Non-Monetary News in Central Bank Communication

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We quantify the importance of non-monetary news in central bank communication. Using evidence from four major central banks and a comprehensive classification of events, we decompose news conveyed by central banks into news about monetary policy, economic growth, and separately, shocks to risk premia. Our approach exploits high-frequency comovement of stocks and interest rates combined with monotonicity restrictions across the yield curve. We find significant differences in news composition depending on the communication channel used by central banks. Non-monetary news prevails in about 40% of policy decision announcements by the Fed and the ECB, and this fraction is even higher for communications that provide context to policy decisions such as press conferences. We show that non-monetary news accounts for a significant part of financial markets' reaction during the financial crisis and in the early recovery, while monetary shocks gain importance since 2013.

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The relevance of central bank communication has risen significantly over the past decade as policy goals and associated operations have become more complex. Constrained by the effective lower bound on policy rates, major central banks have resorted to unconventional measures. Communicating these policies poses a challenge, as evidenced by the rise in the verbosity of central bank statements. New empirical methods are needed to quantify the effects of monetary policy, especially when monetary shocks can be confounded by other information.

This paper proposes a new approach to analyze the information content of central bank communication. Drawing on the joint dynamics of government bond yields with equity returns around central bank releases, we quantify the importance of different economic shocks that drive the response of financial markets to policy communication. Specifically, we classify the information revealed by central banks into monetary policy, economic growth, and risk premium shocks. By the latter, we mean news that affects investors' risk valuations (via changes in risk appetite or sentiment) separately from changes in economic fundamentals.

Our approach to dissecting the news content of central bank communication exploits both the direction of the comovement between stocks and yield as well as the effect of news across the maturity dimension of the yield curve. We build our intuition using a stylized macro-finance model that delivers the following predictions. A conventional monetary policy shock affects the real rate and induces a negative comovement of stocks and yields that is stronger at short maturities. Both growth and risk premium shocks induce a positive comovement of stocks and yields. However, their effects differ in the maturity dimension. Growth shocks have a greater bearing on the short-to-intermediate segment, whereas risk premium shocks affect more the long segment of the yield curve. While the effects of growth and monetary policy shocks are standard, the positive comovement of stocks and yields via the risk premium channel arises when nominal bonds hedge bad economic times. We derive restrictions on the joint dynamics of macroeconomic factors, monetary policy and asset prices necessary to support this intuition, and argue that these restrictions plausibly hold true during the period of our analysis.

To gauge the comovement of stocks with the entire yield curve, we introduce the notion of the term-structure of stock-yield covariances, i.e., covariances of stock returns with changes in yields of different maturities. We rely on high-frequency data to construct the term structures of covariances at the level of a single event. The sign and the maturity pattern of those covariances allows us to determine the dominant piece of economic news revealed by central banks across a variety of communications beyond just monetary policy decision statements.

To this end, we compile a novel database of time-stamped monetary policy events by the four main central banks—the Federal Reserve (Fed), the European Central Bank (ECB), the Bank of England (BOE) and the Bank of Japan (BOJ)—spanning the period from the late 1990s through the end of 2017. We classify events on several dimensions. At the basic level, we distinguish events by types of communication tools, most importantly (i) statements of monetary policy decisions, (ii) press conferences, (ii) releases of minutes of the policy meeting and, in the case of the BOE, inflation reports. We further introduce a classification of unconventional policy interventions, e.g., distinguishing between the phases of asset purchase programs. We additionally characterize announcements by whether they are accompanied by changes in explicit forward guidance.

As the key result, we show that the non-monetary component—i.e., news about economic activity and shocks to risk premia—dominates more than half of communication events. We find significant differences in the news composition across communication tools and over time. Monetary news prevails in the announcements of monetary policy decisions. News about economic growth, instead, is the dominant piece of information gleaned by market participants during press conferences and other communication events whose aim is to explain the context of policy decisions. Risk premium shocks exert substantial non-linear effects on asset prices, and their importance increases with the implementation of unconventional monetary policies.

For example, focusing only on scheduled announcements by the Federal Open Market Committee (FOMC), we find negative stock-yield comovement for 60% of events, consistent with the monetary policy channel; however, the remaining 40% suggest a non-trivial role of non-monetary news as well. This distinction becomes even more pertinent to understanding the news conveyed at the central bank press conferences. As one prominent example, press conferences by the ECB transmit non-monetary content in about 65% of the cases, with growth and risk premium news carrying the largest weight in terms of economic significance. Importantly, we find that although many of the unconventional policy announcements have a significant non-monetary content, forward guidance works as a powerful monetary policy shock.

We document that the news content of central bank announcements varies significantly over time. Studying the period of the financial crisis and its aftermath, we uncover a break in the composition of central bank news that occurs around mid-2013. Specifically, non-monetary news drives communication in the period from 2008 through mid-2013, while from mid-2013 through the end of our sample in 2017 the role of monetary news gains prominence. We associate this shift with the market's anticipation and then the actual announcements of the exit from policy accommodation.

To corroborate our news classification based on the term structure of stock-yield covariances, we propose an alternative empirical strategy that allows us to assess the fraction of asset price variance stemming from different shocks. Specifically, we achieve identification by imposing two types of restrictions: sign restrictions on the comovement of stocks and yields and monotonicity restrictions along the yield curve. We then decompose high-frequency (reduced-form) shocks to stocks and yields around FOMC decision announcements and ECB press conferences into monetary, growth and risk premium shocks that have the structural interpretation we discuss above. The estimates for the Fed and the ECB are broadly consistent with each other. The most important sources of variation are growth and monetary shocks (in roughly equal proportions) for the two-year yield, risk premium shocks for the ten-year yield and monetary policy shocks for the equity returns. The results from this approach are complementary to those based on the term structure of covariances.

Our findings have several implications for understanding central bank communication and beyond. Most importantly, common event-window identification using responses of short-term rates confounds monetary policy shocks with other information transmitted by central bank announcements. One natural example is the so-called path shock that is commonly inferred from the response of yields beyond the shortest maturities (Gürkaynak et al., 2005a). To the extent that news about growth, news about the future course of policy, and shocks to risk premia can all affect yields at longer maturities, path shocks may arise as a combination of several structural shocks. Our results indicate that non-monetary news dominates unless central banks employ explicit forward guidance. Using the maturity dimension of the yield curve together with the comovement between yields and stocks helps disentangle those economically distinct pieces of information. Our results also suggest that caution needs to be applied when measuring monetary policy shocks by lower frequency responses of interest rates (e.g., daily frequencies). With monetary policy decision announcements nowadays commonly followed by a press conference, we show that the news content of those two communication channels can be very different despite their proximity in time. Additionally, at daily frequencies, risk premium shocks may obscure other information effects.

Related literature. A growing literature studies the role of central bank information effects, i.e. the notion that central bank announcements reveal relevant information about the economy that is not in the information set of the public. Campbell et al. (2012a) document that tightening shocks by the Fed increase output growth expectations and decrease unemployment expectations of professional forecasters. This finding is inconsistent with the standard monetary transmission whereby a tightening leads to a drop in output relative to potential. In follow-up work, Campbell et al. (2017) refer to this finding as "the event-study activity puzzle," and argue that by observing a tightening, investors revise their economic projections upwards and mark up their expectations of future interest rates. Miranda-Agrippino and Ricco (2018) show that such information effects distort the identification of monetary transmissions. To recover a pure monetary policy signal, they control for central bank's private information using survey forecasts. Nakamura and Steinsson (2018) propose a model in which monetary policy announcements convey information about both future monetary policy and economic fundamentals; this information, in turn, affects investors' beliefs about the natural real rate.

The studies above suggest that the central bank information effect works through short-rate expectations. Hanson and Stein (2015) take a different view. They argue that monetary policy affects bond risk premia and hence can exert a significant effect on long-term interest rates. Our results help reconcile these seemingly opposing views by quantifying the importance of monetary news, growth news and news affecting investor risk appetite. Moreover, we show that the relative importance of each of those channels varies significantly across the communication tools used by central banks.

The idea of using the comovement of stocks and interest rates to discriminate between the types of economic shocks builds on the work of Rigobon and Sack (2003, 2004). Rigobon and Sack (2003) distinguish between monetary policy shocks versus shocks originating in the stock market. They posit that the covariance between interest rate changes and stock returns is negative when the variance of policy shocks increases, and it is positive when the variance of stock market shocks increases. To implement their identification, Rigobon and Sack (2004) assume that the variance of policy shocks is naturally elevated around major Fed communication events such as days of the FOMC policy decisions. By observing stock-yield comovement around every single event, our approach suggests that non-monetary news in fact frequently drives asset price variation on such policy days.

Several authors exploit the comovement of stocks and interest rates to distinguish between growth and monetary policy shocks. Matheson and Stavrev (2014) propose to use a bi-variate VAR with sign restrictions on the structural covariance matrix of shocks. They estimate the VAR with S&P 500 index, and 10-year US Treasury yields to study the events around the so-called taper tantrum. Relatedly, Jarocinski and Karadi (2018) impose sign restrictions on short-term rates and stocks, which they then embed within a more complex VAR that also includes macro variables. Our approach complements these studies in several ways. First, we exploit the high-frequency covariance structure of shocks to stocks and yields. Second, we draw upon the entire maturity dimension of the yield curve, which allows us to take a stance on the role of risk premium shocks induced by policy communication. Finally, we document differences in the types of news coming out via distinct communication channels, and study these channels across the main central banks.

The remainder of this paper is structured as follows. Section I presents a simple conceptual framework of the joint dynamics of stocks and yields that guides the subsequent empirical analysis. Section II introduces our database of central bank communication events and describes the intraday data on equity and fixed income futures. Section III reviews the reaction of stock returns and yields changes to different types of central bank communication. Section IV discusses our core results on the effect of communication on stock-yield covariances across the term structure. It also classifies communication events by the types of economic news they transmit. Section V takes a closer look at stock-yield comovement during various phases of unconventional monetary policies. Section VI quantifies the contribution monetary policy, growth and risk premium shocks to the variation of asset prices by exploiting sign restrictions on the comovement of stocks and yields and monotonicity restrictions across the yield curve. Section VII concludes.

I. Conceptual framework

Market commentary frequently asserts that stocks and government bond yields co-move positively in response to news about economic activity and changes in investors' "risk appetite," and negatively to news about monetary policy. A positive growth shock (good economic news) moves yields and stocks higher; a positive monetary policy shock (tightening) moves yields up and stocks lower; a positive risk aversion shock (decline in risk appetite) pushes yields and stock returns down as in "flight-to-safety" or "risk-off" episodes.[1]

This section discusses the economic intuition behind this narrative. We summarize the necessary restrictions on macroeconomic factors and on risk premia that determine the joint behavior of the yield curve and the stock market. We also highlight how the maturity dimension of the yield curve can help identify the effects of different shocks.

