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Federal Reserve Bank of Kansas City

# Unconventional Monetary Policy, (A)Synchronicity and the Yield Curve

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**ABSTRACT**

This paper examines international spillovers from unconventional monetary policy (UMP) between the US, the Euro area, the UK and Japan, exploiting the asynchronous timing of monetary policy normalization to shed light on the term structure implications of UMP divergence. Using high frequency futures data to identify monetary policy surprises and controlling for contemporaneous news, I find that spillovers increase during periods of unconventional monetary policy, and that these strengthen in the period of asynchronous policy normalization. Local projections suggest persistent spillovers from the Federal Reserve, whereas other spillovers fade quickly. Through the lens of a shadow rate term structure model (SRTSM), I find that these surprises elicit, domestically and internationally, revisions to both the expected path of short-term interest rates and required risk compensation, with the latter gaining importance at the effective lower bound of interest rates.

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## 1 Introduction

The speed of economic recovery in the aftermath of the Global Financial Crisis (GFC) has differed markedly among advanced economies, leading to increasingly divergent monetary conditions. While the Euro area and Japan increased their unconventional monetary stimulus, monetary policy normalization in the United States and the UK preceded a gradual inversion of the yield curve. These dynamics fuel extant interest in the process of exiting from unconventional monetary policy (UMP) and in the role of monetary policy spillovers in explaining patterns of domestic and foreign asset prices at and away from the zero lower bound (ZLB).[1] The timing, overlap, and intensity of unconventional monetary policies among the four largest advanced economy central banks—the Federal Reserve (FOMC), the European Central Bank (ECB), the Bank of England (BoE) and the Bank of Japan (BoJ)— warrants specific attention in light of the unique conditions generated by the ZLB.

In particular, observed patterns in long-term interest rates in these advanced economies suggest that the timing of monetary policy normalization matters for the term structure of interest rates. Large expansionary spillovers to the long end of the yield curve have the potential to dampen the effectiveness of domestic monetary policy normalization, particularly if normalization operates chiefly at the short end of the term structure. Unilateral or asynchronous exit from unconventional monetary policy thus has the potential to flatten or invert the yield curve, while monetary policy normalization has the potential to impact the effectiveness of ongoing quantitative easing (QE) elsewhere.

Evidence from the US suggests that unconventional monetary policy successfully lowered interest rates on domestic long-maturity assets, but also suggests that large scale asset purchases (LSAPs) by the Federal Reserve induced large asset price spillovers (see for example Krishnamurthy and Vissing Jorgensen 2011; Bauer and Rudebusch 2014; Neely 2015; Fratzscher *et al.* 2013; Christensen and Rudebusch 2012; Gagnon *et al.* 2011; Hamilton and Wu 2012; D'Amico and King 2013; Wright 2012). However, the scale and scope of spillovers from other advanced economy central banks pursuing quantitative easing has received less

[1] Although the term "spillovers" could be used to denote the impact of foreign policy on any number of variables, throughout the text I use "spillovers" to refer to the effect of one central bank's monetary policy surprises on another country's sovereign yield curve.

study.[2] Divergent monetary conditions in advanced economies with a history of unconventional monetary policy underscore this gap in the literature, which this paper seeks to fill.

To that end, this paper analyzes the magnitude of cross-border spillovers between the four largest central banks with policies of quantitative easing—the Federal Reserve, the ECB, the Bank of Japan, and the Bank of England. In documenting these spillovers from unconventional monetary policy, I further exploit the asynchronous withdrawal of unconventional monetary policy to shed light on the implications of this unprecedented type of monetary policy divergence for domestic and international transmission. The paper thus focuses on three key questions. First, how does monetary policy at the zero lower bound differ from conventional periods in its effect on the shape of the term structure, both domestically and internationally? Second, what role do term premia play in domestic and international transmission compared to more conventional channels? Finally, how do spillover dynamics change when (unconventional) monetary policy conditions diverge?

To answer these questions, I use high frequency identification to extract monetary policy surprises from futures contracts on the dates of monetary policy announcements in the spirit of Kuttner (2001), Gürkaynak *et al.* (2005) and others. A novel application includes contemporaneous advanced economy monetary policy and macroeconomic news surprises to examine the effects of (a)synchronous quantitative easing and normalization on the term structure of zero coupon bond yields. Controlling for these contemporaneous surprises on the dates of monetary policy announcements decreases news contamination in the absence of intraday data and enables direct comparisons between central banks. To evaluate the influence of synchronicity, I separate the sample into four distinct periods based on the count of central banks engaged in QE.[3]

Focusing first on zero coupon bond yields, I find that spillovers from monetary policy on the sovereign yield curves of advanced economies not only shift from short maturities

[2] A small but growing body of literature treats spillover effects from the ECB. Fratzscher *et al.* (2014), Falagiarda *et al.* (2015), Bluwstein and Canova (2016), Ciarlone and Colabella (2016) explore the effects of the ECB's asset purchase programs on emerging and non-euro European markets, while Georgiadis and Gräb (2015), Fratzscher *et al.* (2014), and Curcuru *et al.* (2018) examine spillovers from ECB monetary policy on advanced economy assets.

[3] I focus on announcements related to QE entry and exit because these programs represent the most direct targeting of unconventional (particularly long-duration) asset prices. In so doing, my paper differs from others comparing the time-varying spillovers of the four largest central banks, which to date address differential effects between the pre- and post-crisis periods only.

to long ones in periods of unconventional monetary policy, but that they increase in magnitude as well. In addition, these spillovers increase further in the period of asynchronous monetary policy normalization. In the case of the Federal Reserve, spillovers to the UK, the Euro area, and Japan during the period of normalization dominate those observed during the period of peak US UMP. Moreover, spillovers do not emanate only from the Federal Reserve. The ECB and Bank of England generate substantial spillovers to the long end of the US yield curve during the most divergent episode in the sample, following the announcement of the ECB's policy of quantitative easing, the Extended Asset Purchase Program (EAPP).[4] This latter result stands in contrast to some of the previous literature on spillovers suggesting a unique role for the Federal Reserve in generating spillovers (Ehrmann and Fratzscher 2005; Fratzscher *et al.* 2016; Brusa *et al.* 2017; Mueller *et al.* 2017; Rogers *et al.* 2014), while complementing other results finding that the ECB generates spillovers to US asset prices (see for example Curcuru, De Pooter and Eckerd 2018; Rogers *et al.* 2016).[5]

These increased spillovers, concentrated on the long end of the yield curve, may complicate the independent conduct of monetary policy in the pursuit, or unwinding, of unconventional monetary policy. Conventional monetary policy, on the other hand, generates vanishingly small spillovers that are concentrated in the short end of the yield curve. By contrast, unconventional monetary policy and its unwinding therefore uniquely generate conditions under which central banks may face challenges in implementing independent monetary policy, due to its impact on long-term bond yields, which tend to move together.

Second, to pinpoint the channels of monetary policy transmission, I decompose each market's zero coupon bond yield into an expected path of short rates and a term premium

[4]Throughout this paper, I follow Bernanke (2009) and others and define quantitative easing as a central bank balance sheet expansion focused on the mix of loans and securities that the central bank holds, with explicit consideration on the effect this composition of assets affects credit conditions. This definition distinguishes the experience of the ECB from the Fed, the Bank of England, and the Bank of Japan. In contrast to these other central banks, the ECB's balance sheet expansion during its early crisis response mainly reflects its increased intermediation role and the growth of its lending to banks, which play a crucial part in financing the Euro area's private sector. While the other central banks orchestrated the growth of their balance sheets as part of their policies of quantitative easing, in the case of the ECB, the discretion of commercial banks and their need for refinancing drove balance sheet expansion. The contraction of the ECB's balance sheet that began in 2012 reflected the banks' declining need for liquidity following the reduction in financial fragmentation in the Euro area (de Sola Perea and Van Nieuwenhuyze, 2014).

[5]Rogers *et al.* (2016) find that ECB monetary policy does not affect US bond yields, while the Bank of England and Bank of Japan do exert influence. This conflicts in part with my finding that the ECB QE does affect US bond yields.

using the shadow rate term structure model (SRTSM) of Wu and Xia (2016). The choice of a shadow rate term structure model with daily data further distinguishes this paper from the existing literature by taking into account the influence of the zero lower bound on the expected path of short rates (Kearns *et al.* 2018; Rogers *et al.* 2014; Shah 2018).

Results from this yield decomposition suggest that, in most subsamples and most sender-recipient pairings, the term premium drives the bulk of spillovers. I find that these term premium spillovers are strongest in the period of asynchronous monetary policy normalization both in absolute terms (i.e., compared to term premium spillovers in other subsamples) and in comparison to the expected path of short rates. By contrast, the expected path of short rates drives (modest) spillovers in the pre-crisis period. The strength of the term premium channel further underscores the uniqueness of unconventional monetary policy both in terms of spillovers and in driving domestic interest rate pass-through.[6] This finding also has potential implications for the conduct of unconventional monetary policy. In particular, the dominance of the term premium in driving these increased spillovers further suggests that, in their absence, both quantitative easing and normalization may be more effective domestically because of the potential for portfolio balance effects.

A telling break from these patterns emerges in normalizing economies during the period of ECB quantitative easing and US interest rate normalization. In this period, the UK receives large expected short rate path spillovers from the Federal Reserve and the ECB. At the same time, expected path spillovers to the US from ECB monetary policy increase in importance compared to previous subsamples. Together, these results suggest that the expected path of short rates becomes increasingly important in the liftoff from the zero lower bound, implying decreased perceived monetary policy independence of normalizing central banks.

In terms of domestic transmission, these central banks impact yields in their respective markets primarily through the term premium in periods of domestic quantitative easing; otherwise, the bulk of the domestic effect runs through the expected path of short rates. These differential channels of transmission map onto the maturity structure of interest rate pass-through: periods of unconventional monetary policy correspond to a larger impact on the

[6] Periodically throughout the paper, I use the term "pass-through" to denote the effect of domestic monetary policy surprises on the domestic sovereign yield curve.

long end of the yield curve through term premia, while periods of conventional monetary policy largely act on shorter interest rates through expectations of future policy rates. By considering domestic transmission channels, I am able to comment in some instances where confidence channels appear to dominate portfolio balancing with respect to duration risk; in particular, an absence of term premium effects at home implies that term premium changes abroad stem from growth, inflation or interest rate risk rather than portfolio balance effects.

Finally, I trace the persistence of these monetary policy spillovers to long-term sovereign bond yields using the method of local projections (Jordà 2005; Stock and Watson 2018). While it is common in the literature on monetary policy transmission to use vector autoregression to document the persistence of shocks, these models have a number of drawbacks for the identification of cross-border monetary policy surprises.[7] Local projection methods allow the inclusion of multiple monetary policy surprises and macroeconomic news shocks without raising concerns of parameter proliferation and without imposing additional assumptions over the baseline model.

In some cases, results from local projections diminish the economic significance of estimated spillovers. While contemporaneous spillovers to the US increase in magnitude during the period of asynchronous normalization, these effects dissipate within a week's time. By contrast, spillovers from the Federal Reserve typically last for more than a month, often matching the persistence of domestic pass-through. The persistence of US monetary policy surprises, compared to the transitory nature of spillovers from other central banks, supports findings in existing literature that emphasizes the uniqueness of the Federal Reserve (Brusa *et al.* 2017; Gerko and Rey 2017; Mueller *et al.* 2017 and Rogers *et al.* 2014).

The paper proceeds as follows. Section 2 briefly describes the related literature on monetary policy spillovers and reviews the transmission mechanisms of unconventional monetary policy. Section 3 presents stylized facts from the data to motivate the main approach. Section 4 presents the baseline model for estimating the effects of monetary policy surprises on zero coupon bond yields, including the decomposition of these yields into a rational expectations-implied path of short rates and a term premium to test their relative importance in monetary

[7] See, for example, Rogers *et al.* (2014); Rogers *et al.* (2016); Gertler and Karadi (2015); and Bluwstein and Canova (2016)

policy transmission. Section 5 presents further evidence on the channels of passthrough to term premia in greater depth and discusses a number of robustness checks. Section 6 concludes and outlines future directions for research.

## 2 Motivation: Spillovers at the Zero Lower Bound

### 2.1 Related Literature

This paper relates chiefly to the literature documenting empirical patterns in cross-border monetary policy spillovers. The nearest neighbors of this paper compare the magnitude of sovereign bond yield spillovers from monetary policy among advanced economy central banks, particularly from quantitative easing and its unwinding (Rogers *et al* 2014, 2016; Kearns *et al* 2018; Shah 2018; Zhang 2018). While Rogers *et al* (2014), Fratzscher *et al* (2017) and Shah (2018) find that the Federal Reserve uniquely propagates cross-border yield curve spillovers, Rogers *et al* (2016), Kearns *et al* (2018) and Zhang (2018) find a role for other advanced economy central banks in influencing long-term bond yields internationally. Similarly, in a paper comparing cross-border spillovers between the US and the Euro area, Curcuru *et al* (2018a) find that the ECB generates spillovers to the US comparable to those generated by the Federal Reserve in German long-term bond yields.

A related literature examines central bank announcement premia in other types of returns. Mueller *et al* (2017) document that a trading strategy that is short in the U.S. dollar and long in other currencies exhibits larger excess returns on days with scheduled Federal Reserve announcements. The authors interpret these excess returns as compensation for monetary policy uncertainty and find that no other central bank except Bank of Japan generates a similar pattern. Examining excess equity returns, Brusa *et al*. (2017) find that there is an equity premium associated with Fed announcement days that is not shared by any other central bank. Aizenmann *et al* (2016) also devote attention to the other major central banks pursuing quantitative easing and find that the Federal Reserve uniquely propagates international monetary policy spillovers.

Papers on monetary policy spillovers from the largest central banks increasingly measure the international impact of their quantitative easing programs and contrast these with the

period of conventional monetary policy. While Neely (2011), Wright (2012), Fratzscher *et al* (2017), Bauer and Neely (2014), and Rogers *et al* (2016) find that QE's international impact distinguishes unconventional from conventional monetary policy, Curcuru *et al* (2018b) find that QE does not exert larger international spillovers. Taking time-varying impacts further into the period of monetary policy normalization, Chari, Dilts Stedman, and Lundblad (2018) find that asset price spillovers from monetary policy in the US do not differ substantially between the conventional and unconventional periods, but that the normalization of US monetary policy had substantial consequences for emerging market asset prices.

This paper also relates to literature on the identification of monetary policy asset price pass-through using high frequency identification of monetary policy shocks (Kuttner 2001; Gükaynak, Sack and Swanson 2005, 2007; Gertler and Karadi 2015; Leombroni *et al* 2017; Gorodnichenko and Weber 2016; Ozdagli and Weber 2017). I extend the methodology used in this literature to generate a daily monetary policy surprise measure that is consistent between central banks and that maintains variation at the zero lower bound. I depart from the existing literature by jointly estimating spillovers from multiple central banks instead of censoring concurrent observations.

## 2.2 Mechanisms of Transmission: Conventional versus Unconventional Monetary Policy

In typical circumstances, central banks conduct monetary policy by buying and selling short-term debt and, in most instances, target short-term interest rates. However, at the zero lower bound, the availability of cash as an asset negates stimulus from decreasing the short-term policy rate indefinitely below zero. Beyond the effective lower bound of interest rates, recent years saw central banks pursue policies such as direct lending, liquidity provision to key credit markets, and large-scale asset purchases. These large-scale asset purchases, coupled with forward guidance regarding the path of policy, aim specifically to lower long-term interest rates through heavier management of expectations and adjustments to term premia.[8] Thus, to distinguish between conventional and unconventional monetary policy, it is conve-

[8] Bernanke, Ben S. (19 November 2013) *Communication and Monetary Policy*. Retrieved from https://www.federalreserve.gov/newsevents/speech/bernanke20131119a.htm

nient to consider the yield on an $n$-period risk-free bond as the average level of short-term interest rates over the maturity of the bond and a term premium:

$$Y_t^{(n)} = \mathbf{E}[\bar{Y}_{t,t+n}|I_t] + YTP_t^{(n)} \tag{1}$$

where $\mathbf{E}[\bar{Y}_{t,t+n}|I_t]$ is the average short-term rate expected to prevail over the period $t$ to $t+n$ (that is, the component of the yield that would drive yield variation if the expectations hypothesis were to hold exactly), and $YTP_t^{(n)}$ is a maturity-specific term premium. The term premium captures the additional required compensation for holding a long-term bond (duration risk), subsuming the price and amount of interest rate risk, inflation risk, and macroeconomic growth risk. In theory, conventional monetary policy operates chiefly via the expected path of short-term interest rates, as compensation for maturity risk shrinks to zero with the maturity of the bond (see for example Hamilton (2009)). However, unconventional monetary policy influences both terms of (1), either by signaling the central bank's intention to keep interest rates low, thereby reducing $\mathbf{E}[\bar{Y}_{t,t+n}|I_t]$, or by removing duration risk from the market (decreasing $YTP_t^{(n)}$).

Focusing on the first term of (1), forward guidance can lower the expected path of interest rates by communicating the central bank's intention to keep interest rates low (or to pursue ongoing asset purchases), committing often to a specific time horizon or level of fundamentals. However, large-scale asset purchases themselves also contribute to the force of forward guidance by acting as a commitment mechanism. Growing and maintaining the balance sheet signals low future interest rates in the sense that a central bank that has purchased a large quantity of long-dated assets when interest rates are low stands to see the value of its portfolio decline when interest rates begin to climb (Fawley and Neely 2013). Similarly, forward guidance and large-scale asset purchases have the potential to lower term premia by decreasing the volatility of expected interest rates.

However, as the maturity of an asset increases, the expected path of short interest rates explains less of the return. For this reason, monetary policy at the zero lower bound also explicitly aims at decreasing the term premium. To target longer-term interest rates, central

banks purchase long duration assets, reducing the effective supply of such assets and thereby raising their prices, lowering their yields, and decreasing the duration risk associated with holding them. As investors rebalance their portfolios in response to quantitative easing, the prices of the assets they acquire rise as well, decreasing their respective yields through the term premium and potentially prompting further rebalancing. "Restricted" or preferred habitat investors at home and abroad can amplify this portfolio balancing channel by purchasing additional long-dated assets, even as their prices rise in order to balance long-dated obligations on their balance sheets or to search for yield.[9] Thus, an expansionary monetary policy shock with strong portfolio balance effects has the potential to decrease international term premia.

Financial center monetary policy can also generate changes in international term premia by revealing information about the state of the economy, thereby altering the amount of perceived (duration) risk in the market. Central banks release information purposefully through forward guidance, but policy actions also contain information regarding policy makers' level of confidence in economic fundamentals. For example, while an episode like the "Taper Tantrum" of 2013 may increase yields by signaling an increase in the path of US interest rates, it also suggests optimism on the part of the FOMC regarding the state of the US economy. This might, in turn, be expected to benefit the global economic outlook, raising yields via projected future growth and, in turn, expected real interest rates. Thus, unconventional monetary policy may affect international term premia through a "confidence" channel.

However, the overlapping but asynchronous nature of unconventional monetary policy suggests the potential expansion of (perceived) interaction of policy between central banks. As mentioned above, on the domestic front, quantitative easing serves as a signal to markets regarding the future path of interest rate policy. How might this operate internationally?

In practice, central bank policy rates can be correlated internationally for various reasons, especially among countries with close economic ties. These can emerge through trade flows, or they can comprise information flows that manifest through business cycle comovement (see, for example, Kose *et al* (2003) and Baxter and Kouparitsas (2005)). For instance, as long

[9] Shin (2017) provides an illuminating example of long-term bond yield amplification through the duration balancing activities of German insurance firms.

as the UK and the Euro area maintain tight financial and trade linkages, their policy rates may be expected to move together due to synchronous demand conditions. That is, foreign monetary policy reveals information on the state of the global economy to which the marginal investor expects the domestic central bank to react. Such informational spillovers can manifest through the expected path of short rates (average path) as well as term premia (volatility).

Conversely, central banks increasingly act on a mandate to safeguard financial stability.[10] Central banks in countries facing expansionary financial spillovers may therefore be expected by the marginal investor to *withdraw* stimulus in the face of increased liquidity from abroad. We would expect the same reaction by central banks if expansionary monetary conditions abroad generally engender expansionary domestic demand conditions through a trade channel.

Through these additional channels, in contrast to conventional monetary policy, unconventional monetary policy stands to generate larger financial spillovers due to its focus on long-term interest rates, meaning that asynchronous normalization of monetary policy has the potential to shape the term structure of normalizing and non-normalizing economies. However, before I can estimate the channels through which unconventional monetary policy operates, I need first to identify it. The next section discusses challenges inherent to identifying cross-country spillovers from unconventional monetary policy, while Section 4 presents solutions for identification.

## 3 Stylized Facts: Inference via Heteroskedasticity

In the baseline analysis, I utilize daily data on bond yields and interest rate futures to jointly estimate the spillover effects of monetary policy surprises among the four central banks, controlling for macroeconomic news surprises. Daily data is not only more accessible, but it also possesses some advantages over intraday data. First, using intraday data increases the risk of excluding information through leaks that limit the "firmness" of the announcement time, particularly in international contexts. Similarly, intraday windows cut off slow market reactions without guaranteeing sole influence from the announcement of interest. Similarly, fu-

[10] *Financial Stability: The Role of the Federal Reserve System*. Retrieved from https://www.newyorkfed.org/newsevents/speeches/2013/bax131120

tures markets retain a higher risk of "dead quotes" for windows wherein the assets of interest do not turn over often due to lack of liquidity. This issue is particularly acute in international contexts.

However, the choice of daily data also poses challenges for identification. To expand on this and to motivate my approach, I examine monetary policy spillovers in an assumption-light fashion, testing for the *presence* of spillovers between the US, the UK, the Euro area, and Japan with an inference via heteroskedasticity-type exercise in the spirit of Rigobon (2003), Rigobon and Sack (2003), and Rigobon and Sack (2004). These straightforward estimates suggest some tentative conclusions about the presence of spillovers and highlights the importance of considering them jointly. In particular, these results underline some challenges of the event study approach for uniquely identifying monetary policy from the Bank of England and ECB using daily data due to an abundance of concurrent monetary policy surprises. Given the size of the ECB's program of QE, this represents a non-trivial barrier to identification.

### 3.1 Methodology

In a regression framework, one can express an asset price's relationship to monetary policy as

$$\Delta y_{i,t} = \begin{cases} \alpha_i + \beta MP_t^j + \epsilon_{i,t} & t = Announcement\ day \\ \alpha_i + \epsilon_{i,t} & t = Non-announcement\ day, \end{cases}$$

where $\Delta y_{i,t}$ is the change in the asset return in question for market $i$ at time $t$, and $MP_t^j$ is the monetary policy surprise originating from country $j$ at time $t$ (or in the case of a domestic monetary policy surprise, $i = j$). This setup requires only that returns during announcement windows would have the same distribution as those during non-announcement windows in the absence of central bank announcements. Taking the variance of returns on announcement

and non-announcement days separately, we see that the following holds:

$$\begin{aligned} \Delta y_{i,t}^{(a)} &= \alpha_i + \beta MP_t^j + \epsilon_{i,t} & (2) \\ var(\Delta y_{i,t}^{(a)}) &= \beta^2 var(MP_t^j) + var(\epsilon_{i,t}) \\ \Delta y_{i,t}^{(n)} &= \alpha_i + \epsilon_{i,t} & (3) \\ var(\Delta y_{i,t}^{(n)}) &= var(\epsilon_{i,t}) \end{aligned}$$

In order to test the null hypothesis that $\beta = 0$, I need only test whether the variance of returns on announcement days equals that on non-announcement days:

$$\begin{gathered} var(\Delta y_{i,t}^{(a)}) = \beta^2 var(MP_t^j) + var(\Delta y_{i,t}^{(n)}) \qquad (4) \\ var(\Delta y_{i,t}^{(a)}) > var(\Delta y_{i,t}^{(n)}) \implies \beta \neq 0 \end{gathered}$$

Note that the above holds regardless of the sign of $\beta$. To test the equality of return variances on announcement versus non-announcement days, I use the Brown-Forsythe test, comprising the F-statistic from an analysis of variance on absolute deviations from the median. As opposed to a test of mean squared deviations (such as an F-test), the Brown-Forsythe test is robust to non-normal data such as financial returns. Testing the difference in variances provides an initial picture of monetary policy spillovers without leaning heavily on many assumptions.

### 3.2 Data, Announcements and Timing Conventions

The sample of returns consists of daily data from September 4, 2004, to December 15, 2017.[11] For this exercise, I collect data on government bond yields at maturities of one, five, and ten years for each country from Bloomberg.

Because responses to the Global Financial Crisis (GFC) and turbulence surrounding the euro often elicited unscheduled policy decisions from all central banks in the sample, an-

[11] The sample dates match those used in the baseline, which reflects the availability of zero coupon bond yield data from the ECB.

nouncement days include both scheduled and unscheduled events. Central bank websites supply the majority of announcement dates; I take additional unscheduled dates from Rogers *et al* (2014) and Chari *et al* (2018).

