allows us to study cross-sectional differences between core and peripheral countries.

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.

⁸Indeed, 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.”

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, the idea is 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 $F = Y\Omega$.

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 five 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, publishing forecasts (including interest rates) with a projection horizon of two years (extended to three years as of December 2016).⁹

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.

[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

⁹See here <http://www.ecb.europa.eu/pub/projections/html/index.en.html>.

constructed during the target rate window. For PC1, we find that the t -statistics are highly significant from the shortest maturity swap rate (one month) out to two years, and adjusted R^2 s 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.

We now want to study the joint effect of the first PCs from the target rate and communication window onto swap rate changes. To this end, we run the following multivariate regression:

$$\Delta y_t^\tau = \beta_r \text{PC1}_t^{\text{target}} + \beta_\theta \text{PC1}_t^{\text{comm}} + \epsilon_t^\tau,$$

where Δy_t^τ are changes in swap rates during the monetary policy window, and $\text{PC1}_t^{\text{target}}$ ($\text{PC1}_t^{\text{comm}}$) is the first PC from the target (communication) window, respectively.

Figure 3 depicts estimated coefficients together with the 90% confidence intervals. We note that in line with the univariate results, PC1 from the target rate window has a strong and significant effect mostly at the short-end and dies off as the maturity increases. PC1 from the communication window, however, mostly has an effect on intermediate maturities.

[Insert table 3 here]

Overall, we conclude that one shock extracted from the target rate and the communication window can well explain the variation of yields. Whereas the former is mostly responsible for

movements at the short end of the term structure, communication shocks affect intermediate maturities around one and two years.

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 target and communication shocks exhibit significant excess kurtosis.

[Insert table IV here]

Figure 4 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 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 4: On July 5, 2012, the ECB cut interest rates by 25bps to an all-time low.

[Insert figure 4 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, unemployment, and inflation forecasts from Consensus Economics. We have four quarter forecasts on Germany, France, Netherlands, Spain, and Italy. Belgium, Portugal, and 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. 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.

¹⁰Markit 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.

A. Daily swap rates

Before moving to sovereign bond yields, we explore the effect of monetary policy shocks on daily swap yield changes. What we are mostly interested in is whether monetary policy shocks which are estimated from high-frequency yield changes with maturity up to two years have an effect on longer maturity yields. Earlier literature documents a strong impact of monetary policy shocks on U.S. 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. Both papers cast the large effect as a puzzle.

To examine the effect of target and communication shocks on swap rates, we run multivariate regressions from swap rate changes on our two proxies of monetary policy shocks. The results are gathered in Table VI. Target rate shocks have a highly significant effect on daily swap rate changes, especially at the short end and the effect dies out and becomes insignificant for maturities larger than nine years. Estimated coefficients for communication shocks, on the other hand, 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 32bps change in the one-year maturity swap rate whereas communication shocks induce a 77bps increase. For the ten-year swap rate, the effect of communication shocks is still economically large, as it is around 40bps. An effect which is similar in size to the one reported for U.S. Treasury yields.

[Insert table VI here]

B. Sovereign bond yields

The main focus of our paper is to study how ECB monetary policy affects sovereign bond yields. As a first exercise, we regress changes in yields onto the target rate and communication shocks jointly:

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

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. 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 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. 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:

$$\Delta (y_{p,t}^\tau - y_{c,t}^\tau) = \beta_{pc,r}^\tau Z_{r,t} + \beta_{pc,c}^\tau Z_{\theta,t} + \epsilon_{pc,t}^\tau,$$

where $y_{p,t}^\tau$ is the median maturity- τ yield of all peripheral countries and $y_{c,t}^\tau$ is the corresponding yield of core countries at time t . We summarize the results on target rate shocks in the left panel and on communication shocks in the right panel of Figure 7. Indeed, we find that monetary policy shocks have strong effects on the yield spread between risky and safer Eurozone countries, especially at the short-end. For example, for any 100bps target rate shock, there is a 40bps change and similarly a 40bps change for communication shocks for the three-month spread. To summarize, these results indicate that before 2009, ECB monetary policy had a uniform effect on both core and peripheral countries. Any cross-country differences emerged only since then.

[Insert figure 7 here]

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. Since our analysis includes both conventional and unconventional announcements, it is natural to ask whether the conduct of monetary policy since 2009 in general has affect yield spreads. We first plot in Figure 9 (upper panels) the cumulative target and communication shocks for the entire period and for the period between January 2009 to December 2014.

[Insert figure 9 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 points towards the fact that the target rate which was set was higher than what the market expected. For the communication shock, however, we find the opposite: The 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 coefficients for the yield spread, we can derive the cumulative effect of target and communication shocks during the crisis period. In Figure 9 (lower panels), we plot the cumulative effect of target (left lower panel) and communication (right lower panel) shocks onto the yield spread, where we multiply the cumulative shocks with the estimated coefficients from Figure 8. 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 evaporated and is hovering around zero. Communication shocks, on the other hand, have a positive effect on the yield spread which is increasing until 2011/2012 and then slightly decreasing again but still positive.

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 actually making peripheral countries' bonds more risky relative to core countries' bonds. 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 signalled (unintentionally) bad news to the market about peripheral countries.

D.1. 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.¹¹

In case of the ECB, information can be revealed either through interest rate setting or through communication. One prominent example 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 check whether monetary policy shocks are linked to inflation, output, and unemployment 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. The results are summarized in Table VII

[Insert table VII 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 raise unemployment and lower inflation. Our estimates indicate mixed results depending on the time period considered.¹² We summarize our findings as follows. First,

¹¹For 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.

¹²Campbell, 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.

private forecasters significantly revise their expectations after a monetary policy surprise, both pre- and post-crisis.¹³ For example, for the pre-2009 period, we find that a positive target shock leads to a downward revision of expected output which is fully aligned with standard New Keynesian macro models. Interestingly, communication shocks seem to have the opposite effects and estimated loadings are of similar size than for target rate shocks. Post-2009, the signs switches for the estimated effect on output. Positive target rate shocks lead to an upward revision in expected output. Communication shocks still increase inflation but the estimated effect is not statistically different from zero. Second, more important for our purposes, we now want to assess whether the estimates can explain the fact that communication shocks increase spreads between peripheral and core countries. To this end, we can look at the interaction terms between the monetary policy shocks and the dummy. For example, the interaction term on the communication shocks is never significant except for for expected output in the post-crisis period, however, the coefficient on the communication shock itself is not significant. This implies that there is no differential effect between peripheral and core countries from the transmission mechanism of central bank communication.

D.2. Credit risk

An obvious channel through which monetary policy can affect bond yields is through their credit risk. To see why, we plot in Figure 10 five-year bond yields (upper panel) and CDS (lower panel) for core and peripheral countries. We notice that right up until the Eurozone crisis, neither the bond yields nor the CDS are significantly different between core and peripheral countries. However, the core and peripheral yields diverge after the eruption of the Eurozone debt crisis in the summer of 2008. One natural driver between peripheral and core countries could therefore be credit risk.¹⁴

[Insert figure 10 here]

To check our hypothesis, we run a panel regression of changes in log CDS around monetary policy announcements on policy shocks interacted with a dummy:

$$\Delta \log \text{cds}_{i,t} = \beta_r Z_{r,t} + \gamma_r \mathbf{1}^P Z_{r,t} + \beta_\theta Z_{\theta,t} + \gamma_\theta \mathbf{1}^P Z_{\theta,t} + \epsilon_{i,\text{cds},t},$$

¹³Not surprisingly, R^2 are low since we do not expect monetary policy to account for the bulk of macroeconomic information. In the Online Appendix, we control for realized macroeconomic outcomes and we find R^2 to be significantly higher.

¹⁴It 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 debt.

where $\mathbf{1}^P$) is an indicator function that takes the value of one if country i is a peripheral country. In this regression, we are mainly interested in parameters γ_r and γ_θ which tell us how target and communication shocks affect countries' CDS in addition when they are a peripheral country. We account for country fixed-effects, and standard errors are clustered at the country level. Results of this regression are presented in Table VIII.

[Insert figure VIII here]

We note that both target and communication shocks have an insignificant effect on countries' credit risk both in the pre-crisis period. Moreover, also the estimated coefficients on the dummies are insignificant which implies that there is no differential effect between core and peripheral countries on countries' CDS. In the post-2009 period both estimated coefficients for the target and communication shock are significant. Since target rate shocks were negative

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. If anything, the results go in the wrong direction: Central bank communication decreased the credit risk component between peripheral and core countries.

D.3. Reaching for yield

Recent empirical evidence shows strong reaching-for-yield behavior both for the U.S. and Europe. For example, Barbu, Fricke, and Moench (2016) document that a majority of German investment funds reach for yield in low interest rate environments.¹⁵ In the following, we propose a mechanism based on reach-for-yield investors which could potentially rationalize our findings.

IV. Model

In this section we propose a parsimonious dynamic equilibrium term structure model to rationalize our baseline empirical results about the role of central bank communication on the yield curve. Interest rates are determined by the interaction between risk-averse arbitrageurs and yield-oriented investors, who operate only in a subset of countries. Proofs of our main results, as well as alternative models, are presented in the Appendix.

¹⁵Di Maggio and Kacperczyk (2016) document a similar finding for U.S. mutual funds. In particular, they find that these mutual funds react to Federal Reserve announcements when tilting their portfolio towards riskier assets. Becker and Ivashina (2015) find that U.S. insurance companies engage in reach for yield within regulatory-confined risk categories.

A. Bond market

Time is continuous and goes from zero to infinity. Agents, specified below, can buy defaultable zero-coupon bonds of countries $i = 1, \dots, I$ or put their money into an instantaneously riskfree money market account that pays net return r_t . We denote the time t price of a zero-coupon bond of country i paying one dollar at maturity $t + \tau$, $\tau \in (0, T]$, by $P_{i,t}^\tau$, its yield-to-maturity by

$$y_{i,t}^\tau = -\frac{\log P_{i,t}^\tau}{\tau}, \quad (3)$$

and the instantaneous forward rate by

$$f_{i,t}^\tau = \lim_{\Delta\tau \rightarrow 0} \left\{ -\frac{\log P_{i,t}^\tau - \log P_{i,t}^{\tau-\Delta\tau}}{\Delta\tau} \right\} = -\frac{\partial \log P_{i,t}^\tau}{\partial \tau}. \quad (4)$$

The instantaneously riskfree short rate r_t is assumed to be exogenously given, and its dynamics under the physical probability measure follows

$$dr_t = \kappa_r (\theta_t - r_t) dt + \sigma_r dB_{r,t}, \quad (5)$$

where

$$d\theta_t = \kappa_\theta (\bar{\theta} - \theta_t) dt + \sigma_\theta dB_{\theta,t}. \quad (6)$$

According to (5), the short rate 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 unconditional long-run mean of θ_t and hence of r_t . We think of r_t as being the target rate set by the central bank, and interpret $dB_{r,t}$ as changes to the target rate unexpected by investors, and $dB_{\theta,t}$ as the unexpected component of changes to the future path of interest rates, i.e., forward guidance or communication shocks.