I.A. Reduced-form shock decompositions for yields and stocks

Let i_t denote the nominal one-period short-term interest rate, and let π_{t+1} denote the log change in the price level from t to $t+1$. The ex-ante real rate, r_t, is defined as the nominal short rate less one-period expected inflation, $r_t := i_t - E_t(\pi_{t+1})$. Based on yield curve arithmetics (e.g., Campbell and Ammer, 1993), we can link the n-period nominal yield to inflation expectations, real rate expectations, and expected bond returns:

[1]For example, on Sep 6, 2016, a WSJ article claimed: "A generation of traders have grown up with the idea that stock prices and bond yields tend to rise and fall together, as what is good for stocks is bad for bonds (pushing the price down and yield up), and vice versa."

$$y_t^{(n)} = \frac{1}{n}\sum_{i=1}^{n} E_t(\pi_{t+i}) + \frac{1}{n}\sum_{i=0}^{n-1} E_t(r_{t+i}) + \frac{1}{n}\sum_{i=1}^{n-2} E_t(ex_{t+i}^{(n-i+1)}), \tag{1}$$

where $ex_{t+1}^{(n)} = -(n-1)y_{t+1}^{(n-1)} + ny_t^{(n)} - i_t$ represents one-period excess return on an n-period bond. The third term in (1)—summing expected one-period returns over the life of the bond—is usually referred to as the term premium. The decomposition shows that yield curve shocks, denoted $\tilde{y}_{t+1}^{(n)}$ below, arise from shocks to expected inflation, shocks to expected real rate and/or shocks to the term premium:

$$\tilde{y}_{t+1}^{(n)} := y_{t+1}^{(n)} - E_t(y_{t+1}^{(n)}) = u_{\pi,t+1}^{(n)} + u_{r,t+1}^{(n)} + u_{tp,t+1}^{(n)}. \tag{2}$$

Let r_{t+1}^s denote the total log return on the aggregate stock market, pd_t the log price-dividend ratio, and Δd_{t+1} the aggregate log dividend growth rate; r_{t+1}^s and Δd_{t+1} are expressed in real terms. Following Campbell and Shiller (1988), the log price-dividend ratio is given by

$$pd_t = \frac{\kappa_0}{1-\kappa_1} + \sum_{j=1}^{\infty} \kappa_1^{j-1} E_t\left(\Delta d_{t+j} - (ex_{t+j}^s + r_{t+j-1})\right), \tag{3}$$

where ex_{t+1}^s is the stock excess return with $ex_{t+1}^s = r_{t+1}^s - r_t$ and κ_0, κ_1 are linearization constants. With log-linearization, $r_{t+1}^s \approx \kappa_0 + \kappa_1 pd_{t+1} + \Delta d_{t+1} - pd_t$, shocks to stock returns, $\tilde{r}_{t+1}^s$, are driven by news about future cash-flows (dividends), real rates and excess returns (risk premia):

$$\tilde{r}_{t+1}^s := r_{t+1}^s - E_t(r_{t+1}^s) = u_{d,t+1}^s - u_{r,t+1}^s - u_{ex,t+1}^s. \tag{4}$$

Equations (2) and (4) follow from present-value accounting, and have no structural interpretation. Next, we discuss how meaningful economic shocks are expected to affect those reduced-form objects.

I.B. Comovement of stocks and bond yields in response to economic shocks

To provide intuition for our empirical approach, we lay out how monetary, growth and risk premium shocks are expected to affect stocks and yields at different maturities. In the Appendix to the paper, we formalize this intuition using a simple macro-finance model with a log-normal stochastic discount factor. Our discussion is tailored to the properties of the joint dynamics of stock returns and bond yields in the sample from the late 1990s, which is the period of focus in our empirical analysis. For simple notation, we denote monetary, growth and risk premium shocks as $\epsilon_t^m, \epsilon_t^g$ and ϵ_t^p, respectively.

Monetary policy shocks. Conventional monetary policy shocks operate by changing the real short rate r_t. A monetary tightening depresses stock prices by increasing the risk-free component of discount rates ($\frac{\partial \tilde{r}^s}{\partial \epsilon^m} < 0$ as $\frac{\partial u_r^s}{\partial \epsilon^m} > 0$). Yields increase across maturities ($\frac{\partial \tilde{y}^{(n)}}{\partial \epsilon^m} > 0$ as $\frac{\partial u_r^{(n)}}{\partial \epsilon^m} > 0$). To the extent that the real rate is persistent but mean-reverting, the effect of such shocks is larger at the short end of the yield curve than it is at the long end ($\frac{\partial \tilde{y}^{(k)}}{\partial \epsilon^m} > \frac{\partial \tilde{y}^{(l)}}{\partial \epsilon^m} > 0$ for $k < l$).[2] Such intuition of how conventional monetary policy shocks propagate across the term structure is confirmed by a number of studies (e.g., Rigobon and Sack, 2004; Gürkaynak et al., 2005a).

Growth shocks. We label shocks to investors' expectations about real activity collectively as growth shocks. Growth shocks can encompass updates to investors's expectations about output growth, the output gap or unemployment. According to the Gordon growth model, positive shocks to expectations about economic growth raise stock prices via the cash-flow news channel ($\frac{\partial u_d^s}{\partial \epsilon^g} > 0$). This effect, however, is dampened by the degree to which such shocks also lead to an increase in the real rate ($\frac{\partial u_r^s}{\partial \epsilon^g} > 0$). The first effect dominates (and hence $\frac{\partial \tilde{r}^s}{\partial \epsilon^g} > 0$) if the real rate does not adjust one-for-one with growth expectations. Empirical estimates of various specifications of the Taylor rule suggest that this condition plausibly holds in the US data (Clarida et al., 2000; Coibion and Gorodnichenko, 2011). The effect of real activity news on the yield curve is typically found to be hump-shaped, declining from the short-to-intermediate-maturity segment (2–3 years) through the long-maturity segment of the yield curve (e.g., Fleming and Remolona, 2001; Gürkaynak et al., 2005b) (i,e., $\frac{\partial \tilde{y}^{(k_1)}}{\partial \epsilon^g} < \frac{\partial \tilde{y}^{(k_2)}}{\partial \epsilon^g} > \frac{\partial \tilde{y}^{(k_3)}}{\partial \epsilon^g}$ for $k_1 < k_2 < k_3$, and $\frac{\partial \tilde{y}^{(k)}}{\partial \epsilon^g} > 0$ across maturities).

Risk premium shocks. By risk premium shocks, we mean shocks to financial risk premia that are uncorrelated with the fundamental shocks in the economy. They can be interpreted as shifts in the (effective) risk aversion, sentiment or risk appetite more broadly.[3] In the context of our model in the Appendix, risk premium shocks arise from changes in the market prices of risk. To the extent that government bonds become valuable when premia on risky asset increase (as in flight-to-safety episodes), risk premium shocks are expected to move stocks and bond yields in the same direction. The key mechanism is that bonds provide

[2]With the zero lower bound, the effective short-end of the yield curve shifts toward longer maturities (e.g., Swanson and Williams, 2014), as the central bank uses forward guidance to communicate its expectations about, or commitment to, the path of the policy rate several quarters ahead.

[3]Such shock to investors' risk attitudes are a key component of models such as Lettau and Wachter (2007) or Albuquerque et al. (2016) to explain variation in asset risk premia. Using the terminology common among market participants, such shocks lead to "risk-on/-off" behavior frequently observed over the past decade with investors switching between safe and risky assets (e.g., Kroencke et al., 2018). Bekaert et al. (2013) argue that monetary policy affects investors' risk aversion, even after controlling for business cycle movements and uncertainty. As one possible mechanism suggested in the literature, monetary policy can affect the balance sheets of financial intermediaries, alleviating Value-at-Risk constraints and thereby changing their effective risk aversion (see, e.g. Adrian and Shin, 2010, and the evolving literature on intermediary asset pricing).

a hedge against those shocks that make stocks risky. As stocks do well in expansions, when marginal utility is low, and poorly in recessions, when marginal utility is high, equity investors require compensation for facing recession risk ($\frac{\partial \tilde{r}^s}{\partial \epsilon^p} < 0$ as $\frac{\partial u^s_{ex}}{\partial \epsilon^p} > 0$). When inflation is procylical, as during the period we study (e.g., Campbell et al., 2017), nominal bonds hedge recession risk and provide insurance in bad times ($\frac{\partial u^{(n)}_{tp}}{\partial \epsilon^p} < 0$). This effect is expected to be stronger at longer maturities (so $\frac{\partial \tilde{y}^{(l)}}{\partial \epsilon^p} < \frac{\partial \tilde{y}^{(k)}}{\partial \epsilon^p} < 0$ for $l > k$).[4]

The table below summarizes the expected effects of ϵ^m_t, ϵ^g_t, and ϵ^p_t shocks on stocks and the yield curve. The size of arrows indicates the strength of the effect at short and long yield maturities.

Shock	Yields		Stocks	Comovement
	Short/Intermed.	Long		of stocks and yields
Monetary policy: $\epsilon^m_t \uparrow$	$\uparrow$	$\uparrow$ (small)	$\downarrow$	−
Growth: $\epsilon^g_t \uparrow$	$\uparrow$	$\uparrow$ (small)	$\uparrow$	+
Risk premium:*: $\epsilon^p_t \uparrow$	$\downarrow$ (small)	$\downarrow$	$\downarrow$	+

*A positive risk premium shock is normalized such that it implies an increase in the risk premium on risky assets.

In sum, stocks and bond yields co-vary *negatively* in response to monetary policy shocks, but *positively* in response to growth and risk premium shocks. While the comovement of stocks with a single yield of a specific maturity does not immediately allow to distinguish between growth and risk premium shocks, such a distinction can be drawn by studying jointly the comovement of stocks with yields across maturities.

I.C. Discussion

Our approach to news classification uses only asset prices, which reflect the information set of investors. In contrast, the literature following Campbell et al. (2012a) relies on survey forecasts to identify non-monetary news and exploits the differences between forecasts of the public and policymakers. The usual approach is to project monetary policy shocks identified from high-frequency interest rate futures on a survey-based measure of the gap between the information set of the central bank and the public. The residual from this regression is then used as a measure of the "pure" monetary policy surprise purged of information effects. We circumvent the need of using survey forecasts by drawing on information not

[4]The illustrative model presented in the Appendix provides more intuition for the effect of risk premium shocks across the term structure. The fact that the effect of risk premia on the yield curve increases with maturity is documented by Cieslak and Povala (2015, 2016), Hanson and Stein (2015), among others. In support of bonds being hedges, empirical estimates of bond risk premia in the US show that they declined and even turned negative over our sample period (Kim and Wright, 2005; Cieslak, 2018).

only in yields but also in stocks, and by imposing economically motivated restrictions on the comovement between stocks and the entire yield curve. These two elements allow us to achieve identification of the different types of news revealed by communication.