In the current framework, identification requires the exclusion of announcement days with overlapping meetings or macroeconomic news events. While announcements from the ECB, the Bank of England, and the Bank of Japan seldom overlap with those from the Federal Reserve, important exceptions occur, especially in the period during which central banks responded to the GFC (see Table 1a).[12] Moreover, ECB and Bank of England dates overlap frequently throughout the sample. To highlight the informational content of these concurrent announcement dates, I test the response of asset returns to shared ECB/Bank of England dates separately from those with a single central bank announcement. In such concurrent instances, I define an announcement date as one on which *both* the Bank of England and the ECB release a monetary policy announcement.

Due to the geographic dispersion of these markets, I adjust the timing ascribed to each announcement to reflect trading hours and the time difference between source and recipient countries. For example, an FOMC announcement concluded at 2:45pm on date $t$ may not affect Japanese bond yields until trading begins at 8:45am (GMT+9) on day $t+1$. For this reason, I measure announcement effects from the US to other countries in the sample as the daily difference in yields from $t$ to $t+1$, whereas the impact of the ECB, Bank of England, and Bank of Japan on the US are measured as the daily difference of US yields from $t-1$ to $t$. Table 1b provides a summary of timing conventions between the four markets.

### 3.3 Results

Table 2 displays the results. Statistically significant results ($\leq 10$ percent) are expressed as the ratio of standard deviations on announcement days to those on non-announcement days:

$$\frac{\sigma_i^{a_j}}{\sigma_i^n} - 1, \tag{5}$$

where $j$ is the central bank generating a monetary policy announcement and $i$ is the re-

[12] For example, on March 18, 2009, the FOMC and Bank of Japan both announced asset purchase programs. On this date, the US 10-year bond yield exhibited the largest single day drop from 1987 to the time of this writing.

cipient market. Blank cells represent results insignificant at the 10 percent level. Finally, cells with red text denote spillovers from combined ECB/Bank of England dates that do not exhibit spillovers from either Bank of England or ECB announcements individually.

Several patterns stand out. First, these central banks influence their own yield curves at every maturity. In terms of spillovers, the UK and Euro area's monetary policies exhibit the most consistent connection, impacting each other's term structure at every maturity. In line with much of the extant literature, the results in Table 2 suggest that the FOMC generates spillovers to the Euro area and the UK, while no central bank in the sample generates unilateral spillovers to the US. This result aligns with some of the current literature addressing cross-country spillovers to the United States from other central banks (Ehrmann and Fratzscher 2005; Rogers *et al* 2014; Shah 2018; Mueller *et al* 2017; Brusa *et al* 2017). Unique within the sample, the Bank of Japan does not appear to generate spillovers to the bond yields of any of the other markets in the sample, nor does Japan appear to receive detectable spillovers.

Notably, however, when I consider dates that contain both an ECB and a Bank of England announcement, these concurrent events increase the volatility of medium and longer-dated US yields. In this case, Bank of England and ECB monetary policies are not separately identified, but the receptiveness of US yields to these concurrent shocks suggest a shortcoming in measuring unilateral spillovers from the ECB or Bank of England using daily data in a univariate event study framework.

Beyond the preliminary and intuitive documentation of spillovers among these advanced economy central banks, this stylized fact from the data suggests that shared dates among these central banks matter for identification, especially in the case of the ECB and the Bank of England. The conservative approach embodied in this exercise leaves important information underutilized, and thus the impact of some central banks in the sample appears less well identified. These concerns motivate the main approach of the paper, to which I turn next.

# 4 Baseline Regressions

The previous section highlighted some potential pitfalls of identifying monetary policy surprises using daily data.[13] In this section, the baseline analysis displays a number of characteristics intended to capture the full impact of monetary policy surprises while addressing these obstacles in analyzing the influence of asynchronous monetary policy normalization on spillovers.

## 4.1 Monetary Policy Surprises

This paper follows the high frequency identification (HFI) literature pioneered by Cook and Hahn (1989), Kuttner (2001), Cochcrane and Piazzesi (2002), Gürkaynak *et al* (2005), and others. This literature often defines a monetary policy surprise (in the United States) as the daily difference in the implied yield on a Fed Funds futures contract on a date with some Federal Reserve activity and zero on all other dates. This approach requires some adjustments, however, in international applications and at the zero lower bound.

First, aside from case of the Federal Reserve, no futures market instruments track the other central banks' policy rates directly. Each of these markets does, however, have an active interbank lending market with its own Interbank Offered Rate. One year ahead futures contracts on the three-month Euro Interbank Offered Rate (Euribor), Sterling London Interbank Offered Rate (Sterling Libor), and Euroyen Tokyo Interbank Offered Rate (Euroyen Tibor) are all traded continuously throughout the sample and maintain variation at the ZLB (see Figure 1). Because these interbank rates are strongly influenced by current expectations of future policy rates, overnight futures contracts can act as close substitutes for a contract based explicitly on the policy.[14]

Further complicating identification, variation in the price of Fed Funds futures contracts decreased considerably at the zero lower bound. From December 2008 until December of 2015, the FOMC announced no changes to the target Fed Funds rate, and in much of that period, the FOMC worked to maintain the message that the policy rate would continue near

[13]See Nakamura and Steinsson (2015), Rogers *et al* (2014), and Curcuru *et al* (2018a) for more work in this area.

[14]Bernoth and Von Hagen (2004), for example, find that the three month Euribor futures rate is an unbiased predictor of Euro area policy rate changes.

zero. To account for this issue, I follow Gertler and Karadi (2015) in using the one year ahead, three-month Eurodollar futures contract instead of Fed Funds futures, which alleviates the issue of attenuation apparent in the Fed Funds Futures data. The use of Eurodollar futures also brings the monetary policy measure for the FOMC in line with measures for the other central banks. Thus, I use the daily change in the yields implied by these overnight interbank interest rate futures prices (Eurodollar, Euribor, Euroyen and Short Sterling) as my measure of the surprise element contained in announcements by each respective central bank. The majority of included central bank announcement dates in the sample come from central bank websites. However, as in the previous exercise, I also include additional unscheduled dates.

Although attenuation does not appear to pose a problem in the sample period for the chosen contracts, time varying volatility of any short term interest rate into and away from the zero lower bound may still be a concern (see Figures 1a - 1d). To this end, and in recognition of quantitative easing's explicit goal of influencing longer-term interest rates, I also measure the surprise as the daily change in the two-year zero coupon bond yield as a robustness check, following Gilchrist *et al* (2014).[15] While these assets do not possess the desirable quality of serving as insurance against future interest rate changes, one may still reasonably attribute changes in the price of these assets on announcement days primarily to reactions to monetary policy surprises.

Tables 3a and 3b show summary statistics of the measured monetary policy surprises. For ease of interpretation and to make comparisons between central banks more germane, I normalize monetary policy surprises to a one standard deviation loosening in basis points.

### 4.2 Yield Curve Measures

In the baseline regressions and to estimate the shadow rate term structure model, I use zero coupon bond yield data gathered from central banks. The Federal Reserve publishes daily data on US zero coupon bond yields from Gürkaynak, Sack, and Swanson (2005).[16] The Bank

[15] A suitable futures contract on a medium duration bond is not available for all sample countries. Contracts for Japan and the UK (5-year JGB futures and Medium Gilt futures) do not have an adequately long trading history, and no futures contract exists for a generic European bond yield. In the case of Japan, trade in 5-year JGB futures ceased entirely from June of 2002 to January of 2008, while in the case of the UK, Medium Gilt Futures did not launch until November of 2009.

[16] https://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html

of England and ECB websites publish UK and Euro area zero coupon bond yields, respectively.[17] For Japan, zero coupon curve smoothing parameters are produced from JGB coupon bonds using the Nelson-Siegel-Svensson method, as described in Gürkaynak, Sack, and Wright (2007). All zero coupon curves comprise AAA-rated sovereign bonds.[18] To give a more complete picture of term structure adjustments, I estimate the impact of monetary policy surprises on yields with maturities of 1, 3, 5, 7, and 10 years. As in the previous section, the sample spans September 4, 2004, to December 13, 2017. The availability of zero coupon bond yields from the Euro area determines the start date of the sample.

To extract the term premium and expected path of short rates from the term structure, I estimate the shadow rate term structure model of Wu and Xia (2016). Many papers in the literature on monetary policy spillovers utilize Gaussian affine term structure models (GATSM) to estimate term premia. However, because these models assume the short rate to be linear in Gaussian factors, GATSMs place a positive probability on negative nominal interest rates and therefore face challenges in periods of a binding effective lower bound. By contrast, the SRTSM used here is a latent factor model where the state variables have Gaussian dynamics but the short rate has a shadow rate interpretation. Following Black (1995), the shadow rate class of term structure models represents the policy rate as the maximum of the effective lower bound and a shadow interest rate reflecting the value of the short rate if it could move freely below zero:

$$r_t = max\{\underline{r}, s_t\} \tag{6}$$

The nonlinearity introduced by this representation makes such models difficult to estimate beyond one factor. However, Wu and Xia (2016) propose an analytical representation for the forward rate that makes a nonlinear term structure model tractable in empirical estimation for multiple factors. Having estimated the expected path of short rates for each of the US, the UK, the Euro area and Japan, I calculate the term premium as a residual in accordance with Eqn. 1.

[17]http://sdw.ecb.europa.eu/browse.do?node=9691417
https://www.bankofengland.co.uk/statistics/yield-curves

[18]Note that the ECB also publishes a series using all Euro area central government bonds (including AAA-rated), but this collection of bonds is less likely to be considered free of default risk. Nevertheless, repeating the exercise with all Euro area sovereign bonds yields similar results.

Appendix D contains additional details from Wu and Xia's (2016) model. To save space, summary statistics on yields, expected short rates, and term premia for each of the four markets can be found in the Internet Appendix.

### 4.3 Control variables

As mentioned above, this paper uses daily data to identify a monetary policy surprise in order to capture as much of the asset price's reaction as possible. In measuring the informational impact of monetary policy surprises, too narrow a window may miss part of the monetary policy surprise, but too wide a window risks the inclusion of non-monetary news. To retain the information of the announcement while reducing noise from other concurrent events, I control for macroeconomic news surprises from systemic economies using the Citigroup Economic Surprise Index (CESI) for Japan, the Euro area, the UK, and the US, in addition to controlling for concurrent monetary policy announcements. The CESI tracks how economic data compare to expectations; the indices rise when economic data exceed economists' consensus forecasts and falls when data come in below forecast estimates.[19] In order to ensure that monetary policy surprises enter the regressions only through the futures-implied measures, I orthogonalize these news shocks to the monetary policy surprise measures. Finally, the lagged bilateral nominal exchange rate in local currency per unit of foreign currency controls for the influence of currency-based arbitrage, and a Friday dummy captures day-of-the-week effects.

### 4.4 Methodology

Given my interest in what might be considered different global monetary policy phases, I partition the sample by count of central banks engaged in QE. The first subsample, ranging from September 4, 2004, to September 15, 2008 (the collapse of Lehman Brothers), encompasses the pre-crisis period and constitutes broadly the period of conventional monetary policy (with the periodic exception of Japan). The period of initial quantitative easing (December 1, 2008

[19] Indices are defined as weighted historical standard deviations of data surprises (actual releases vs. Bloomberg survey median) and are calculated daily in a rolling three-month window. The weights of economic indicators are derived from relative high-frequency spot FX impacts of one standard deviation data surprises. The indices also employ a time decay function to replicate the limited memory of markets.

- May 21, 2013) comprises the introduction of multiple large-scale asset purchase programs, including LSAPs from the Federal Reserve, the Bank of England, and the Bank of Japan. Although the Bank of England and Bank of Japan began their asset purchase programs after the Federal Reserve (in March 2009 and October 2010, respectively), I group their entry with that of the United States as initial reactions to the deepening financial crisis that meet the definition of quantitative easing outlined previously.[20]

Beginning the period of asynchronous monetary policy normalization, the next subsample begins with the "Taper Tantrum" of May 22, 2013, when then-Chair Ben Bernanke first suggested the FOMC's intention to taper US large-scale asset purchases. From this point on, I consider the United States to have begun normalizing monetary policy. Thus, from May 22, 2013, to January 21, 2015, only the Bank of Japan and Bank of England actively pursued quantitative easing. Throughout the text, I refer to this period as the "intra-QE" period, although there are still two quantitative easing programs in place. Finally, I partition the period from the start of the ECB's program of quantitative easing to the end of the sample and refer to this as the EAPP period. During this last subsample, the Bank of Japan also intensified its unconventional monetary stimulus, instating policy frameworks such as "Quantitative and Qualitative Easing (QQE) with Negative Interest Rates" and "QQE with Yield Curve Control". I refer to this latter period with the "EAPP" label throughout the text.

I consider each major QE entry or exit as a potential "critical juncture" and run piecewise regressions of the following form:

$$\Delta y_{it}^{(n)} = \alpha + \beta \Delta y_{it-1}^{(n)} + \sum_k \psi_k D_k MP_t^i + \sum_j \sum_k \gamma_k^j D_k MP_t^j + \theta_1^i S_t^i + \sum_j \theta_j S_t^j + \sum_j \phi_j \Delta e_{t-1}^{i,j} + \delta Fri + \epsilon_{it} \tag{7}$$

$$MP_t^j = \begin{cases} Y_{j,t} - Y_{j,t-1} & t = Announcement_j \\ 0 & Otherwise, \end{cases}$$

[20] I contrast here entry in response to the GFC with the ECB's initiation of quantitative easing in response to the deterioration of real economic conditions in the Euro area after the initial recovery of financial markets from the GFC.

where $y_{it}^{(n)}$ is either the zero coupon yield on an $n$-year bond in country $i$, the average expected path of short rates in country $i$ from $t$ to $t+n$ ($\mathbf{E}[\bar{Y}_{t,t+n}|I_t]$), or the term premium ($YTP_t^{(n)}$) on an $n$-year bond for country $i$ at time $t$. To match asset reactions to markets, the timing conventions in Table 1b apply to this exercise as well. $D_k$ refers to dummy variables equal to one in each of the aforementioned policy phases (k = {pre-crisis, US QE, intra-QE, EAPP}), while $MP_t^i$ is the domestic monetary policy surprise from country $i$'s central bank, and $MP_t^j$ is the monetary policy surprise emanating from foreign central banks ($j \neq i$). In calculating the monetary policy surprise, $Y_{j,t}$ is the implied yield on the short futures contract in use for central bank $j$ (or the yield on the 2-year zero coupon bond in market $j$). $\Delta e_{t-1}^{i,j}$ is the lagged daily change in the exchange rate (LC/FC), and $S_t^{JP}$, $S_t^{US}$, $S_t^{EU}$, and $S_t^{UK}$ are the orthogonalized CESI for Japan, the US, the Euro area, and the UK, respectively. Finally, I include a Friday dummy to capture day-of-the-week effects.

To account for some of the unique characteristics of financial data, such as excess kurtosis, negative skewness, and serial correlation, I include an AR(1) term in the regressions and utilize HAC standard errors, where the bandwidth for the Parzen kernel is selected using Newey and West's (1994) procedure. Chow breakpoint tests support the chosen partition dates.

### 4.5 Results

Tables 4 - 9 display the main results.[21] In these tables I provide parameter estimates at 1-, 3-, 5-, 7-, and 10-year maturities; however, I largely limit discussion in the text to maturities of 1, 5, and 10 years for ease of exposition. Before turning to the baseline (piecewise) regressions and to provide a useful contrast, I document first the broad patterns in the full sample (Table 4).

Domestic monetary policy surprises pass through to domestic interest rates in a manner roughly similar across economies. These domestic monetary policy surprises elicit a statistically significant reaction along the yield curve in every market; in particular, point estimates suggest that an expansionary monetary policy surprise decreases the zero coupon bond yield at each maturity. In each case, this domestic effect dominates the size of spillovers from

[21]Full results, including estimates for control variables, can be found in the Internet Appendix.

foreign central banks by a factor of roughly 1.5 to 8. In general, domestic surprises generate changes in a hump-shaped pattern (increasing and then decreasing with maturity) that peaks at the 3-year bond for the UK and the Euro area, the 5-year bond for the US, and the 7-year bond for Japan. For example, taking point estimates from Table 4 and standard deviations from Table 3a, a one standard deviation (8.66 basis point) loosening surprise in the full sample induces statistically significant decreases in US zero coupon bond yields of 1-, 5-, and 10-year duration, amounting to 3.7, 5.9, and 4.5 basis points, respectively. For the UK (Euro area), these point estimates are 3.3 (3.0), 3.7 (3.2), and 2.6 (1.6) basis points on 1-, 5-, and 10-year bond yields, respectively.[22] For Japan, the domestic pass-through from a one standard deviation (2.29 basis point) monetary policy surprise to 1-, 5- and, 10-year bond yields are 0.4, 1.9, and 1.8 basis points, respectively.

Turning to cross-border spillovers in the full sample, the Euro area, the UK, the US, and Japan vary in the degree to which they generate spillovers to one another. Surprisingly, these central banks generate spillovers in the full sample of similar magnitude regardless of the source. That is, while the Federal Reserve exhibits the most consistent statistically significant spillovers in the sense that it influences every other yield curve, its point estimates do not stand out in terms of magnitude compared to other central banks. The ECB generates the second-most consistent set of spillovers, eliciting term structure adjustments in the UK and the US. In the full sample, only the ECB plays this role vis-à-vis the US. This latter pattern maps partially onto the results noted in Section 3, wherein only concurrent ECB/BoE monetary policy announcements appear to elicit a US yield response. The Bank of England, by contrast, has a statistically significant effect only on the long end of the Euro area yield curve, while the Bank of Japan generates modest spillovers to medium duration European bond yields.

Breaking the data into subsamples based on entry into and exit from QE, some additional nuance emerges. Tables 5 - 9 condense the results of the baseline regressions to allow for easier comparison between the sources of monetary policy surprises and between the channels of transmission. To show how the size, dispersion and maturity structure of spillovers has

[22]In the full sample, a one standard deviation surprise in the UK is 7.23 basis points, while for the Euro area it is 6.27 basis points.

changed for time, Figures 2a - 2l plot statistically significant point estimates of domestic and international passthrough, adjusted to reflect the sample-specific standard deviation. For ease of exposition, the remainder of this section treats domestic effects by market (Table 5) and discusses spillovers by central bank (Tables 6 - 9).

#### 4.5.1 Domestic Transmission of Monetary Policy: Piecewise Baseline

Table 5 summarizes the estimated impact of domestic monetary policy surprises on yields, expected short rates, and term premia. As in the full sample, domestic effects dominate those of spillovers in all subsamples (i.e., $\gamma_k^j < \psi_k$ for all $j$). However, the loading of monetary policy surprises by maturity differs by subsample for both domestic monetary policy effects and spillover effects, reflecting changing channels of transmission. To compare subsample coefficients statistically, Tables 10 - 13 display Wald tests for equality of coefficients for each market.

In each market, expansionary monetary policy surprises decrease yields all along the domestic yield curve, but the "shape" of the loading pattern differs at and away from the zero lower bound, consistent with results from Rogers *et al* (2014). In the pre-crisis period, the impact of monetary policy decreases with the maturity of the bond, in line with the conduct of conventional monetary policy. In this subsample, an expansionary monetary policy surprise decreases the 1-year zero coupon bond yield at a rate two to three times that of the 10-year yield. Among the four central banks, the Federal Reserve exhibits the highest domestic pass-through to the 10-year bond yield at 2.6 basis points, similar to point estimates from Gürkaynak *et al* (2005).[23]

Related to decreasing pass-through by maturity, this period also exhibits a dominant domestic role for the expected path of short rates, which decreases monotonically with maturity. In fact, in line with results from Nakamura and Steinsson (2015), the term premium does not appear to strongly influence domestic bond yields at any maturity in the pre-crisis period. What small effect the term premium does have on bond yields runs counter to the force exerted by the expected path of short rates. That is, an expansionary monetary policy surprise increases the term premium, indicating that market participants anticipate future growth, in-

[23]Gürkaynak *et al* (2005) find that a 25 basis point expansionary monetary policy surprise caused 10-year yields to fall about 10 basis points. Similarly, my results suggests US domestic pass-through to the 10-year bond yield of 8.7 basis points from a 25 basis point monetary policy surprise.

flation or interest rate volatility, or a combination thereof.

These patterns begin to diverge, however, after the onset of the GFC. Starting with the US, domestic patterns of interest rate pass-through shift with the onset of US QE. During this initial period of quantitative easing, the effect of US monetary policy increases with the maturity of the bond (although pass-through begins to decrease at a maturity of ten years), which aligns with the stated goals of the FOMC's unconventional monetary policy and fits with other results observed in the literature (Christensen and Rudebusch (2012); Shah (2018); Rogers *et al* (2016); Georgiadis and Gräb (2015); and Neely (2015), for example). During this period, a 8.66 basis point loosening surprise induced a 5.4 basis point change in the 10-year US bond yield on average.[24] The domestic impact of FOMC monetary policy peaks along the yield curve at the 7-year bond yield in the initial period of quantitative easing, compared to the 5-year yield in the intra-QE period and the 3-year yield in the EAPP period. In the context of interest rate normalization, this implies that monetary policy exerts decreasing influence over domestic long-term bond yields as the Federal Reserve normalizes US monetary policy. We observe this in the transition from dominant term premium effects to dominant expected short rate effects over the US QE, intra-QE and EAPP periods in sequence.

The Euro area and the UK exhibit several shared patterns, accompanied by important divergences. Similar to results for the United States, domestic monetary policy shocks load more heavily onto their respective short-term bond yields in the pre-crisis period and generate a larger effect on medium- and long-term bond yields during and after the Global Financial Crisis. For the Euro area, this transition takes place in the period following the US tapering announcement, coinciding with Mario Draghi's renewed intent to support the euro "whatever it takes".[25] In terms of transmission channels within the Euro area, the expected path of interest rates dominates the term premium in explaining domestic yield changes in every subsample until the announcement of the ECB's policy of quantitative easing. However, the transition toward term premium dominance relative to the path of expected short

[24] To provide some context, the announcement of QE1 on November 25, 2008, was associated with a 26.5 basis point drop in the implied yield on the three month ahead Eurodollar futures contract and a 19.2 basis point drop in the implied yield from the 5-year Treasury bond futures contract. Across the three FOMC announcement dates from November 25 to December 16, 2008, the cumulative drop in these implied yields was 55 basis points and 53.3 basis points, respectively.

[25] Draghi, Mario. (2012 July 26). Remarks to Global Investment Conference in London. Retrieved from https://www.ecb.europa.eu/press/key/date/2012/html/sp120726.en.html

rates begins in the period before the announcement of the EAPP, reflecting the increasing bind of the effective lower bound.

In the UK, the transition from short- to long-term bond yield transmission corresponds to the beginning of its own QE program shortly after the Federal Reserve in March 2009. Domestic results from the UK diverge from those of the US and Euro area in the sense that, although the Bank of England pursued unconventional monetary policies throughout the GFC and post-GFC subsamples, the expected path of short rates drives the majority of bond yield responses to monetary policy surprises, with a comparatively smaller role for term premia. This indicates that Bank of England unconventional monetary policy operated to a substantial degree through forward guidance and balance sheet-based commitment. These results counter those found by Joyce *et al* (2012), who find a dominant role for the term premium from individual QE announcements from the Bank of England. However, periods following US tapering indicate that monetary policy increasingly reduced term premia as well. Still, signaling appears to have played a larger role in the UK's domestic monetary policy transmission compared to domestic transmission from other central banks with policies of quantitative easing.

Domestic monetary policy surprises from the Bank of Japan generate the smallest impact among the central banks considered. However, considering the size of the measured surprises (see Table 3a), its degree of passthrough is similar to other central banks. In the pre-crisis period, monetary policy surprises load onto the yield curve in a hump-shaped fashion, peaking between the 3- and 5-year yield. However, in the periods following the collapse of Lehman Brothers, the Bank of Japan consistently generates pass-through to its medium- and long-term bonds. In these subsamples, domestic monetary policy acts entirely through the term premium. Overall, pass-through is largest in the last subsample, which contains the introduction of the Bank of Japan's QQE with Japan's Negative Interest Rates and QQE with Yield Curve Control programs.

The results depicting spillovers suggest fewer commonalities between markets. Thus, for the sake of exposition, I organize the discussion of these results by central bank, rather than by recipient market (Tables 6 - 9).

### 4.5.2 Spillovers from the Federal Reserve

My discussion pf spillovers begins with the Federal Reserve (Table 6), as it generates the most consistent spillovers in the full sample and is the focus of much of the literature on the international effects of unconventional monetary policy. Curiously, in the pre-crisis period, the FOMC exhibits negligible pass-through to the UK and the Euro area (Panels A and B), which operates through contrasting channels cancelling one another out. In this period, an expansionary surprise brings down the path of short rates, but increases the term premium, generating an undetectable net effect. The sign of the term premium indicates that expansionary Fed policy generated upside growth and inflation risk. In each of the subsamples following the GFC, spillovers increase in the maturity of the bond and reflect a mix of signaling and changes to the term premium. Counter to emphasis in the literature on US quantitative easing, the largest FOMC spillovers occur not during its implementation of QE, but during the periods of asynchronous monetary policy normalization.

The largest FOMC spillovers accrue to UK bond yields. From a subsample perspective, spillovers reach their peak during the years following the FOMC's tapering announcement and remain elevated for the remainder of the sample (Table 6, Panel A). In addition to the overall size of spillovers to the UK, this sender-recipient pairing stand apart from the others in the strength of the signaling channel. Also unlike other pairings, the signaling channel from the FOMC to the UK increases in strength relative to changes in term premia during periods of heaviest global quantitative easing. These results imply that, to some extent, the Federal Reserve "heralded" the Bank of England in expectation in these latter subsamples.