We assume that the net supply of bonds coming from governments, central banks, and other unmodelled market participants is exogenously given: at time t , the dollar value of the bond of country i with time-to-maturity τ supplied to investors is $s_{i,t}^\tau$. For simplicity, we assume that bond supply is constant over time for every i and τ , i.e., $s_{i,t}^\tau = s_i^\tau$.¹⁶

The default of country i is triggered by the jump of an unpredictable process $Z_{i,t} \equiv 1_{\{v_i \leq t\}}$,

¹⁶This assumption, for instance, implies that governments and central banks actively trading all bonds in a manner that keeps aggregate debt constant. In the Appendix we consider an alternative model in which the number of bonds remains constant over time but the dollar value changes due to price changes, which corresponds to governments issuing the longest possible maturity bond at all times but not actively participating in bond markets afterwards. In order to solve the model in closed form, we need to rely on a linear approximation, and we show that that specification leads to qualitatively similar predictions as the one considered here.

where v_i is the random default time that occurs with default intensity $\lambda_{i,t}$ under the physical probability measure. Specifically, we have

$$\mathbb{E}_t^\mathbb{P}[dZ_{i,t}] = \mathbb{E}_t^\mathbb{P}[(dZ_{i,t})^2] = \lambda_{i,t} 1_{\{v_i > t\}} dt. \quad (7)$$

We allow $\lambda_{i,t}$ to be stochastic; we assume that $\lambda_{i,t}$ is given by

$$d\lambda_{i,t} = \kappa_{\lambda,i} (\bar{\theta}_{\lambda,i} - \lambda_{i,t}) dt + \sigma_{\lambda,i} dB_{\lambda,i,t}, \quad (8)$$

independent of all $Z_{i,t}$ s.¹⁷ Finally, we assume that the Brownian motions of the model are pairwise independent of each other.¹⁸

Bonds are held by competitive financial institutions, who can be of two types. Institutions from the first class, in measure $0 < 1 - \phi \leq 1$, have mean-variance preference over the instantaneous change in the value of their bond portfolio. If $x_{i,t}^\tau$ denotes the dollar amount they hold in country- i maturity- τ bonds at time t , their budget constraint is

$$dW_t = \left(W_t - \sum_{i=1}^I \int_0^T x_{i,t}^\tau d\tau \right) r_t dt + \sum_{i=1}^I \int_0^T x_{i,t}^\tau \frac{dP_{i,t}^\tau}{P_{i,t}^\tau} d\tau, \quad (9)$$

and their optimization problem is given by

$$\max_{\{x_{i,t}^\tau\}_{i=1,\dots,I;\tau \in (0,T]}} \mathbb{E}_t[dW_t] - \frac{\alpha}{2} \text{Var}_t[dW_t], \quad (10)$$

where α is their absolute risk aversion. Financial institutions from the second class, referred to as yield-oriented or reaching-for-yield investors, are in measure ϕ . They have slightly different preferences from mean-variance investors that we discuss below, and their bond holdings are denoted by $z_{i,t}^\tau$. The two types of financial institutions have to hold all bonds in equilibrium, so the market clearing condition is

$$(1 - \phi) x_{i,t}^\tau + \phi z_{i,t}^\tau = s_i^\tau \quad (11)$$

¹⁷Notice that under (8), $\lambda_{i,t}$ can go negative. Instead, we could assume a volatility term $\sqrt{m_i + n_i \lambda_{i,t}}$ that would keep $\lambda_{i,t}$ above a pre-specified level; this, while making our analytical solutions more elaborate, would lead to the same qualitative predictions as our current model.

¹⁸Alternatively, we could allow for stochastic bond supply, and set the default intensity constant over time but varying across countries. In that case, just as in the current setting, we would obtain an equilibrium with bond yields affine in the factors of the model. This alternative would not only lead to qualitatively similar predictions, but would in fact imply the same loadings on the short rate and the communication rate. Assuming that both bond supply and default intensity are stochastic, however, would take us outside the class of affine models.

for all i , t , and τ .

B. Equilibrium term structures

We look for equilibria in which bond prices can be written as

$$P_{i,t}^\tau(r_t, \theta_t, \lambda_{i,t}) = e^{-[A_i(\tau) + B_i(\tau)r_t + C_i(\tau)\theta_t + D_i(\tau)\lambda_{i,t}]} (1 - Z_{i,t}), \quad (12)$$

which also implies bond yields and forward rates are affine in the factors r_t , θ_t and $\lambda_{i,t}$ as long as country i does not default:

$$y_{i,t}^\tau = \frac{A_i(\tau)}{\tau} + \frac{B_i(\tau)}{\tau} r_t + \frac{C_i(\tau)}{\tau} \theta_t + \frac{D_i(\tau) \lambda_{i,t}}{\tau} \quad (13)$$

and

$$f_{i,t}^\tau = A'_i(\tau) + B'_i(\tau) r_t + C'_i(\tau) \theta_t + D'_i(\tau) \lambda_{i,t}. \quad (14)$$

Applying Itô's lemma to (12), the price processes are in the form

$$\frac{dP_{i,t}^\tau}{P_{i,t}^\tau} = \mu_{i,t}^\tau dt - \sigma_{r,i,t}^\tau dB_{r,t} - \sigma_{\theta,i,t}^\tau dB_{\theta,t} - \sigma_{\lambda,i,t}^\tau dB_{\lambda,i,t} - dZ_{i,t}, \quad (15)$$

with

$$\begin{aligned} \mu_{i,t}^\tau &= A'_i(\tau) + B'_i(\tau) r_t + C'_i(\tau) \theta_t + D'_i(\tau) \lambda_{i,t} - B_i(\tau) \kappa_r (\theta_t - r_t) - C_i(\tau) \kappa_\theta (\bar{\theta} - \theta_t) \\ &\quad - D_i(\tau) \kappa_{\lambda,i} (\bar{\theta}_{\lambda,i} - \lambda_{i,t}) + \frac{1}{2} B_i^2(\tau) \sigma_r^2 + \frac{1}{2} C_i^2(\tau) \sigma_\theta^2 + \frac{1}{2} D_i^2(\tau) \sigma_{\lambda,i}^2, \\ \sigma_{r,i,t}^\tau &= B_i(\tau) \sigma_r, \quad \sigma_{\theta,i,t}^\tau = C_i(\tau) \sigma_\theta, \text{ and } \sigma_{\lambda,i,t}^\tau = D_i(\tau) \sigma_{\lambda,i}. \end{aligned} \quad (16)$$

Combining (9), (10), and (15), we obtain that the optimization problem of mean-variance investors is equivalent to

$$\begin{aligned} \max_{\{x_{i,t}^\tau\}_{i=1,\dots,I;\tau \in (0,T]}} & \sum_{i=1}^I \int_0^T x_{i,t}^\tau (\mu_{i,t}^\tau - r_t - \lambda_{i,t}) d\tau - \frac{\alpha}{2} \left[\sum_{i=1}^I \int_0^T x_{i,t}^\tau \sigma_{r,i,t}^\tau d\tau \right]^2 \\ & - \frac{\alpha}{2} \left[\sum_{i=1}^I \int_0^T x_{i,t}^\tau \sigma_{\theta,i,t}^\tau d\tau \right]^2 - \frac{\alpha}{2} \sum_{i=1}^I \left[\int_0^T x_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau \right]^2 - \frac{\alpha}{2} \sum_{i=1}^I \lambda_{i,t} \left[\int_0^T x_{i,t}^\tau d\tau \right]^2. \end{aligned} \quad (17)$$

After some algebra, the FOC with respect to $x_{i,t}^\tau$ becomes

$$\begin{aligned} \mu_{i,t}^\tau - r_t - \lambda_{i,t} = & \alpha \sigma_{r,i,t}^\tau \left[\sum_{j=1}^I \int_0^T x_{j,t}^\tau \sigma_{r,j,t}^\tau d\tau \right] + \alpha \sigma_{\theta,i,t}^\tau \left[\sum_{j=1}^I \int_0^T x_{j,t}^\tau \sigma_{\theta,j,t}^\tau d\tau \right] \\ & + \alpha \sigma_{\lambda,i,t}^\tau \left[\int_0^T x_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau \right] + \alpha \lambda_{i,t} \left[\int_0^T x_{i,t}^\tau d\tau \right]. \end{aligned} \quad (18)$$

Equation (18) states that a bond's expected excess return $\mu_{i,t}^\tau - r_t$ compensates mean-variance bondholders for all the risk they bear when holding bond τ of country i . These include the risks of target rate changes and of communication shocks, and the default risk intensity of the given country ($\lambda_{i,t}$) and its stochastic nature. The four components of the right-hand side of (18) are all proportional to the amount of risk held per bond (e.g. $\sigma_{r,i,t}^\tau$ for the target rate shocks), and the proportionality coefficient ($\alpha \sum_{j=1}^I \int_0^T x_{j,t}^\tau \sigma_{r,j,t}^\tau d\tau$ in the case of the target rate shocks) is the market price of the corresponding risk factor. In turn, the market prices of risk depend on how much (target-rate) risk investors have to hold on aggregate, and it is the same for all bonds exposed to the specific risk factor, simply due to the absence of arbitrage, and regardless of other ingredients of the model.

We directly write the optimization problem of the reaching-for-yield agents as

$$\begin{aligned} \max_{\{z_{i,t}^\tau\}_{\tau \in (0,T], i \in \mathcal{J}}} & \sum_{i \in \mathcal{J}} \int_0^T z_{i,t}^\tau (f_{i,t}^\tau - B'_i(\tau) r_t - \lambda_{i,t}) d\tau - \frac{\alpha}{2} \left[\sum_{i \in \mathcal{J}} \int_0^T z_{i,t}^\tau \sigma_{r,i,t}^\tau d\tau \right]^2 \\ & - \frac{\alpha}{2} \left[\sum_{i \in \mathcal{J}} \int_0^T z_{i,t}^\tau \sigma_{\theta,i,t}^\tau d\tau \right]^2 - \frac{\alpha}{2} \sum_{i \in \mathcal{J}} \left[\int_0^T z_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau \right]^2 - \frac{\alpha}{2} \sum_{i \in \mathcal{J}} \lambda_{i,t} \left[\int_0^T z_{i,t}^\tau d\tau \right]^2, \end{aligned} \quad (19)$$

and require $z_{i,t}^\tau = 0$ for $i \notin \mathcal{J}$.

Yield-oriented agents are assumed to be different from mean-variance investors in two aspects. The first difference between (17) and (19) is that we assume that reaching-for-yield investors buy (long-term) bonds of only a subset of the countries, potentially due to unmodelled entry or transaction costs; we denote this subset by $\mathcal{J}$ where $|\mathcal{J}| = J < I$.

Second, we replace the instantaneous expected return of the bond, $\mu_{i,t}^\tau - r_t$, with the term $f_{i,t}^\tau - B'_i(\tau) r_t$. The motivation for this objective is that while yield-oriented investors dislike risk, they care about the shape of the current yield or forward curve instead of only the expected instantaneous returns: Intuitively, having the forward rate in the objective implies that if the yield curve is upward sloping, then reaching-for-yield investors think of long-maturity bonds as a better deal than short-maturity bonds, and want to buy more of them for each unit risk of

the bond.¹⁹ The adjustment term $B'_i(\tau) r_t$ makes sure that a level shift that moves the target rate r_t has no impact on the demand of reaching-for-yield investors.