Both approaches—survey-based and asset-price-based—have pros and cons. The survey-based approach requires that the forecasts of the public and the policymakers be well-synchronized with each other and measured accurately ahead of a communication event.[5] Both of these requirements are rarely perfectly satisfied in practice. Private survey forecasts are available at most at the monthly frequency and their timing relative to both central bank announcements and policymakers' forecasts can be ambiguous (as is the case with the commonly used Blue Chip forecasts). This limits the number of communication events one can study to those cases where these issues are least severe (e.g., monetary policy decision announcements). By not relying on survey expectations, our approach allows us to study a variety of communication events beyond monetary policy decisions (e.g., minutes, press conferences, inflation reports, speeches) as asset prices are available at high frequencies. This flexibility, however, comes at the cost of other identifying assumptions. Additionally, the survey-based approach does not directly take a stance on the relative importance of shocks to growth expectations versus shocks to risk premia, a question we address by exploiting comovement of stocks and yields across maturities.

Our interpretation of growth shocks emanating from central bank communication agrees with the information effects literature. In particular, the conceptual framework we build on is consistent with the so-called Delphic forward guidance interpretation first introduced by Campbell et al. (2012a). They define Delphic forward guidance as arising from additional information about macro fundamentals revealed by central bank announcements: "(...) the forecast revision following a positive policy rate innovation encompasses the revelation of unexpectedly strong macroeconomic fundamentals as well as the contractionary effects of the innovation itself." Growth shocks communicated by central banks thus tend to be entangled with the central bank reaction function, and it is important to distinguish them from monetary policy shocks themselves. In line with the monetary economics literature, monetary policy shocks in our framework have a structural interpretation in that they orthogonal to economic fundamentals (see e.g., Ramey, 2016). As such, they drive the *non-systematic* component of the central bank reaction function. Growth shocks, instead, affect interest rates through the systematic part of the reaction function.

[5] Recently, Hansen et al. (2018) propose a narrative approach to identify information effects of central bank communication. Using the BOE's inflation reports, they show that there is an information effect stemming from the central bank narrative about the economic outlook, and this effect is separate from that of quantitative forecasts.

Related to the Delphic forward guidance, markets can perceive monetary policy announcements as being expansionary or contractionary, given the information that central banks reveal. Consider the expansionary case in which the central bank response is weaker than the communicated expected (and positive) output growth. The event is a combination of both an information shock about growth ϵ_t^g as well as a pure monetary policy shock ϵ_t^m. In this scenario, equity prices increase (under conditions we discuss in Section I.B), but the reaction of bond yields depends on the size of ϵ_t^m. Specifically, stocks gain more (and yields less) than upon pure growth news. While the presence of ε_t^m contaminates the identification of the growth shock, we can still make a statement about which shock is the dominant one. If the monetary policy shock is large enough as to dominate the growth news, interest rates will move down and stocks will move up. We would classify such an event as being mainly driven by monetary policy news. If growth news dominates, instead, interest rates and stocks both increase, and we would classify such event as growth news.[6]

II. Data

II.A. Monetary policy events database

We compile a new and comprehensive database of time-stamped communication events by major central banks. We focus on the central banks of the two main currency areas, the Fed, and the ECB, and we complement the analysis by studying the BOJ and the BOE. Our sample period runs from September 1997 through December 2017, although starting dates differ across countries due to the availability of high-frequency data on futures. The overall number of events is 1,997.

Construction of the event dataset. Our main source of communication events is the Bloomberg economic calendar. In instances where the event coverage provided by Bloomberg is incomplete (e.g., for the BOJ), we collect information from central bank websites. We conduct extensive cross-checking of events in Bloomberg with both central bank websites as well as extant studies such as Rogers et al. (2014) and Ferrari et al. (2017), complementing the list of events where appropriate. Partly drawing and expanding upon the two above-mentioned papers, we further compile a list of unconventional monetary policy (UMP) events, such as news about asset purchases, provision of term liquidity for banks or forward guidance about the future path of policy rates. We classify UMP events by type and policy phase at

[6] Similarly, in the contractionary case, the central bank is more hawkish than the communicated expected output growth. Similar to the case above, this event is also a combination of growth and monetary policy news. The difference is that yields unambiguously increase (more than justified by pure growth news), and the reaction of stocks depends on the size of ϵ_t^m. If ϵ_t^m is large enough to dominate the effect of positive cash flow news, then stocks move down. We would then say that the event is mostly driven by monetary policy news. Otherwise, if growth news dominates, yield increases are accompanied by stock market gains.

a high level of granularity. During the period of our study, it has been common for central banks to unveil major UMP news not only at scheduled policy announcements, but also through speeches or other communication channels. We classify these events accordingly in our data.

Type of communication. An important part of our analysis relies on distinguishing events by types of central bank communication. The most basic classification we use is by (i) monetary policy decisions (MPD), (ii) press conferences (PC), and (iii) releases of the minutes of policy meetings (MIN). For the BOE, we also include the releases of the inflation report (IR). Table I presents an overview of the number of events in these categories.

[Insert Table I about here]

Fed. Our dataset covers 359 Fed events. The largest category are MPD statements (169 events) which are released immediately following the policy decision at the FOMC meeting. The Fed holds eight scheduled meetings per year (with six unscheduled FOMC meetings during our sample period). It also traditionally publishes, with a delay, minutes of the policy meeting (136 events). Press conferences are a relatively new development and were first introduced in April 2011 (28 events). Possibly because historically there were no press conferences to provide background on the policy decision, MPD statements have been longer than those of other central banks. They contain 12 sentences on average, and have been increasing in length since the financial crisis. Until 2011, statements were regularly released at 14:15 New York time. The release time changed in 2011, alternating between 12:30 and 14:15 depending on whether the meeting was followed by a press conference; currently statements are published at 14:00, with the press conference at 14:30.[7]

ECB. The ECB has 609 events, the highest number among the central banks in our database, of which 251 are classified as MPDs. Monetary policy meetings of the Governing Council take place every 6 weeks. Unlike the other major central banks, the ECB has no history of releasing minutes.[8] By contrast, press conferences (218 events) have historically played a key role in its communication strategy. Compared to the Fed, the ECB's MPD statements are short as the press conference serves to transmit further information to the public. While the average length of the ECB's MPD announcement is less than three sentences, transcripts of the ECB's press conference (including introductory statement and the Q&A part) contain

[7]Until June 2018, the Fed held a press conference after every second FOMC meeting. At its June 2018 meeting, Chairman Powell announced that the Fed will hold a press conference after every meeting starting from January 2019.

[8]Since November 2015, the ECB publishes the so-called account of the monetary policy meeting. The released information, however, is less granular than minutes published by other major central banks (e.g., the BOJ discloses votes of different members of the policy committee on key decisions by name).

on average 230 sentences.[9] With a few exceptions, the ECB announces its policy decisions at 13:45 Frankfurt time, whereas the press conference begins at 14:30.

BOE. For the BOE, our database records 578 events, with 230 MPDs. Similar to the Fed, nowadays the BOE's monetary policy committee meets on average 8 times per year, down from originally 12 meetings per year prior to 2016. Publishing minutes of the policy meeting has also been common as indicated by the 207 events in our sample. Additionally, the BOE publishes the quarterly inflation report (79 events) which constitutes an important piece of information that financial markets in the UK pay attention to. In recent years, the BOE has also made increasing use of verbal communication channels to provide context to the policy decision. Since August 2015 under Governor Carney, a press conference is regularly held after those policy meetings when the BOE's inflation report is published. Interest rate decisions are announced at 12:00 London time and the press briefing begins at 12:45. Market commentary confirms that such "Super-Thursdays"—when the policy decision is coupled with the publication of the inflation report and the minutes—are particularly news-intensive and, hence, market reactions are more pronounced.

BOJ. The BOJ contributes 449 events in our sample, of which 203 are MPD statements. Like the other major central banks, the BOJ takes policy decisions 8 times per year, down from 14 policy meetings per year prior to 2015. The MPD statements are released immediately after the meeting (yet not on a fixed time) and have traditionally been fairly detailed. The BOJ has also regularly published minutes (179 events). Since at least 2013, but less regularly, the BoJ also holds press conferences at 15:30 Tokyo time. The timing of the press conference in the afternoon means that trading is usually thinner. Given measurement issues, we do not consider the 52 PC events in our empirical analysis.

II.B. High-frequency data

We obtain high frequency data for equity and interest rate futures from TickData. The coverage of maturities for interest rate futures differs by country. For the US, we have Treasury bond futures with maturities of 2, 5, 10 and 30 years as well as 3-month Eurodollar futures and S&P 500 E-mini futures. For the euro area, we obtain futures on German bonds with maturities of 2, 5 and 10 years, as well as 3-month Euribor futures, and DAX index futures for the stock market. The coverage of bond maturities is scarcer for the UK and Japan. For the UK, we have Sterling 3-month futures and Long Gilt futures for bonds and FTSE 100 index futures for stocks. For Japan, we use 10-year bond futures and TOPIX equity futures. Table IA-1 in the Internet Appendix summarizes the available data.

[9] Internet Appendix Figure IA-5 shows the number of sentences contained in the FOMC statements and ECB decision announcements and press conferences.

Bond futures are written on a hypothetical government bond paying coupon. To convert futures returns into yield changes, we divide log futures price changes by the negative of duration. Duration data are obtained from Bloomberg at the daily frequency using futures equivalent duration based on the notional. While bonds underlying futures contracts are not zero coupon, for simplicity, we label yield changes approximated this way by referencing the maturity of the underlying.

II.C. Controlling for variation in asset prices on non-event days

Our subsequent analysis exploits high-frequency variation in asset price returns as well as realized variances and covariances around events. It is therefore important to define the baseline relative to which we measure the impact of those events. To control for the baseline variation in asset prices, we construct stock returns and yield changes as well as measures of realized variances and covariances on days without central bank news. Those controls are always computed for the same window length as the event window we study (which differs across event types). We avoid the dependence of the results on a particular time of day by sampling controls three times per day at 10:00, 12:00 and 14:00 local time. This reflects the fact that central bank announcements can occur at different times of the day. The control group excludes all local cental bank announcements contained in our event database. Using the US as an example, when we analyze the effect of Fed communication, our controls exclude days with announcements by the Fed but not by other central banks.[10]

III. Asset price sensitivity to central bank communication: An overview

A large literature studies how asset prices respond to central bank announcements (see, e.g., Gürkaynak and Wright (2013) for a literature overview). In this section, we review the evidence for the main four central banks that their communication induces significant responses of stocks and yields. Specifically, we document how the strength of those reactions differs by the type of communication and across the maturity dimension of the yield curve.