On the other hand, the term premia explain the majority of spillovers received from the FOMC following the announcement of tapering and before the instatement of the EAPP, suggesting that contractionary monetary policy in the US also generated perceived growth or inflation risk, and may reflect portfolio rebalancing toward the United States in this initial normalization period. Disentangling these forces remains a challenge. However, an international confidence channel can be inferred by the absence of domestic term premium effects, since a decrease in the domestic term premium is a logical pre-condition to international portfolio effects. If domestic term premia do not decrease, then there has not been a change in the rel-

ative supply of assets sufficient to change domestic asset prices, and thus to incentivize substitution into other assets. It is not feasible, however, to positively and independently identify the presence of an international portfolio balancing channel because the *presence* of domestic term premium effects can arise through either confidence or portfolio balancing. Thus, that US monetary policy surprises in this subsample increase expected domestic interest rates at longer horizons offers corroborating evidence for an FOMC confidence channel to UK bond yields. These two observations (term premium spillovers and domestic impact on expected short rates in the US) together offer evidence that term premium spillovers in these later subsamples emanate from expected growth and interest rate volatility rather than pure portfolio balance effects.

Turning to the Euro area (Table 6, Panel B), the Federal Reserve generated its strongest spillovers to the European yield curve during the intra-QE period, although the channels of transmission are not well-identified using the preferred monetary policy indicator. Point estimates in the baseline, though insignificant, suggest that the signaling channel strengthened during this period, indicating that market participants on average expected the Euro area to move toward normalization in the face of contractionary US monetary policy surprises. In the Online Appendix, results obtained using the two-year yield as the monetary policy measure corroborate the evidence from futures.

By contrast, periods of US and Euro area QE (the initial QE and EAPP periods) display smaller spillovers from the Federal Reserve to the Euro area. The term premium drives the modest spillovers observed in these subsamples. The importance of the term premium for determining US domestic pass-through in the initial QE period suggests that FOMC-induced European term premium changes in that era could result from either portfolio balancing or expected growth. However, since the domestic effect of monetary policy from the FOMC indicates that portfolio balancing does not have a large impact on US yields in the period of Euro area quantitative easing, spillovers to the Euro area during the EAPP appear to manifest through changes in expected macroeconomic growth (i.e., a contractionary monetary policy shock from the US raises expected future growth and inflation risk) by revealing good news about market conditions.

As in previous exercises, results suggest that spillovers to Japan are smaller and less con-

sistent (Table 6, Panel C). This (non)result could represent an issue of identification, but may also reflect a level of disconnect between financial conditions in Japan and those in other advanced economies. To wit, the covariances between JGB bond yields and the sovereign bond yields of the other three markets hover near zero throughout the sample at every maturity. Regardless, point estimates suggest passthrough in the periods marked by numerous QE programs (the initial QE and EAPP periods), which operate through the term premium.

#### 4.5.3 Spillovers from the European Central Bank

The decomposition of ECB spillovers to the US (Table 7, Panel A) reveals a marked departure from the magnitudes estimated in the full sample. In particular, ECB spillovers to the US during and after the GFC increase substantially. Moreover, the periods of heaviest QE activity exhibit spillovers to the United States that mirror transmission channels from the FOMC to the Euro area in each of the subsamples (Panel B). That is, the signaling channel drives (modest) spillovers in the pre-crisis period, whereas the term premium takes on additional importance for spillovers in the periods of US and Euro area quantitative easing. In the periods of quantitative easing, spillovers from ECB monetary policy announcements to US long-term bond yields in particular increase.

Again, I appeal to the domestic effects of QE in the Euro area as a guide and suggest that portfolio balance effects dominate spillovers in the EAPP period and that the confidence channel played a comparatively larger role during the period of initial quantitative easing. In this subsample, ECB monetary policy surprises influenced domestic interest rates almost entirely through the expected path of short rates, implying that loosening monetary policy in the Euro area during that period lowered term premia in the US by generating expectations of lower economic growth or interest rate volatility. This pattern is consistent with a flight to safety. Given, however, that domestic monetary policy influenced Euro area yields primarily through term premia during the EAPP, portfolio balancing remains a candidate explanation in this last subsample.

Among sender-recipient pairings in the pre-crisis period, spillovers from the ECB to the UK rank largest in magnitude (Table 7, Panel A). These pre-crisis spillovers operate almost exclusively through the term premium, suggesting a confidence channel without a strong sig-

naling component. However, the instances of high UMP activity in particular suggest that market participants expect the Bank of England to act in the same direction as the ECB in the context of unconventional monetary policy, reflecting a comparatively high degree of interconnection between these markets. In the EAPP subsample, additional monetary stimulus from the ECB generates a substantial decrease in the path of expected interest rates in the UK, suggesting that expansionary ECB monetary policy pushes back expected normalization by the Bank of England. Interestingly, it appears that this signaling channel operates asymmetrically; spillovers from the ECB act through the UK's expected path of short rates near the zero lower bound, while spillovers from the Bank of England influence Euro area yields to a much lower degree (Table 8, Panel A).

#### 4.5.4 Bank of England Spillovers

Spillovers from the Bank of England (Table 8) appear roughly on par with those from the ECB. In the case of spillovers to the US (Panel B), a Bank of England monetary policy surprise exhibits a statistically significant effect in the periods of asynchronous normalization, which increases with maturity and acts primarily through the term premium. Coefficients from the EAPP subsample suggest that the reduction in spillovers observed from the previous subsample result almost entirely from a reduced impact on term premia, consistent with moves toward normalization in each of those markets. The dominance of the expected path of short rates over the Bank of England's domestic transmission suggests that these term premium spillovers result from confidence effects more than portfolio balancing in these subsamples.

The Bank of England generates spillovers of similar magnitude to the Euro area (Panel A). These increasingly act through European term premia from one subsample to the next. Here again, domestic UK surprises drive changes in the expected path of domestic short rates at long horizons in the EAPP period, suggesting portfolio balancing plays a smaller in spillovers to these maturities compared to confidence effects.

#### 4.5.5 Bank of Japan Spillovers

Spillovers from Bank of Japan (Table 9) generally lack statistical significance or else are vanishingly small, reflecting low co-movement with the other economies in general. The excep-

tion is the intra-QE period, during which expansionary monetary policy surprises from the Bank of Japan increases US yields substantially. Given the Japanese yen's role as a dominant carry trade funding currency, it could be that these coefficients reflect changes in carry trade activity. Although the influence of monetary policy on carry trade activity lies beyond the scope of this paper, it is reasonable to posit that expansionary Japanese monetary policy might increase the attractiveness of in yen relative to other currencies, decreasing the price and increasing the yield of other safe assets.

#### 4.5.6 Control variables

Turning to the effect of control variables, a number of consistent patterns emerge across markets (Tables 14 - 17). For all countries in the sample, "expectations-beating" economic news in the US, the UK, and the Euro area triggers increased bond yields at most maturities for all countries, but especially at longer maturities. Second, most daily changes in the yield exhibit modest but statistically significant persistence, suggesting that bond prices exhibit some autocorrelation even in first differences. These prices, then, tend to go on brief "runs".

While point estimates from the baseline provide valuable information regarding the immediate effect of monetary policy on asset prices, the economic significance of monetary policy surprises emerges in part from their persistence, to which I turn next.

### 4.6 Persistence of Monetary Policy Surprises

Lagged exchange rates are insignificant in many of the baseline regressions, with some notable exceptions. In particular, previous day appreciation of the euro against the pound or yen is associated with increased yields in the Euro area, while an appreciation of the euro against the dollar is associated with lower euro area yields. Similarly, previous day appreciation of the pound against the yen is associated with decreasing UK bond yields. Finally, a depreciation of the yen against the dollar is associated with an increase in the Japanese yield. These exchange rate effects tend to increase slightly in maturity of the bond.

To characterize the persistence of spillovers, I extend my baseline estimations using local projection methods (Jordà 2005; Stock and Watson 2018).[26] Specifically, I estimate the follow-

[26] I favor local projection over external instrument vector autoregression in this context primarily due to the ex-

ing:

$$\Delta y^{(10)}_{i,t+h} = \alpha + \beta_{i,h}\Delta y^{(10)}_{i,t-1} + \psi_{i,h}MP_{i,t} + \sum_j \gamma_{j,h}MP_{j,t} + \sum_{k=0}^{K}\theta_{i,h,k}x_{t-k} + \sum_{l=1}^{L}\sum_j \phi_{j,l}\Delta e^{i,j}_{t-l} + \delta Fri + \epsilon_{it}, \quad (8)$$

where $h = 0, \ldots, H$ is the estimation horizon and $x_{t-k}$ represents the vector of news controls. I plot impulse responses to a horizon of 25 days to reflect the average observed number of business days between announcements among the four central banks (23.75 days). $\psi_{i,h}$ and $\gamma_{j,h}$ represent the average monetary policy pass-through to the ten year bond yield in market $i$ from domestic shocks ($j$) and spillovers from central bank $j$, respectively. As suggested by the Bayes Information Criterion (BIC), I include one lag of the dependent variable, one lag ($K = 1$) of the macro news controls $x_t$, and one lag over the baseline of the bilateral exchange rate $\Delta e^{i,j}_{t-l}$ (two lags total, $L = 2$).

Although local projection methods offer a number of improvements over vector autoregression in the current context, they tend to produce jagged impulse responses that can be difficult to interpret. To smooth excess variability of the estimator, I apply a compound moving median smoother to the estimated series $\hat{\beta}_i = \{\hat{\beta}_{i,0} \ldots \hat{\beta}_{i,H}\}$ for the domestic impact and $\hat{\beta}_j = \{\hat{\beta}_{j,0} \ldots \hat{\beta}_{j,H}\}$ for spillovers from central bank $j$.[27]

Due to the unique role long-term bond yields play in the conduct of unconventional monetary policy, I limit my discussion to the persistence of monetary policy pass-through to 10-year zero coupon bond yields in each market. In terms of subsample periods, I contrast here the full sample results to those from the EAPP period, as this latter period exhibits the largest spillovers in static estimates. Figures 3 - 4 depict the persistence of domestic monetary policy surprises, plotting the smoothed path of the parameter estimates with smoothed 90% and 95% confidence bands. As in the baseline, monetary policy surprises are normalized to a one standard deviation loosening. Figures 5 - 8 depict the persistence of spillover effects.

egencies of daily data. Parameter proliferation in a VAR renders controlling for concurrent monetary and macroeconomic surprises intractable. Moreover, a principal components analysis suggests that these variables are not easily explained by one or two factors, meaning that a factor augmented VAR would not be appropriate.

[27] In particular, I first apply a 3-spline moving median smoother with repetition to convergence, followed by a Hanning linear binomial smoother.

Figures 3 and 4 indicate that, for each central bank, domestic monetary policy generates persistent pass-through to 10-year zero coupon bond yields lasting at least 25 days at the 10% level in both the full sample and the EAPP subsample period. Spillover persistence, on the other hand, varies by central bank/recipient pair. Overall, while the *magnitudes* of spillovers increase in the EAPP subsample period compared to the full sample, their persistence does not change drastically.

Nevertheless, interesting distinctions do arise in comparing the central bank/recipient pairs to one another in terms of persistence. Spillovers to the US from the ECB (Figures 6a, 6b) and Bank of England (Figures 7c, 7d), while larger in the EAPP subsample, generally last just under a week before becoming statistically insignificant.[28] On the other hand, spillovers from the Federal Reserve to the UK and Euro area persist to the end of the estimation horizon, in agreement with literature suggesting the centrality of the Federal Reserve in producing spillovers (Figures 5a - 5d). Interestingly, spillovers to the Euro area from the Bank of England persist past the 25 day estimation horizon, while ECB pass-through to Gilt yields dissipate in less than a week. As in the static estimates, spillovers to and from Japan are not significant (Figure 8).

Taken together, these results suggest that controlling for news from other large markets and taking into account the cross-country nature of unconventional monetary policy in a time series context provides a more nuanced image of international spillovers, but also of domestic pass-through. Spillovers from unconventional monetary policy appear to change with both the domestic response and the comparative policy stance of other markets. While spillovers increase during periods of heavy multilateral quantitative easing, asynchronous normalization has engendered the largest cross-country spillovers from monetary policy.

[28]It is worth noting, however, that although the parameter estimates become stastistically insignificant, the path of the point values does not generally converge toward zero in the 25-day horizon.

# 5 Robustness and Extensions

## 5.1 Monetary Policy News Channels

Recent literature on the information channel of monetary policy transmission argues that central banks affect asset prices via agents' beliefs (Leombroni *et al* 2018; Nakamura and Steinsson 2018; Melosi *et al* 2016). This information falls into two broad categories. Central banks can produce "Odyssean" forward guidance in the form of information about the path of policy. In the baseline analysis, results obtained using the expected path of short rates provides evidence regarding the (limited) importance of this transmission channel for international spillovers. However, as mentioned previously in reference to the confidence channel of monetary policy transmission, the central bank also generates "Delphic" information, wherein the announcement reveals news about the state of the economy. For example, if the central bank enacts a more aggressive rate cut than expected or communicates a longer cycle than expected, agents may infer that the central bank possesses better information on downside growth risks and update their beliefs accordingly.[29]

Standard theory predicts that an expansionary announcement characterized only by information about the path of policy (without Delphic effects) should lead to a stock price rally through discount and dividend channels; that is, we would expect negative co-movement of surprises and equity returns (as in Bernanke and Kuttner 2005). In turn, if market participants extract information suggesting a weaker outlook for economic of financial conditions, stock prices would rise less or even fall on reduced expectations of cash flows or of higher risk. Thus, looser monetary policy that is accompanied by an decrease in stock returns (positive co-movement) must indicate diminished economic or financial conditions. Thus, the sign of high-frequency co-movement of stocks and the implied yields on futures contracts can help disentangle events with strong risk premium implications versus no (or weak) risk premium implications.

In the context of spillovers, Delphic news shocks can propagate via two potential channels. The first mirrors that for domestic asset prices, but is two-fold. That is, bad news gleaned from monetary policy decreases yields through downward revisions to growth expectations.

[29] See Leombroni *et al* 2018 for an in-depth discussion of the mechanism.

These revisions, in turn, should drive a lower path of expected future interest rates. On the other hand, downside risk to economic growth should increase risk premia, so to the (albeit modest) extent that these sovereign bonds are subject to a risk premium, this would increase yields on expansionary events if the information effect dominates. The second channel reflects flight to safety—increased risk revealed from monetary policy should induce capital to flow toward other safe assets, compressing their yields.

To test for the presence of risk-induced effects I separate surprises with positive equity return co-movement using the dummy variable $RPday$. For each market I use Fama/French excess returns (Rm - Rf) and test interaction effects one at a time to economize on parameters. Regressions take two separate forms to account for spillovers. In the first set of specifications, $RPday$ takes a value of 1 on announcement days characterized by positive equity return co-movement in the same country as the monetary policy surprise in question. For example, when considering risk premium effects from the ECB, I look for positive co-movement with the equity return in the Euro area.

$$\Delta y_{it}^{(10)} = \alpha + \rho \Delta y_{it-1}^{(10)} + \beta_1 RPday_t^j + \beta_2 MP_t^j + \beta_3 RPday_t^j * MP_t^j + \sum_k \gamma_k MP_t^k + X_t' \theta_i + \epsilon_{it} \quad (9)$$

Where $y_{it}^{(10)}$ is either the yield on the 10 year sovereign bond or the expected path of short rates over a ten year horizon. In this and the next specification, $X_t$ is a transposed vector of controls identical to the baseline. In the second set of specification, $RPday$ takes a value of 1 on announcement days characterized by positive equity return co-movement in the same country as the sovereign bond of interest. Thus, when considering risk premium effects on the US 10 year yield from the ECB, I look for positive co-movement with the equity return in the United States.

$$\Delta y_{it}^{(10)} = \alpha + \rho \Delta y_{it-1}^{(10)} + \beta_1 RPday_t^{i,j} + \beta_2 MP_t^j + \beta_3 RPday_t^{i,j} * MP_t^j + \sum_k \gamma_k MP_t^k + X_t' \theta_i + \epsilon_{it} \quad (10)$$

Tables 18 and 19 display the results. Ten-year Treasuries evince the most consistent pattern of the exercise; that is, spillovers from the ECB, the Bank of England and the Bank of Japan exhibit a statistically significant risk component. Some of the impact (about 21%, 26%

and 59% for the Bank of England, ECB and Bank of Japan, respectively, based on Panels 10B and 11B) results from changes to the expected path of short rates and thus from revisions to the expected level of the domestic growth rate. I attribute the other roughly 41 - 75% to flight to safety. Interestingly, the Federal Reserve also appears to exert this type of risk premium effect on the the Euro area, albeit at a rate about on third of that observed in the opposite direction. Curiously, when measured using domestic equity market comovement, risk premium days in Japan are associated with a dampening of spillovers to US yields—that is, when the BoJ generates bad news for the Japanese equity market, yields in the US rise abstracting completely from discount effects.

In the context of the current study, the question naturally arises as to whether these risk shocks contribute to increased spillovers in periods of unconventional monetary policy.[30] To comment on the time variation in risk-based spillovers, I plot measured monetary policy surprises against changes in the Fama/French returns each of the baseline subsamples (See Figures 9 - 12). In the interest of space, I plot only the pairings associated with statistically significant interactions. If risk-based spillovers drive increased spillovers to ten year yields in general, we should expect more of these types of surprises latter subsamples compared to the pre-crisis period.

Put differently, if monetary policy surprises with a strong risk component dominate the latter subsamples, the plots in Figures 9 - 11 should show increased pairings in the first and third quadrants, with a fit line nearer a slope of one compared to other periods. In fact, we observe just the opposite in most cases (the exceptions being the ECB's interaction with Japanese Equity returns). Thus, while spillovers in some country pairings rise in the presence of news effects, an increased incidence of risk-surprises does not appear to explain increased spillovers in the period of asynchronous monetary policy normalization.

## 5.2 Asymmetric Responses: Contractionary Versus Expansionary Surprises

Another candidate explanation arises from the distribution of contractionary versus expansionary surprises in the various subsamples. That is, if expansionary surprises generate larger

[30]For example, Leombroni *et al* (2018) find that risk premium shocks in the Euro area rise in importance in the context of the European debt crisis.

spillovers than contractionary ones, we should expect periods marked by a prevalence of expansionary surprises to evince larger spillovers. To test for these asymmetric effects, I run the following specification, testing one interacting at a time:

$$\Delta y_{it}^{(10)} = \alpha + \rho \Delta y_{it-1}^{(10)} + \beta_1 MP_t^j + \beta_2 \mathbb{1}[MP_t^j < 0] + \beta_3 \mathbb{1}[MP_t^j < 0] * MP_t^j + \sum_k \gamma_k MP_t^k + \theta_1^i S_t^i + \sum_j \theta_j S_t^j + \sum_j \phi_j \Delta e_{t-1}^{i,j} + \delta Fri + \epsilon_{it} \quad (11)$$

Where $\mathbb{1}[MP_t^j < 0]$ is an indicator function equal to one where the monetary policy surprise takes a negative value (i.e., an expansionary surprise).

Table 20 shows that yields do not in general react differently to expansionary monetary policy surprises compared to contractionary ones from the Bank of England or the Bank of Japan. On the other hand, yields in the US and the UK do appear to react more to expansionary surprises from the Federal Reserve, while these same yields react more to ECB contractionary surprises than to expansionary ones. Although the responses to expansionary versus contractionary shocks differ, shocks do not appear to be overwhelmingly contractionary or expansionary in any of the subsamples for the FOMC or the ECB. In Table 21, I show that the mean of the absolute value of expansionary shocks does not differ from that of contractionary shocks in any of the chosen subsamples in the case of the FOMC or the ECB. Only the Bank of England evinces shocks leaning in one direction—in the last subsample (EAPP) contractionary monetary policy shocks dominate expansionary shocks in size.

### 5.3 Yield-based Measure of Monetary Policy Surprises

As noted previously, I also measure the surprise as the daily change in the two-year zero coupon bond yield as a robustness check, following Gilchrist *et al* (2014). While these zero coupon bond yields lack the desirable quality of serving as insurance against future interest rate changes, one may still reasonably attribute changes in their yields on announcement days primarily to monetary policy surprises. Although the point estimates from this exercise differ from the baseline, the broad patterns remain. Spillovers increase in periods of unconventional monetary policy and transmit primarily through term premia. In the interest of space, the results are displayed in the supplemental appendix.

## 6 Concluding Remarks and Directions for Future Research

In this paper, I utilize high frequency identification, a shadow rate term structure model, piecewise regressions, and local projection methods to identify the effect of monetary policy spillovers to and from advanced economies engaged in quantitative easing across the yield curve over time. I provide evidence for the existence of heightened spillovers between the US, the UK, Japan, and the Euro area during the period of asynchronous monetary policy normalization, with the most persistent spillovers emanating from the Federal Reserve.

However, I also find evidence of surprisingly strong spillovers from the ECB and Bank of England to the US and to each other. Results suggest that these central banks' programs of unconventional monetary policy compressed long-term bond yields in each other's markets primarily through the term premium, indicating the dominance of portfolio balance and confidence channels of transmission over signaling. However, results from the Federal Reserve suggest that large term premium spillovers may also arise through interest rate-based monetary policy, as evinced by spillovers in the period of asynchronous monetary policy normalization. During this latter period, the Federal Reserve returned to interest rate-based monetary policy and yet still appears to drive spillovers at longer maturities.

The mechanisms of unconventional monetary policy that distinguish it from conventional monetary policy imply unique challenges to the withdrawal of monetary stimulus, particularly in the presence of spillovers. Long-term bond yields compressed during the period of unconventional monetary policy may be less upwardly sensitive to conventional policy given the role of term premia in determining long-term interest rates. In the face of ongoing quantitative easing in other systemic, advanced economies, this implies that normalizing central banks conduct monetary policy primarily by exerting pressure on the expected path of short-rates (which is diminishing in maturity) compared to periods of quantitative easing, while international spillovers have the potential to exert force in the opposite direction on the term premium (which increases with maturity) (Hamilton 2009).

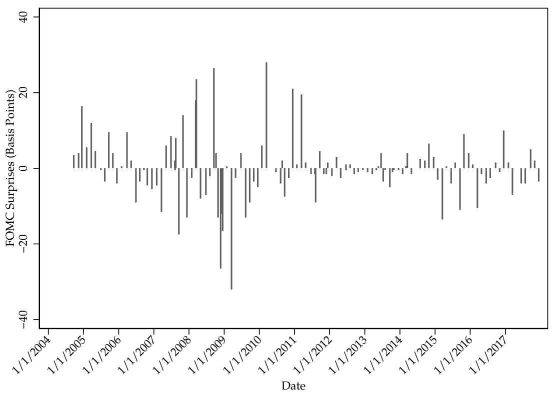
The asynchronicity of unconventional monetary policy in these systemically important markets makes the cross-country spillovers that I document particularly salient. For example, the evidence presented here suggests that US monetary policy normalization in the period of

writing effectively exerts contractionary monetary policy on European bond yields. This implies that the ECB will need to withdraw its stimulus more slowly (or even increase it) in order to keep credit conditions from tightening more than intended when it ultimately halts its asset purchases. From another angle, in the absence of international portfolio balance effects, domestic long-term bond yields would be more responsive to quantitative easing.

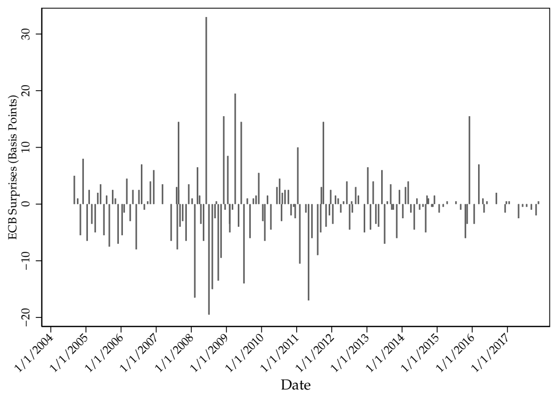
It is likely that normalizing central banks will find themselves at the effective lower bound again in shared macroeconomic or financial circumstances.[31] For that reason, central banks do well to acknowledge the impact of spillovers on the shape of the sovereign yield curve, which makes monetary policy more or less effective. Future research further exploring the factors driving increased spillovers will represent a valuable contribution to this literature.