Why the focus on remaining lifespan returns on bonds instead of instantaneous returns over the next dt period? This assumption arises naturally in the case of large financial institutions that classify debt as 'held-to-maturity' for accounting purposes. Unlike securities classified as 'available-for-sale' or for 'trading' purposes, which are marked to market, held-to-maturity-classified securities are reported as amortized cost and not subject to intermediate accounting losses. The amount of securities declared as 'held-to-maturity' typically constitute a large fraction of the balance sheet of financial institutions.²⁰ Overall, the two components of our assumption are rooted in the observation of Acharya and Steffen (2015), who find that European banks were pursuing risky investments in high-yielding long-term sovereign debt, and financed them with low-yielding short-term wholesale funds.

Similar to (18), the FOC with respect to $z_{i,t}^\tau$ for $i \in \mathcal{J}$ then becomes

$$\begin{aligned} f_{i,t}^\tau - B'_i(\tau) r_t - \lambda_{i,t} &= \alpha \sigma_{r,i,t}^\tau \left[\sum_{j \in \mathcal{J}} \int_0^T z_{j,t}^\tau \sigma_{r,j,t}^\tau d\tau \right] + \alpha \sigma_{\theta,i,t}^\tau \left[\sum_{j \in \mathcal{J}} \int_0^T z_{j,t}^\tau \sigma_{\theta,j,t}^\tau d\tau \right] \\ &+ \alpha \sigma_{\lambda,i,t}^\tau \int_0^T z_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau + \alpha \lambda_{i,t} \int_0^T z_{i,t}^\tau d\tau. \end{aligned} \quad (20)$$

Combining (11), (18), and (20), we obtain

$$\begin{aligned} \mu_{i,t}^\tau - r_t - \lambda_{i,t} &= \frac{1}{1-\phi} \alpha \sigma_{r,i,t}^\tau \left[\sum_{j=1}^I \int_0^T s_i^\tau \sigma_{r,j,t}^\tau d\tau \right] + \frac{1}{1-\phi} \alpha \sigma_{\theta,i,t}^\tau \left[\sum_{j=1}^I \int_0^T s_i^\tau \sigma_{\theta,j,t}^\tau d\tau \right] \\ &+ \frac{1}{1-\phi} \alpha \sigma_{\lambda,i,t}^\tau \int_0^T s_i^\tau \sigma_{\lambda,i,t}^\tau d\tau + \frac{1}{1-\phi} \alpha \lambda_{i,t} \int_0^T s_i^\tau d\tau - \mathbf{1}_{i \in \mathcal{J}} \frac{\phi}{1-\phi} (f_{i,t}^\tau - B'_i(\tau) r_t - \lambda_{i,t}). \end{aligned} \quad (21)$$

Finally, substituting (14) and (16) into (21), after some algebra, we obtain the equilibrium functions $A_i(\cdot)$ to $D_i(\cdot)$ for both $i \in \mathcal{J}$ and $i \notin \mathcal{J}$:

¹⁹The exact relationship of yields and forward rates, as implied by (3) and (4), is given by $f_{i,t}^\tau = \frac{\partial}{\partial \tau} (\tau y_{i,t}^\tau) = y_{i,t}^\tau + \tau \frac{\partial}{\partial \tau} y_{i,t}^\tau$, that is, the objective of yield-oriented investors is not equivalent to replacing $f_{i,t}^\tau$ by $y_{i,t}^\tau$. In the Appendix, we consider alternatives to this modelling choice, including having $y_{i,t}^\tau$ in the optimization problem instead of $f_{i,t}^\tau$. We show that some of these alternatives do not admit affine equilibria, whereas others result in a more elaborate analytical solution for the equilibrium term structure, while neither having any additional intuition nor changing the qualitative results of this section. We further show that our specification with forward rates essentially generalizes the discrete-time two-asset setup (short- and long-term bonds) of Hanson and Stein (2015) to continuous time and a continuum of bonds.

²⁰According to an IMF analysis of sovereign holdings by European banks, 12% of these exposures were included in the trading book, 49% were classified as available for sale and 39% were classified as held to maturity. Some banks had the bulk of their exposure of sovereign bonds on their banking book. For example, the National Bank of Greece classified almost 70% of their sovereign bonds as held-to-maturity.

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:*

$$B_i(\tau) = \frac{1 - e^{-\kappa_r \tau}}{\kappa_r}, \quad C_i(\tau) = \frac{\kappa_r}{\kappa_\theta} \left(\frac{1 - e^{-\kappa_r \tau}}{\kappa_r} + \frac{e^{-\kappa_\theta \tau} - e^{-\kappa_r \tau}}{\kappa_\theta - \kappa_r} \right), \quad \text{and} \quad (22)$$

$$D_i(\tau) = \left(1 + \frac{1}{1 - \phi} \alpha \int_0^T s_i^\tau d\tau \right) \frac{1 - e^{-\kappa_{\lambda,i} \tau}}{\kappa_{\lambda,i}}.$$

In peripheral countries, with yield-oriented investors ($i \in \mathcal{J}$), we have

$$B_i(\tau) = \frac{1 - e^{-\kappa_r \tau}}{\kappa_r}, \quad C_i(\tau) = \frac{\kappa_r}{\kappa_\theta} \left(\frac{1 - e^{-\kappa_r \tau}}{\kappa_r} + \frac{e^{-\kappa_\theta^* \tau} - e^{-\kappa_r \tau}}{\kappa_\theta^* - \kappa_r} \right), \quad \text{and} \quad (23)$$

$$D_i(\tau) = \left(1 + \alpha \int_0^T s_i^\tau d\tau \right) \frac{1 - e^{-\kappa_{\lambda,i}^* \tau}}{\kappa_{\lambda,i}^*},$$

where $\kappa_\theta^* = \kappa_\theta (1 - \phi) < \kappa_\theta$ and $\kappa_{\lambda,i}^* = \kappa_{\lambda,i} (1 - \phi) < \kappa_{\lambda,i}$. The functional forms of A_i , for both $i \in \mathcal{J}$ and $i \notin \mathcal{J}$, are given in the appendix.

C. Model Predictions

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

We consider the effect of target rate and communication shocks in two main specifications. We start with multivariate regressions of yield changes of country- i bonds with maturity τ on both the target rate shock and the communication shock, that is,^{21,22}

$$dy_{i,t}^\tau = \alpha_i^\tau + \beta_{i,r}^\tau dB_{r,t} + \beta_{i,\theta}^\tau dB_{\theta,t} + \epsilon_{i,t}. \quad (24)$$

It is imminent that $\beta_{i,r}^\tau = \frac{B_i(\tau)}{\tau} \sigma_r$ and $\beta_{i,\theta}^\tau = \frac{C_i(\tau)}{\tau} \sigma_r$. Thus, we obtain the following results on the impact of target shocks:

Proposition 1. *We have $\lim_{\tau \rightarrow 0} \beta_{i,r}^\tau = \sigma_r$ and $\lim_{\tau \rightarrow \infty} \beta_{i,r}^\tau = 0$, and $d\beta_{i,r}^\tau/d\tau < 0$ for all $\tau > 0$ and i . Hence, $\beta_{i,r}^\tau$ is positive and decreasing across maturities.*

For communication shocks, we have the following results:

²¹Defining the target shock as dr_t instead of the Brownian increment would only change the level of the coefficients proportionally, because the volatility of r_t , σ_r , is constant.

²²Because 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.

Proposition 2. *We have $\lim_{\tau \rightarrow 0} \beta_{i,\theta}^\tau = \lim_{\tau \rightarrow \infty} \beta_{i,\theta}^\tau = 0$, and there exists $\bar{\tau}_i > 0$ such that $d\beta_{i,\theta}^\tau/d\tau > 0$ for all $\tau \in (0, \bar{\tau}_i)$ and $d\beta_{i,\theta}^\tau/d\tau < 0$ for all $\tau \in (\bar{\tau}_i, \infty)$. Thus, $\beta_{i,\theta}^\tau$ is positive and hump-shaped across maturities.*

Bond yields are the average expected returns earned through the lifetime of bonds, which in turn depend on expected future risk-free rates and risk premia. Therefore, when the central bank announces changes to either the current target rate or the intended future path of monetary policy, yield curves can be affected via two channels: a direct impact operates through the expectation channel, while the second, indirect effect works through the risk premium channel.

Propositions 1 and 2 are both in line with the predictions originating simply from the expectation hypothesis. 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: $\beta_{i,r}^\tau$ 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 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 across maturities.

Next we study the effect of the two types of shocks across countries: to highlight cross-sectional differences, we look at regressions similar to (24), where the left-hand-side variable is changes in the yield difference of peripheral vs core countries:

$$d(y_{p,t}^\tau - y_{c,t}^\tau) = \alpha_{pc}^\tau + \beta_{pc,r}^\tau dB_{r,t} + \beta_{pc,\theta}^\tau dB_{\theta,t} + \epsilon_{pc,t}. \quad (25)$$

From (24), the theoretical regression coefficients satisfy $\beta_{pc,r}^\tau = \beta_{p,r}^\tau - \beta_{c,r}^\tau$ and $\beta_{pc,\theta}^\tau = \beta_{p,\theta}^\tau - \beta_{c,\theta}^\tau$, which in turn depend on the difference between the B_i and C_i functions. As the former are identical across countries, our model predicts $\beta_{pc,r}^\tau = 0$. Regarding the loading on communication shocks, we obtain the following predictions:

Proposition 3. *We have $\lim_{\tau \rightarrow 0} \beta_{pc,\theta}^\tau = \lim_{\tau \rightarrow \infty} \beta_{pc,\theta}^\tau = 0$, and there exists $0 < \bar{\tau}_{pc}$ such that $d\beta_{pc,\theta}^\tau/d\tau < 0$ for all $\tau \in (0, \bar{\tau}_{pc})$ and $d\beta_{pc,\theta}^\tau/d\tau > 0$ for all $\tau \in (\bar{\tau}_{pc}, \infty)$. Thus, $\beta_{pc,\theta}^\tau$ is negative and U-shaped across maturities.*

The heterogeneity across countries is driven by our assumption on heterogeneity in the bond-market participation of agents. In fact, yield-oriented investors are absent in core countries, hence the only effect of target rate and communication shocks on the yield curve in those is due

to the expectation hypothesis as described above.²³ In peripheral countries, when the central bank announces changes to the current target rate or changes to the intended future path of monetary policy, there is potentially an indirect effect that works through the risk premium channel: shocks, by influencing the demand of yield-oriented investors, effectively manifest as changes to the relative net supply of bonds that risk-averse arbitrageurs have to hold in equilibrium.

By construction, the demand of yield-oriented investors is target-rate neutral. Thus, the net supply of bonds that risk-averse arbitrageurs have to hold in equilibrium remains constant, and the risk premium remains unaffected.

At the same time, a positive communication shock that lifts all yields also increases the relative demand of yield-oriented investors for bonds of all maturities. In turn, this change in relative net supplies translates to a decreasing equilibrium risk premium for all bonds. Therefore, the risk premium channel dampens the direct effect of a communication shocks on all yields, effectively decreasing the hump. The difference in the proportion of yield-oriented investors across countries implies that the indirect effect is more prominent in peripheral countries than in core countries. Hence, our model provides an understanding of how communication shocks can affect the term structure in equilibrium, both in the cross-section of maturities and across countries.