Since our goal is to assess the sensitivity of asset prices to communication, we focus on changes in absolute (as opposed to signed) stock returns and yield changes around events. For each central bank in our sample, we estimate regressions of absolute stock returns or yield changes on a dummy variable indicating a particular communication type: monetary policy decisions, press conferences, minutes or inflation reports. For monetary policy decisions, returns are computed from -15 to +15 minutes around the event. For press conferences,

[10] We have verified that excluding days with announcements by all central banks does not significantly change the results.

minutes and inflation report releases, they are computed over a longer window, from -15 to +90 minutes, given that these communications tend to be more extensive and contain broader information, and hence, they may take longer for investors to process.

Figure 1 summarizes the main results (Internet Appendix A contains the details). Bars in each plot show the *incremental* effect of communication events (in basis points) relative to the baseline variation in asset prices absent central bank news, along with 95% robust confidence intervals. The numbers superimposed on the bars report the increase in absolute returns (or yield changes) around a given communication event relative to other days (e.g., "2" means that average absolute returns are 200% higher on average around, say, press conferences than their variation on non-announcement days).

[Insert Figure 1 about here]

Fed. For the Fed, both stock returns and yield changes become significantly more volatile around Fed communication events compared to other days (Panel A of Figure 1). The response is the strongest around MPDs, followed by PCs[11] and then by minutes releases.[12] Absolute stock returns are 137% higher around MPDs and 97% higher around PCs compared to non-event days. Yield changes are smaller in basis-point terms than stock returns, as they normalize bond returns by duration. That said, they are large compared to the baseline variation on non-Fed days. Around MPDs (PCs), absolute yield changes are 438% (260%) higher at the two-year maturity and 293% (160%) higher at the ten-year maturity compared to non-event days. Across events of different types, the yield curve displays a hump-shaped pattern along the maturity dimension. This pattern is suggestive of the Fed announcements containing news about the economy, rather than just monetary policy, as we explore below.[13]

ECB. The ECB's press conferences induce much larger asset price reactions than actual decision statements (Panel B of Figure 1). Absolute stock returns are about 31% higher for the PCs, while absolute two- and ten-year yield changes are 219% and 112% higher, respectively, than on days without ECB news. Around MPDs, instead, volatility of stocks relative to other days is not statistically higher and represents just about a quarter of the

[11] The regressions for the Fed's PCs are estimated on a sample starting from 2011, i.e., the year when they were first introduced.

[12] However, we find that the importance of Fed minutes has increased over time. During the effective zero lower bound (ELB) period, minutes releases have seen a market reaction approximately twice as strong as that estimated over the whole sample. Therefore, we do not omit minutes in our subsequent analysis.

[13] This smaller sensitivity at the short end of the yield curve is partially due to the ELB which constrained yields at shortest maturities for a significant part of our sample. However, estimating the regressions on a sample ending in 2007 (before the ELB) continues to show a nonmonotonic pattern with the peak of the response located at the two-year maturity.

reaction around the PCs. Bond volatility picks up significantly around MPDs, with the effect most pronounced at the very short end of the term structure. Here too, however, the response is just a fraction of that observed for PCs. Also note that the yield curve response to PCs is hump-shaped, with a peak around the two-year maturity.[14]

BOE. For the BOE, the largest reaction (in basis point terms) pertains to the release of the inflation report (Panel C of Figure 1). We observe a similar rise in volatility around MPD announcements. Minutes releases feature statistically significant reactions, but similar to the Fed and the ECB, the economic effect on asset prices is smaller.

BOJ. For the BOJ (Panel D of Figure 1) we focus on policy decision announcements and minutes releases. Perhaps not surprisingly, due to persistently low rates and subdued bond market volatility in Japan over our sample, reactions of yields are just a fraction of a basis point, but they remain statistically significant. More interestingly, absolute stock returns display large increases around minutes releases.

In sum, both stocks and the yield curve register meaningful increases in volatility on central bank communication. The results highlight significant differences across types of communication in their impact on asset prices, and across the term structure.

IV. Stock-yield comovement and the nature of central bank news

We now turn to the analysis of monetary versus non-monetary news, drawing on the comovement of stocks and yields around central bank releases. Specifically, we introduce the term structure of stocks-yield covariances, where "term structure" refers to the maturity dimension of the yield curve. This dimension, in addition to the direction of the comovement of yields with stocks, facilitates the identification of economic shocks that drive the market reaction to news.

As a convention, throughout this article, we report results in terms of the comovement between stock returns and bond *yields*, while some authors report comovement between stock and bond *returns*. Clearly, a positive sign for the covariance of stock returns with yields changes implies a negative sign for covariance of stock returns with bond returns. Using the yield convention is more convenient as it makes the term structure aspect of covariances explicit (bond returns scale mechanically with the duration of the underlying bond).

[14]While our sample spans the financial crisis period, these results echo the earlier findings of Brand et al. (2010), confirmed more recently by the analysis of Leombroni et al. (2017).

IV.A. Term structure of realized stock-yield covariances

Let τ denote the time of a communication event, and $\tau^- = \tau - h^-$ and $\tau^+ = \tau + h^+$ the time before and after the event. Divide the interval $h^+ + h^-$ into N subintervals of length $\Delta = \frac{h^+ + h^-}{N}$. The realized covariance of shocks around event τ is computed as:

$$\text{RCov}_\tau^{(n)}(\tau^-, \tau^+, N) = \sum_{i=0}^{N} \Delta y_{\tau^- + i\Delta}^{(n)} \times r_{\tau^- + i\Delta}^s, \tag{5}$$

where $\Delta y_{\tau+k\Delta}^{(n)} = y_{\tau+k\Delta}^{(n)} - y_{\tau+(k-1)\Delta}^{(n)}$ and $r_{\tau+k\Delta}^s = p_{\tau+k\Delta}^s - p_{\tau+(k-1)\Delta}^s$, and p^s is the log stock market index. The use of high frequency data to measure covariation of returns has been proposed by Barndorff-Nielsen and Shephard (2004). We construct covariances by summing up the products of one-minute yield changes with one-minute stock returns over an event window: from -15 minutes before to +15 minutes after the monetary policy decision, and from -15 minutes before to +90 minutes after other communication events (press conferences, minutes releases, BOE's inflation report).[15] We measure both $\Delta y_{\tau^- + i\Delta}^{(n)}$ and $r_{\tau^- + i\Delta}^s$ in basis points, hence realized covariances are expressed in units of basis points squared.

We focus on the covariances, rather than correlations, as they allow to compare covariances across the maturity dimension. The interpretation of correlations is complicated because yield volatilities are also differentially affected by shocks to short-rate expectations and to risk premia (Cieslak and Povala, 2016). Thus, scaling covariances by volatilities obliterates the effects of shocks across the term structure.

IV.B. Non-monetary policy days and macro announcements

We begin by studying the stock-yield covariances on days without monetary policy news and around key macroeconomic releases. This evidence serves as a point of reference for our subsequent results on the effects of central bank communication.

Non-monetary policy days. Figure 2 presents the distributions of realized stock-yield covariances on non-monetary policy days in the US, Germany, UK and Japan. Covariances are computed over daily windows, excluding days with announcements by the respective local central bank. A large literature documents that the comovement of stocks and yields switched sign in the late 1990s from negative to positive (e.g., Andersen et al. (2007), d'Addona and Kind (2006), among others). In line with those studies, Figure 2 shows positive average covariance across the four major currency areas during our sample.

[15] The robustness of our results to alternative choices of the window size is discussed in the Internet Appendix B.

A new insight from Figure 2 is that covariances generally increase with maturity. This suggests that, on most days, the stock-yield comovement stems from variation in risk premia. Indeed, Baele et al. (2010) find that while macro fundamentals contribute little to explaining the stock-bond correlations, other factors, especially liquidity proxies, play a more important role. Connolly et al. (2005) relate that fact to the "flight-to-safety" phenomenon.

[Insert Figure 2 about here]

Macroeconomic announcements. Ideally, we would like to study directly how stocks and yields comove in response to news that drive investors' expectations about economic activity. One complication is that such news is hard to find as macro releases may also induce risk premium variation. However, from a baseline New-Keynesian model it is known that, absent confounding effects from the risk premium variation, output shocks affect short-to-intermediate yields more than long-term yields (see e.g., Gürkaynak et al., 2005b). Thus, we expect such news to generate positive comovement of stocks and yields that is more pronounced at the shorter maturity range. We verify that stock-yield covariances around key real activity announcements behave in a way consistent with those predictions. We summarize the main results below and relegate regression estimates to Section C in the Internet Appendix.

We characterize stock-yield comovement around the announcements of unemployment, GDP growth rate and CPI inflation in the US. The time stamps for the releases (typically 8:30am New York time) are from the Bloomberg economic calendar. To allow sufficient time for the news to be reflected in prices after markets open, we construct covariances for the (-15,+60) minutes window around the release time. In terms of asset price sensitivity, the unemployment release raises volatilities of stocks and yields significantly more compared to either the CPI or GDP release and the effect is the strongest at intermediate yield maturities.

Figure 3 plots the distribution of covariances for the three announcements. Covariances are on average positive around the unemployment release, and significantly larger in magnitude than for inflation and GDP growth. Compared to non-event windows in our control sample, unemployment announcements are associated with a statistically significant increase in stock-yield covariance, which again is the largest in the intermediate range of maturities. The positive and non-monotonic term structure of covariances is consistent with the expected effect of growth news laid out in our conceptual framework. Inflation announcements lead to a small but statistically significant reduction in stock-yield covariances, which is consistent with investors perceiving inflation news as a signal about monetary policy. GDP announcements increase covariances at intermediate maturities, but the difference compared to non-announcement days is not statistically significant.[16]

IV.C. Selected central bank communication events

We first illustrate the behavior of stock-yield covariances around selected central bank events. We interpret these events through the lens of our conceptual framework. Figures 4 and 5 showcase the joint stock-yield curve dynamics in response to specific ECB and Fed events.

The ECB events depicted in Figure 4 are the press conference on Feb 7, 2008, the monetary policy decision and the press conference on Nov 3, 2011, and President Draghi's speech on July 26, 2012.

[Insert Figure 4 about here]

In the policy decision on Feb 7, 2008, the ECB decided to leave rates unchanged, but in the press conference President Trichet expressed concern about economic growth, saying: "Uncertainty about the prospects for economic growth is unusually high and the risks surrounding the outlook for economic activity have been confirmed to lie on the downside." As expected when growth is the key piece of news, the term structure of covariances around the press conference is positive with a peak at two-year maturity (Panel A of Figure 4).