[31] Yellen, Janet. (2017 October 20) *A Challenging Decade and a Question for the Future*. Retrieved from https://www.federalreserve.gov/newsevents/speech/yellen20171020a.htm

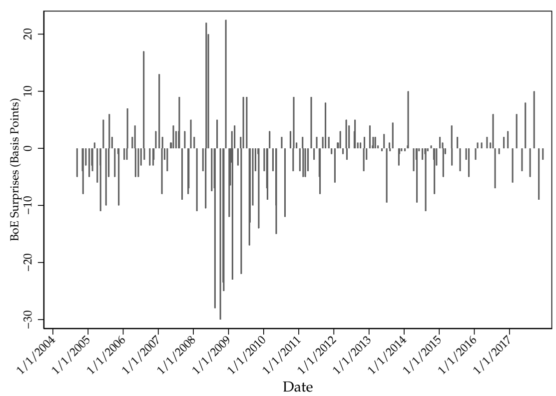
# 7 Appendix A: Figures



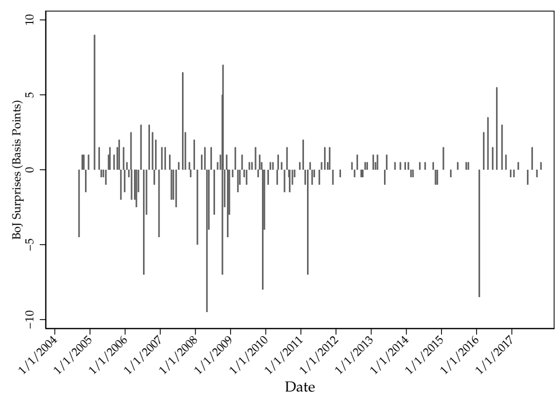

(a) FOMC




(b) ECB



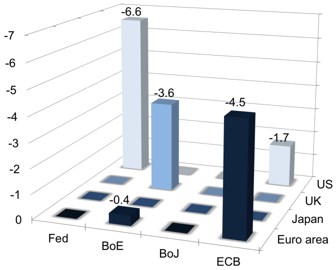

(c) Bank of England



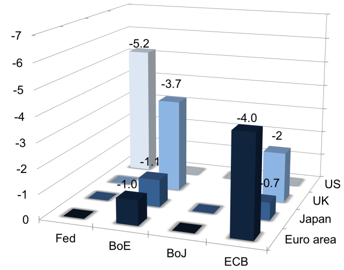

(d) Bank of Japan

Figure 1: Monetary Policy Surprises Measured with Interbank Futures

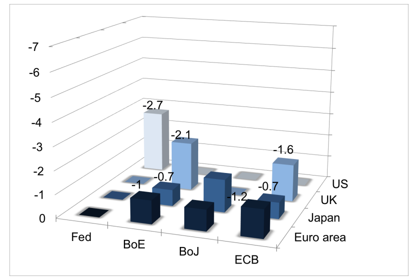
Figure 1 shows the open to close change in the implied yield on the one-year ahead futures contract based on the three-month (1a) Eurodollar on FOMC announcement days, (1b) Euribor on ECB announcement days, (1c) Short Sterling on BoE announcement days, and (1d) Euroyen Tibor on BoJ announcement days.



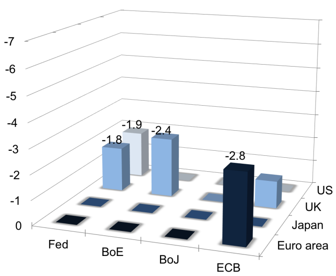

(a) 1 Year Yield: Pre-crisis



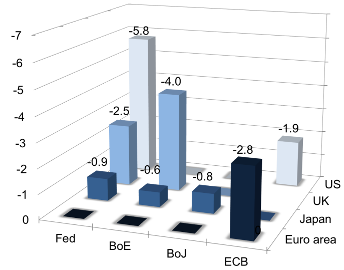

(b) 5 Year Yield: Pre-crisis



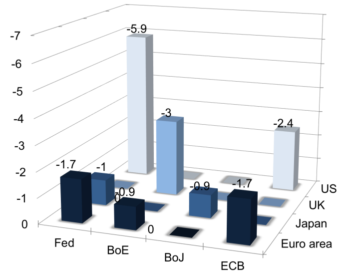

(c) 10 Year Yield: Pre-crisis



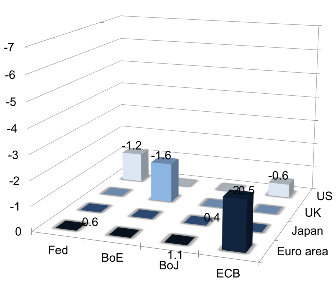

(d) 1 Year Yield: Initial QE



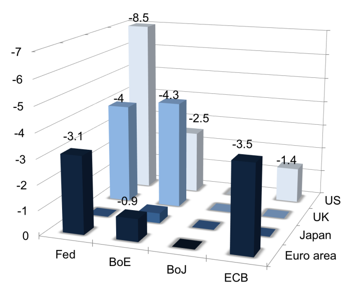

(e) 5 Year Yield: Initial QE



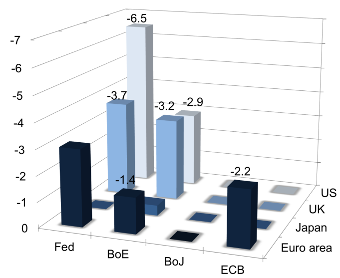

(f) 10 Year Yield: Initial QE



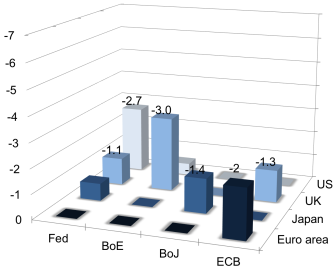

(g) 1 Year Yield: Intra-QE



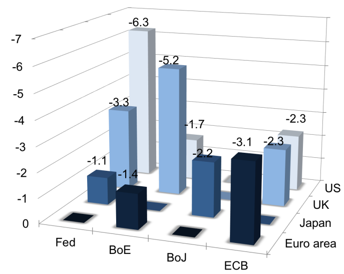

(h) 5 Year Yield: Intra-QE



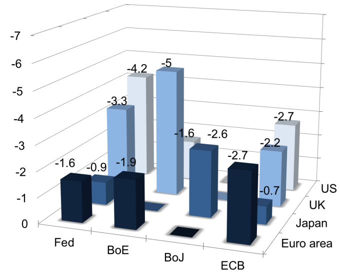

(i) 10 Year Yield: Intra-QE




(j) 1 Year Yield



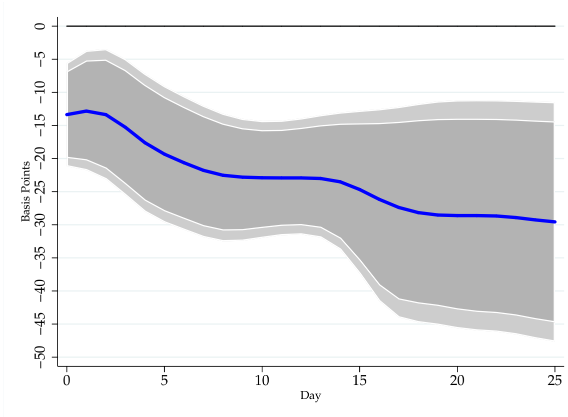

(k) 5 Year Yield



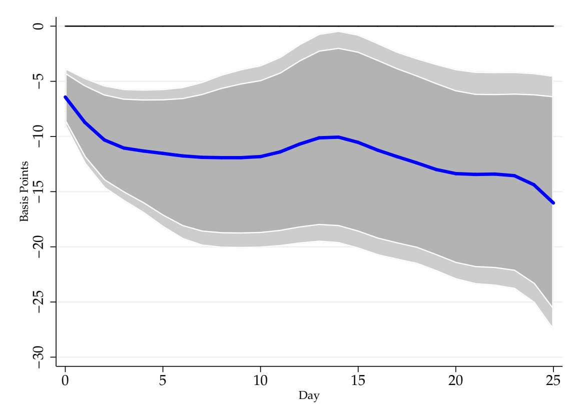

(l) 10 Year Yield

Figure 2: Effect of a One Standard Deviation Monetary Policy Loosening Surprise on Yields

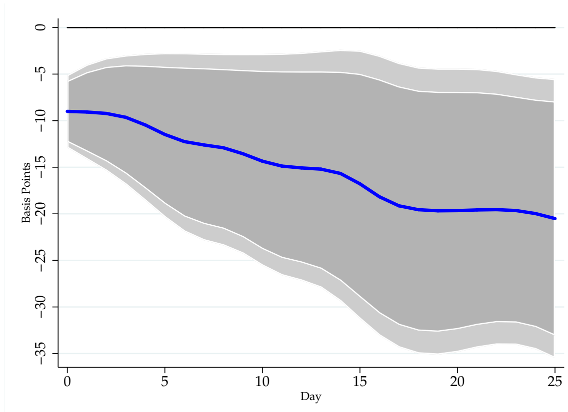
Figures 2a - 2l summarize the results of daily piecewise regressions where the dependent variable is the change in zero coupon bond yields for maturities of 1, 5, and 10 years. The monetary policy shock is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening, where standard deviations are calculated by sub-sample. All control variables from the baseline are included in the regression and their point estimates are available on request. All bars represent parameter estimates that are statistically significant at the 10% level or better.



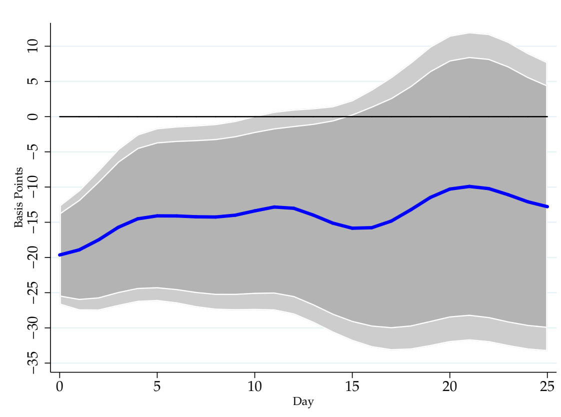

(a) US




(b) Euro area



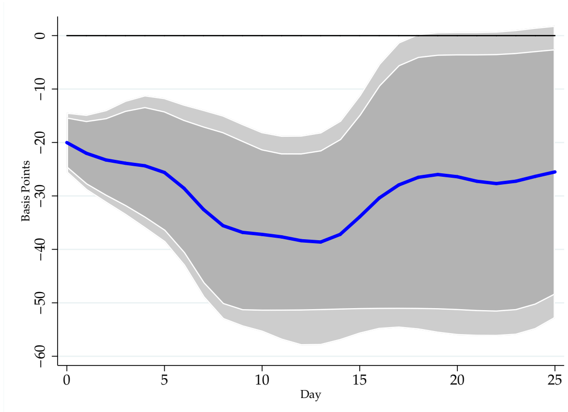

(c) UK



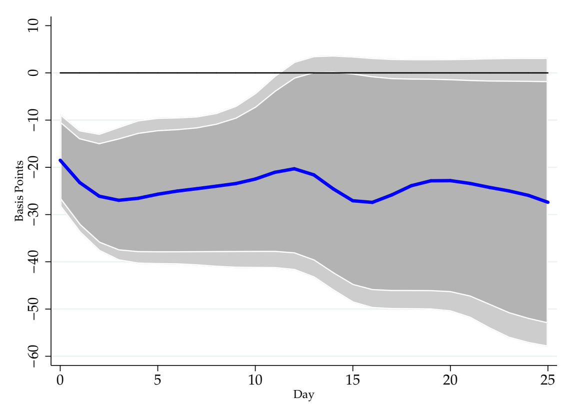

(d) Japan

Figure 3: Effect of a One Standard Deviation Expansionary Surprise on Domestic 10 Year Bond, Full Sample

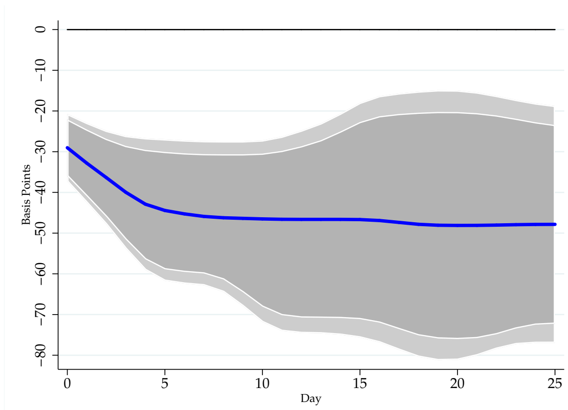
Figure 3 summarizes the results of daily local projections in the full sample where the dependent variable is the change in the domestic 10 year zero coupon bond from 0 to 25 days after the date of a domestic monetary policy announcement. The impulse variable is the daily change in the implied yield for the year-ahead futures contract on the (a.) Eurodollar (Fed), (b.) Euribor (ECB), (c.) Short Sterling (BoE) and (d.) Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening. Red lines show the unsmoothed estimates from local projections, $\hat{\beta}_{i,0}, \ldots, \hat{\beta}_{i,25}$, where $i$ indexes the source of the monetary policy surprise.. Thick blue lines show the path of the smoothed estimate for the path of $\hat{\beta}_i$ using a compound moving median smoother. The dark and light gray areas indicate smoothed confidence intervals at 95% and 90% confidence intervals, respectively.



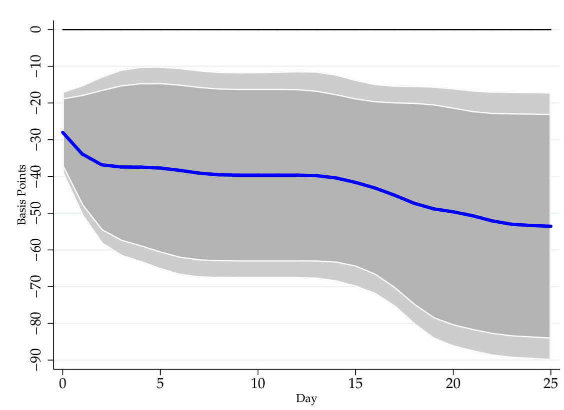

(a) US




(b) Euro area



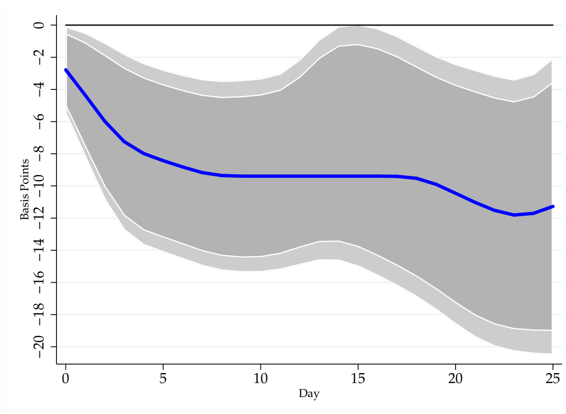

(c) UK



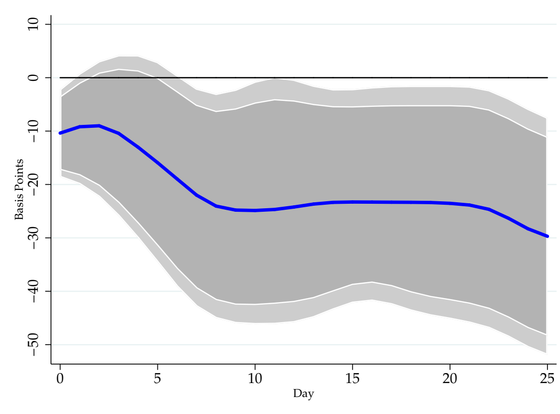

(d) Japan

Figure 4: Effect of a One Standard Deviation Expansionary Surprise on Domestic 10 Year Bond, EAPP

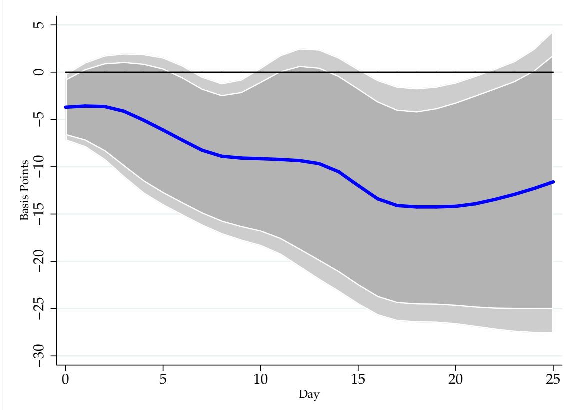
Figure 4 summarizes the results of daily local projections in the EAPP subsample period, where the dependent variable is the change in the domestic 10 year zero coupon bond from 0 to 25 days after the date of a domestic monetary policy announcement. The impulse variable is the daily change in the implied yield for the year-ahead futures contract on the (a.) Eurodollar (Fed), (b.) Euribor (ECB), (c.) Short Sterling (BoE) and (d.) Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening. Red lines show the unsmoothed estimates from local projections, $\hat{\beta}_{i,0}, \ldots, \hat{\beta}_{i,25}$, where $i$ indexes the source of the monetary policy surprise., where $i$ indexes the source of the monetary policy surprise. Thick blue lines show the path of the smoothed estimate for the path of $\hat{\beta}_i$ using a compound moving median smoother. The dark and light gray areas indicate smoothed confidence intervals at 95% and 90% confidence intervals, respectively.



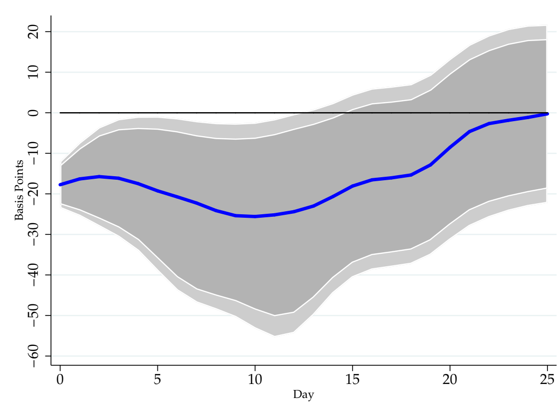

(a) Euro area, Full Sample



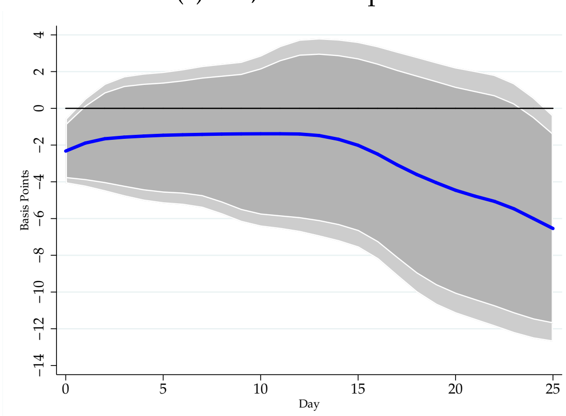

(b) Euro area, EAPP



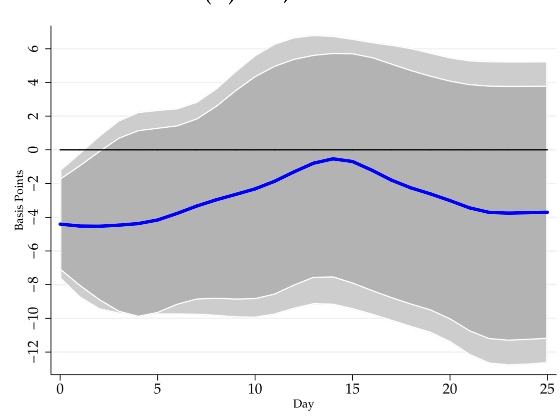

(c) UK, Full Sample




(d) UK, EAPP



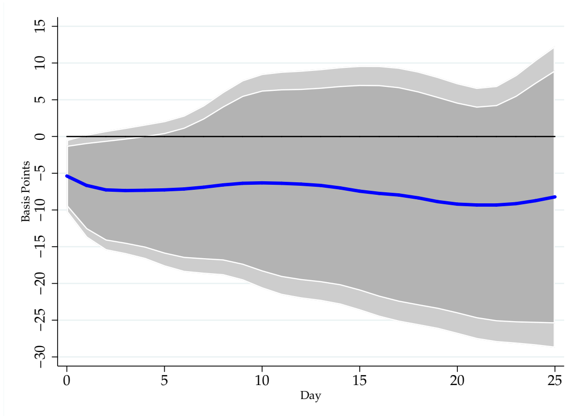

(e) Japan, Full Sample



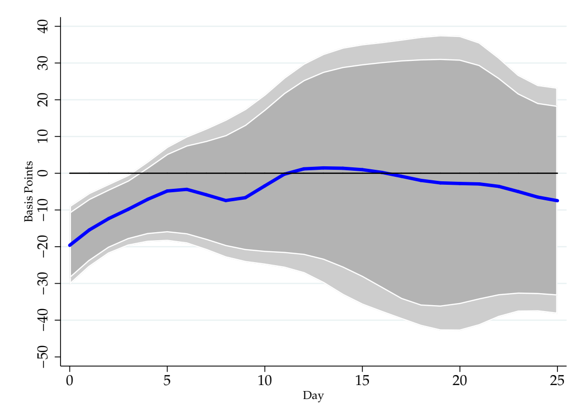

(f) Japan, EAPP

Figure 5: Effect of a One Standard Deviation Expansionary FOMC Surprise on 10 Year Bond Yields

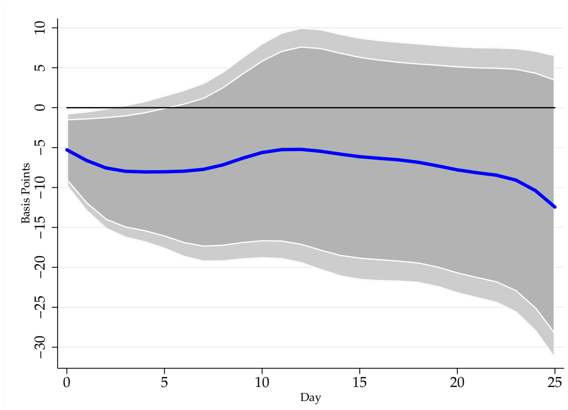
Figure 5 summarizes the results of daily local projections, where the dependent variable is the change in 10-year zero coupon yields in the Euro area (Panels 5a, 5b), UK (Panels 5c, 5d), and Japan (Panels 5e, 5f) from 0 to 25 days after the date of a Fed monetary policy announcement. The impulse variable is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar on FOMC announcement days. Monetary policy measures are normalized to be a one standard deviation loosening. Red lines show the unsmoothed estimates from local projections, $\hat{\beta}_{i,0}, \ldots, \hat{\beta}_{i,25}$, where $i$ indexes the source of the monetary policy surprise.. Thick blue lines show the path of the smoothed estimate for the path of $\hat{\beta}_i$ using a compound moving median smoother. The dark and light gray areas indicate smoothed confidence intervals at 95% and 90% confidence intervals, respectively.



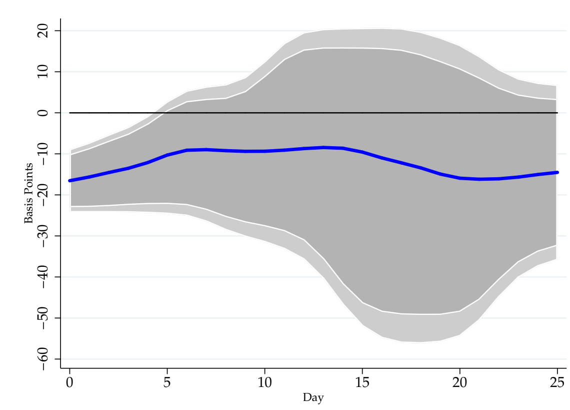

(a) US, Full Sample



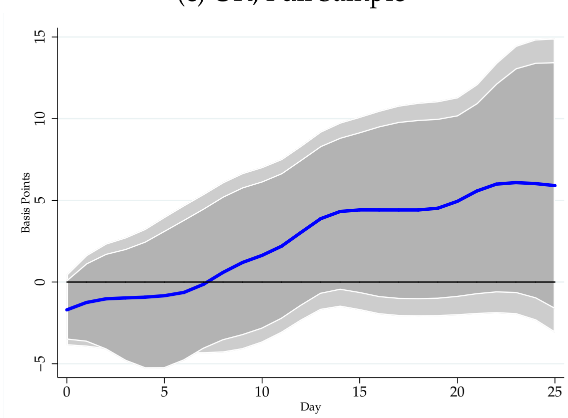

(b) US, EAPP



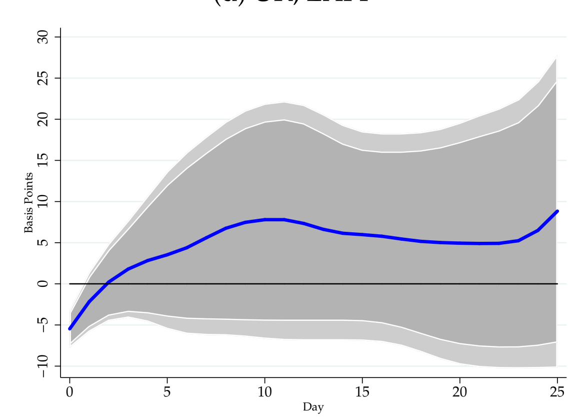

(c) UK, Full Sample




(d) UK, EAPP



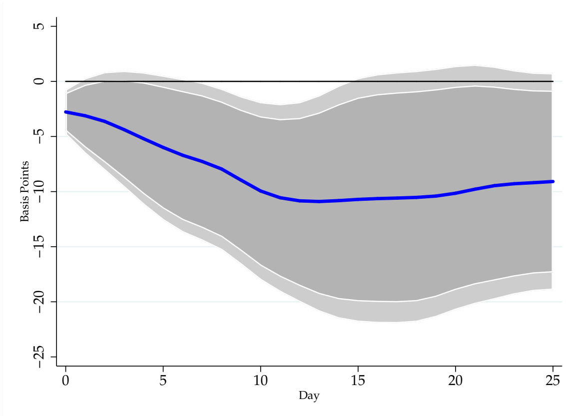

(e) Japan, Full Sample



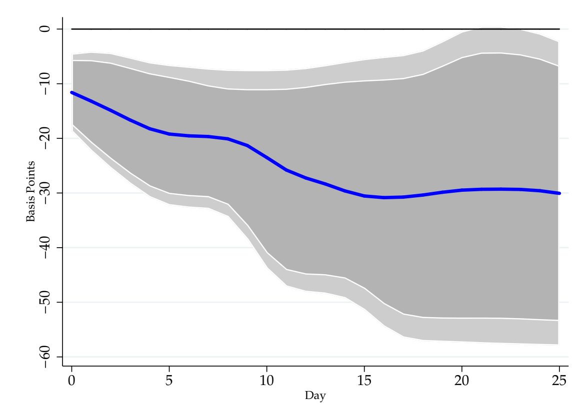

(f) Japan, EAPP

Figure 6: Effect of a One Standard Deviation Expansionary ECB Surprise on 10 Year Bond Yields

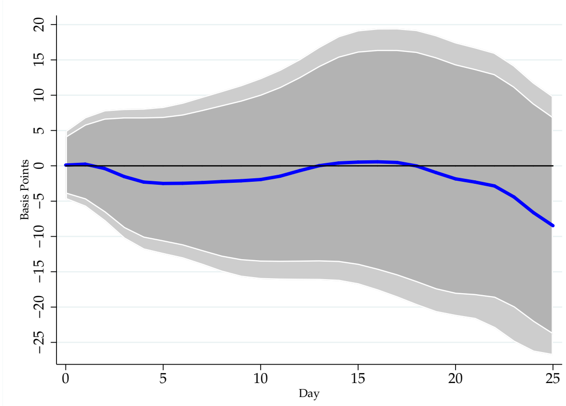
Figure 6 summarizes the results of daily local projections, where the dependent variable is the change in 10-year zero coupon yields in the US (Panels 6a, 6b), UK (Panels 6c, 6d), and Japan (Panels 6e, 6f) from 0 to 25 days after the date of an ECB monetary policy announcement. The impulse variable is the daily change in the implied yield for the year-ahead futures contract on the Euribor on ECB announcement days. Monetary policy measures are normalized to be a one standard deviation loosening. Red lines show the unsmoothed estimates from local projections, $\hat{\beta}_{i,0}, \ldots, \hat{\beta}_{i,25}$, where $i$ indexes the source of the monetary policy surprise.. Thick blue lines show the path of the smoothed estimate for the path of $\hat{\beta}_i$ using a compound moving median smoother. The dark and light gray areas indicate smoothed confidence intervals at 95% and 90% confidence intervals, respectively.