D. Calibration

Finally, we ask the question whether reaching for yield investors can impact the role of monetary policy shocks in a manner quantitatively consistent with the data. We address this question by estimating the model parameters in a two-step procedure.

Theorem 1 implies that target rate loadings in core and peripheral countries depend only on the persistence and volatility of target shocks, κ_r and σ_r . We choose these parameters by performing a grid search to minimize the distance between the model implied loadings and a simple average of pre-2009 empirical estimates in core and peripheral countries. The remaining parameters of the model are the persistence and volatility of communication shocks, κ_θ and σ_θ , and the mass of reaching-for-yield investors in peripheral countries, ϕ . We choose these parameters via a second grid search, in which we minimize the difference between the country-specific model-implied loadings and the post-2009 empirical estimates for core and periphery, while holding the target-rate parameters fixed.

²³Our results would remain qualitatively the same if we allowed for some yield-oriented investors to trade bonds in core countries, too, as long as their proportion remains higher among the peripheral country investors.

Table IX reports the calibrated parameters, while Figure 11 presents model-implied loadings versus their empirical counterparts. First, we note the high persistence and the low volatility of the target rate. Our κ_r parameter corresponds to a half-life of around 14 years, which is significantly higher than the 5-year target rate shock half-life that studies based on US data generally find.²⁴ This persistence is responsible for target rate shocks having a significant effect even for very long-term bonds since it takes a long time for shocks to die out on average. On the other hand, the volatility parameter is approximately one third of typical US numbers.

Second, it is interesting to compare the estimated parameters of target rate and communication shocks to each other. We find that communication shocks are around 10 times more volatile than target rate shocks, and have much lower persistence – the estimated mean-reversion parameter implies a half-life of 6 years. Finally, given that the parameter ϕ only affects the difference in the reaction to communication shocks between core and peripheral countries, to match our empirical observation for long-term bonds, we need to introduce a large fraction of reaching-for-yield investors. The calibrated ϕ implies that post-2009 95% of investors in peripheral sovereign bonds has reaching for yield preferences.

Second, it is interesting to compare the estimated parameters of target rate and communication shocks to each other. We find that communication shocks are much more volatile than target rate shocks, and have lower persistence – the estimated mean-reversion parameter implies a half-life of 9 months. Finally, given that the parameter ϕ only affects the difference in the reaction to communication shocks between core and peripheral countries, to match our empirical observation for long-term bonds, we need to introduce a large fraction of reaching-for-yield investors.

[Insert figure 11 and table IX here]

Figure 11 compares the model-implied regression coefficients to the data (see Figure 7). We notice that in the pre-2009 period, estimated coefficients are almost perfectly matched as the model-implied coefficients are virtually the same as the ones implied by the data. For the post-2009 period, we find that, in line with the data, the effect on peripheral countries is muted vis-à-vis core countries.

²⁴For an estimation of short rate parameters in the U.S, see, e.g., Malkhozov, Mueller, Vedolin, and Venter (2016).

V. Conclusion

Much research has been devoted to the study of the impact of forward guidance on asset prices ever since interest rate around the globe have hit the zero lower bound. However, the precise measurement of forward guidance shocks in the US is complicated by the fact that target rate and communication about the future path of interest rates announcements coincide. In this paper, we propose a novel measure of target rate and communication shocks on days when the ECB announces its monetary policy for two reasons. First, target rate and communication about the future path of interest rates happen at different points in time which allows for a clean identification. Second, the ECB has a long history of communicating with market participants. Using high-frequency data on a host of money market rates using 14 years of data, we estimate target and communication shocks separately and study their effect on Eurozone bond yields.

We document the following empirical findings. Target rate shocks have a much smaller impact on Eurozone bond yields, whereas communication shocks have highly significant effect not just statistically but also economically. Moreover, we find the effect to be the strongest for bond yields at intermediate maturities. As the maturity increases, the effect of the communication shocks dissipates. We also find that while monetary policy shocks had a homogeneous effect on bond yields of core and peripheral countries until 2009, we document large cross-sectional heterogeneity across core and peripheral countries post 2009. More specifically, we find that for the 2009 to 2014 period, target rate shocks significantly lowered the yield spread between peripheral and core countries, however, 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 taken since May 2010. We reject the hypothesis that these results are driven by credit risk or information revelation by the central bank to private investors.

We rationalize these findings through the lens of a parsimonious dynamic term structure model with heterogeneous investors and credit risk. Equilibrium yields are determined by risk-averse arbitrageurs who interact with reaching-for-yield investors who give rise to a monetary policy risk premium. 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 the expectation hypothesis, but also an indirect one, by influencing the demand of yield-oriented investors, effectively creating a shock to the net supply of bonds mean-variance investors have to hold in equilibrium.

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Appendix: Proofs

Proof of Theorem 1. Substituting (15) into (9), we obtain that the budget constraint of mean-variance investors is

$$\begin{aligned} dW_t = & \left[r_t W_t + \sum_{i=1}^I \int_0^T x_{i,t}^\tau (\mu_{i,t}^\tau - r_t) d\tau \right] dt - \left[\sum_{i=1}^I \int_0^T x_{i,t}^\tau \sigma_{r,i,t}^\tau d\tau \right] dB_{r,t} \\ & - \left[\sum_{i=1}^I \int_0^T x_{i,t}^\tau \sigma_{\theta,i,t}^\tau d\tau \right] dB_{\theta,t} - \sum_{i=1}^I \left[\int_0^T x_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau \right] dB_{\lambda,i,t} - \sum_{i=1}^I \left[\int_0^T x_{i,t}^\tau d\tau \right] dZ_{i,t}. \end{aligned}$$

From here, using (7), we can express $E_t[dW_t]$ and $\text{Var}_t[dW_t]$. Substituting them into (10) results in (17). Point-wise maximization of (17) with respect to $x_{i,t}^\tau$ yields (18). Similarly, point-wise maximization of (19) with respect to $z_{i,t}^\tau$ for $i \in \mathcal{J}$ yields (20).

To solve for equilibrium bond prices and yields, we apply Ito's lemma to (12) and compare the result to (21). Collecting r_t , θ_t , λ_t , and constant terms, respectively, we obtain

$$B'_i(\tau) + B_i(\tau) \kappa_r - 1 = -\mathbf{1}_{i \in \mathcal{J}} \frac{\phi}{1 - \phi} (B'_i(\tau) - 1) \quad (26)$$

and

$$C'_i(\tau) - B_i(\tau) \kappa_r + C_i(\tau) \kappa_\theta = -\mathbf{1}_{i \in \mathcal{J}} \frac{\phi}{1 - \phi} C'_i(\tau) \quad (27)$$

and

$$D'_i(\tau) + D_i(\tau) \kappa_{\lambda,i} = \frac{1}{1 - \phi} \alpha \int_0^T s_i^\tau d\tau - \mathbf{1}_{i \in \mathcal{J}} \frac{\phi}{1 - \phi} (D'_i(\tau) - 1) + 1. \quad (28)$$

and

$$\begin{aligned} A'_i(\tau) + \frac{1}{2} B_i^2(\tau) \sigma_r^2 + \frac{1}{2} C_i^2(\tau) \sigma_\theta^2 + \frac{1}{2} D_i^2(\tau) \sigma_{\lambda,i}^2 \\ = \frac{1}{1 - \phi} \alpha B_i(\tau) \sigma_r^2 \left[\sum_{j=1}^I \int_0^T B_j(\tau) s_j^\tau d\tau \right] \\ + C_i(\tau) \left\{ \kappa_\theta \bar{\theta} + \frac{1}{1 - \phi} \alpha \sigma_\theta^2 \left[\sum_{j=1}^I \int_0^T C_j(\tau) s_j^\tau d\tau \right] \right\} \\ + D_i(\tau) \left\{ \kappa_{\lambda,i} \bar{\theta}_{\lambda,i} + \frac{1}{1 - \phi} \alpha \sigma_{\lambda,i}^2 \left[\int_0^T D_i(\tau) s_i^\tau d\tau \right] \right\} - \mathbf{1}_{i \in \mathcal{J}} \frac{\phi}{1 - \phi} A'_i(\tau). \end{aligned} \quad (29)$$

From (26), (27), and (28), together with $B_i(0) = C_i(0) = D_i(0) = 0$, we get (22) for $i \notin \mathcal{J}$ countries, while we obtain (23) for $i \in \mathcal{J}$. Given those functions, we can solve for the functional forms of the A_i s from (29). $\square$

Proof of Propositions 2-3. As $\beta_{i,r}^\tau = \frac{B_i(\tau)}{\tau} \sigma_r$ and $\beta_{i,\theta}^\tau = \frac{C_i(\tau)}{\tau} \sigma_\theta$, and the $B_i(\cdot)$ and $C_i(\cdot)$ functions for $i \in \mathcal{J}$ and $i \notin \mathcal{J}$ only differ in the positive constants with and without asterisk (e.g. κ_θ and κ_θ^*), it is sufficient to prove our statements in Propositions 2-1 for the $i \notin \mathcal{J}$ case.

First, it is straightforward that

$$\lim_{\tau \rightarrow \infty} \beta_{i,r}^\tau = \lim_{\tau \rightarrow \infty} \frac{1 - e^{-\kappa_r \tau}}{\kappa_r \tau} \sigma_r = 0 \text{ and } \lim_{\tau \rightarrow \infty} \beta_{i,\theta}^\tau = \lim_{\tau \rightarrow \infty} \left[\frac{1 - e^{-\kappa_\theta \tau}}{\kappa_\theta \tau} + \frac{e^{-\kappa_\theta \tau} - e^{-\kappa_r \tau}}{(\kappa_\theta - \kappa_r) \tau} \right] \sigma_\theta = 0$$

as the numerators of all fractions remain finite, whereas the denominators diverge to plus or minus infinity. Second, L'Hospital's Rule implies that

$$\lim_{\tau \rightarrow 0} \beta_{i,r}^\tau = \lim_{\tau \rightarrow 0} \frac{1 - e^{-\kappa_r \tau}}{\kappa_r \tau} \sigma_r = \lim_{\tau \rightarrow 0} e^{-\kappa_r \tau} \sigma_r = \sigma_r,$$

while

$$\lim_{\tau \rightarrow 0} \beta_{i,\theta}^\tau = \lim_{\tau \rightarrow 0} \left[\frac{1 - e^{-\kappa_\theta \tau}}{\kappa_\theta \tau} + \frac{e^{-\kappa_\theta \tau} - e^{-\kappa_r \tau}}{(\kappa_\theta - \kappa_r) \tau} \right] \sigma_\theta = \lim_{\tau \rightarrow 0} \left[e^{-\kappa_\theta \tau} + \frac{-\kappa_\theta e^{-\kappa_\theta \tau} + \kappa_r e^{-\kappa_r \tau}}{(\kappa_\theta - \kappa_r)} \right] \sigma_\theta = 0.$$

Third, regarding slopes,

$$\frac{d\beta_{i,r}^\tau}{d\tau} = \frac{(\kappa_r e^{-\kappa_r \tau})(\kappa_r \tau) - (1 - e^{-\kappa_r \tau})(\kappa_r)}{(\kappa_r \tau)^2} = -\frac{1 - e^{-\kappa_r \tau} - \kappa_r \tau e^{-\kappa_r \tau}}{\kappa_r \tau^2},$$

which has the opposite sign as $F(\kappa_r \tau) \equiv 1 - e^{-\kappa_r \tau} - \kappa_r \tau e^{-\kappa_r \tau}$. But $\lim_{x \rightarrow 0} F(x) = 0$ and $F'(x) = x e^{-x} > 0$ when $x > 0$. Hence, $F(\kappa_r \tau) \geq 0$ for all $\tau \geq 0$, and $\beta_{i,r}^\tau$ is downward sloping. Since $\lim_{\tau \rightarrow \infty} \beta_{i,r}^\tau = 0$, it is positive and downward sloping for all $\tau > 0$.