Nov 3, 2011 marks the first decision under the incoming President Draghi when, in the first cut in two years, the ECB lowered its main policy rate by 25 bps. Stock markets rallied and short-term yields declined in reaction to the news. Consistent with the conventional effect of monetary policy news, the stock-yield covariances are negative with magnitude that declines (in absolute value) in maturity (Panel B). Importantly, however, during the press conference following the decision Draghi predicted that Europe is heading towards a recession, which reversed the initial reaction of asset prices. Accordingly, Panel C shows a dramatic change in stock-yield comovement during the press conference with realized covariances switching to positive and strengthening with maturities. Through the lens of our framework, a more pronounced comovement at the long end of the yield curve suggests risk premium shocks as the main channel.

The influential speech by President Draghi on July 26, 2012 directly demonstrates how risk premium shocks affect the covariance term structure. Notably, in that speech, Draghi

[16]We have conducted a similar analysis for the German macro announcements. In contrast to the results for the US, we found little evidence for increased sensitivity of asset prices around releases for inflation, unemployment, factory orders and industrial production. Therefore, we do not discuss the details of these results.

directly referenced the "risk aversion factor" and the importance of risk premia to monetary transmission. His promise to do "whatever it takes" to save the Euro has been viewed by many as a move to reduce risk premia on the sovereign bonds in eurozone peripheral countries. In what was interpreted as a shift towards a major "risk-on" episode, the ten-year German yield increased by nearly 8 bps as investors switched to risky assets (DAX futures gained more than 2.3%). By contrast, the short end of the yield curve barely changed. As such, Panel D displays a positive and increasing covariance term structure around that event, similar to that in Panel C.

Turning to the Fed, Figure 5 displays stock-yield covariances at FOMC announcements on Jan 22, 2008, Dec 16, 2008, and Aug 9, 2011. Similar to the ECB, these events feature distinct patterns of stock-yield comovement in response to the news.

[Insert Figure 5 about here]

In an unscheduled move on Jan 22, 2008, the Fed lowered the target rate by 75 bps on concerns about economic growth. Short-rates went down, but longer term yields rose as the stock market gained at the news. This generated a negative comovement of stocks and yields at the short end of the curve but a positive comovement at intermediate and long maturities (Panel A of Figure 5), suggesting a combination of a monetary shock with news about growth and/or risk premia.

On Dec 16, 2008, the Fed lowered the target rate further to the 0–25 bps range. The decision was coupled with forward guidance about future policy suggesting "exceptionally low" rates for "some time." The announcement generated a negative comovement of stocks and yields, most pronounced at the short end and declining in strength across maturities. The dynamics indicate that investors deemed the news about monetary policy as the main content of the announcement, likely because the anticipation of economic weakness was already impounded into market expectations at that point.

Quite a different pattern is seen on Aug 9, 2011. The statement revealed the Fed's negative assessment of growth—"(...) economic growth so far this year has been considerably slower than the Committee had expected." The downward revision in growth expectations was combined with explicit forward guidance about exceptionally low rates "at least thought mid-2013." While the growth and forward guidance elements are similar to the Dec 18, 2008 statement above, the covariance is now positive and largest at the intermediate maturity (Panel C), which suggests that this time the updating of growth expectations drove the market reaction.

IV.D. Properties of stock-yield comovement around communication events

We now turn to a systematic investigation of the term structure of stock-yield covariances. We contrast properties of covariances on non-event days (discussed above) with their properties around policy decision announcements, and separately, around those communication events that provide background to policy decisions. We find stark differences in covariance dynamics across types of communication and over time.

Monetary policy decisions. The release of monetary policy decisions diametrically changes the properties of stock-yield comovement. We illustrate this fact for the MPD announcements by the ECB and the Fed. Figure 6 superimposes the realized covariances for two event windows: (i) pre-event window from 24 hours to 15 minutes before an MPD announcement, and (ii) event window from 15 minutes before to 15 minutes after the announcement. The yield maturity is five years.

[Insert Figure 6 about here]

While covariances are generally positive in the pre-event window, the MPD announcement pushes them significantly lower, and most of the time, the sign switches to negative. This is the usual effect one would expect to observe with a monetary policy shock, and it is particularly clear for the ECB. Indeed, due to their brevity, EBC decision announcements offer a good laboratory for isolating monetary policy shocks as they are typically unconfounded by other information.

The stock-yield covariance reactions around the release of FOMC statements are also negative most of the time. However, around 2008, we observe a period when their sign switches to positive. Notably, this is especially visible at the unscheduled FOMC announcements. The more varied results for the Fed align with a broader scope of information conveyed in its policy decision statement.

In Table II, we formally test the impact of MPDs on realized covariances, where in addition to the Fed and the ECB, we also consider decision statements by the BOE and the BOJ. We estimate the following regressions by yield maturity and by each central bank:

$$\mathrm{RCov}_{\tau}^{(n)} = \alpha^{(n)} + \beta_{\mathrm{MPD}}^{(n)} \mathbf{1}_{\tau,\mathrm{MPD}} + \varepsilon_{\tau}^{(n)}. \tag{6}$$

To control for the baseline variation in covariances on non-monetary policy days, we construct covariances over the window of the same length as for the MPDs (i.e., -15, +15 minutes). The constant $\alpha^{(n)}$ captures the average level of covariances on non-announcement days; its estimates are consistently positive and increase in maturity, consistent with Figure 2.

[Insert Table II about here]

MPD announcements push covariances significantly lower relative to the baseline, with the effect generally stronger at short maturities. The monotonic pattern of $\beta^{(n)}_{\text{MPD}}$ coefficients is clear for the ECB. For the Fed, the effect is hump-shaped, with the lowest $\beta^{(n)}_{\text{MPD}}$ coefficient at the five-year maturity. This non-monotonicity is related both to the ELB as well as a more complex information content of the FOMC statements compared to ECB's announcements. Policy decisions of the BOE and the BOJ also lead to a change in the sign of covariances, but the magnitude of the effect is smaller than for the ECB and the Fed.[17]

Overall, these results corroborate the significance of the standard monetary policy channel as studied by Bernanke and Kuttner (2005), Gürkaynak et al. (2005a), and by a large related literature. While this literature commonly relies on full-sample regressions of stock returns on monetary policy shocks, and thus documents average effects, the realized-covariance approach allows us take a conditional view and trace the effects over time. This turns out to be important in analyzing other communication events, which we discuss next.

Communication of the context of policy decisions. A new set of insights follows from the analysis of those communication events whose aim is to provide the public with a context of policy decisions. Among those, we study press conferences of the ECB, minutes releases and press conferences of the Fed, minutes releases and inflation report of the BOE, and minutes of the BOJ.

[Insert Figure 7 about here]

Figure 7 plots the dynamics of stock-yield covariances around those events. The most important message from the graph is that stock-yield covariances switch sign in 2013—a consistent finding across the ECB, the Fed and the BOE. The vertical lines in the plots indicate break dates in average covariances identified with the Bai and Perron (1998) test; detailed results of the test are provided in Table III.

[Insert Table III about here]

From early 2008 through 2013, the covariances are generally positive. The strongly positive comovement around the ECB's press conferences in that period is particularly noteworthy, as press conferences give almost immediate context to the actual policy decision. They are also

[17] Figure IA-6 in the Internet Appendix characterizes the whole distribution of covariances around MPD announcements and other communication events.

the most significant channel of the ECB's communication in terms of its asset price impact (Figure 1). A similar behavior can be seen for communications of other central banks as well. The positive sign suggests that during the financial crisis and in the early phase of the recovery, the market's perception of important news telegraphed by central banks was not mainly about monetary policy. Instead, it was dominated either by shocks to growth expectations or to risk premia.

In contrast, from early summer of 2013, communication drives stocks and yields in opposite directions.[18] This shift in sign is directly preceded by FOMC Chairman Bernanke's testimony on May 22, 2013. In that testimony, he discussed the possibility of tapering asset purchases against the backdrop of improving labor market conditions; all the while, up to that point, asset purchases had been primarily linked to forward guidance about future policy rates. The resulting confusion among market participants about the central banks' reaction function led to a significant pick up in volatility, an episode known as the "taper tantrum" (e.g., Feroli et al., 2014).

One interpretation is that Bernanke's statement may have led market participants to turn away their focus from watching economy-related news for signs of the future direction of monetary policy. In line with this interpretation, the WSJ later summarized the market situation: "When the focus is on the discount rate used to value all assets, bond and stock prices rise and fall together, creating the inverse relationship between bond yields and shares. (...) Such a focus on monetary policy isn't healthy. It leaves markets more exposed to sudden shocks, both from changes in policy and from an economy to which less attention is being paid" (WSJ, Sep 6, 2016).

We also study how the comovement of stocks and yields changed across the entire term structure following the events of 2013. We find that for announcements other than policy decisions by the Fed, ECB and BOE, the entire average term structure of covariances changes sign from positive pre-2013 to negative post-2013. Additionally, compared to the post-2013 sample, the period from 2008 to 2012 is characterized by a larger dispersion in realized covariances, suggesting significant heterogeneity of the news telegraphed by the central banks (see Internet Appendix Figure IA-7).

[18] Although the formal test for the BOE finds the break in February 2013, the large negative covariance is registered around the minutes release on Jul 17, 2013. Interestingly, one of the most pronounced negative covariance realizations post 2013 can be seen for the BOE on Aug 4, 2016. This event deserves a separate note as it marks a change in the BOE's communication as the first "Super Thursday." It also follows in close proximity to the Brexit vote on Jun 23, 2016. The negative covariance suggests a significant monetary policy shock. The market commentary highlights the unexpectedly large and diverse stimulus package by the Bank of England which provided cheap funding for banks (e.g., https://www.wsj.com/articles/bank-of-england-cuts-key-interest-rate-to-new-low-1470309155.)

IV.E. Classification of central bank news based on second moment dynamics

What is the relative importance of different types of news conveyed via central bank communication? We classify events on two dimensions—by volatility of yields across maturities and by comovement of yields with stocks. This leads to the following news classification matrix:

Central bank news classification matrix

	Stock-yield cov > 0	Stock-yield cov ≤ 0
$\text{Var}(y^{\text{Short/Mid}}) > \text{Var}(y^{\text{Long}})$	(1,1) economic growth	(1,2) monetary policy (conventional, via short-rate expectations)
$\text{Var}(y^{\text{Short/Mid}}) \leq \text{Var}(y^{\text{Long}})$	(2,1) risk premia (risk on/off)	(2,2) monetary policy (unconventional, via long rates/risk premia)

Specifically, we assign events into categories based on whether (i) yields comove positively or negatively with stocks, and (ii) short/intermediate yields vary more or less than long yields. While an announcement can in principle convey several types of news, it is important to acknowledge that the above classification can only help identify the *dominant* piece of news.