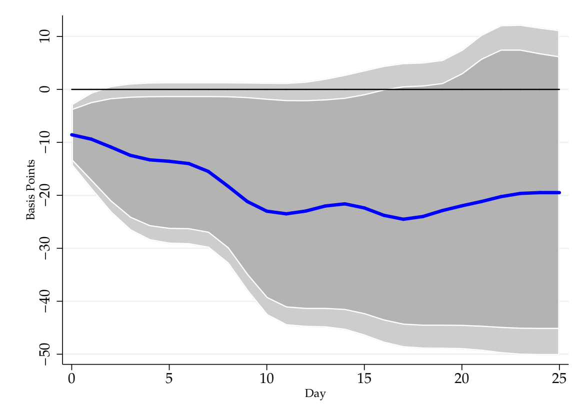

(a) Euro area, Full Sample



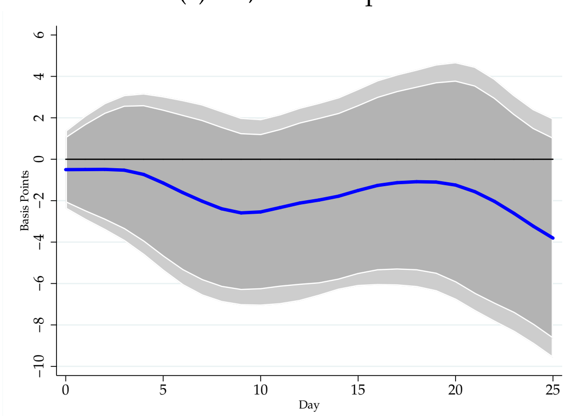

(b) Euro area, EAPP



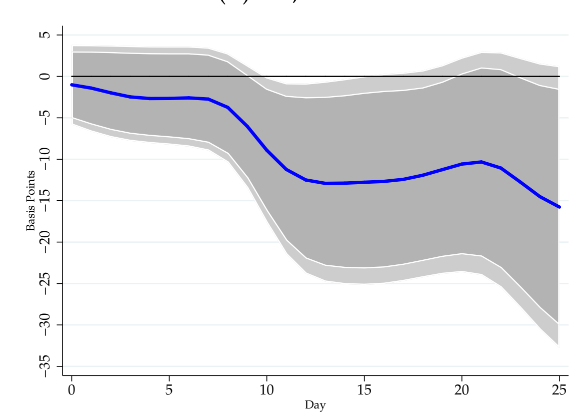

(c) US, Full Sample




(d) US, EAPP



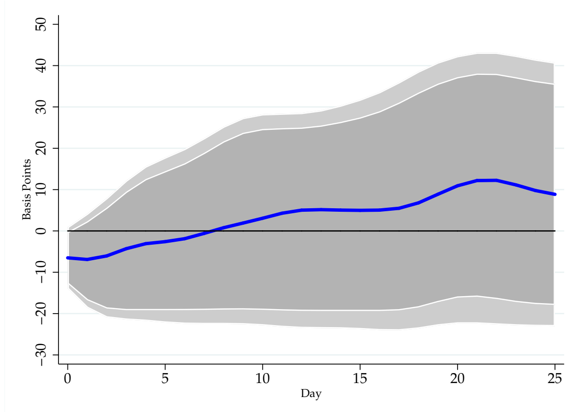

(e) Japan, Full Sample



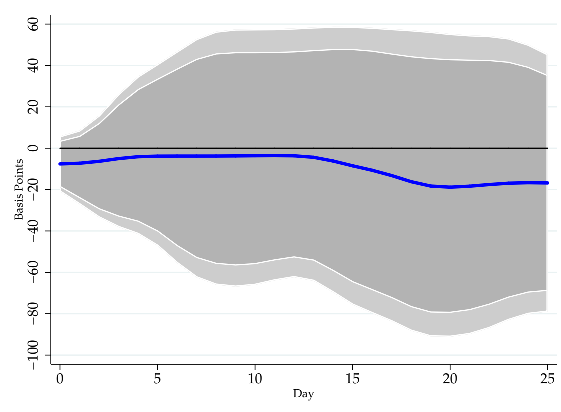

(f) Japan, EAPP

Figure 7: Effect of a One Standard Deviation Expansionary BoE Surprise on 10 Year Bond Yields

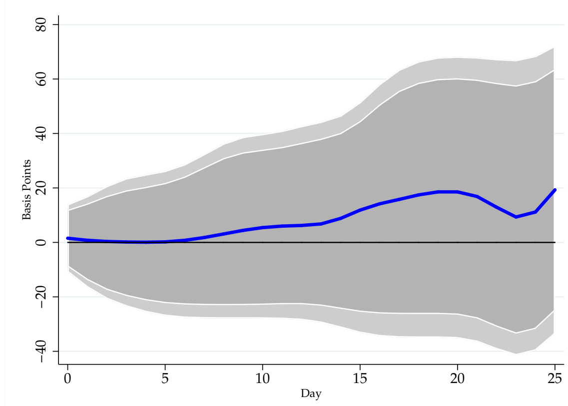
Figure 7 summarizes the results of daily local projections, where the dependent variable is the change in 10-year zero coupon yields in the Euro area (Panels 7a, 7b), US (Panels 7c, 7d), and Japan (Panels 7e, 7f) from 0 to 25 days after the date of a BoE monetary policy announcement. The impulse variable is the daily change in the implied yield for the year-ahead futures contract on the Short Sterling on BoE announcement days. Monetary policy measures are normalized to be a one standard deviation loosening. Red lines show the unsmoothed estimates from local projections, $\hat{\beta}_{i,0}, \ldots, \hat{\beta}_{i,25}$, where $i$ indexes the source of the monetary policy surprise.. Thick blue lines show the path of the smoothed estimate for the path of $\hat{\beta}_i$ using a compound moving median smoother. The dark and light gray areas indicate smoothed confidence intervals at 95% and 90% confidence intervals, respectively.



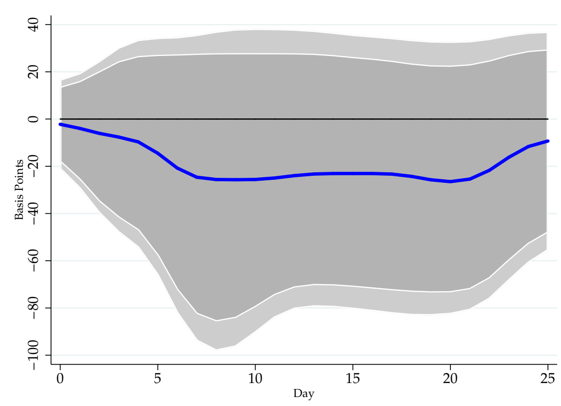

(a) Euro area, Full Sample



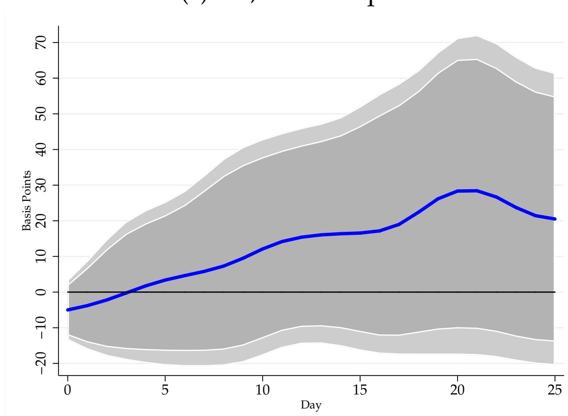

(b) Euro area, EAPP



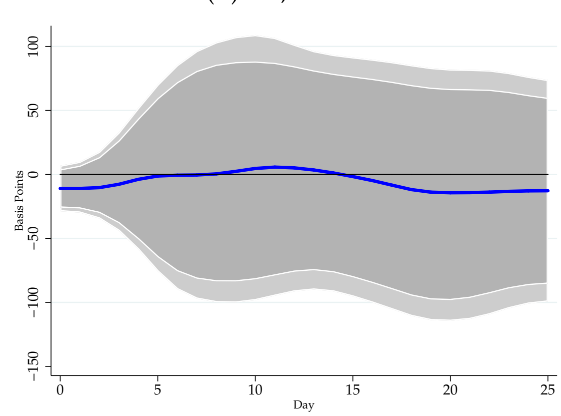

(c) US, Full Sample




(d) US, EAPP



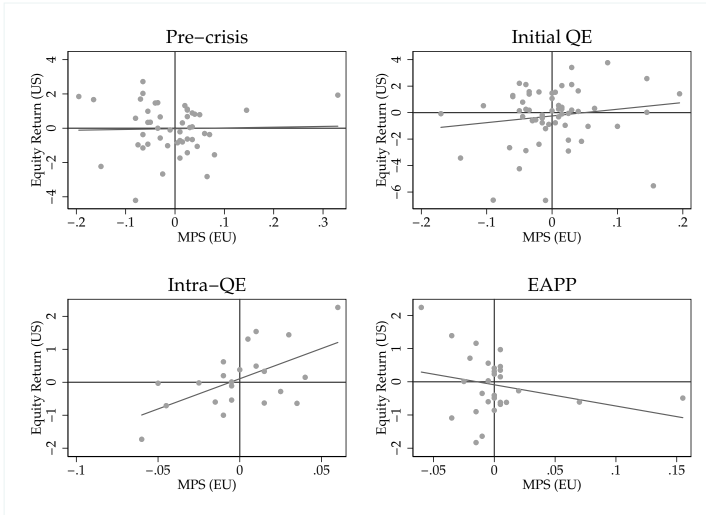

(e) UK, Full Sample



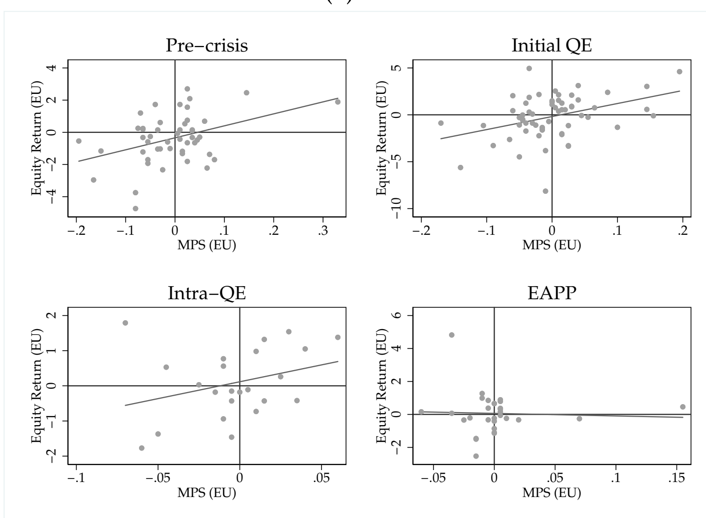

(f) UK, EAPP

Figure 8: Effect of a One Standard Deviation Expansionary BoJ Surprise on10 Year Bond Yields

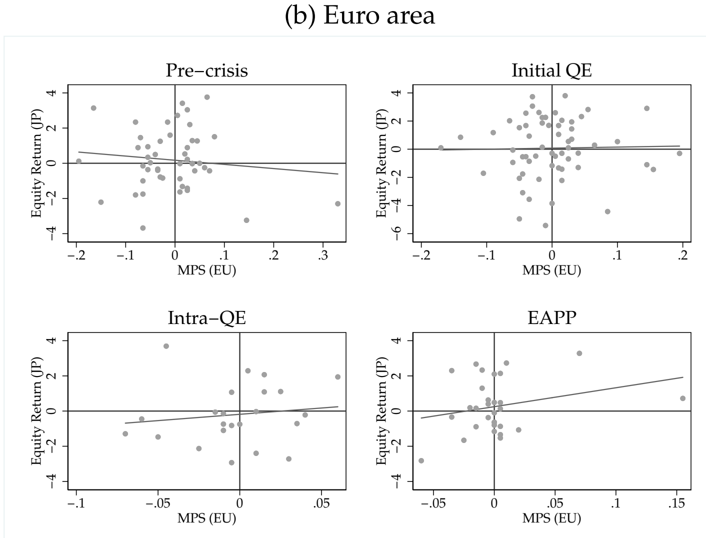
Figure 8 summarizes the results of daily local projections, where the dependent variable is the change in 10-year zero coupon yields in the Euro area (Panels 8a, 8b), US (Panels 8c, 8d), and UK (Panels 8e, 8f) from 0 to 25 days after the date of a BoJ monetary policy announcement. The impulse variable is the daily change in the implied yield for the year-ahead futures contract on the Euroyen Tibor on BoJ announcement days. Monetary policy measures are normalized to be a one standard deviation loosening. Red lines show the unsmoothed estimates from local projections, $\hat{\beta}_{i,0}, \ldots, \hat{\beta}_{i,25}$, where $i$ indexes the source of the monetary policy surprise.. Thick blue lines show the path of the smoothed estimate for the path of $\hat{\beta}_i$ using a compound moving median smoother. The dark and light gray areas indicate smoothed confidence intervals at 95% and 90% confidence intervals, respectively.




(a) US




(b) Euro area




(c) Japan

Figure 9: Positive Co-movement Days, ECB Announcements against US, EU and JP Equity Returns

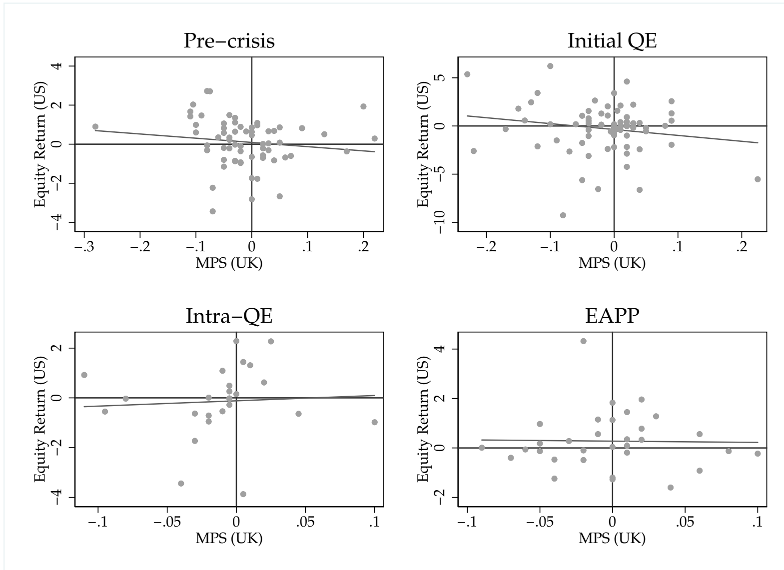



Figure 10: Positive Co-movement Days, BoE Announcements and US Equity Returns

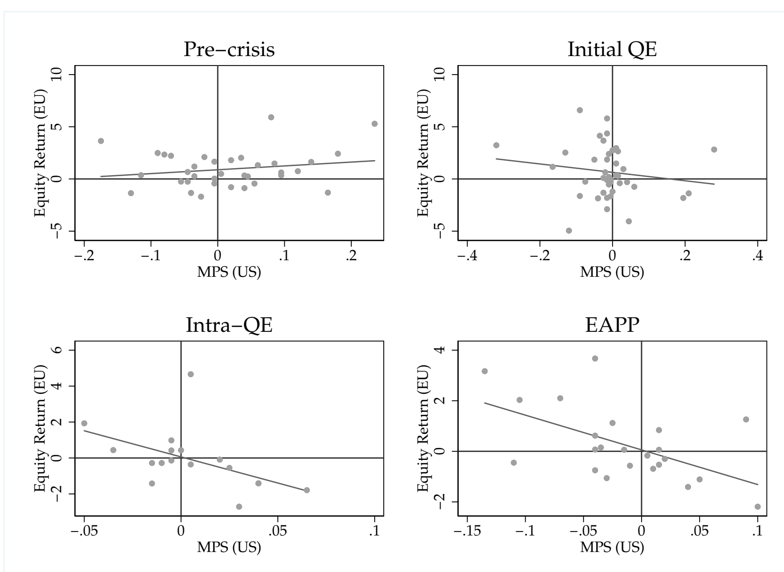
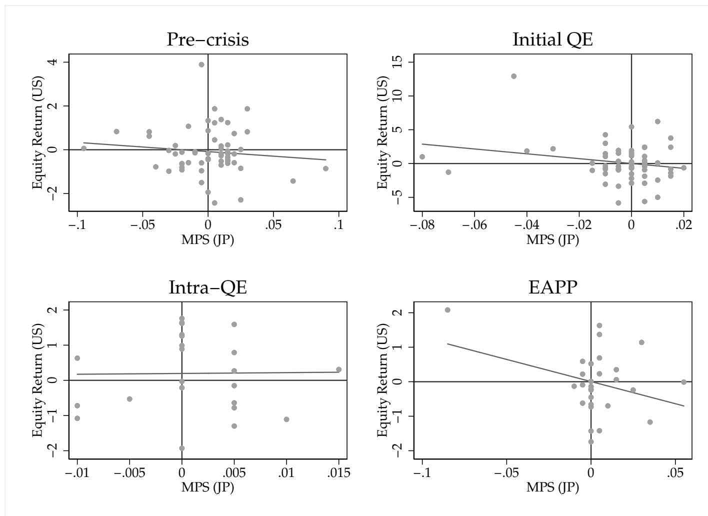
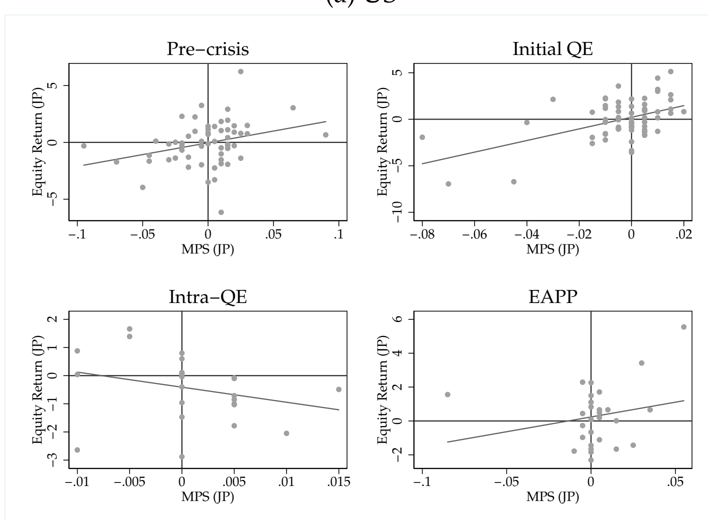



Figure 11: Positive Co-movement Days, FOMC Announcements and EU Equity Returns




(a) US




(b) Japan

Figure 12: Positive Co-movement Days, BoJ Announcements against US, JP Equity Returns

# 8 Appendix B: Tables

Table 1: Monetary Policy Sample Counts and Market Timing Conventions

| Central Bank | Full Sample | Pre-crisis | US QE | Post-Taper | EU QE |
|---|---|---|---|---|---|
| FOMC | 162 | 86 | 42 | 40 | 23 |
| ECB | 244 | 116 | 60 | 53 | 30 |
| BoE | 275 | 135 | 74 | 58 | 32 |
| BoJ | 259 | 125 | 67 | 52 | 28 |
| ECB or BoE | 406 | 198 | 100 | 94 | 60 |
| ECB and BoE | 113 | 60 | 34 | 17 | 2 |

(a) Count of Announcement Days

| Source | Recipient Market | | | |
|---|---|---|---|---|
| | US | UK | Euro area | Japan |
| FOMC | $t-1, t$ | $t, t+1$ | $t, t+1$ | $t, t+1$ |
| BoE | $t-1, t$ | $t-1, t$ | $t-1, t$ | $t, t+1$ |
| ECB | $t-1, t$ | $t-1, t$ | $t-1, t$ | $t, t+1$ |
| BoJ | $t-1, t$ | $t-1, t$ | $t-1, t$ | $t-1, t$ |

(b) Timing of Asset Price Changes

Table 2: Inference via Heteroskedasticity

**Panel A: 1 Year Yields**

| | EUR | JPY | UK | US |
|---|---|---|---|---|
| ECB | 0.421*** | | 0.134* | |
| BOJ | | 0.249* | | |
| BOE | | | 0.352*** | |
| FOMC | 0.448*** | | 0.188** | 0.36*** |
| BOE & ECB | 0.769*** | | 0.526*** | |

**Panel B: 5 Year Yields**

| | EUR | JPY | UK | US |
|---|---|---|---|---|
| ECB | 0.36*** | | 0.154** | |
| BOJ | | 0.116* | | |
| BOE | | | 0.32*** | |
| FOMC | 0.337*** | | 0.479*** | 0.441*** |
| BOE & ECB | 0.429*** | | 0.189** | 0.154** |

**Panel C: 10 Year Yields**

| | EUR | JPY | UK | US |
|---|---|---|---|---|
| ECB | 0.267*** | | 0.184*** | |
| BOJ | | 0.136* | | |
| BOE | 0.117* | | 0.333*** | |
| FOMC | 0.388*** | | 0.402*** | 0.392*** |
| BOE & ECB | 0.187** | | | 0.179** |

Table 2 summarizes the results of a Brown-Forsythe test for equality of variance across the full sample of zero coupon bond yield changes for maturities of 1, 5, and 10 years on announcement days compared to non-announcement days. Columns represent the central bank generating potential surprises. Rows indicate recipient markets. Empty cells indicate results which are not significant at the 10% level (minimum). Cells with text in red indicate yields for which the ECB and BoE monetary policy surprise is not identified, but where joint days generate a statistically significant response. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 3: Monetary Policy Surprise Summary Statistics by Subsample

(a) Summary Statistics: Interbank Interest Rate Futures Measure

| Central | Full Sample | | Pre-crisis | | Initial QE | | Intra-QE | | EAPP | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bank | Mean | St. Dev. | Mean | St. Dev. | Mean | St. Dev. | Mean | St. Dev. | Mean | St. Dev. |
| FOMC | -0.16 | 8.66 | 1.54 | 9.05 | -0.95 | 9.35 | 0.53 | 2.88 | -1.46 | 5.81 |
| BoE | -1.58 | 7.23 | -1.17 | 7.57 | -1.55 | 7.19 | -1.44 | 4.44 | -0.28 | 4.29 |
| ECB | -0.35 | 6.27 | -0.58 | 8.11 | -0.07 | 6.45 | -0.28 | 3.21 | 0.10 | 3.60 |
| BoJ | -0.08 | 2.29 | -0.14 | 2.87 | -0.34 | 1.71 | 0.08 | 0.60 | 0.34 | 2.24 |