For $\beta_{i,\theta}^\tau$, notice that, after some algebra,

$$\frac{d\beta_{i,\theta}^\tau}{d\tau} = \frac{\kappa_r}{(\kappa_\theta - \kappa_r)} \left[\frac{F(\kappa_\theta \tau)}{\kappa_\theta \tau^2} - \frac{F(\kappa_r \tau)}{\kappa_r \tau^2} \right], \quad (30)$$

and for any $\kappa > 0$ we have

$$\lim_{\tau \rightarrow 0} \frac{F(\kappa \tau)}{\kappa \tau^2} = \lim_{\tau \rightarrow 0} \frac{\kappa e^{-\kappa \tau}}{2} = \frac{\kappa}{2} \text{ and } \lim_{\tau \rightarrow \infty} \frac{F(\kappa \tau)}{\kappa \tau^2} = 0$$

$$\frac{d}{d\tau} \frac{F(\kappa \tau)}{\kappa \tau^2} \equiv \frac{d}{d\tau} \frac{1 - e^{-\kappa \tau} - \kappa \tau e^{-\kappa \tau}}{\kappa \tau^2} = -2 \frac{e^{-\kappa \tau}}{\kappa \tau^3} \left[e^{\kappa \tau} - \left(1 + \kappa \tau + \frac{\kappa^2 \tau^2}{2} \right) \right] < 0.$$

But $1 + \kappa \tau + \frac{\kappa^2 \tau^2}{2}$ are the first three terms of the power series of $e^{\kappa \tau}$, and it is well-known that

the difference can be approximated by $\frac{\kappa^3 \tau^3}{6}$; therefore,

$$\frac{d}{d\tau} \left[\frac{F(\kappa_\theta \tau)}{\kappa_\theta \tau^2} - \frac{F(\kappa_r \tau)}{\kappa_r \tau^2} \right] \approx \frac{1}{3} [\kappa_r^2 e^{-\kappa_r \tau} - \kappa_\theta^2 e^{-\kappa_\theta \tau}]$$

Finally, it is easy to show that the function $\tau \mapsto \kappa_r^2 e^{-\kappa_r \tau} - \kappa_\theta^2 e^{-\kappa_\theta \tau}$ is first negative then positive if and only if $\kappa_\theta > \kappa_r$ (and vice versa for $\kappa_\theta < \kappa_r$). Therefore, the RHS of (30) is positive for small positive τ values and turns negative after a threshold $\bar{\tau}_i$. But this, together with the previous observations, implies that $\beta_{i,\theta}^\tau$ must be hump shaped.

Finally, notice that since

$$\beta_{p-c,r}^\tau = \beta_{p,r}^\tau - \beta_{c,r}^\tau = \left[\frac{1 - e^{-\kappa_r \tau}}{\kappa_r \tau} - \frac{1 - e^{-\kappa_r^* \tau}}{\kappa_r^* \tau} \right] \sigma_r,$$

we have

$$\frac{d\beta_{p-c,r}^\tau}{d\tau} = \left[\frac{1 - e^{-\kappa_r \tau} - \kappa_r \tau e^{-\kappa_r \tau}}{\kappa_r \tau^2} - \frac{1 - e^{-\kappa_r^* \tau} - \kappa_r^* \tau e^{-\kappa_r^* \tau}}{\kappa_r^* \tau^2} \right] \sigma_r = \left[\frac{F(\kappa_r \tau)}{\kappa_r \tau^2} - \frac{F(\kappa_r^* \tau)}{\kappa_r^* \tau^2} \right] \sigma_r.$$

Here we have that $\lim_{\tau \rightarrow 0} \beta_{p-c,r}^\tau = 0$ and $\lim_{\tau \rightarrow \infty} \beta_{p-c,r}^\tau = 0$, moreover, we have shown above that the sign of the term in brackets is positive for small positive τ and negative afterwards if and only if $\kappa_r > \kappa_r^* = \kappa_r (1 - \phi)$. Therefore $\beta_{p-c,r}^\tau$ is positive and hump shaped. This concludes the proof of Propositions 2-3. $\square$

A. Alternative continuous time specifications

Suppose that, unlike in (19), where we replace the instantaneous drift $\mu_{i,t}^\tau$ by the instantaneous forward rate $f_{i,t}^\tau$, we use the actual maturity- τ yield, $y_{i,t}^\tau$, in the yield-oriented investors' optimization problem to obtain

$$\begin{aligned} & \max_{\{z_{i,t}^\tau\}_{\tau \in (0,T], i \in \mathcal{J}}} \sum_{i \in \mathcal{J}} \int_0^T z_{i,t}^\tau [y_{i,t}^\tau - r_t - \lambda_{i,t}] d\tau - \frac{\alpha}{2} \left[\sum_{i \in \mathcal{J}} \int_0^T z_{i,t}^\tau \sigma_{r,i,t}^\tau d\tau \right]^2 \\ & - \frac{\alpha}{2} \left[\sum_{i \in \mathcal{J}} \int_0^T z_{i,t}^\tau \sigma_{\theta,i,t}^\tau d\tau \right]^2 - \frac{\alpha}{2} \sum_{i \in \mathcal{J}} \left[\int_0^T z_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau \right]^2 - \frac{\alpha}{2} \sum_{i \in \mathcal{J}} \lambda_{i,t} \left[\int_0^T z_{i,t}^\tau d\tau \right]^2, \end{aligned} \quad (31)$$

The FOC w.r.t. $z_{i,t}^\tau$ then becomes

$$\begin{aligned} y_{i,t}^\tau - r_t - \lambda_{i,t} = & \alpha \sigma_{r,i,t}^\tau \left[\sum_{j \in \mathcal{J}} \int_0^T z_{j,t}^\tau \sigma_{r,j,t}^\tau d\tau \right] + \alpha \sigma_{\theta,i,t}^\tau \left[\sum_{j \in \mathcal{J}} \int_0^T z_{j,t}^\tau \sigma_{\theta,j,t}^\tau d\tau \right] \\ & + \alpha \sigma_{\lambda,i,t}^\tau \left[\int_0^T z_{i,t}^\tau \sigma_{\lambda,i,t}^\tau d\tau \right] + \alpha \lambda_{i,t} \left[\int_0^T z_{i,t}^\tau d\tau \right], \end{aligned} \quad (32)$$

and combining (11), (18), and (32) implies

$$\begin{aligned} \mu_{i,t}^\tau - r_t - \lambda_{i,t} = & \frac{1}{1-\phi} \alpha \sigma_{r,i,t}^\tau \left[\sum_{j=1}^I \int_0^T s_j^\tau \sigma_{r,j,t}^\tau d\tau \right] + \frac{1}{1-\phi} \alpha \sigma_{\theta,i,t}^\tau \left[\sum_{j=1}^I \int_0^T s_j^\tau \sigma_{\theta,j,t}^\tau d\tau \right] \\ & + \frac{1}{1-\phi} \alpha \sigma_{\lambda,i,t}^\tau \left[\int_0^T s_j^\tau \sigma_{\lambda,i,t}^\tau d\tau \right] + \frac{1}{1-\phi} \alpha \lambda_{i,t} \int_0^T s_j^\tau d\tau - \mathbf{1}_{i \in \mathcal{J}} \frac{\phi}{1-\phi} (y_{i,t}^\tau - r_t - \lambda_{i,t}). \end{aligned} \quad (33)$$

As before, we want to solve for equilibrium bond prices in an affine form. Conjecturing bond prices and yields to be as in (12) and (13), respectively, applying Ito's lemma and collecting r_t and θ_t terms, we obtain that the functions $B_i(\tau)$ and $C_i(\tau)$ for the core countries are the same as before, whereas for periphery countries, $i \in \mathcal{J}$,

$$B_i'(\tau) + B_i(\tau) \kappa_r - 1 = -\frac{\phi}{1-\phi} \left(\frac{B_i(\tau)}{\tau} - 1 \right) \quad (34)$$

and

$$C_i'(\tau) - B_i(\tau) \kappa_r + C_i(\tau) \kappa_\theta = -\frac{\phi}{1-\phi} \frac{C_i(\tau)}{\tau} \quad (35)$$

for all $\tau > 0$, while $B_i(0) = C_i(0) = 0$. It turns out, however, that all solutions to (34) can be written in the form of

$$B_i(\tau) = \frac{1}{\kappa_r} \frac{1}{1-\phi} + e^{-\kappa_r \tau} \tau^{-\frac{\phi}{1-\phi}} \left[Z - \frac{\phi}{(1-\phi)^2} (-\kappa_r)^{-\frac{1}{1-\phi}} \Gamma \left(\frac{\phi}{1-\phi}, -\kappa_r \tau \right) \right], \quad (36)$$

where Z is an arbitrary constant and

$$\Gamma(a, z) \equiv \int_z^\infty t^{a-1} e^{-t} dt$$

denotes the incomplete gamma function. As $\lim_{\tau \rightarrow 0} \Gamma(a, z) = \Gamma(a)$, the gamma function, which is finite for all $a > 0$, we obtain that in (36) the term inside the bracket has a finite limit when $\tau \rightarrow 0$, whereas $\lim_{\tau \rightarrow 0} \tau^{-\frac{\phi}{1-\phi}} = \infty$. Hence, we cannot have $\lim_{\tau \rightarrow 0} B_i(\tau) = 0$ for any real Z , and we conclude that there exists no meaningful solution to the alternative model where the

objective function of yield-oriented investors has y_t^τ instead of f_t^τ .

We also consider the case when the expected instantaneous excess return term, $\mu_{i,t}^\tau - r_t$, is replaced by $\tau(y_t^\tau - r_t)$ in (19), which simply follows the discrete-time specification of Hanson and Stein (2015). Writing down the FOC of reaching-for-yield investors, combining it with (11) and (18), then looking for equilibrium bond prices in an affine form, we obtain that the coefficients of r_t and θ_t have to solve

$$B_i'(\tau) + B_i(\tau) \kappa_r - 1 = -\frac{\phi}{1-\phi} (B_i(\tau) - \tau), \quad (37)$$

and

$$C_i'(\tau) - B_i(\tau) \kappa_r + C_i(\tau) \kappa_\theta = -\frac{\phi}{1-\phi} C_i(\tau). \quad (38)$$

Equation (37) then, together with $B_i(0) = 0$, implies

$$B_i(\tau) = \tau + \kappa_r \frac{1 - \left(\kappa_r + \frac{\phi}{1-\phi}\right) \tau - e^{-(\kappa_r + \frac{\phi}{1-\phi})\tau}}{\left(\kappa_r + \frac{\phi}{1-\phi}\right)^2},$$

and this result, together with $C_i(0) = 0$ and (38), leads to

$$C_i(\tau) = \frac{\kappa_r}{(\kappa_\theta - \kappa_r)} \left[\kappa_r \frac{1 - \left(\kappa_r + \frac{\phi}{1-\phi}\right) \tau - e^{-(\kappa_r + \frac{\phi}{1-\phi})\tau}}{\left(\kappa_r + \frac{\phi}{1-\phi}\right)^2} - \kappa_\theta \frac{1 - \left(\kappa_\theta + \frac{\phi}{1-\phi}\right) \tau - e^{-(\kappa_\theta + \frac{\phi}{1-\phi})\tau}}{\left(\kappa_\theta + \frac{\phi}{1-\phi}\right)^2} \right].$$

Conducting our analysis of Propositions 2-3 with these functions leads to qualitatively similar predictions as our main specification.