Quadrants (1,1), (1,2) and (2,1) of the above matrix label shocks according to their properties laid out in Section I.B. Quadrant (2,2), with the "unconventional" monetary policy category, falls outside of the types of shocks we have discussed so far—it characterizes events that move stocks and yields in opposite directions (like a monetary policy shock), but generate more volatility at long maturities (like a risk premium shock). Such dynamics could arise when a central bank directly affects the long-end of the yield curve, for example, via purchases of long-term bonds.[19] We discuss examples of such shocks below, and more extensively in Section V.

We implement this classification for the Fed and the ECB for which we have sufficient coverage of yield maturities. Before the ELB, we categorize events based on variances at the two- and ten-year yield maturity and the two-year covariance. After the ELB is reached (from Jan 1, 2009 for the Fed and from Jul 1, 2012 for the ECB) through the end of our sample, we replace the two-year maturity with the five-year maturity.[20] Similar to the

[19] Using an event study, Gagnon et al. (2011) attribute the yield reaction to initial rounds of QE by the Fed to compression in the term premium. Based on yield curve decompositions, Christensen and Rudebusch (2012) assign a larger role to short-rate expectations as drivers of the long-term yield response for the US, but an important effect on term premia in case of the BOE's QE program.

[20] The Fed lowered the federal funds target rate to a range between 0 and 25 bps on Dec 16, 2008. The ECB decreased its deposit facility rate to zero in July 2012; we follow Lemke and Vladu (2017) in treating this as the moment when the euro area reached the ELB.

realized covariances in equation (5), realized variances around events are constructed by summing up the squared one-minute yield changes over a given window.

For the Fed, we separately consider scheduled FOMC announcements, and we combine minutes releases and press conferences into one group.[21] For the ECB, we distinguish between policy decisions and press conferences. Remaining events in our database are grouped as "other." We report the number and frequencies of events falling into each quadrant of our classification. In addition, we also provide medians and means of stock-yield covariances by quadrant to assess the economic significance of each news category.

[Insert Table IV and Figure 8 about here]

Table IV reports the results. For an easier comparison between the Fed and the ECB and across types of communication, event frequencies and mean covariances by quadrants are also shown in Figure 8.

Several parallels between the Fed and the ECB are worth highlighting. We first focus on monetary policy decisions. Conventional monetary shocks (quadrant (1,2)) account for most of the market reaction for more than half of MPD announcements. These shocks are also the most significant channel, economically and statistically, when gauged by the average stock-yield covariance. Growth news (quadrant (1,1)) ranks second both by frequency and economic importance, and accounts for about a third of MPD announcements. For the ECB, the conventional monetary channel is by a wide margin the most important one in terms of economic significance. For example, the impact of growth news on the average stock-yield covariance is about 9% (=7.6/82.5) of that of conventional monetary news; an analogous number for the Fed is 68% (=98.7/144.7). A comparison of means and medians suggests that monetary news by the ECB generates a large negative tail in realized covariances, with few events having a dramatic impact (see also Figure 6).

The second important observation is that the importance of conventional monetary news declines significantly in communications other than MPDs such as press conferences and minutes. Growth news dominates in more than 50% of those cases, while conventional monetary shocks represent only about 30%. This finding is particularly relevant for the ECB, where the economic importance of PCs has been large relative to the MPDs.

Finally, the other two news categories—risk preference shocks (quadrant (2,1)) and unconventional monetary shocks (quadrant (2,2))—are less common, each constituting less than 20% of events across different event types. Although infrequent, these shocks can have

[21] There are only 28 press conferences in our sample. We combine them with the minutes releases, as both show similar dynamics of covariances (see Figure 7).

strong effects on asset prices. For example, for the Fed, the large negative covariance in the unconventional policy quadrant (2,2)—visible in the top right panel of Figure 8—stems from the March 18, 2009 quantitative easing announcement.[22] The economic magnitude of the risk premium channel is especially pronounced for the ECB's press conferences (bottom right panel of Figure 8), where it accounts for some of the biggest movements in covariances during the past decade.

To summarize, the conventional monetary news channel drives the market reactions at about a half of policy decision announcements. Non-monetary news—growth and risk premium shocks—is the key component of those communications that provide context to policy decisions, press conferences being a primary example.

V. Stock-yield comovement and unconventional monetary policy

We next use the comovement of stocks and yields to discriminate between the types of news conveyed via different unconventional monetary policies (UMP). Our classification of events builds on a large literature,[23] which we extend to include the latest events related to policy normalization. We rely on a granular distinction by official policy programs or well-known policy phases. We also account for whether a specific announcement contained explicit forward guidance (FG) on the path of policy rates. We do not include communication that just restated the objectives of a specific program or left the parameters of forward guidance unaltered. For brevity, we refer to the various policies using the common abbreviations of program names. These abbreviations are explained in the corresponding tables. Details of the design and goals of the interventions are discussed in Internet Appendix D.

We estimate regressions of stock-yield covariances on dummy variables for a given UMP program or phase, controlling for covariances on non-monetary policy days. Covariances are measured from -15 minutes before to +90 minutes after each event.

[Insert Table V about here]

[22]On this day, the Fed announced purchases of $300bn in Treasuries, $750bn of agency MBS, increase holdings of agency debt to $200bn. On the announcement, S&P500 futures gained more than 175 bps, yields two-year bond futures dropped by 8 bps and on 30-year bond futures by more than 40 bps. In support of the announcement strongly affecting yield risk premia, Cieslak and Povala (2016) show that the term premium volatility in US Treasuries reached its 18-year peak in the week of this announcement, moving long yields significantly more than short and intermediate yields.

[23]See, e.g., Fratzscher et al. (2016), Krishnamurthy et al. (2017) for an analysis of the ECB's UMPs, and Fratzscher et al. (2018), Hattori et al. (2016), Krishnamurthy and Vissing-Jorgensen (2013), for recent studies for the Fed, among others. A survey of the literature on the effects of unconventional policies by the Fed is provided by Bhattarai and Neely (2016), while Borio and Zabai (2016) also cover studies on the UMPs of other major central banks. Bauer and Neely (2014) study the international transmission of Fed policies, while Rogers et al. (2014) study the effect of UMPs by the main four central banks.

Fed. Table V presents results for the Fed. Consistent with the literature that emphasizes significant asset price responses to the early QE announcements, the largest changes in covariances can be observed for QE1. On average, QE1 sent stocks and yields in opposite directions, in line with those announcements triggering significant monetary shocks. Importantly, however, the most pronounced negative comovement occurred at those QE1 events which simultaneous contained a forward guidance element (Dec 16, 2008 and Mar 18, 2009). QE1 announcements without forward guidance actually moved stocks and yields in the same direction, most so at the intermediate maturity, suggestive of an important growth news component.

The effect of other policy packages is generally more muted. This is perhaps not surprising as—in contrast to the large surprises associated with QE1—by the time QE2 and QE3 were announced, the markets may have better understood the Fed's reaction function and anticipated that further accommodation is needed. However, the MEP announcement shifted stock-yield covariances higher at the long-end, indicating that non-monetary policy content dominated the news.[24]

Table V further shows that starting from 2013, announcements pertaining to the Fed's exit from policy accommodation and to the wind-down of its balance sheet drove the stock-yield covariances into negative territory. The break in stock-yield comovement around 2013 suggests that monetary shocks regained importance at the prospect of the monetary stimulus being removed.

[Insert Table VI about here]

ECB. Table VI reports estimates for the ECB. Unlike conventional policies, which work primarily through the short-end of the yield curve, the results in Table VI suggest that the ECB's unconventional policies operated mostly by affecting longer-term yields. Hence, we observe a stronger reaction of the longer-end of the stock-yield covariance term structure. Indeed, the comovement of stocks with the short-end of the curve (three-month maturity) was largely insignificant over the period of ECB's UMPs, including the period before the ELB. The picture looks different for maturities of two-years and beyond. As in the case of the Fed, non-monetary news dominated during the earlier phases of unconventional policies. This is the case for announcements related to the provision of US dollar liquidity, the early phases of LTROs, ECB purchases of peripheral country debt under the SMP, and later LTRO announcements. Similar to the Fed, however, announcements that contained forward guidance induced negative covariances of stocks and yields.

[24] The first MEP-related announcement happened on Aug 9, 2011, and covariances around that event are depicted in Figure 5 and discussed in Section IV.C.

The results also suggest that the market reaction to the OMT program—to some degree foreshadowed by President Draghi's "whatever it takes" speech—was not about monetary policy news per se. Instead, the upward sloping term-structure of covariances suggests a shock to risk premia as the likely explanation of the pattern we see in the data (see also Figure 4). Following the OMT-related announcements, the flight-to-safety to German government bonds subsided while stocks and other risk assets gained. Policies unveiled by the ECB after the euro area sovereign debt crisis abated, e.g., its asset purchase programs (PSPP and later CSPP), show a response consistent with monetary policy shocks as main drivers of asset price responses.

[Insert Table VII about here]

Results for the BOE and BOJ are presented in Table VII. Due to data limitations for futures contracts, we can investigate at most two points on the stock-yield covariance term structure.

BOE. Several similarities between the BOE and the Fed and ECB are worth noting. Just like in the case of the Fed and the ECB, non-monetary shocks dominate the financial market transmission in the early phases of the BOE's unconventional policies, although the statistical significance is weaker than in the previous cases. Likewise, the negative covariance in response to forward guidance is in line with a monetary policy shock as the underlying driver. The most significant and negative covariance pertains to the announcements related to APF4, which aimed to provide stimulus in the aftermath of the Brexit referendum. As such, the response undertaken by the BOE worked as a powerful monetary policy shock.

BOJ. The estimates for the BOJ suggest that the QE measures—including those conducted already prior to the financial crisis—were consistent with monetary policy shocks, driving stocks and yields in opposite directions. By contrast, the reaction to the announcement of yield curve control indicates a role for non-monetary news, albeit the economic importance of this announcement is smaller than that of other QE measures. One caveat is that over a large part of our sample, Japanese bond yields were affected by the ELB (even for fairly long maturities). As such, both volatility and turnover in the market were subdued dampening asset price reactions to BOJ's news.