(b) Summary Statistics: 2-Year Yield Measure

| Central | Full Sample | | Pre-crisis | | Initial QE | | Intra-QE | | EAPP | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bank | Mean | St. Dev. | Mean | St. Dev. | Mean | St. Dev. | Mean | St. Dev. | Mean | St. Dev. |
| FOMC | 0.11 | 6.93 | 1.90 | 8.71 | -1.09 | 5.58 | 1.02 | 4.16 | -1.48 | 5.56 |
| BoE | -1.19 | 5.51 | -1.16 | 5.76 | -1.14 | 5.66 | -0.71 | 3.89 | -0.46 | 4.01 |
| ECB | -1.24 | 6.04 | -0.41 | 5.66 | -2.22 | 7.42 | -0.56 | 5.09 | -0.58 | 2.66 |
| BoJ | -0.04 | 1.37 | 0.03 | 1.10 | -0.20 | 1.16 | 0.06 | 0.51 | 0.13 | 1.54 |

Table 4: Response of Yield Changes to a One Standard Deviation Monetary Policy Surprise (Benchmark Specification), Full Sample

| | Monetary Policy Surprises | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| US | | Y1 (US) | Y3 (US) | Y5 (US) | Y7 (US) | Y10 (US) |
| **Domestic Pass-through** | MPS, Full Sample, FOMC | -3.7*** | -5.7*** | -5.9*** | -5.5*** | -4.6*** |
| | | (0.663) | (0.920) | (1.120) | (1.267) | (1.297) |
| **Spillovers by Central Bank** | MPS, Full Sample, ECB | -0.9*** | -1.2*** | -1.3** | -1.3** | -1.3** |
| | | (0.314) | (0.430) | (0.551) | (0.603) | (0.635) |
| | MPS, Full Sample, BoE | 0.2 | -0.1 | -0.1 | -0.1 | -0.1 |
| | | (0.390) | (0.564) | (0.715) | (0.772) | (0.764) |
| | MPS, Full Sample, BoJ | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| | | (0.341) | (0.539) | (0.646) | (0.653) | (0.606) |
| UK | | Y1 (UK) | Y3 (UK) | Y5 (UK) | Y7 (UK) | Y10 (UK) |
| **Domestic Pass-through** | MPS, Full Sample, BoE | -3.2*** | -4.2*** | -3.6*** | -3.1*** | -2.6*** |
| | | (0.359) | (0.546) | (0.591) | (0.599) | (0.592) |
| **Spillovers by Central Bank** | MPS, Full Sample, ECB | -0.8** | -1.4** | -1.4** | -1.4** | -1.4** |
| | | (0.358) | (0.562) | (0.577) | (0.590) | (0.605) |
| | MPS, Full Sample, BoJ | -0.6*** | -0.7** | -0.7* | -0.6 | -0.5 |
| | | (0.182) | (0.371) | (0.397) | (0.402) | (0.392) |
| | MPS, Full Sample, FOMC | -1.3*** | -1.7*** | -1.6*** | -1.4** | -1.1* |
| | | (0.346) | (0.534) | (0.532) | (0.569) | (0.595) |
| Euro area | | Y1 (EU) | Y3 (EU) | Y5 (EU) | Y7 (EU) | Y10 (EU) |
| **Domestic Pass-through** | MPS, Full Sample, ECB | -3.0*** | -4.0*** | -3.2*** | -2.4*** | -1.6*** |
| | | (0.286) | (0.325) | (0.348) | (0.345) | (0.350) |
| **Spillovers by Central Bank** | MPS, Full Sample, BoE | -0.7 | -0.5 | -0.7 | -0.8** | -0.9*** |
| | | (0.456) | (0.438) | (0.412) | (0.355) | (0.310) |
| | MPS, Full Sample, BoJ | 0.0 | -0.8*** | -0.9*** | -0.7** | -0.6* |
| | | (0.312) | (0.229) | (0.248) | (0.292) | (0.358) |
| | MPS, Full Sample, FOMC | -0.8** | -1.0* | -1.1** | -1.1** | -1.1** |
| | | (0.331) | (0.492) | (0.477) | (0.467) | (0.499) |
| Japan | | Y1 (JP) | Y3 (JP) | Y5 (JP) | Y7 (JP) | Y10 (JP) |
| **Domestic Pass-through** | MPS, Full Sample, BoJ | -0.4 | -1.5*** | -1.9*** | -2.0*** | -1.8*** |
| | | (0.439) | (0.305) | (0.286) | (0.304) | (0.334) |
| **Spillovers by Central Bank** | MPS, Full Sample, ECB | 0.6 | -0.1 | -0.2 | -0.4 | -0.5* |
| | | (0.687) | (0.221) | (0.276) | (0.296) | (0.275) |
| | MPS, Full Sample, BoE | -0.1 | -0.4** | -0.5* | -0.4 | -0.2 |
| | | (0.292) | (0.160) | (0.272) | (0.312) | (0.276) |
| | MPS, Full Sample, FOMC | 0.2 | -0.5** | -0.9*** | -1.1*** | -0.9*** |
| | | (0.618) | (0.222) | (0.312) | (0.326) | (0.316) |

Table 4 summarizes the results of daily regressions where the dependent variable is the change in zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years. MPS is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). Full results, including control variables, are shown in the Internet Appendix. Standard errors are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

## Table 5: The Impact of a Domestic One Standard Deviation Monetary Policy Surprise on Yields, Expected Short Rates and Term Premia (Benchmark Specification)

| | | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| Panel A: US Domestic Passthrough | Dep. Var. | Y1 (US) | Y3 (US) | Y5 (US) | Y7 (US) | Y10 (US) |
| MPS (Interbank Futures), Pre-crisis, FOMC | Yield | -6.2*** | -6.3*** | -5.0*** | -3.8*** | -2.7*** |
| | E(Short rate) | -7.5*** | -7.1*** | -6.3*** | -5.5*** | -4.5*** |
| | Term premium | 1.3** | 0.8 | 1.3** | 1.7** | 2.0*** |
| MPS (Interbank Futures), US QE, FOMC | Yield | -1.8* | -4.0** | -5.4** | -5.8** | -5.4* |
| | E(Short rate) | -0.8 | -1.2* | -1.6** | -1.7*** | -1.6*** |
| | Term premium | -1.0* | -2.9** | -3.8* | -4.1* | -3.7 |
| MPS (Interbank Futures), TT to EAPP, FOMC | Yield | -3.6*** | -18.4*** | -24.8*** | -23.8*** | -18.6*** |
| | E(Short rate) | -0.2 | -5.8** | -10.5*** | -11.5*** | -10.9*** |
| | Term premium | -3.3*** | -12.7*** | -14.4** | -12.4* | -7.7 |
| MPS (Interbank Futures), EAPP, FOMC | Yield | -3.9*** | -9.7*** | -9.6*** | -8.3*** | -6.6*** |
| | E(Short rate) | -7.4*** | -9.1*** | -8.7*** | -7.9*** | -6.7*** |
| | Term premium | 3.4*** | -0.6 | -0.8 | -0.3 | 0.3 |
| Panel B: Euro Area Domestic Passthrough | Dep. Var. | Y1 (EU) | Y3 (EU) | Y5 (EU) | Y7 (EU) | Y10 (EU) |
| MPS (Interbank Futures), Pre-crisis, ECB | Yield | -3.4*** | -4.2*** | -3.1*** | -2.1*** | -1.2*** |
| | E(Short rate) | -4.5*** | -4.5*** | -4.0*** | -3.6*** | -2.9*** |
| | Term premium | 0.9*** | -0.1 | 0.5** | 1.1*** | 1.5*** |
| MPS (Interbank Futures), US QE, ECB | Yield | -2.7*** | -3.5*** | -2.7*** | -2.1*** | -1.6*** |
| | E(Short rate) | -3.2*** | -3.2*** | -2.9*** | -2.6*** | -2.2*** |
| | Term premium | 0.5 | -0.2 | 0.3 | 0.6 | 0.6 |
| MPS (Interbank Futures), TT to EAPP, ECB | Yield | -3.8*** | -6.7*** | -6.9*** | -6.0*** | -4.4*** |
| | E(Short rate) | -1.5* | -1.7* | -3.6*** | -4.0*** | -3.8*** |
| | Term premium | -2.2** | -5.0*** | -3.4*** | -2.2** | -0.7 |
| MPS (Interbank Futures), EAPP, ECB | Yield | -3.4*** | -5.2*** | -5.4*** | -5.3*** | -4.8*** |
| | E(Short rate) | -0.0 | -0.1 | -0.6 | -1.6*** | -2.1*** |
| | Term premium | -3.4*** | -5.1*** | -4.9*** | -3.6*** | -2.7*** |
| Panel C: UK Domestic Passthrough | Dep. Var. | Y1 (UK) | Y3 (UK) | Y5 (UK) | Y7 (UK) | Y10 (UK) |
| MPS (Interbank Futures), Pre-crisis, BoE | Yield | -3.4*** | -4.3*** | -3.5*** | -2.8*** | -2.1*** |
| | E(Short rate) | -4.0*** | -3.8*** | -3.4*** | -3.1*** | -2.6*** |
| | Term premium | 0.5*** | -0.4 | 0.1 | 0.5 | 0.7 |
| MPS (Interbank Futures), US QE, BoE | Yield | -2.4*** | -4.5*** | -4.1*** | -3.6*** | -3.1*** |
| | E(Short rate) | -3.0** | -3.3*** | -3.2*** | -2.9*** | -2.4*** |
| | Term premium | 0.6 | -1.3* | -1.0 | -0.7 | -0.6 |
| MPS (Interbank Futures), TT to EAPP, BoE | Yield | -2.5*** | -6.4*** | -6.9*** | -6.2*** | -5.2*** |
| | E(Short rate) | -1.7 | -2.8*** | -3.7*** | -3.7*** | -3.3*** |
| | Term premium | -0.8 | -3.5*** | -3.1** | -2.4* | -1.7 |
| MPS (Interbank Futures), EAPP, BoE | Yield | -4.9*** | -7.4*** | -8.1*** | -8.3*** | -7.9*** |
| | E(Short rate) | -1.7 | -3.2*** | -4.8*** | -6.4*** | -6.7*** |
| | Term premium | -3.1*** | -4.1*** | -3.5* | -2.1 | -1.5 |
| Panel D: Japan Domestic Passthrough | Dep. Var. | Y1 (JP) | Y3 (JP) | Y5 (JP) | Y7 (JP) | Y10 (JP) |
| MPS (Interbank Futures), Pre-crisis, BoJ | Yield | -0.0 | -1.6*** | -1.6*** | -1.5*** | -1.4*** |
| | E(Short rate) | -0.6* | -0.7* | -0.5* | -0.4* | -0.3* |
| | Term premium | 0.7 | -0.8* | -1.0** | -1.1** | -1.1** |
| MPS (Interbank Futures), US QE, BoJ | Yield | -0.6** | -1.7*** | -2.4*** | -2.3*** | -1.6*** |
| | E(Short rate) | -0.1 | -0.1 | -0.1 | -0.0 | -0.0 |
| | Term premium | -0.4 | -1.6*** | -2.4*** | -2.2*** | -1.5*** |
| MPS (Interbank Futures), TT to EAPP, BoJ | Yield | 0.0 | -1.2 | -1.6** | -1.6* | -1.8* |
| | E(Short rate) | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 |
| | Term premium | -1.3 | -1.9* | -2.0 | -2.0 | -2.2 |
| MPS (Interbank Futures), EAPP, BoJ | Yield | -1.5*** | -2.0*** | -2.5*** | -2.8*** | -2.8*** |
| | E(Short rate) | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| | Term premium | -1.7*** | -2.1*** | -2.5*** | -2.8*** | -2.8*** |

Table 5 summarizes the results of daily piecewise regressions where the dependent variable is the change in domestic (i) zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years, (ii) the path of the expected short rate over the life of the bond, and (iii) the term premium relevant for each maturity. Measures of the expected short rate and the term premium are estimated using a shadow rate term structure model from Wu and Xia (2016). The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6: The Impact of a One Standard Deviation FOMC Monetary Policy Surprise on Yields, Expected Short Rates and Term Premia (Benchmark Specification)

| | | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| Panel A: UK yields | Dep. Var. | Y1 (UK) | Y3 (UK) | Y5 (UK) | Y7 (UK) | Y10 (UK) |
| MPS (Interbank Futures), Pre-crisis, FOMC | Yield | -0.9 | -0.5 | -0.0 | 0.4 | 0.7 |
| | E(Short rate) | -1.5* | -1.3* | -1.2* | -1.1* | -0.9* |
| | Term premium | 0.6 | 0.9** | 1.2** | 1.5** | 1.7*** |
| MPS (Interbank Futures), US QE, FOMC | Yield | -1.7** | -2.4** | -2.3** | -2.1** | -1.8* |
| | E(Short rate) | -1.5* | -1.6** | -1.5** | -1.3** | -1.1** |
| | Term premium | -0.2 | -0.7 | -0.7 | -0.7 | -0.7 |
| MPS (Interbank Futures), TT to EAPP, FOMC | Yield | -1.5 | -9.9** | -13.0** | -13.1** | -11.8* |
| | E(Short rate) | 0.4 | -2.4 | -3.7** | -3.9** | -3.6** |
| | Term premium | -1.9 | -7.5* | -9.3* | -9.2 | -8.2 |
| MPS (Interbank Futures), EAPP, FOMC | Yield | -1.7** | -4.4*** | -5.3*** | -5.5*** | -5.5*** |
| | E(Short rate) | -0.5 | -2.5** | -3.1*** | -3.1*** | -2.8*** |
| | Term premium | -1.3** | -1.8** | -1.9** | -1.9** | -2.2** |
| Panel B: Euro area yields | Dep. Var. | Y1 (EU) | Y3 (EU) | Y5 (EU) | Y7 (EU) | Y10 (EU) |
| MPS (Interbank Futures), Pre-crisis, FOMC | Yield | -0.4 | -0.7 | -0.4 | 0.0 | 0.5 |
| | E(Short rate) | -1.2** | -1.2* | -1.2* | -1.0* | -0.9* |
| | Term premium | 0.9* | 0.9** | 1.0** | 1.2** | 1.5** |
| MPS (Interbank Futures), US QE, FOMC | Yield | -0.8 | -1.1 | -1.4 | -1.6* | -1.7* |
| | E(Short rate) | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 |
| | Term premium | -0.6 | -0.8** | -1.1** | -1.3** | -1.4* |
| MPS (Interbank Futures), TT to EAPP, FOMC | Yield | -2.4 | -6.9 | -8.9 | -9.4 | -8.8 |
| | E(Short rate) | -4.0 | -5.9 | -6.7 | -6.7 | -6.0 |
| | Term premium | 1.6 | -1.1 | -2.3 | -2.8 | -2.7 |
| MPS (Interbank Futures), EAPP, FOMC | Yield | -0.1 | -0.6 | -1.6 | -2.4** | -3.2** |
| | E(Short rate) | 1.3 | 1.0 | 0.6 | 0.1 | -0.2 |
| | Term premium | -1.2 | -1.2 | -1.6** | -2.0** | -2.5** |
| Panel C: Japan yields | Dep. Var. | Y1 (JP) | Y3 (JP) | Y5 (JP) | Y7 (JP) | Y10 (JP) |
| MPS (Interbank Futures), Pre-crisis, FOMC | Yield | 1.2 | -1.0** | -0.6 | -0.7 | -0.5 |
| | E(Short rate) | -0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Term premium | 1.8 | -0.4 | -0.2 | -0.4 | -0.3 |
| MPS (Interbank Futures), US QE, FOMC | Yield | -0.3 | -0.5 | -0.9** | -1.0*** | -1.0*** |
| | E(Short rate) | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| | Term premium | -0.2 | -0.6 | -0.9** | -1.1*** | -1.1*** |
| MPS (Interbank Futures), TT to EAPP, FOMC | Yield | 1.2 | 0.4 | -1.0 | -1.6* | -1.4 |
| | E(Short rate) | -0.0 | 0.3 | 0.3 | 0.2 | 0.2 |
| | Term premium | 2.5* | 0.5 | -1.0 | -1.6 | -1.3 |
| MPS (Interbank Futures), EAPP, FOMC | Yield | 0.3 | -0.5 | -1.3*** | -1.4*** | -1.5** |
| | E(Short rate) | 1.6 | 1.0 | 0.8 | 0.6 | 0.4 |
| | Term premium | -0.8 | -1.3* | -1.8*** | -1.8*** | -1.8*** |

Table 6 summarizes the results of daily piecewise regressions where the dependent variable is the change in (i) zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years, (ii) the path of the expected short rate over the life of the bond, and (iii) the term premium relevant for each maturity in the UK, Euro area and Japan. Measures of the expected short rate and the term premium are estimated using a shadow rate term structure model from Wu and Xia (2016). The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar on monetary policy FOMC meeting days. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 7: The Impact of a One Standard Deviation ECB Monetary Policy Surprise on Yields, Expected Short Rates and Term Premia (Benchmark Specification)

| | | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| Panel A: UK yields | Dep. Var. | Y1 (UK) | Y3 (UK) | Y5 (UK) | Y7 (UK) | Y10 (UK) |
| MPS (Interbank Futures), Pre-crisis, ECB | Yield | -0.4 | -1.4** | -1.6*** | -1.6*** | -1.6*** |
| | E(Short rate) | 0.0 | -0.2 | -0.2 | -0.1 | -0.1 |
| | Term premium | -0.4*** | -1.2*** | -1.5*** | -1.7*** | -1.7*** |
| MPS (Interbank Futures), US QE, ECB | Yield | -1.1* | -1.7 | -1.5 | -1.5 | -1.4 |
| | E(Short rate) | -2.1 | -1.8 | -1.6* | -1.5* | -1.3** |
| | Term premium | 1.0 | -0.0 | -0.1 | -0.1 | -0.2 |
| MPS (Interbank Futures), TT to EAPP, ECB | Yield | -0.4 | -1.1 | -1.3 | -1.4 | -1.4 |
| | E(Short rate) | 0.8 | 1.2* | 0.1 | -0.3 | -0.5 |
| | Term premium | -1.1* | -2.3** | -1.7 | -1.3 | -1.0 |
| MPS (Interbank Futures), EAPP, ECB | Yield | -2.4*** | -4.0*** | -4.3*** | -4.3*** | -4.2*** |
| | E(Short rate) | -0.9*** | -2.8*** | -3.0*** | -3.0*** | -2.7*** |
| | Term premium | -1.6*** | -1.2*** | -1.0 | -1.1 | -1.2 |
| Panel B: US yields | Dep. Var. | Y1 (US) | Y3 (US) | Y5 (US) | Y7 (US) | Y10 (US) |
| MPS (Interbank Futures), Pre-crisis, ECB | Yield | -1.3** | -1.0 | -0.7 | -0.6 | -0.4 |
| | E(Short rate) | -1.3* | -1.1 | -0.9 | -0.8 | -0.6 |
| | Term premium | -0.0 | 0.1 | 0.2 | 0.2 | 0.2 |
| MPS (Interbank Futures), US QE, ECB | Yield | -0.3 | -1.2** | -1.8** | -2.2** | -2.4** |
| | E(Short rate) | -0.3 | -0.5 | -0.5 | -0.5 | -0.5 |
| | Term premium | -0.0 | -0.8 | -1.3* | -1.7* | -1.9* |
| MPS (Interbank Futures), TT to EAPP, ECB | Yield | -1.0* | -2.2** | -2.8* | -2.6 | -1.6 |
| | E(Short rate) | -0.3 | -0.8** | -1.3** | -1.4** | -1.3** |
| | Term premium | -0.7 | -1.3 | -1.5 | -1.2 | -0.4 |
| MPS (Interbank Futures), EAPP, ECB | Yield | -0.9** | -2.7*** | -4.2*** | -4.8*** | -5.0*** |
| | E(Short rate) | 0.4 | 0.2 | 0.1 | -0.0 | -0.1 |
| | Term premium | -1.3 | -2.9* | -4.2** | -4.8** | -4.9** |
| Panel C: Japan yields | Dep. Var. | Y1 (JP) | Y3 (JP) | Y5 (JP) | Y7 (JP) | Y10 (JP) |
| MPS (Interbank Futures), Pre-crisis, ECB | Yield | 1.1 | -0.4 | -0.5 | -0.8** | -0.7*** |
| | E(Short rate) | -0.3 | -0.1 | -0.1 | -0.1 | -0.0 |
| | Term premium | 1.5 | -0.4 | -0.5 | -0.8* | -0.7** |
| MPS (Interbank Futures), US QE, ECB | Yield | 0.1 | 0.0 | -0.0 | -0.1 | -0.3 |
| | E(Short rate) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Term premium | 0.1 | 0.1 | -0.1 | -0.2 | -0.3 |
| MPS (Interbank Futures), TT to EAPP, ECB | Yield | -0.0 | 0.2 | -0.3 | -0.6 | -0.5 |
| | E(Short rate) | -0.7 | -0.5 | -0.3 | -0.3 | -0.2 |
| | Term premium | 0.4 | 0.7 | 0.0 | -0.4 | -0.4 |
| MPS (Interbank Futures), EAPP, ECB | Yield | -0.2 | -0.1 | -0.2 | -0.7*** | -1.2*** |
| | E(Short rate) | 1.0*** | 0.5*** | 0.4** | 0.3** | 0.2** |
| | Term premium | -1.7*** | -0.8 | -0.8** | -1.2*** | -1.6*** |

Table 7 summarizes the results of daily piecewise regressions where the dependent variable is the change in (i) zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years, (ii) the path of the expected short rate over the life of the bond, and (iii) the term premium relevant for each maturity in the US, UK and Japan. Measures of the expected short rate and the term premium are estimated using a shadow rate term structure model from Wu and Xia (2016). The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Euribor (ECB) on ECB meeting days. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 8: The Impact of a One Standard Deviation BoE Monetary Policy Surprise on Yields, Expected Short Rates and Term Premia (Benchmark Specification)

| | | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| Panel A: Euro area yields | Dep. Var. | Y1 (EU) | Y3 (EU) | Y5 (EU) | Y7 (EU) | Y10 (EU) |
| MPS (Interbank Futures), Pre-crisis, BoE | Yield | -0.4* | -0.8** | -0.9** | -1.0** | -1.0** |
| | E(Short rate) | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 |
| | Term premium | -0.2 | -0.4 | -0.5 | -0.6 | -0.7 |
| MPS (Interbank Futures), US QE, BoE | Yield | -0.3 | -0.8 | -0.7 | -0.8 | -0.9* |
| | E(Short rate) | -0.1 | -0.2 | -0.2 | -0.2 | -0.2 |
| | Term premium | -0.1 | -0.5 | -0.4 | -0.5 | -0.7 |
| MPS (Interbank Futures), TT to EAPP, BoE | Yield | 0.0 | -0.6 | -1.3* | -1.8** | -2.2** |
| | E(Short rate) | -0.9 | -1.1 | -1.1** | -1.0** | -0.9** |
| | Term premium | 0.9 | 0.6 | 0.0 | -0.5 | -1.1 |
| MPS (Interbank Futures), EAPP, BoE | Yield | -0.8 | -1.7** | -2.4*** | -2.8*** | -3.2*** |
| | E(Short rate) | 0.5* | 0.4* | 0.3 | -0.1 | -0.9** |
| | Term premium | -1.3 | -2.0*** | -2.6*** | -2.7*** | -2.2*** |
| Panel B: US yields | Dep. Var. | Y1 (US) | Y3 (US) | Y5 (US) | Y7 (US) | Y10 (US) |
| MPS (Interbank Futures), Pre-crisis, BoE | Yield | -0.8 | -1.2 | -1.1 | -0.9 | -0.7 |
| | E(Short rate) | -0.7 | -0.7 | -0.6 | -0.6 | -0.5 |
| | Term premium | -0.0 | -0.4 | -0.3 | -0.3 | -0.2 |
| MPS (Interbank Futures), US QE, BoE | Yield | 0.7* | 0.1 | -0.1 | -0.3 | -0.3 |
| | E(Short rate) | 0.2 | 0.3 | 0.2 | 0.1 | 0.1 |
| | Term premium | 0.5 | -0.1 | -0.2 | -0.3 | -0.4 |
| MPS (Interbank Futures), TT to EAPP, BoE | Yield | -0.1 | -2.8*** | -4.2*** | -4.5*** | -4.7*** |
| | E(Short rate) | 0.4 | 0.2 | -0.4 | -0.6 | -0.6 |
| | Term premium | -0.5 | -2.9*** | -3.7*** | -3.9*** | -4.2*** |
| MPS (Interbank Futures), EAPP, BoE | Yield | -0.8** | -2.4*** | -3.2*** | -3.4*** | -3.2*** |
| | E(Short rate) | -0.1 | -0.5 | -0.6 | -0.6 | -0.6 |
| | Term premium | -0.7 | -1.9** | -2.6** | -2.8** | -2.6* |
| Panel C: Japan yields | Dep. Var. | Y1 (JP) | Y3 (JP) | Y5 (JP) | Y7 (JP) | Y10 (JP) |
| MPS (Interbank Futures), Pre-crisis, BoE | Yield | -0.5 | -0.8*** | -1.1*** | -0.9*** | -0.7*** |
| | E(Short rate) | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| | Term premium | -1.4 | -1.1** | -1.3*** | -1.2*** | -0.9*** |
| MPS (Interbank Futures), US QE, BoE | Yield | -0.1 | -0.4** | -0.8*** | -0.8** | -0.5 |
| | E(Short rate) | -0.2 | -0.1 | -0.1 | -0.1 | -0.0 |
| | Term premium | -0.0 | -0.4* | -0.7*** | -0.7** | -0.5 |
| MPS (Interbank Futures), TT to EAPP, BoE | Yield | -0.5 | -0.1 | -0.3 | -0.4 | -0.6* |
| | E(Short rate) | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| | Term premium | -0.5 | -0.2 | -0.3 | -0.4 | -0.6 |
| MPS (Interbank Futures), EAPP, BoE | Yield | 0.3 | -0.1 | -0.6 | -0.6 | -0.3 |
| | E(Short rate) | -1.0 | -0.7 | -0.5 | -0.4 | -0.3 |
| | Term premium | 1.1 | 0.5 | -0.2 | -0.3 | -0.1 |