Figures

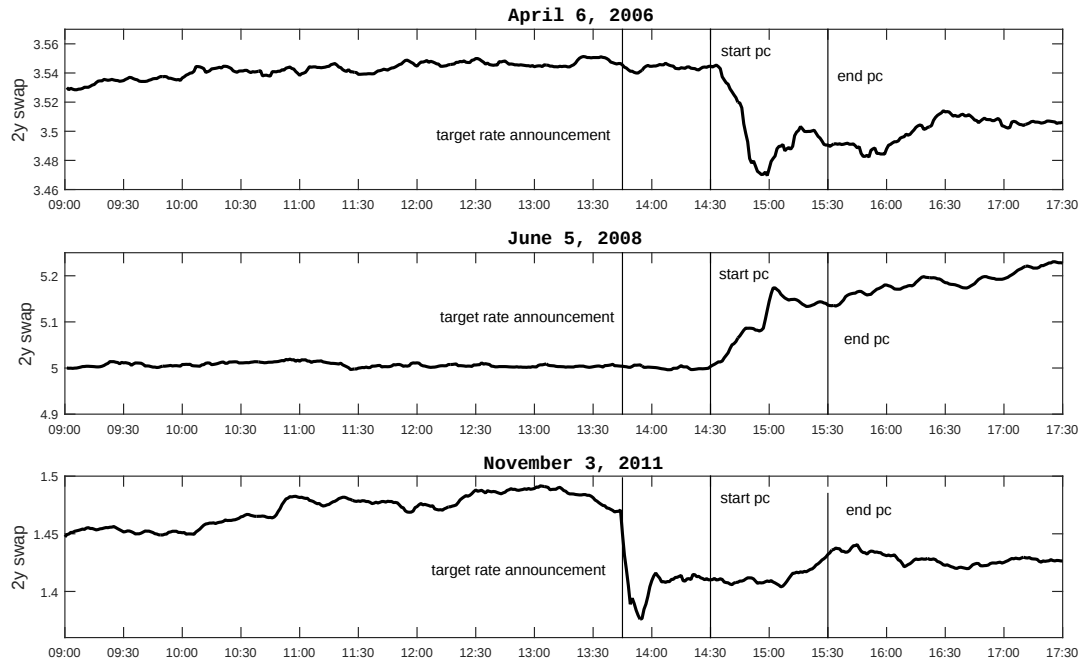


Figure 1. Two-year Swap Rate during Target Announcement and Press Conference

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.

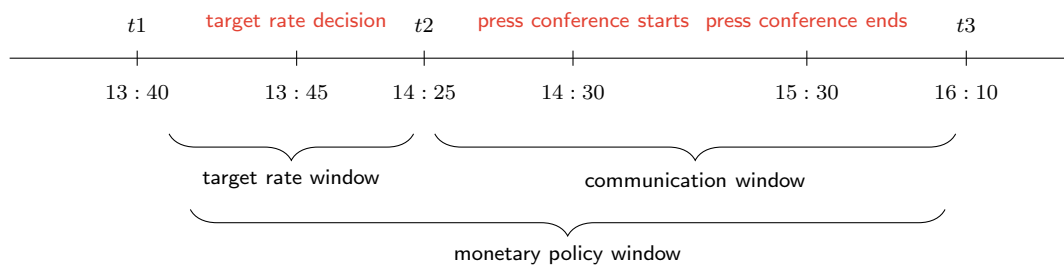


Figure 2. Monetary policy decision window

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

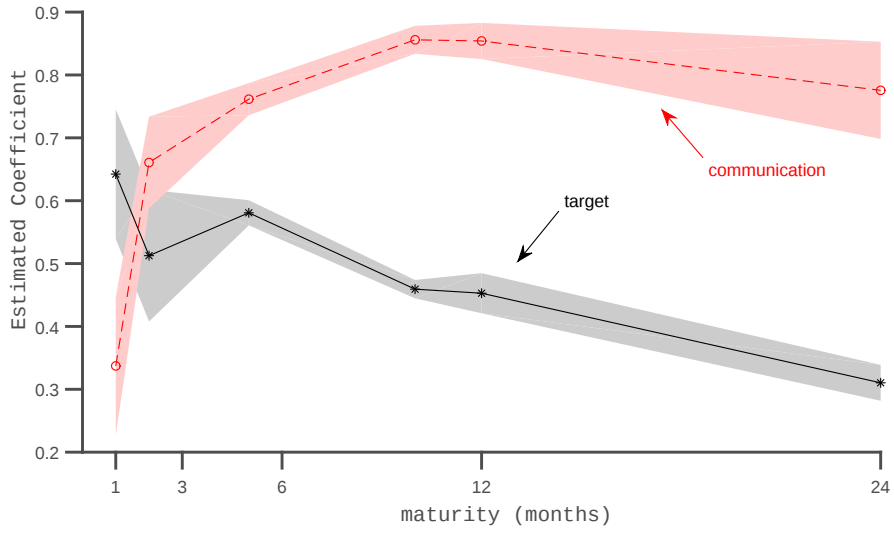


Figure 3. Loadings of PCs on Swap Rates

This figure plots estimated coefficients from a multivariate regression from changes in swap rates on the first principal component (PC) from the target rate and the first PC from the communication window around ECB monetary policy announcements:

$$\Delta y_t^\tau = \beta_r \text{PC1}_t^{\text{target}} + \beta_\theta \text{PC1}_t^{\text{comm}} + \epsilon_t^\tau,$$

where Δy_t^τ are swap rate changes between 13:40 CET and 16:10 CET with maturities $\tau = 1, \dots, 24$ months. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2001 to December 2014.

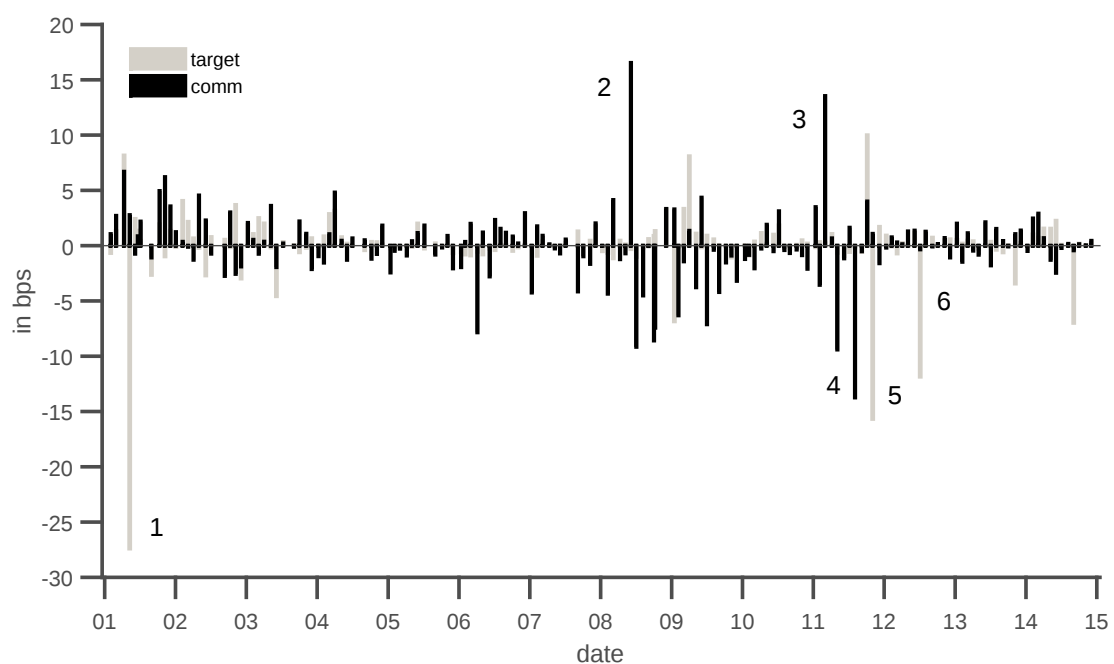


Figure 4. Time-Series of Target and Communication Shocks

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 and Draghi's announcement that "ECB will do whatever it takes."

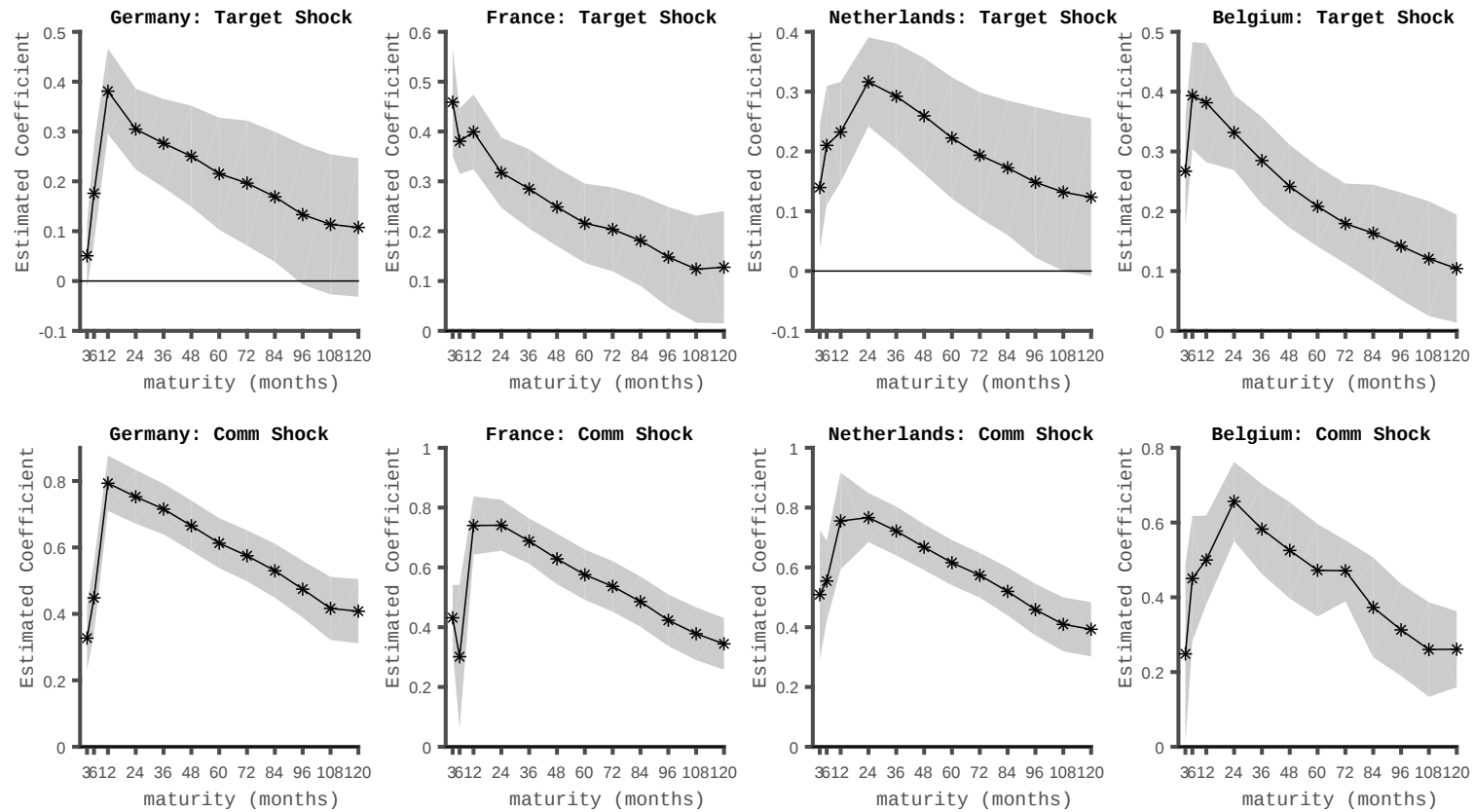


Figure 5. Core Countries' Yield Response to Target and Communication Shock

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.