VI. Decomposing asset price responses to central bank communication

Section I links reduced-form shocks in yields and equities to shocks that have a structural interpretation. A natural question of interest is which fraction of variation in stock returns and yield changes around communication events stems from each structural shock. To cast light on this question, we rotate reduced-form shocks into monetary policy, growth and risk premium shocks that are consistent with the effects laid out in Section I. Our identification exploits both the comovement of stocks and yields via sign restrictions as well as differential effects of shocks across the maturity dimension of the yield curve.[25] The results in this section both complement and corroborate the news classification based on the term structure of realized covariances discussed so far.

VI.A. Sign and monotonicity restrictions

Denote structural shocks as $\epsilon_t = (\epsilon_t^g, \epsilon_t^m, \epsilon_t^p)'$, and reduced-form shocks as $u_t = (\tilde{y}_t^{2y}, \tilde{y}_t^{10y}, \tilde{r}_t^s)'$. Reduced-form shocks u_t contain changes in a two- and ten-year yield and stock returns within a narrow window around announcements. We use three reduced-form shocks to identify three structural shocks by:

$$u_t = A^{-1}\epsilon_t, \tag{7}$$

where A^{-1} is the matrix of contemporaneous dependencies of asset prices with $Var(u_t) = \Sigma_u$ and $Var(\epsilon_t) = I_{3\times 3}$ with I denoting an identity matrix. To identify the structural shocks, we require that A^{-1} fulfills sign restrictions given by:

$$A^{-1} = \begin{pmatrix} a_{2g} & a_{2m} & a_{2p} \\ a_{10g} & a_{10m} & a_{10p} \\ a_{sg} & a_{sm} & a_{sp} \end{pmatrix} = \begin{pmatrix} + & + & - \\ + & + & - \\ + & - & - \end{pmatrix}. \tag{8}$$

These restrictions capture the following effects: (i) a positive growth shock ϵ_t^g increases stock prices and yields (first column of A^{-1}); (ii) a positive monetary policy shock ϵ_t^m increases yields and lowers stock prices (second column of A^{-1}); (iii) a positive risk premium shock ϵ_t^p reduces stock prices and depresses yields making bonds more valuable (third column of A^{-1}). Notice that the sign restrictions in (8) do not allow to distinguish between growth and risk premium shocks, as both move stocks and yields in the same direction. To separate these shocks, we additionally exploit the maturity dimension of the yield curve. In particular, we impose monotonicity restrictions across the yield curve as follows:

[25] Matheson and Stavrev (2014) and Jarocinski and Karadi (2018) also use sign restrictions to distinguish growth and monetary policy news. These studies use one point on the yield curve. By including the maturity dimension across the term structure, we are able to take a stance on how shocks propagate across maturities, and on the relative importance of risk premium shocks.

$$
\begin{array}{llll}
|a_{2p}| & < & |a_{10p}| & \text{2y yield responds less than 10y yield to } \epsilon_t^p \text{ shock} \\
|a_{2g}| & > & |a_{10g}| & \text{2y yield responds more than 10y yield to } \epsilon_t^g \text{ shock} \\
|a_{2m}| & > & |a_{2p}| & \text{2y yield responds to } \epsilon_t^m \text{ more than } \epsilon_t^p \text{ shock} \\
|a_{10m}| & < & |a_{10p}| & \text{10y yield responds to } \epsilon_t^m \text{ less than to } \epsilon_t^p \text{ shock}
\end{array}
$$

The first two conditions reflect the notion from Section I.A that risk premium (growth) shocks affect long-term yields more (less) than short-term yields. Empirically, we find that the first restriction is crucial for separating growth and risk premium shocks, while imposing the other restrictions only marginally changes the results.

We implement this approach following the algorithm of Rubio-Ramirez et al. (2010) (see also Kilian and Lütkepohl (2017)). Here, we summarize the main findings, while Appendix E presents the implementation details.[26] Since the algorithm relies on a simulation of a large number of matrices that satisfy the restrictions, below we report averages of the quantities of interest across simulations; standard errors for those averages are constructed as standard deviations across simulations.

VI.B. Results

We use the above approach to analyze the news content of scheduled FOMC announcements and ECB press conferences. We focus on these events because they represent the key communication channels as measured by their market impact (see Figure 1). We decompose shocks to yields and stock returns accruing around those communication events into the respective contributions of economic shocks. We present both unconditional variance decompositions (variance ratios) as well as historical decompositions, in which we split each reduced-form shock into structural components over time.

Table VIII presents the variance ratios. The estimates for the Fed and the ECB are broadly consistent with each other. The most important sources of variation are growth shocks for the two-year yield, risk premium shocks for the ten-year yield, and monetary policy shocks for equity returns. It is interesting to note that the variance of equity returns around announcements is mostly driven by the monetary policy news component, and most visibly so for the FOMC announcements. This is consistent with the narrative that emphasizes the role of monetary policy for supporting the stock market recovery in the aftermath of the financial crisis.

[26] Starting with a Cholesky decomposition of the covariance matrix of reduced-form shocks, $Var(u_t) = PP'$, $u_t = P\epsilon_t^{Cholesky}$, the idea is to select a rotation matrix Q ($Q'Q = QQ' = I$) such that PQ' satisfies the restrictions above. Then, $\epsilon_t^Q = Q\epsilon_t$ represents the candidate structural shocks (as $u_t = PQ'Q\epsilon_t$). We simulate of a large number of candidate Q matrices and store those that satisfy the restrictions. The results are obtained by averaging across 2000 simulations.

Figure 9 provides a visual illustration of how different shocks contribute to the variation in yields and stocks around the same set of announcements. Specifically, we plot cumulative historical decompositions of yields and stock returns around announcements. Stock returns and yield changes are demeaned, and therefore the results should be interpreted in terms of deviations from the means. One can see that since the financial crisis, monetary policy news at the scheduled FOMC announcements have exerted downward pressure on yields and an upward pressure on stocks. Growth shocks, in contrast, have impacted short-term rates negatively in the early parts of the financial crises, but since around 2013 have contributed to their increase. The effect of ECB's press conferences is more varied, which becomes especially clear in the effect of monetary policy shocks on the equities. For the ECB, monetary policy shocks explain a smaller portion of variation in stock returns compared to the FOMC announcements. However, at least since 2012 those shocks have generally contributed positively to stock valuations.

These results cast new light on the discussion in the literature as to whether central bank announcements can affect risk premia, as argued by Hanson and Stein (2015), or short-rate expectations (over relatively long horizons), as argued by Nakamura and Steinsson (2018). The answer is that both channels are present and their importance changes with the yield maturity. An additional implication of these results pertains to the interpretation of the path shocks in the literature following Gürkaynak et al. (2005a). Typically, path shocks are obtained by studying responses of yields with short to intermediate maturities. For example, maturities between two to three years are commonly considered to reflect the variation in market expectations of the future short rate (i.e., the path of monetary policy over the course of several quarters). Our decomposition of the two-year yield suggests that the effect of growth expectations can be at least as important as that of monetary policy shocks, and therefore could be an important driver of the path factor. In this way, we are able to quantify the importance of the so-called Delphic component of monetary policy announcements—that reveals policymakers' forecasts of the macroeconomy rather than just path of monetary policy—first studied by Campbell et al. (2012b).

VII. Conclusion

The joint dynamics of stocks and the yield curve at high-frequency reveal the nature of economic shocks induced by central bank announcements. We highlight the importance of non-monetary news transmitted via communication channels such as press conferences and minutes, whose goal is to provide context of policy decisions. We also document a considerable variation in the composition of news types released by central banks over time.

In terms of breadth of events covered as well as their taxonomy, ours is probably the most comprehensive dataset of communication by the four main central banks that has been studied in the literature. Even so, relying on asset price behavior around selected events likely does not capture the entirety the news telegraphed by central banks. In particular, we abstract from the fact that central banks may exert significant effect on asset prices outside of the public communication events, as suggested by the findings of Lucca and Moench (2015) and Cieslak et al. (2018).

Another broad set of issues pertains to understanding the economic mechanism whereby central banks convey new information to the public about the state of the economy. Our contribution is to show that such effects drive a considerable fraction of asset price variation around announcements. It is not yet resolved, however, whether the empirical evidence should be interpreted through the lens of rational models of expectations formation in which central banks have information advantage over the public, or whether it would be better understood via other mechanisms (e.g., with behavioral features). These questions are a direction for future research.

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Table I. Overview of central bank communication events

This table provides an overview of the number of monetary policy events for the four major central banks (Federal Reserve, ECB, Bank of Japan and Bank of England) in our study. It reports the number of events pertaining to i) monetary policy decisions (MPD), ii) press conferences (PC), iii) the release of minutes of the policy meeting (MIN), iv) the release of the inflation report (IR). The number of MPD events is broken down further to indicate the number of unscheduled meetings (Unsched.). Column "Other" reports the number other central bank communication events (in particular speeches by the central bank governors or other statements).

	MPD		PC	MIN	IR	Other	Total
	(Total)	(Unsched.)					
Federal Reserve (Fed) (30 Sep 1997 to 31 Dec 2017)	169	6	28	136	–	26	359
European Central Bank (ECB) (09 Jun 1998 to 31 Dec 2017)	251	2	218	–	–	140	611
Bank of England (BOE) (09 Jul 1998 to 31 Dec 2017)	230	2	9	207	79	53	578
Bank of Japan (BOJ) (15 Jul 2003 to 31 Dec 2017)	203	5	52	179	–	15	449

Table II. Monetary policy decisions and stock-yield covariances

This table presents the regressions of realized covariances on monetary policy decision dummy. The event window spans from -15 minutes before to +15 minutes after the announcement. The sample of control covariances is constructed over the same window for days without local monetary policy news, as discussed in Section II.C. The covariances are reported in units of basis points squared. Robust standard errors are reported in parentheses. We exclude unscheduled monetary policy announcements from the regression.

A. Fed

	3m	2y	5y	10y	30y
MPD dummy	-75.1***	-52.0***	-91.5***	-70.0**	-56.2*
	(-3.90)	(-2.95)	(-2.78)	(-2.11)	(-1.71)
Constant	2.20***	6.27***	10.3***	10.0***	9.81***
	(15.68)	(23.31)	(39.98)	(47.71)	(52.65)

B. ECB

	3m	2y	5y	10y
MPD dummy	-44.6***	-35.2***	-25.6***	-13.6***
	(-3.08)	(-3.36)	(-4.08)	(-3.84)
Constant	0.85***	3.40***	4.97***	5.19***
	(10.84)	(26.77)	(37.52)	(43.24)

C. BOE

	3m	10y
MPD dummy	-54.6*	-17.2***
	(-1.83)	(-3.12)
Constant	0.31***	3.05***
	(4.45)	(35.88)

D. BOJ

	10y
MPD dummy	-4.43*
	(-1.67)
Constant	2.45***
	(30.88)

Table III. Test for structural breaks in event covariances

This table reports test results for multiple breaks in mean of realized covariances using the sequential test of Bai and Perron (1998). The test is conducted over the sample from Jan 1, 2008 through Dec 31, 2017. The table provides robust F-statistics and 10% critical values. We allow error distributions to differ across breaks. The set of communication events used in estimation is reported in each column header. For brevity, for the Fed and the ECB we only report results for average covariances across maturities.