Table 8 summarizes the results of daily piecewise regressions where the dependent variable is the change in (i) zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years, (ii) the path of the expected short rate over the life of the bond, and (iii) the term premium relevant for each maturity in the US, Euro area and Japan. Measures of the expected short rate and the term premium are estimated using a shadow rate term structure model from Wu and Xia (2016). The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Short Sterling (BoE) on Bank of England meeting days. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 9: The Impact of a One Standard Deviation BoJ Policy Surprise on Yields, Expected Short Rates and Term Premia (Benchmark Specification)

| | | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| Panel A: US yields | Dep. Var. | Y1 (US) | Y3 (US) | Y5 (US) | Y7 (US) | Y10 (US) |
| MPS (Interbank Futures), Pre-crisis, BoJ | Yield | -0.4 | -0.4 | -0.5 | -0.6 | -0.5 |
| | E(Short rate) | -0.1 | -0.1 | -0.0 | -0.0 | -0.0 |
| | Term premium | -0.2 | -0.2 | -0.4 | -0.5 | -0.5 |
| MPS (Interbank Futures), US QE, BoJ | Yield | -0.2 | -0.8 | -1.0 | -0.9 | -0.7 |
| | E(Short rate) | -0.2 | -0.3* | -0.4 | -0.4 | -0.3 |
| | Term premium | 0.0 | -0.4 | -0.5 | -0.5 | -0.4 |
| MPS (Interbank Futures), TT to EAPP, BoJ | Yield | -0.0 | 1.5 | 4.2* | 6.7** | 8.9*** |
| | E(Short rate) | 0.1 | -0.4 | -0.3 | -0.3 | -0.2 |
| | Term premium | -0.2 | 2.1 | 4.8*** | 7.2*** | 9.3*** |
| MPS (Interbank Futures), EAPP, BoJ | Yield | -0.1 | -0.4 | -0.4 | -0.3 | -0.1 |
| | E(Short rate) | -0.6 | -0.6 | -0.6 | -0.5 | -0.4 |
| | Term premium | 0.5 | 0.2 | 0.2 | 0.2 | 0.3 |
| Panel B: UK yields | Dep. Var. | Y1 (UK) | Y3 (UK) | Y5 (UK) | Y7 (UK) | Y10 (UK) |
| MPS (Interbank Futures), Pre-crisis, BoJ | Yield | -0.5** | -0.5 | -0.4 | -0.4 | -0.3 |
| | E(Short rate) | -0.5** | -0.5** | -0.4** | -0.4** | -0.3** |
| | Term premium | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| MPS (Interbank Futures), US QE, BoJ | Yield | -0.5 | -1.7** | -1.9** | -1.9** | -1.8 |
| | E(Short rate) | 0.0 | -0.2 | -0.3 | -0.2 | -0.2 |
| | Term premium | -0.5 | -1.2** | -1.4 | -1.5 | -1.5 |
| MPS (Interbank Futures), TT to EAPP, BoJ | Yield | -0.8 | -2.5 | -2.9 | -2.1 | -0.9 |
| | E(Short rate) | -0.4 | -0.6 | -1.8 | -2.2 | -2.2 |
| | Term premium | -0.5 | -2.3 | -1.2 | 0.1 | 1.3 |
| MPS (Interbank Futures), EAPP, BoJ | Yield | -0.5 | -1.4* | -1.4 | -1.3 | -1.1 |
| | E(Short rate) | -0.3 | -0.7** | -1.1** | -1.1** | -1.0* |
| | Term premium | -0.2 | -0.6 | -0.2 | -0.2 | -0.1 |
| Panel C: Euro area yields | Dep. Var. | Y1 (EU) | Y3 (EU) | Y5 (EU) | Y7 (EU) | Y10 (EU) |
| MPS (Interbank Futures), Pre-crisis, BoJ | Yield | -0.1 | -0.6* | -0.9** | -0.9** | -0.9** |
| | E(Short rate) | 0.1 | -0.0 | -0.1 | -0.1 | -0.1 |
| | Term premium | -0.1 | -0.5* | -0.8** | -0.8** | -0.8* |
| MPS (Interbank Futures), US QE, BoJ | Yield | -0.7* | -1.1* | -1.0 | -0.8 | -0.7 |
| | E(Short rate) | -1.0 | -0.9 | -0.8 | -0.7 | -0.6 |
| | Term premium | 0.2 | -0.1 | -0.1 | 0.0 | 0.0 |
| MPS (Interbank Futures), TT to EAPP, BoJ | Yield | 2.7 | -3.7 | -4.5 | -5.1 | -4.7 |
| | E(Short rate) | -1.8 | -3.0 | -3.0 | -2.9 | -2.6 |
| | Term premium | 4.5*** | -0.5 | -1.2 | -1.9 | -1.9 |
| MPS (Interbank Futures), EAPP, BoJ | Yield | -0.3 | -0.5 | -0.7 | -0.7 | -0.7 |
| | E(Short rate) | -0.0 | -0.0 | -0.0 | -0.2** | -0.3* |
| | Term premium | -0.3 | -0.4 | -0.5 | -0.4 | -0.3 |

Table 9 summarizes the results of daily piecewise regressions where the dependent variable is the change in (i) zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years, (ii) the path of the expected short rate over the life of the bond, and (iii) the term premium relevant for each maturity in the US, UK and Euro area. Measures of the expected short rate and the term premium are estimated using a shadow rate term structure model from Wu and Xia (2016). The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Euroyen Tibor (BoJ) on monetary policy meeting days. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 10: Test for Equality of Coefficients between Break Points (US Yields)

| Panel A: Piecewise Comparison | Y1 (US) | Y3 (US) | Y5 (US) | Y7 (US) | Y10 (US) |
|---|---|---|---|---|---|
| Pre-crisis = US QE, US | 0.00*** | 0.31 | 0.91 | 0.52 | 0.36 |
| US QE = Intra-QE, US | 0.08* | 0.00*** | 0.00*** | 0.00*** | 0.02* |
| Intra-QE = EAPP, US | 0.85 | 0.00*** | 0.00*** | 0.01*** | 0.02* |
| Pre-crisis = US QE, EA | 0.17 | 0.81 | 0.35 | 0.22 | 0.15 |
| US QE = Intra-QE, EA | 0.21 | 0.41 | 0.57 | 0.85 | 0.72 |
| Intra-QE = EAPP, EA | 0.82 | 0.62 | 0.38 | 0.23 | 0.13 |
| Pre-crisis = US QE, UK | 0.05* | 0.17 | 0.42 | 0.63 | 0.8 |
| US QE = Intra-QE, UK | 0.12 | 0.00*** | 0.00*** | 0.01*** | 0.02* |
| Intra-QE = EAPP, UK | 0.19 | 0.65 | 0.45 | 0.5 | 0.43 |
| Pre-crisis = US QE, Japan | 0.32 | 0.27 | 0.35 | 0.41 | 0.45 |
| US QE = Intra-QE, Japan | 0.03* | 0.72 | 0.64 | 0.31 | 0.2 |
| Intra-QE = EAPP, Japan | 0.12 | 1 | 0.93 | 0.54 | 0.33 |
| Panel B: Cumulative Comparision | | | | | |
| Pre-crisis = US QE, US | 0.00*** | 0.31 | 0.91 | 0.52 | 0.36 |
| Pre-crisis = US QE = Intra-QE, US | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.01*** |
| Pre-crisis = US QE = Intra-QE = EAPP, US | 0.01*** | 0.00*** | 0.00*** | 0.00*** | 0.00*** |
| Pre-crisis = US QE, Euro area | 0.17 | 0.81 | 0.35 | 0.22 | 0.15 |
| Pre-crisis = US QE = Intra-QE, Euro area | 0.25 | 0.63 | 0.45 | 0.39 | 0.35 |
| Pre-crisis = US QE = Intra-QE = EAPP, Euro area | 0.37 | 0.16 | 0.00*** | 0.01*** | 0.01*** |
| Pre-crisis = US QE, UK | 0.05* | 0.17 | 0.42 | 0.63 | 0.8 |
| Pre-crisis = US QE = Intra-QE, UK | 0.10* | 0.00*** | 0.00*** | 0.01*** | 0.02* |
| Pre-crisis = US QE = Intra-QE = EAPP, UK | 0.04* | 0.00*** | 0.00*** | 0.01*** | 0.02* |
| Pre-crisis = US QE, Japan | 0.32 | 0.27 | 0.35 | 0.41 | 0.45 |
| Pre-crisis = US QE = Intra-QE, Japan | 0.08* | 0.54 | 0.62 | 0.51 | 0.4 |
| Pre-crisis = US QE = Intra-QE = EAPP, Japan | 0.16 | 0.74 | 0.81 | 0.7 | 0.58 |

Table 10 shows the results from a two-way Wald test for equality of coefficients between sub-sample periods. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 11: Test for Equality of Coefficients between Break Points (Euro area Yields)

| Panel A: Piecewise Comparison | Y1 (EU) | Y3 (EU) | Y5 (EU) | Y7 (EU) | Y10 (EU) |
|---|---|---|---|---|---|
| Pre-crisis = US QE, US | 0.58 | 0.71 | 0.34 | 0.11 | 0.02* |
| US QE = Intra-QE, US | 0.38 | 0.21 | 0.19 | 0.19 | 0.22 |
| Intra-QE = EAPP, US | 0.21 | 0.16 | 0.19 | 0.24 | 0.33 |
| Pre-crisis = US QE, EA | 0.15 | 0.35 | 0.57 | 0.95 | 0.48 |
| US QE = Intra-QE, EA | 0.09* | 0.00*** | 0.00*** | 0.00*** | 0.02* |
| Intra-QE = EAPP, EA | 0.55 | 0.21 | 0.33 | 0.62 | 0.8 |
| Pre-crisis = US QE, UK | 0.86 | 0.94 | 0.79 | 0.76 | 0.81 |
| US QE = Intra-QE, UK | 0.61 | 0.89 | 0.53 | 0.29 | 0.2 |
| Intra-QE = EAPP, UK | 0.28 | 0.25 | 0.36 | 0.43 | 0.51 |
| Pre-crisis = US QE, Japan | 0.91 | 0.39 | 0.51 | 0.73 | 0.85 |
| US QE = Intra-QE, Japan | 0.07* | 0.81 | 0.61 | 0.4 | 0.37 |
| Intra-QE = EAPP, Japan | 0.06* | 0.65 | 0.47 | 0.32 | 0.33 |
| **Panel B: Cumulative Comparision** | | | | | |
| Pre-crisis = US QE, US | 0.58 | 0.71 | 0.34 | 0.11 | 0.02* |
| Pre-crisis = US QE = Intra-QE, US | 0.47 | 0.38 | 0.22 | 0.09* | 0.03* |
| Pre-crisis = US QE = Intra-QE = EAPP, US | 0.6 | 0.55 | 0.33 | 0.08* | 0.01*** |
| Pre-crisis = US QE, Euro area | 0.15 | 0.35 | 0.57 | 0.95 | 0.48 |
| Pre-crisis = US QE = Intra-QE, Euro area | 0.19 | 0.00*** | 0.00*** | 0.00*** | 0.02* |
| Pre-crisis = US QE = Intra-QE = EAPP, Euro area | 0.34 | 0.00*** | 0.00*** | 0.00*** | 0.00*** |
| Pre-crisis = US QE, UK | 0.86 | 0.94 | 0.79 | 0.76 | 0.81 |
| Pre-crisis = US QE = Intra-QE, UK | 0.6 | 0.95 | 0.8 | 0.55 | 0.43 |
| Pre-crisis = US QE = Intra-QE = EAPP, UK | 0.66 | 0.72 | 0.42 | 0.2 | 0.13 |
| Pre-crisis = US QE, Japan | 0.91 | 0.39 | 0.51 | 0.73 | 0.85 |
| Pre-crisis = US QE = Intra-QE, Japan | 0.19 | 0.64 | 0.66 | 0.63 | 0.67 |
| Pre-crisis = US QE = Intra-QE = EAPP, Japan | 0.22 | 0.81 | 0.81 | 0.78 | 0.8 |

Table 11 shows the results from a two-way Wald test for equality of coefficients between sub-sample periods. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 12: Test for Equality of Coefficients between Break Points (UK Yields)

| Panel A: Piecewise Comparison | Y1 (UK) | Y3 (UK) | Y5 (UK) | Y7 (UK) | Y10 (UK) |
|---|---|---|---|---|---|
| Pre-crisis = US QE, US | 0.45 | 0.18 | 0.09* | 0.05* | 0.05* |
| US QE = Intra-QE, US | 0.45 | 0.15 | 0.09* | 0.09* | 0.10* |
| Intra-QE = EAPP, US | 0.5 | 0.29 | 0.23 | 0.25 | 0.29 |
| Pre-crisis = US QE, EA | 0.36 | 0.69 | 0.94 | 0.96 | 0.93 |
| US QE = Intra-QE, EA | 0.47 | 0.75 | 1 | 0.93 | 0.94 |
| Intra-QE = EAPP, EA | 0.01*** | 0.05* | 0.12 | 0.17 | 0.21 |
| Pre-crisis = US QE, UK | 0.16 | 0.91 | 0.57 | 0.48 | 0.43 |
| US QE = Intra-QE, UK | 0.9 | 0.09* | 0.06* | 0.14 | 0.31 |
| Intra-QE = EAPP, UK | 0.00*** | 0.12 | 0.09* | 0.04* | 0.02* |
| Pre-crisis = US QE, Japan | 0.29 | 0.81 | 0.67 | 0.55 | 0.45 |
| US QE = Intra-QE, Japan | 0.05* | 0.4 | 0.54 | 0.55 | 0.58 |
| Intra-QE = EAPP, Japan | 0.02* | 0.29 | 0.41 | 0.43 | 0.45 |
| Panel B: Cumulative Comparision | | | | | |
| Pre-crisis = US QE, US | 0.45 | 0.18 | 0.09* | 0.05* | 0.05* |
| Pre-crisis = US QE = Intra-QE, US | 0.69 | 0.08* | 0.03* | 0.02* | 0.02* |
| Pre-crisis = US QE = Intra-QE = EAPP, US | 0.78 | 0.02* | 0.00*** | 0.00*** | 0.00*** |
| Pre-crisis = US QE, Euro area | 0.36 | 0.69 | 0.94 | 0.96 | 0.93 |
| Pre-crisis = US QE = Intra-QE, Euro area | 0.65 | 0.92 | 1 | 1 | 1 |
| Pre-crisis = US QE = Intra-QE = EAPP, Euro area | 0.00*** | 0.01*** | 0.03* | 0.07* | 0.17 |
| Pre-crisis = US QE, UK | 0.16 | 0.91 | 0.57 | 0.48 | 0.43 |
| Pre-crisis = US QE = Intra-QE, UK | 0.14 | 0.07* | 0.04* | 0.09* | 0.23 |
| Pre-crisis = US QE = Intra-QE = EAPP, UK | 0.00*** | 0.00*** | 0.00*** | 0.00*** | 0.00*** |
| Pre-crisis = US QE, Japan | 0.29 | 0.81 | 0.67 | 0.55 | 0.45 |
| Pre-crisis = US QE = Intra-QE, Japan | 0.04* | 0.66 | 0.74 | 0.68 | 0.61 |
| Pre-crisis = US QE = Intra-QE = EAPP, Japan | 0.09* | 0.68 | 0.75 | 0.76 | 0.77 |

Table 12 shows the results from a two-way Wald test for equality of coefficients between sub-sample periods. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 13: Test for Equality of Coefficients between Break Points (Japan Yields)

| Panel A: Piecewise Comparison | Y1 (JP) | Y3 (JP) | Y5 (JP) | Y7 (JP) | Y10 (JP) |
|---|---|---|---|---|---|
| Pre-crisis = US QE, US | 0.43 | 0.52 | 0.57 | 0.57 | 0.43 |
| US QE = Intra-QE, US | 0.11 | 0.17 | 0.9 | 0.68 | 0.88 |
| Intra-QE = EAPP, US | 0.28 | 0.19 | 0.61 | 0.92 | 0.9 |
| Pre-crisis = US QE, EA | 0.54 | 0.23 | 0.26 | 0.19 | 0.37 |
| US QE = Intra-QE, EA | 0.81 | 0.65 | 0.62 | 0.39 | 0.76 |
| Intra-QE = EAPP, EA | 0.75 | 0.57 | 0.98 | 0.79 | 0.27 |
| Pre-crisis = US QE, UK | 0.61 | 0.28 | 0.57 | 0.82 | 0.71 |
| US QE = Intra-QE, UK | 0.5 | 0.44 | 0.21 | 0.45 | 0.75 |
| Intra-QE = EAPP, UK | 0.21 | 0.98 | 0.68 | 0.86 | 0.67 |
| Pre-crisis = US QE, Japan | 0.49 | 0.33 | 0.16 | 0.08* | 0.07* |
| US QE = Intra-QE, Japan | 0.4 | 0.24 | 0.73 | 0.91 | 0.78 |
| Intra-QE = EAPP, Japan | 0.10* | 0.08* | 0.21 | 0.47 | 0.69 |
| Panel B: Cumulative Comparision | | | | | |
| Pre-crisis = US QE, US | 0.43 | 0.52 | 0.57 | 0.57 | 0.43 |
| Pre-crisis = US QE = Intra-QE, US | 0.19 | 0.22 | 0.85 | 0.76 | 0.72 |
| Pre-crisis = US QE = Intra-QE = EAPP, US | 0.29 | 0.38 | 0.73 | 0.8 | 0.77 |
| Pre-crisis = US QE, Euro area | 0.54 | 0.23 | 0.26 | 0.19 | 0.37 |
| Pre-crisis = US QE = Intra-QE, Euro area | 0.75 | 0.31 | 0.54 | 0.41 | 0.66 |
| Pre-crisis = US QE = Intra-QE = EAPP, Euro area | 0.71 | 0.49 | 0.74 | 0.5 | 0.18 |
| Pre-crisis = US QE, UK | 0.61 | 0.28 | 0.57 | 0.82 | 0.71 |
| Pre-crisis = US QE = Intra-QE, UK | 0.74 | 0.3 | 0.2 | 0.52 | 0.93 |
| Pre-crisis = US QE = Intra-QE = EAPP, UK | 0.57 | 0.42 | 0.36 | 0.73 | 0.96 |
| Pre-crisis = US QE, Japan | 0.49 | 0.33 | 0.16 | 0.08* | 0.07* |
| Pre-crisis = US QE = Intra-QE, Japan | 0.61 | 0.38 | 0.38 | 0.2 | 0.19 |
| Pre-crisis = US QE = Intra-QE = EAPP, Japan | 0.17 | 0.22 | 0.15 | 0.05* | 0.03* |

Table 13 shows the results from a two-way Wald test for equality of coefficients between sub-sample periods. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 14: The Impact of Monetary Policy Surprises on US Yields (Benchmark Specification: Interbank Futures, Full Sample)

| VARIABLES | (1)<br>Y1 (US) | (2)<br>Y3 (US) | (3)<br>Y5 (US) | (4)<br>Y7 (US) | (5)<br>Y10 (US) |
|---|---|---|---|---|---|
| MPS, Full Sample, FOMC | -3.7*** | -5.7*** | -5.9*** | -5.5*** | -4.6*** |
| | (0.663) | (0.920) | (1.120) | (1.267) | (1.297) |
| MPS, Full Sample, ECB | -0.9*** | -1.2*** | -1.3** | -1.3** | -1.3** |
| | (0.314) | (0.430) | (0.551) | (0.603) | (0.635) |
| MPS, Full Sample, BoE | 0.2 | -0.1 | -0.1 | -0.1 | -0.1 |
| | (0.390) | (0.564) | (0.715) | (0.772) | (0.764) |
| MPS, Full Sample, BoJ | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| | (0.341) | (0.539) | (0.646) | (0.653) | (0.606) |
| CESI US | 0.6*** | 0.9*** | 0.9*** | 0.9*** | 0.8*** |
| | (0.108) | (0.172) | (0.205) | (0.209) | (0.201) |
| CESI Japan | 0.0 | 0.0 | -0.0 | -0.1 | -0.1 |
| | (0.092) | (0.132) | (0.163) | (0.179) | (0.187) |
| CESI Euro area | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| | (0.149) | (0.216) | (0.262) | (0.259) | (0.237) |
| CESI UK | 0.2* | 0.5*** | 0.7*** | 0.8*** | 0.8*** |
| | (0.103) | (0.165) | (0.214) | (0.246) | (0.258) |
| fri | 1.2*** | 1.4*** | 1.2*** | 1.1** | 0.9* |
| | (0.326) | (0.427) | (0.469) | (0.486) | (0.494) |
| US/EU (t-1) | 8.6 | 14.9 | 0.3 | -15.0 | -31.0 |
| | (19.048) | (25.632) | (29.269) | (33.128) | (37.663) |
| US/UK (t-1) | -26.7 | -27.1 | -21.0 | -14.6 | -8.1 |
| | (20.129) | (24.979) | (25.451) | (26.253) | (26.596) |
| US/JP (t-1) | 16.6 | -41.4* | -61.6* | -55.3 | -36.1 |
| | (16.474) | (24.453) | (32.309) | (37.143) | (38.674) |
| AR(1) | -0.1* | -0.1** | -0.1 | -0.0 | -0.0 |
| | (0.045) | (0.042) | (0.050) | (0.051) | (0.050) |
| Constant | -0.3** | -0.1 | -0.1 | -0.1 | -0.0 |
| | (0.117) | (0.178) | (0.227) | (0.258) | (0.274) |
| Observations | 948 | 948 | 948 | 948 | 948 |
| R-squared | 0.187 | 0.207 | 0.183 | 0.155 | 0.121 |

Table 14 summarizes the results of daily piecewise regressions where the dependent variable is the change in zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years. MPS is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening. Standard errors are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 15: The Impact of Monetary Policy Surprises on Euro Area Yields (Benchmark Specification: Interbank Futures, Full Sample)

| VARIABLES | (1)<br>Y1 (EU) | (2)<br>Y3 (EU) | (3)<br>Y5 (EU) | (4)<br>Y7 (EU) | (5)<br>Y10 (EU) |
|---|---|---|---|---|---|
| MPS, Full Sample, ECB | -3.0*** | -4.0*** | -3.2*** | -2.4*** | -1.6*** |
| | (0.286) | (0.325) | (0.348) | (0.345) | (0.350) |
| MPS, Full Sample, BoE | -0.7 | -0.5 | -0.7 | -0.8** | -0.9*** |
| | (0.456) | (0.438) | (0.412) | (0.355) | (0.310) |
| MPS, Full Sample, BoJ | 0.0 | -0.8*** | -0.9*** | -0.7** | -0.6* |
| | (0.312) | (0.229) | (0.248) | (0.292) | (0.358) |
| MPS, Full Sample, FOMC = L, | -0.8** | -1.0* | -1.1** | -1.1** | -1.1** |
| | (0.331) | (0.492) | (0.477) | (0.467) | (0.499) |
| CESI US | 0.1* | 0.3** | 0.4*** | 0.4*** | 0.4*** |
| | (0.078) | (0.127) | (0.127) | (0.124) | (0.122) |
| CESI Japan | -0.0 | -0.1 | -0.1 | -0.1 | -0.1 |
| | (0.066) | (0.104) | (0.107) | (0.105) | (0.104) |
| CESI Euro area | 0.2* | 0.4*** | 0.4*** | 0.4*** | 0.3** |
| | (0.103) | (0.140) | (0.142) | (0.136) | (0.132) |
| CESI UK | 0.0 | 0.2* | 0.2** | 0.2** | 0.2** |
| | (0.063) | (0.093) | (0.100) | (0.101) | (0.100) |
| fri | 0.2 | -0.1 | -0.2 | -0.3 | -0.5 |
| | (0.190) | (0.262) | (0.272) | (0.282) | (0.303) |
| EU/US (t-1) | 12.0 | 14.5 | 10.6 | 13.8 | 19.4 |
| | (22.761) | (30.535) | (31.769) | (34.055) | (37.923) |
| EU/UK (t-1) | -16.3 | -15.0 | -21.4 | -27.2 | -31.0 |
| | (11.855) | (18.102) | (19.521) | (19.971) | (20.484) |
| EU/JP (t-1) | -37.2 | -34.4 | -37.1 | -42.4 | -43.6 |
| | (24.434) | (23.376) | (25.553) | (25.924) | (27.648) |
| AR(1) | 0.2*** | 0.1 | 0.0 | 0.0 | 0.0 |
| | (0.047) | (0.043) | (0.043) | (0.043) | (0.042) |
| Constant | -0.2** | -0.2 | -0.2 | -0.1 | -0.0 |
| | (0.104) | (0.147) | (0.152) | (0.156) | (0.163) |
| Observations | 983 | 983 | 983 | 983 | 983 |
| R-squared | 0.283 | 0.221 | 0.169 | 0.129 | 0.091 |