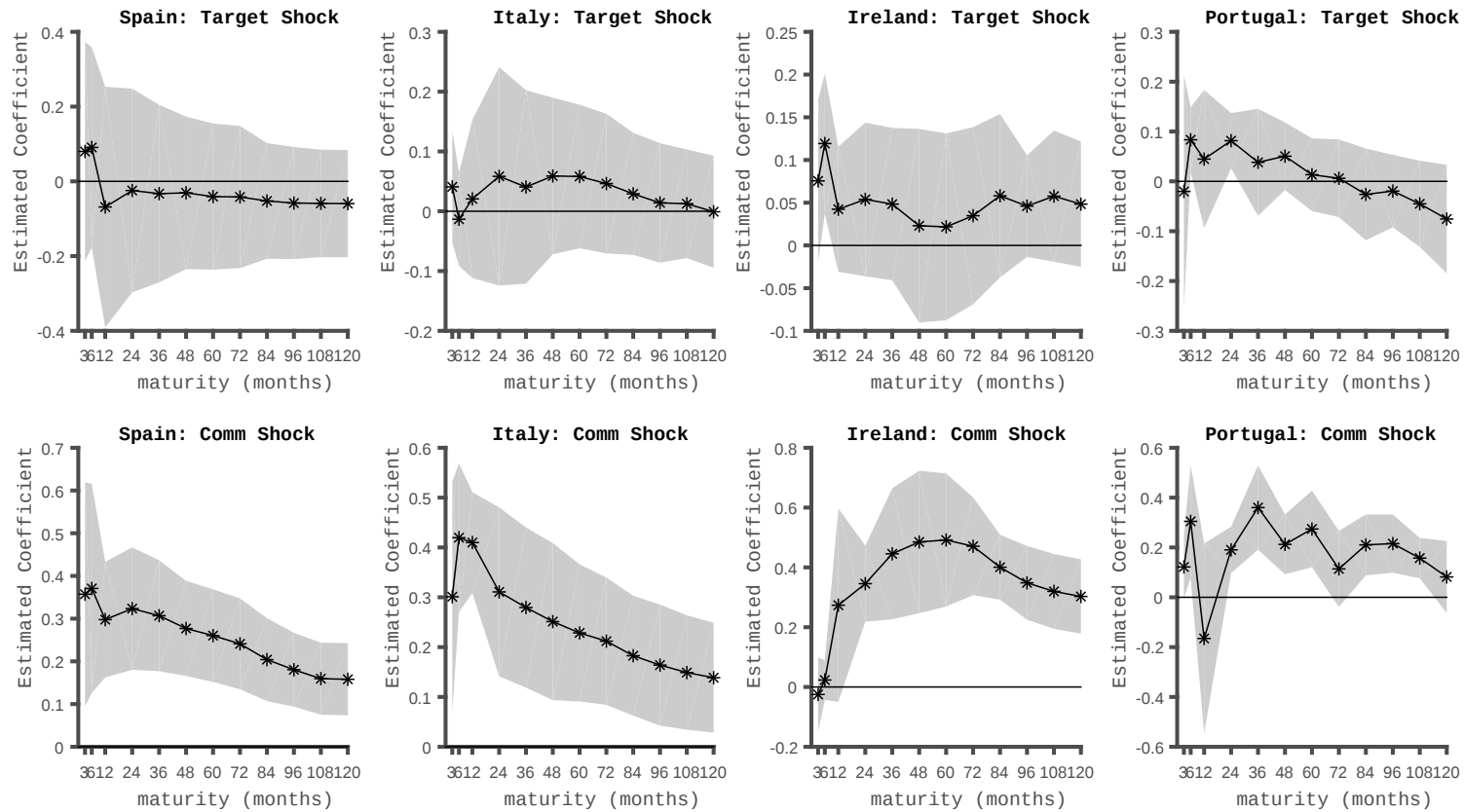


Figure 6. Peripheral Countries' Yield Response to Target and Communication Shock

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.

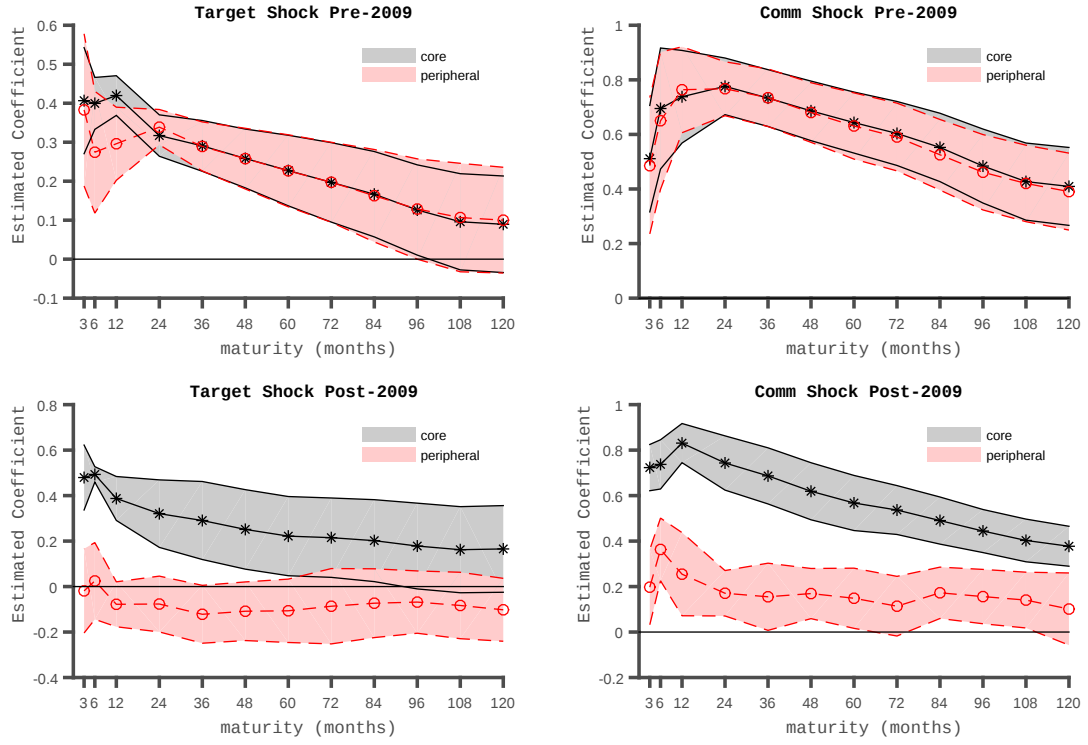


Figure 7. Core and Peripheral Countries' Yield Response before and after the onset of the crisis
This figure plots the response of core (solid line) and peripheral (dashed line) countries' bond yields at different maturities for a target rate (left) and communication (right) shock on ECB announcement days:

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

where $\tau = 3m, \dots, 10y$. 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 lower two panels.

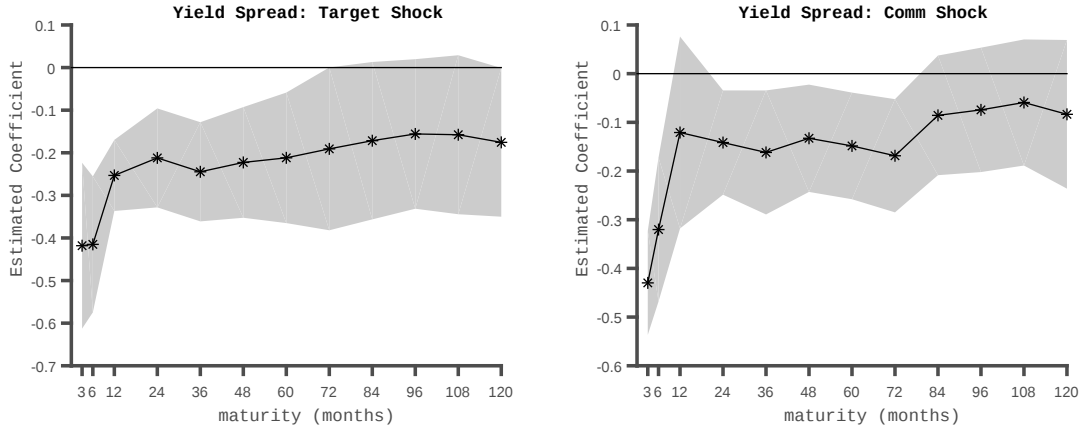


Figure 8. Yield Spread Post Crisis

This figure plots the response of peripheral minus core countries' bond yields at different maturities for a target (left panel) and communication shock (right panel) on ECB announcement days:

$$d(y_{p,t}^\tau - y_{c,t}^\tau) = \beta_{pc,r}^\tau dB_t^r + \beta_{pc,c}^\tau dB_t^\theta + \epsilon_{pc,t}^\tau,$$

where $\tau = 3m, \dots, 10y$. 90% confidence intervals are based on Newey and West (1987) standard errors. The sample period is from January 2009 to December 2014.

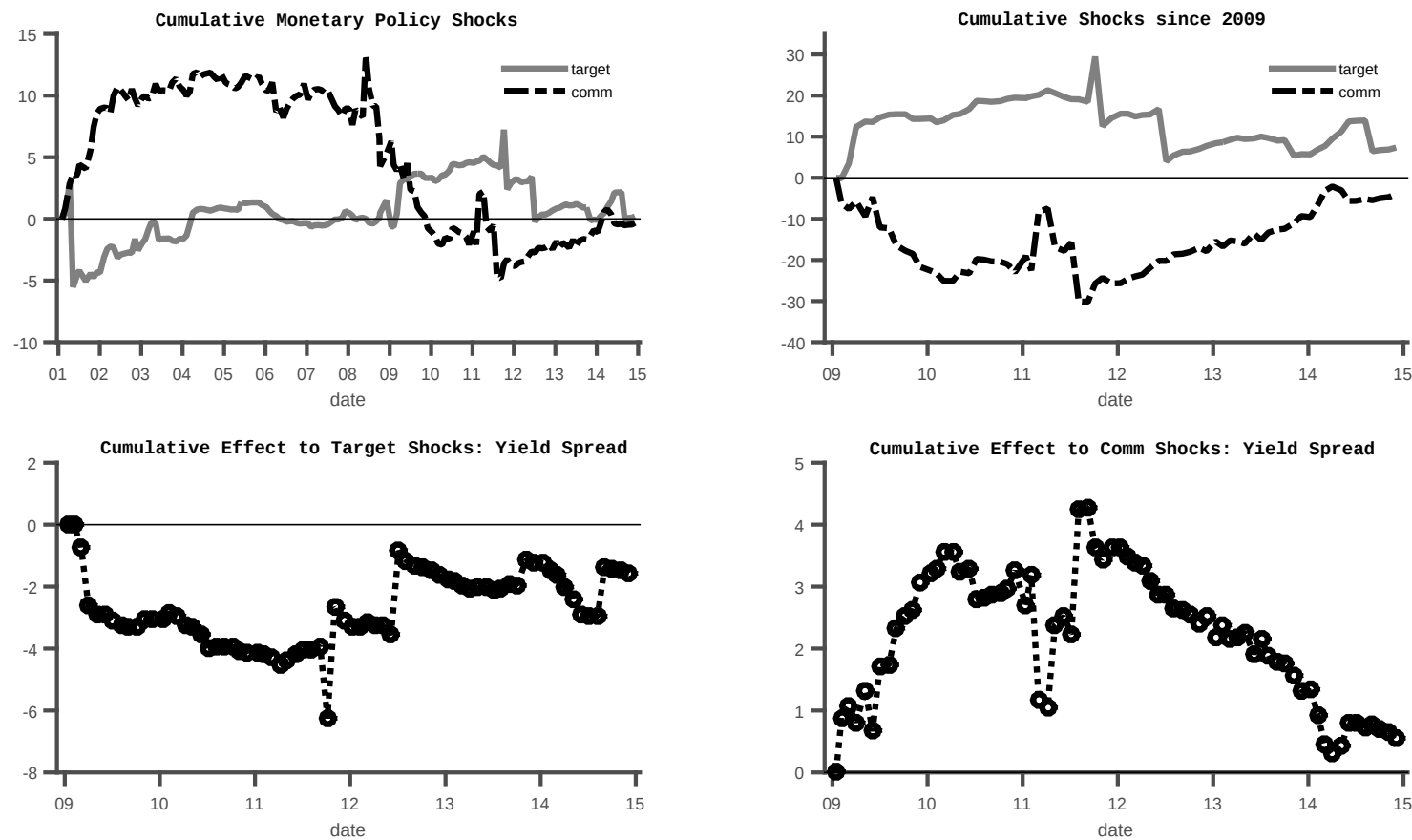


Figure 9. Cumulative Target and Communication Shocks

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.

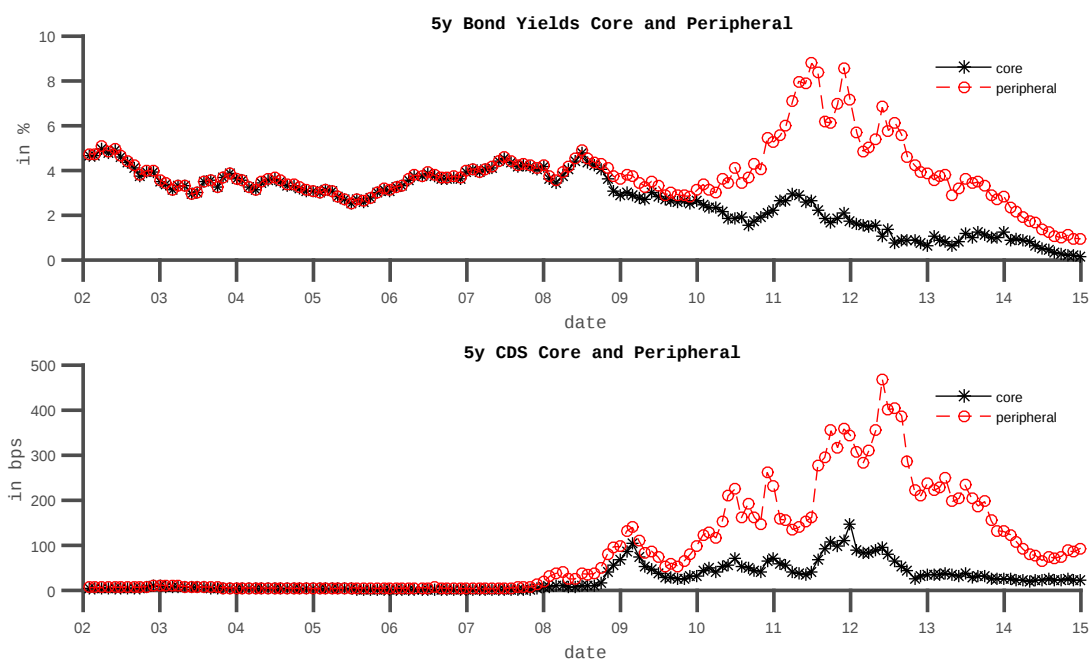


Figure 10. Five-year bond yields and CDS core and peripheral countries

The upper (lower) panel plots the median 5y bond yield (CDS) for core (solid line) and peripheral (dashed line) countries. Core countries are Germany, Netherlands, France and Belgium, peripheral countries are Portugal, Spain, Italy and Ireland. Data is monthly and running from January 2002 to December 2014.

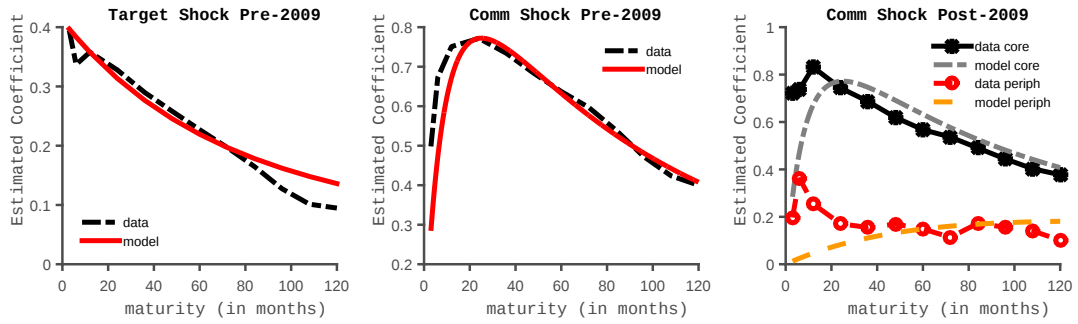


Figure 11. Calibrated vs Empirical Term Structure Loadings

The left and middle panel plot the estimated coefficients from multivariate regressions from core/peripheral countries' bond yields at different maturities on the target and communication shock in the data (dashed line) and the model-implied coefficients (bold line) for the pre-2009 period. The right panel plots the effect of a communication shock on core and peripheral countries in the post-2009 period in the data (lines with markers) and in the theoretical model (dashed lines).

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.

mat	1	2	5	10	12	24
Panel A: 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%
Panel B: 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. Loadings PCs Swaps

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

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

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 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
	Panel A: Germany							Panel E: 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
	Panel B: France							Panel F: 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
	Panel C: Netherlands							Panel G: 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
	Panel D: Belgium							Panel H: 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 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
t-stat	(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
t-stat	(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 shock

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			post-2009		
	unemp	infl	output	unemp	infl	output
Z^r	0.002 (0.95)	0.002 (0.75)	-0.005** (-3.89)	-0.003 (-1.98)	0.008* (2.77)	0.006** (3.15)
Z^θ	-0.002 (-0.44)	0.002*** (5.03)	0.005*** (4.84)	-0.004 (-2.12)	0.003* (2.42)	0.001 (1.48)
dummy target	-0.000 (-0.08)	-0.006 (-1.91)	0.002 (1.31)	-0.007** (-5.14)	0.011** (3.49)	-0.008 (-1.31)
dummy comm	0.007 (1.39)	-0.002 (-0.93)	0.002 (1.25)	0.003 (1.57)	-0.001 (-0.52)	0.002** (2.96)
N	407	671	671	292	510	510
R^2	0.90%	0.37%	3.24%	2.50%	4.02%	2.00%

Table VII. Panel regression economic forecast revisions

This table reports the results of multivariate panel regressions of economic forecast revisions (unemployment, inflation, output) for Germany, France, Netherlands, Spain and Italy on the target and communication shocks and the shocks interacted with a dummy which takes the value of one if country i is a peripheral country and zero otherwise,

$$\Delta E[\text{unemp/infl/output}]_{i,t} = \beta_r Z_{r,t} + \gamma_r \mathbf{1}^P Z_t^r + \beta_\theta Z_{\theta,t} + \gamma_\theta \mathbf{1}^P Z_{\theta,t} + \epsilon_{i,t}^{\text{forecast}}.$$

t -statistics are calculated using robust standard errors clustered at the country level. All regressions also include a constant and country-fixed effects (not reported). Data runs from January 2001 to December 2008 (pre-crisis) and from January 2009 to December 2014 (post-crisis). ***, **, and * denote statistical significance at the 1, 5, and 10% level, respectively.

	pre-2009	post-2009
Z^r	0.006 (1.68)	-0.003*** (-4.11)
Z^θ	-0.001 (-0.70)	-0.003*** (-4.37)
dummy target	-0.004 (-1.22)	0.001 (1.88)
dummy comm	0.000 (0.10)	0.002* (2.25)
N	558	568
R^2	1.72%	3.93%

Table VIII. Panel regression credit risk

This table reports the results of multivariate panel regressions of CDS for all countries in our sample onto the target and communication shocks and the shocks interacted with a dummy which takes the value of one if country i is a peripheral country and zero otherwise,

$$\Delta \log \text{cds}_{i,t} = \beta_r Z_{r,t} + \gamma_r \mathbf{1}^P Z_{r,t} + \beta_\theta Z_{\theta,t} + \gamma_\theta \mathbf{1}^P Z_{\theta,t} + \epsilon_{i,\text{cds},t}.$$

t -statistics are calculated using robust standard errors clustered at the country level. Data runs from January 2002 to December 2008 (pre-crisis) and from January 2009 to December 2014 (post-crisis).

***, **, and * denote statistical significance at the 1, 5, and 10% level, respectively.

κ_r	σ_r	κ_θ	σ_θ	ϕ
0.05	0.55	0.11	4.55	0.95

Table IX. Calibrated Parameters

This table reports parameters used for the calibration exercise. The mean reversion and the volatility of the target rate process are calibrated to match the loading of yield changes on target rate shocks in the period before the crisis. The mean reversion and the volatility of the communication process are calibrated to match the loading of yield changes on communication shocks in core countries post-crisis. The proportion of yield-oriented investors in peripheral countries is calibrated to match the loading of yield changes on communication shocks in peripheral countries post-crisis. Data runs from January 2001 to December 2008 (pre-crisis) and from January 2009 to December 2014 (post-crisis).