Table 15 summarizes the results of daily piecewise regressions where the dependent variable is the change in zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years. MPS is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening. Standard errors are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 16: The Impact of Monetary Policy Surprises on UK Yields (Benchmark Specification: Interbank Futures, Full Sample)

| VARIABLES | (1)<br>Y1 (UK) | (2)<br>Y3 (UK) | (3)<br>Y5 (UK) | (4)<br>Y7 (UK) | (5)<br>Y10 (UK) |
|---|---|---|---|---|---|
| MPS, Full Sample, BoE | -3.2*** | -4.2*** | -3.6*** | -3.1*** | -2.6*** |
| | (0.359) | (0.546) | (0.591) | (0.599) | (0.592) |
| MPS, Full Sample, ECB | -0.8** | -1.4** | -1.4** | -1.4** | -1.4** |
| | (0.358) | (0.562) | (0.577) | (0.590) | (0.605) |
| MPS, Full Sample, BoJ | -0.6*** | -0.7** | -0.7* | -0.6 | -0.5 |
| | (0.182) | (0.371) | (0.397) | (0.402) | (0.392) |
| MPS, Full Sample, FOMC = L, | -1.3*** | -1.7*** | -1.6*** | -1.4** | -1.1* |
| | (0.346) | (0.534) | (0.532) | (0.569) | (0.595) |
| CESI US | 0.2** | 0.4*** | 0.5*** | 0.5*** | 0.5*** |
| | (0.077) | (0.115) | (0.129) | (0.142) | (0.149) |
| CESI Japan | -0.1 | -0.1 | -0.1 | -0.0 | -0.1 |
| | (0.114) | (0.155) | (0.151) | (0.151) | (0.152) |
| CESI Euro area | -0.0 | 0.2 | 0.3* | 0.3** | 0.3** |
| | (0.116) | (0.160) | (0.167) | (0.166) | (0.168) |
| CESI UK | 0.2** | 0.4*** | 0.5*** | 0.5*** | 0.5*** |
| | (0.116) | (0.137) | (0.138) | (0.149) | (0.161) |
| fri | 0.6** | 0.7** | 0.4 | 0.1 | -0.1 |
| | (0.248) | (0.317) | (0.328) | (0.348) | (0.362) |
| UK/US (t-1) | 11.7 | 48.5 | 80.8 | 109.2* | 125.9** |
| | (47.435) | (57.477) | (57.243) | (58.091) | (58.454) |
| UK/EU (t-1) | 14.2 | 0.6 | -0.9 | -0.8 | 0.4 |
| | (26.005) | (40.163) | (41.491) | (42.194) | (42.009) |
| UK/JP (t-1) | -32.2 | -41.5 | -64.3* | -78.7** | -83.3** |
| | (30.289) | (39.072) | (38.839) | (37.715) | (36.854) |
| AR(1) | 0.2*** | 0.1** | 0.1 | 0.1 | 0.1 |
| | (0.066) | (0.042) | (0.040) | (0.043) | (0.048) |
| Constant | -0.4*** | -0.4** | -0.2 | -0.1 | 0.0 |
| | (0.117) | (0.164) | (0.186) | (0.200) | (0.207) |
| Observations | 980 | 980 | 980 | 980 | 980 |
| R-squared | 0.330 | 0.256 | 0.197 | 0.156 | 0.123 |

Table 16 summarizes the results of daily piecewise regressions where the dependent variable is the change in zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years. MPS is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening. Standard errors are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 17: The Impact of Monetary Policy Surprises on Japan Yields (Benchmark Specification: Interbank Futures, Full Sample)

| VARIABLES | (1)<br>Y1 (JP) | (2)<br>Y3 (JP) | (3)<br>Y5 (JP) | (4)<br>Y7 (JP) | (5)<br>Y10 (JP) |
|---|---|---|---|---|---|
| MPS, Full Sample, BoJ | -0.4 | -1.5*** | -1.9*** | -2.0*** | -1.8*** |
| | (0.439) | (0.305) | (0.286) | (0.304) | (0.334) |
| MPS, Full Sample, ECB = L, | 0.6 | -0.1 | -0.2 | -0.4 | -0.5* |
| | (0.687) | (0.221) | (0.276) | (0.296) | (0.275) |
| MPS, Full Sample, BoE = L, | -0.1 | -0.4** | -0.5* | -0.4 | -0.2 |
| | (0.292) | (0.160) | (0.272) | (0.312) | (0.276) |
| MPS, Full Sample, FOMC = L, | 0.2 | -0.5** | -0.9*** | -1.1*** | -0.9*** |
| | (0.618) | (0.222) | (0.312) | (0.326) | (0.316) |
| CESI US | -0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| | (0.081) | (0.055) | (0.075) | (0.073) | (0.064) |
| CESI Japan | -0.1 | 0.1 | 0.0 | -0.0 | -0.0 |
| | (0.099) | (0.060) | (0.083) | (0.098) | (0.094) |
| CESI Euro area | -0.0 | 0.1 | 0.1 | 0.0 | 0.0 |
| | (0.129) | (0.059) | (0.067) | (0.075) | (0.068) |
| CESI UK | -0.2 | 0.0 | 0.1 | 0.0 | -0.1 |
| | (0.122) | (0.060) | (0.069) | (0.071) | (0.066) |
| fri | -0.4 | 0.1 | 0.1 | 0.1 | 0.1 |
| | (0.402) | (0.181) | (0.199) | (0.206) | (0.198) |
| JP/US (t-1) | -0.2 | 0.1 | 0.2 | 0.3 | 0.3 |
| | (0.274) | (0.160) | (0.185) | (0.209) | (0.200) |
| JP/UK (t-1) | 0.0 | -0.1 | -0.1 | -0.1 | 0.0 |
| | (0.130) | (0.111) | (0.115) | (0.119) | (0.127) |
| JP/EU (t-1) | 0.1 | 0.1 | 0.3** | 0.3* | 0.2 |
| | (0.181) | (0.105) | (0.133) | (0.135) | (0.127) |
| AR(1) | -0.3*** | -0.1*** | -0.1*** | -0.1*** | -0.1** |
| | (0.064) | (0.040) | (0.037) | (0.036) | (0.037) |
| Constant | 0.1 | 0.0 | -0.1 | -0.1* | -0.1* |
| | (0.121) | (0.077) | (0.081) | (0.082) | (0.083) |
| Observations | 1,002 | 1,002 | 1,002 | 1,002 | 1,002 |
| R-squared | 0.116 | 0.111 | 0.149 | 0.159 | 0.148 |

Table 17 summarizes the results of daily piecewise regressions where the dependent variable is the change in zero coupon bond yields for maturities of 1, 3, 5, 7 and 10 years. MPS is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of the respective central banks. Monetary policy measures are normalized to be a one standard deviation loosening. Standard errors are shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 18: Risk Premium Days: 10-Year Bond Yields

(a) Own-Market Equity Return Co-movement Days

| | i. Federal Reserve | | | | ii. ECB | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (1) Y10 US | (2) Y10 UK | (3) Y10 EU | (4) Y10 JP | (5) Y10 US | (6) Y10 UK | (7) Y10 EU | (8) Y10 JP |
| Sign($MP_i$) = Sign($R_i$) | 0.216 | -0.420 | -1.194* | -0.029 | 1.164 | -0.028 | 0.316 | 0.447 |
| | (1.112) | (0.843) | (0.687) | (0.377) | (0.745) | (0.639) | (0.427) | (0.323) |
| $MP_i$ | -2.879** | -1.655 | -1.185 | -1.126** | 0.521 | 0.018 | -1.841*** | -0.517** |
| | (1.277) | (1.189) | (0.843) | (0.550) | (1.252) | (0.958) | (0.644) | (0.246) |
| Interaction | -2.652 | 0.836 | 0.059 | 0.335 | -2.298 | -1.736 | 0.257 | 0.130 |
| (MP on RP days) | (2.245) | (1.299) | (1.029) | (0.646) | (1.419) | (1.157) | (0.720) | (0.513) |

| | iii. Bank of England | | | | iv. Bank of Japan | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (9) Y10 US | (10) Y10 UK | (11) Y10 EU | (12) Y10 JP | (13) Y10 US | (14) Y10 UK | (15) Y10 EU | (16) Y10 JP |
| Sign($MP_i$) = Sign($R_i$) | 1.298* | 0.033 | -0.086 | -0.372 | 0.506 | 1.665*** | 1.094** | -0.305 |
| | (0.750) | (0.596) | (0.412) | (0.323) | (0.748) | (0.625) | (0.492) | (0.272) |
| $MP_i$ | 0.366 | -2.765*** | -0.806** | -0.485* | -1.859*** | -1.291** | -0.651 | -2.354*** |
| | (0.942) | (0.707) | (0.382) | (0.282) | (0.666) | (0.587) | (0.607) | (0.434) |
| Interaction | -0.727 | 0.363 | -0.129 | 0.604 | 2.672*** | 1.024 | 0.049 | 0.692 |
| (MP on RP days) | (1.381) | (1.048) | (0.528) | (0.488) | (0.944) | (0.790) | (0.627) | (0.564) |

(b) Cross-Market Equity Return Co-movement Days

| | i. Federal Reserve | | | | ii. ECB | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (1) Y10 US | (2) Y10 UK | (3) Y10 EU | (4) Y10 JP | (5) Y10 US | (6) Y10 UK | (7) Y10 EU | (8) Y10 JP |
| Sign($MP_i$) = Sign($R_j$) | 0.216 | -2.690*** | -1.222* | -0.354 | -0.453 | 0.090 | 0.316 | -0.062 |
| | (1.112) | (0.803) | (0.648) | (0.338) | (0.719) | (0.664) | (0.427) | (0.291) |
| $MP_i$ | -2.879** | -1.126** | 0.227 | -0.796 | 0.018 | -2.557*** | -1.841*** | -0.118 |
| | (1.277) | (0.550) | (0.470) | (0.592) | (0.958) | (0.593) | (0.644) | (0.413) |
| Interaction | -2.652 | -1.193 | -2.166*** | -0.167 | -4.785*** | -0.731 | 0.257 | -0.865* |
| (MP on RP days) | (2.245) | (1.130) | (0.754) | (0.680) | (1.427) | (1.153) | (0.720) | (0.488) |

| | iii. Bank of England | | | | iv. Bank of Japan | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (9) Y10 US | (10) Y10 UK | (11) Y10 EU | (12) Y10 JP | (13) Y10 US | (14) Y10 UK | (15) Y10 EU | (16) Y10 JP |
| Sign($MP_i$) = Sign($R_i$) | -0.032 | 0.033 | -0.209 | 0.072 | 0.340 | 1.251* | 1.080** | -0.305 |
| | (0.614) | (0.596) | (0.381) | (0.291) | (0.804) | (0.657) | (0.532) | (0.272) |
| $MP_i$ | -1.205* | -2.765*** | -0.806** | -0.147 | 0.860 | -0.643 | -0.421 | -2.354*** |
| | (0.616) | (0.707) | (0.374) | (0.091) | (0.695) | (0.515) | (0.287) | (0.434) |
| Interaction | -3.985*** | 0.363 | -0.114 | -0.643 | -2.662*** | 0.503 | -0.297 | 0.692 |
| (MP on RP days) | (1.154) | (1.048) | (0.520) | (0.545) | (1.021) | (0.907) | (0.705) | (0.564) |

Table 18 summarizes the results of daily piecewise regressions where the dependent variable is the change in 10 year zero coupon bond yields in the US, UK, Euro area and Japan. The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of respective central banks. The regression interacts these monetary policy surprises with an indicator variable equal to one on announcement dates on which interest rate futures markets and equity returns moved in the same direction. Panel A shows the results where the equity market is in the home economy ($i$), while Panel B shows results where the equity market is in the recipient country ($j$). Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

## Table 19: Risk Premium Days: Expected Path of Short-rates (Based on 10-Year Yield)

### (a) Own-Market Equity Return Co-movement Days

| | i. Federal Reserve | | | | ii. ECB | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (1) SR(10) US | (2) SR(10) UK | (3) SR(10) EU | (4) SR(10) JP | (5) SR(10) US | (6) SR(10) UK | (7) SR(10) EU | (8) SR(10) JP |
| Sign($MP_i$) = Sign($R_i$) | 0.611 | 0.381 | -0.321 | -0.037 | 0.124 | -0.203 | -0.177 | 0.111 |
| | (0.497) | (0.399) | (0.407) | (0.124) | (0.280) | (0.377) | (0.218) | (0.156) |
| $MP_i$ | -3.721*** | -1.342*** | -1.447** | 0.181 | -0.709 | -0.077 | -1.711* | 0.011 |
| | (0.589) | (0.393) | (0.594) | (0.181) | (0.569) | (0.553) | (0.953) | (0.108) |
| Interaction (MP on RP days) | 0.537 | 0.326 | 1.318* | -0.167 | 0.190 | -0.600 | -0.994 | -0.028 |
| | (1.007) | (0.517) | (0.790) | (0.194) | (0.635) | (0.641) | (1.022) | (0.268) |

| | iii. Bank of England | | | | iv. Bank of Japan | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (9) SR(10) US | (10) SR(10) UK | (11) SR(10) EU | (12) SR(10) JP | (13) SR(10) US | (14) SR(10) UK | (15) SR(10) EU | (16) SR(10) JP |
| Sign($MP_i$) = Sign($R_i$) | 0.405 | 0.027 | -0.176 | 0.225 | -0.879** | -0.073 | 0.661* | -0.070 |
| | (0.287) | (0.253) | (0.302) | (0.167) | (0.375) | (0.340) | (0.365) | (0.136) |
| $MP_i$ | -0.282 | -3.200*** | 0.290 | -0.038 | -0.508 | -0.678 | -1.572* | -0.153 |
| | (0.253) | (0.505) | (0.423) | (0.141) | (0.551) | (0.552) | (0.946) | (0.200) |
| Interaction (MP on RP days) | 0.460 | 0.837 | -0.951 | 0.063 | 0.784 | 0.349 | 1.369 | 0.046 |
| | (0.462) | (0.558) | (0.620) | (0.171) | (0.548) | (0.610) | (0.955) | (0.222) |

### (b) Cross-Market Equity Return Co-movement Days

| | i. Federal Reserve | | | | ii. ECB | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (1) SR(10) US | (2) SR(10) UK | (3) SR(10) EU | (4) SR(10) JP | (5) SR(10) US | (6) SR(10) UK | (7) SR(10) EU | (8) SR(10) JP |
| Sign($MP_i$) = Sign($R_j$) | 0.611 | -0.214 | -0.714* | -0.133 | -0.352 | -0.235 | -0.177 | -0.179 |
| | (0.497) | (0.440) | (0.370) | (0.146) | (0.260) | (0.376) | (0.218) | (0.158) |
| $MP_i$ | -3.721*** | 0.181 | -0.384 | 0.072 | -0.077 | -2.762*** | -1.711* | 0.090 |
| | (0.589) | (0.181) | (0.603) | (0.190) | (0.553) | (0.356) | (0.953) | (0.113) |
| Interaction (MP on RP days) | 0.537 | -0.850 | -0.211 | -0.011 | -1.254** | -0.250 | -0.994 | -0.165 |
| | (1.007) | (0.786) | (0.695) | (0.204) | (0.570) | (0.598) | (1.022) | (0.193) |

| | iii. Bank of England | | | | iv. Bank of Japan | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | (9) SR(10) US | (10) SR(10) UK | (11) SR(10) EU | (12) SR(10) JP | (13) SR(10) US | (14) SR(10) UK | (15) SR(10) EU | (16) SR(10) JP |
| Sign($MP_i$) = Sign($R_i$) | 0.313 | 0.027 | -0.373 | -0.084 | -0.118 | -0.246 | 0.841* | -0.070 |
| | (0.252) | (0.253) | (0.280) | (0.177) | (0.317) | (0.336) | (0.441) | (0.136) |
| $MP_i$ | -0.510* | -3.200*** | 0.238 | -0.028 | 0.434 | -1.048*** | -0.198 | -0.153 |
| | (0.282) | (0.505) | (0.436) | (0.036) | (0.355) | (0.373) | (0.259) | (0.200) |
| Interaction (MP on RP days) | -0.840** | 0.837 | -0.823 | -0.021 | -1.566*** | 1.317** | -0.576 | 0.046 |
| | (0.413) | (0.558) | (0.618) | (0.164) | (0.534) | (0.599) | (0.401) | (0.222) |

Table 19 summarizes the results of daily piecewise regressions where the dependent variable is the change in the path of the expected short rate over 10 years in the US, UK, Euro area and Japan. The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of respective central banks. The regression interacts these monetary policy surprises with an indicator variable equal to one on announcement dates on which interest rate futures markets and equity returns moved in the same direction. Panel A shows the results where the equity market is in the home economy ($i$), while Panel B shows results where the equity market is in the recipient country ($j$). Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 20: Asymmetric Responses to Expansionary Monetary Policy Surprises

| VARIABLES | (1) Y10 (US) | (2) Y10 (EU) | (3) Y10 (UK) | (4) Y10 (JP) |
|---|---|---|---|---|
| MPS, Full Sample, FOMC | -2.386** | 0.021 | 0.408 | -0.544 |
| | (1.101) | (0.540) | (0.503) | (0.457) |
| MPS, Full Sample, ECB | -0.264 | -0.984** | -1.913** | -0.185 |
| | (0.955) | (0.414) | (0.864) | (0.231) |
| MPS, Full Sample, BoE | -2.073*** | -1.672*** | -2.132** | -0.869*** |
| | (0.724) | (0.510) | (0.981) | (0.265) |
| MPS, Full Sample, BoJ | -0.006 | -0.491 | -0.512 | -0.243 |
| | (0.416) | (0.309) | (0.430) | (0.571) |
| 1[MPS<0], FOMC | 0.983 | -1.181 | -1.171 | -0.459 |
| | (1.242) | (0.799) | (0.887) | (0.324) |
| 1[MPS<0], BoE | -1.303 | -1.023** | -2.192*** | -0.387 |
| | (0.926) | (0.476) | (0.687) | (0.389) |
| 1[MPS<0], ECB | -2.338** | -1.212* | -1.768 | 0.117 |
| | (1.136) | (0.691) | (1.079) | (0.439) |
| 1[MPS<0], BoJ | -1.355 | 0.893 | 0.360 | -0.472 |
| | (1.478) | (0.708) | (0.986) | (0.508) |
| 1[MPS<0]*MPS (FOMC) | -5.314** | -1.543 | -2.324** | -0.462 |
| | (2.534) | (1.054) | (1.122) | (0.629) |
| 1[MPS<0]*MPS (BoE) | 1.313 | 0.622 | 0.048 | 0.263 |
| | (1.616) | (0.561) | (1.251) | (0.591) |
| 1[MPS<0]*MPS (ECB) | 3.699** | 1.156 | 3.011* | 0.726 |
| | (1.675) | (0.707) | (1.590) | (0.763) |
| 1[MPS<0]*MPS (BoJ) | 0.209 | -0.010 | 0.157 | -1.249* |
| ... | (1.213) | (0.506) | (0.899) | (0.731) |
| Observations | 944 | 976 | 975 | 997 |
| R-squared | 0.148 | 0.107 | 0.148 | 0.106 |

Robust standard errors in parentheses

Table 20 summarizes the results of daily piecewise regressions where the dependent variable is the change in 10 year zero coupon bond yields in the US, UK, Euro area and Japan. The independent variable of interest is the daily change in the implied yield for the year-ahead futures contract on the Eurodollar (Fed), Euribor (ECB), Short Sterling (BoE) and Euroyen Tibor (BoJ) on monetary policy meeting days of respective central banks. The regression interacts these monetary policy surprises with an indicator variable equal to one on announcement dates marked by expansionary surprises, $\mathbb{1}[MP_t^j < 0] * MP_t^j$. Monetary policy measures are normalized to be a one standard deviation loosening (in basis points). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 21: Test of Period Means, Contractionary versus Expansionary Shocks

| Central Bank | Period | Equality of Means Test (p-value) |
|---|---|---|
| FOMC | Pre-crisis | 0.13 |
| | Initial QE | 0.71 |
| | Intra-QE | 0.16 |
| | EAPP | 0.86 |
| ECB | Pre-crisis | 0.58 |
| | Initial QE | 0.36 |
| | Intra-QE | 0.46 |
| | EAPP | 0.24 |
| BoE | Pre-crisis | 0.33 |
| | Initial QE | 0.49 |
| | Intra-QE | 0.44 |
| | EAPP | 0.05 |
| BoJ | Pre-crisis | 0.20 |
| | Initial QE | 0.95 |
| | Intra-QE | 0.81 |
| | EAPP | 0.36 |

Table 21 summarizes the results of a simple t-test for equality of means comparing the absolute value of contractionary monetary policy shocks ($\mathbb{1}[MP_t^j > 0] * MP_t^j$) to that of expansionary monetary policy shocks ($\mathbb{1}[MP_t^j < 0] * MP_t^j$) by subsample. Shaded cells indicate subsamples in which expansionary and contractionary shocks differ in size at the 5% level.

# 9 Appendix C: Shadow Rate Term Structure Model (Wu and Xia 2016)

The model begins by assuming, as in Black (1995), that the short-term interest rate is the maximum of the effective lower bound $\underline{r}$ and a shadow rate $s_t$:

$$r_t = max\{\underline{r}, s_t\} \tag{12}$$

The authors assume that the shadow rate $s_t$ is an affine function of some state variables $X_t$,

$$s_t = \delta_0 + \delta_1 X_t \tag{13}$$

The state variables following a first order autoregressive process (VAR(1)) under the physical measure $\mathbb{P}$:

$$X_{t+1} = \mu + \rho X_t + v_{t+1}; \;\; \mathbf{E}[v_{t+1} v_{t+1}^{'}] = V \tag{14}$$

The log stochastic discount factor is essentially affine, where the price of risk $\lambda_t$ is linear in the factors:

$$log(M_{t+1}) = -\delta_0 - \delta_1^{'} X_t - \frac{1}{2}\lambda_t^{'} V \lambda - \lambda_t^{'} v_{t+1} \tag{15}$$

$$\lambda_t = \lambda_0 + \lambda_1 X_t \tag{16}$$

This implies that the dynamics for the factors under the risk neutral measure $\mathbb{Q}$ are also a VAR(1): The state variables following a first order autoregressive process (VAR(1)) under the physical measure $\mathbb{P}$:

$$X_{t+1} = \mu^{\mathbb{Q}} + \rho^{\mathbb{Q}} X_t + v_{t+1}^{\mathbb{Q}}; \;\; v^{\mathbb{Q}} \sim N(0, I) \tag{17}$$

Wu and Xia propose an analytical approximation for the forward rate. Define $f_{n,n+1,t}$ as the forward rate at time $t$ for a loan starting at $t+n$ and maturity at $t+n+1$,

$$f_{n,n+1,t} = (n+1) y_{n+1,t} - n y_{nt} \tag{18}$$

which is a linear function of yields on risk-free $n$ and $n+1$ period pure discount bonds. Wu and Xia approximate the forward rate in the SRTSM with

$$f_{n,n+1,t}^{SRTSM} = \underline{r} + \sigma_n^{\mathbb{Q}} g\left(\frac{a_n + b_n^{'} X_t - \underline{r}}{\sigma_n^{\mathbb{Q}}}\right) \tag{19}$$

where $(\sigma_n^{\mathbb{Q}})^2 \equiv \mathbb{V}ar(s_{t+n})$. The function $g(z) \equiv z\Phi(z) + \phi(z)$ consists of a normal cumulative distribution function $\Phi(z)$ and a normal probability density function $\phi(z)$. Its nonlinearity is informed by moments of the truncated normal distribution. Expressions for $a_n$, $b_n$ and $\sigma_n^{\mathbb{Q}}$ as well as the derivation can be found in Wu and Xia (2016). Because the observation equation (eqn. 14) is not linear in the factors, parameters are estimated using the extended Kalman filter, which applies the Kalman filter by linearizing g(z) around the current estimates.

Once armed with the model parameters, I combine the definition of the yield, the forward rate, and excess returns from Cochrane and Piazzesi (2008), which gives an expression for the expected yield $n$ periods ahead:

$$\mathbf{E}_t[y^{(1)}_{t+n-1}] = \delta_0 + \delta_1^{'}(I + \rho^{\mathbb{P}} + (\rho^{\mathbb{P}})^2 + \ldots + (\rho^{\mathbb{P}})^{n-1})\mu^{\mathbb{P}} + \delta_1^{'}(\rho^{\mathbb{P}})^n X_t \quad (20)$$

The expect path of the short rate is then the average of $\mathbf{E}_t[y^{(1)}_{t+n-1}]$ from $n = 1$ to $n = 10$. Finally, I calculate the term premium to be the residual between the observed yield on an $n$ year bond and the expected short rate:

$$YTP^{(n)}_t = y^{(n)}_t - \mathbf{E}_t[y^{(1)}_{t+n-1}] \quad (21)$$