	10% Crit val	Fed	ECB	BOE	BOJ
Communication type		PC & MIN	PC	MIN & IR	MIN
Maturities		Avg 2, 5, 10, 30y	Avg 2,5,10y	10y	10y
0 or 1	7.04	8.72*	53.94*	33.02*	5.77
1 or 2	8.51	13.31*	7.54	4.19	
2 or 3	9.41	9.41			
Break dates		6 Jan 2010	4 Jul 2013	20 Feb 2013	
		19 Jun 2013			
		8 Jul 2015			

Table IV. Classification of central bank communication events

This table provides the classification on Fed's and ECB's announcements. Row labels (1,1) though (2,2) indicate the quadrants of the classification matrix described in Section IV.E. For the Fed, in Panel A, we classify the news content at scheduled monetary policy decision announcements, minutes releases and press conferences (considered jointly), and all other events in our database (including unscheduled FOMC announcements). For the ECB, in Panel B, we conduct the analysis on monetary policy decisions, press conferences, and all other events in our database (including speeches). Columns (1) and (2) report the number and the fraction (in percent) of events falling into news-type quadrant, by communication type. Column (3) reports the median covariance within each news-type quadrant, column (4) reports the t-statistics for the median, which is obtained from a quantile regression of realized covariance on a constant (with fewer than 10 observations within a category, standard errors are computed with bootstrap). Column (5) reports the mean covariance within each news-type quadrant, and column (6) provides robust t-statistics for the mean. Covariances are reported in units of basis points squared.

	(1)	(2)	(3)	(4)	(5)	(6)
A. Fed						
News type	No. events	Fraction(%)	Median Cov	t-Median	Mean Cov	t-Mean
A1. Monetary policy decisions (scheduled only), window (-15,+15) minutes						
(1,1) Growth expectations	53	32.5	46.18***	(3.46)	98.72***	(4.69)
(1,2) MP (rate expectations)	86	52.8	−51.88***	(−5.18)	−144.70***	(−5.11)
(2,1) Risk premia	11	6.7	4.06	(0.15)	29.01*	(1.87)
(2,2) MP (long-end)	13	8.0	−11.74	(−0.20)	−427.63	(−1.19)
A2. Minutes and press conferences, window (-15,+90) minutes						
(1,1) Growth expectations	84	51.2	21.26***	(5.74)	53.15***	(3.98)
(1,2) MP (rate expectations)	50	30.5	−17.25***	(−3.10)	−31.58***	(−6.20)
(2,1) Risk premia	26	15.9	11.63**	(2.49)	17.38***	(5.28)
(2,2) MP (long-end)	4	2.4	−8.82*	(−2.25)	−6.07*	(−2.42)
A3. Other events, window (-15,+90) minutes						
(1,1) Growth expectations	23	65.7	120.78	(1.60)	278.35***	(3.23)
(1,2) MP (rate expectations)	3	8.6	−60.14	(−1.35)	−55.97	(−1.80)
(2,1) Risk premia	5	14.3	40.81	(0.40)	130.74	(1.81)
(2,2) MP (long-end)	4	11.4	−86.96	(−1.84)	−87.96	(−1.98)
B. ECB						
News type	No. events	Fraction(%)	Median Cov	t-Median	Mean Cov	t-Mean
B1. Monetary policy decisions, window (-15,+15) minutes						
(1,1) Growth	89	35.6	2.92***	(4.33)	7.64***	(5.55)
(1,2) MP (rate expect)	131	52.4	−5.33***	(−4.01)	−82.46***	(−3.43)
(2,1) Risk premia	20	8.0	3.04	(1.08)	6.12***	(3.61)
(2,2) MP (long-end)	10	4.0	−10.7	(−1.21)	−28.52	(−1.46)
B2. Press conferences, window (-15,+90) minutes						
(1,1) Growth	118	54.1	39.9***	(7.04)	54.68***	(10.03)
(1,2) MP (rate expect)	66	30.3	−22.94***	(−4.65)	−42.28***	(−6.02)
(2,1) Risk premia	20	9.2	39.52*	(1.76)	78.44**	(2.83)
(2,2) MP (long-end)	14	6.4	−36.2**	(−2.87)	−47.11**	(−2.45)
B3. Other events, window (-15,+90) minutes						
(1,1) Growth	86	60.1	21.99***	(3.41)	77.51***	(5.08)
(1,2) MP (rate expect)	23	16.1	−4.00**	(−2.42)	−6.07***	(−5.05)
(2,1) Risk premia	27	18.9	13.03	(0.52)	81.09***	(2.90)
(2,2) MP (long-end)	7	4.9	−6.23	(−0.83)	−14.75*	(−1.92)

Table V. Effect of Fed's unconventional policy measures on joint dynamics of stocks and the yield curve

Panel A reports the number of unconventional monetary policy (UMP) events, broken down by major policy programs or policy phases. The individual programs are described in Online Appendix D. We indicate the first and last observation of key announcements related to each program or policy phase. The subset of UMP events that contained a novel forward guidance element is reported as "of which: FG." Note that summing the number of events over policy programs does not necessarily yield the total number of UMP events, as in some cases the same event may have contained news about more than one policy program. Panel B presents the regressions of realized stock-yield covariances on dummy variables for each program, and interactions of program dummies with a dummy for whether the announcement had a forward guidance component. Robust standard errors are in parentheses. Covariances are measured over the (-15; +90) minute window and are reported in units of basis points squared. The regressions are estimated over the sample from 2008 through 2017, controlling for covariances on non-Fed announcement days.

A. Summary of UMP events

	No. annc.	First obs.	Last obs.
UMP	45	12 Dec 2007	01 Nov 2017
of which: FG	9	16 Dec 2008	18 Mar 2015
Phases:			
QE1 (quantitative easing phase 1)	5	25 Nov 2008	18 Mar 2009
Exit (early)	3	12 Aug 2009	04 Nov 2009
QE2 (quantitative easing phase 2)	5	10 Aug 2010	03 Nov 2010
MEP (maturity extension program/operation twist)	4	26 Aug 2011	01 Aug 2012
QE3 (quantitative easing phase 3)	3	31 Aug 2012	30 Oct 2013
Tapering of asset purchases	2	22 May 2013	19 Jun 2013
Exit (late)	9	18 Dec 2013	29 Oct 2014
Balance sheet wind-down	3	26 Jul 2017	01 Nov 2017

B. Regression analysis of realized stock-yield covariances

	3m	2y	5y	10y	30y
QE1	154.9**	251.8***	415.5***	316.2***	282.8***
	(2.33)	(3.36)	(8.28)	(6.51)	(4.95)
QE1 × FG	-1098.0***	-1168.7***	-3041.8**	-2898.7*	-2753.4*
	(-10.54)	(-14.51)	(-2.03)	(-1.78)	(-1.72)
Exit (early)	38.0*	39.0	83.3	57.0	79.6
	(1.72)	(0.95)	(1.48)	(1.26)	(1.64)
QE2	-15.8	-24.3	-12.3	7.01	14.7
	(-0.55)	(-0.45)	(-0.12)	(0.07)	(0.15)
QE3	-12.4***	-7.87***	1.53	5.51***	13.9***
	(-19.68)	(-6.58)	(1.26)	(5.26)	(15.48)
QE3 × FG	11.4***	32.1	29.8	31.4	85.7
	(9.42)	(0.91)	(0.68)	(0.82)	(1.21)
MEP	-36.8*	-4.80	129.8	172.2*	241.2***
	(-1.81)	(-0.10)	(1.01)	(1.94)	(2.73)
MEP × FG	-45.1	238.9	552.6	397.4	281.6
	(-0.89)	(1.17)	(1.02)	(0.89)	(0.73)
Tapering of asset purchases	-5.16*	-66.6***	-146.4***	-148.8***	-121.2***
	(-1.65)	(-4.35)	(-3.73)	(-5.12)	(-3.84)
Exit (late)	-6.67***	-21.5	-33.5	-27.8	-28.7
	(-2.84)	(-1.41)	(-1.05)	(-1.02)	(-1.24)
Exit (late) × FG	-23.0	-116.6***	-307.3***	-248.2**	-181.0*
	(-1.46)	(-7.62)	(-3.80)	(-2.25)	(-1.90)
Balance sheet wind-down	-14.5***	-34.9***	-41.0***	-41.8***	-34.3***
	(-5.92)	(-6.69)	(-10.51)	(-21.65)	(-32.67)
Constant	5.30***	26.3***	39.3***	36.9***	36.5***
	(8.40)	(21.97)	(32.31)	(35.23)	(40.59)
R^2	0.084	0.027	0.15	0.18	0.20

Table VI. Effect of ECB's unconventional policy measures on joint dynamics of stocks and the yield curve

The table summarizes results for UMP by the ECB. The regressions are estimated over the sample from 2007 though 2017. See caption to Table V for further details.

A. Summary of UMP events

	No. annc.	First obs.	Last obs.
UMP	87	22 Aug 2007	26 Oct 2017
of which: FG	9	04 Jul 2013	21 Jul 2016
Phases:			
LTRO1 (long-term refinancing operations phase 1)	15	22 Aug 2007	17 Nov 2008
USD liquidity (swap lines with the Fed)	23	12 Dec 2007	24 Jan 2014
LTRO2 (long-term refinancing operations phase 2)	15	07 May 2009	06 Oct 2011
CBPP (covered bond purchases)	13	07 May 2009	02 Oct 2014
SMP (securities market program)	8	09 May 2010	06 Oct 2011
LTRO3 (long-term refinancing operations phase 3)	5	01 Dec 2011	28 Feb 2012
OMT (outright monetary transactions)	6	26 Jul 2012	30 Nov 2012
PSPP (public sector debt purchase)	21	06 Nov 2014	26 Oct 2017
LTRO4 (long-term refinancing operations phase 4)	8	05 Jun 2014	10 Mar 2016
CSPP (corporate sector bond purchases)	12	10 Mar 2016	26 Oct 2017

B. Regression analysis of realized stock-yield covariances

	3m	2y	5y	10y
LTRO1	8.24	66.1**	62.7**	38.9*
	(0.82)	(2.14)	(2.00)	(1.79)
USD liquidity	9.90	154.4***	140.9***	115.5***
	(0.58)	(3.27)	(2.92)	(2.81)
LTRO2	-17.5	7.14	21.0	21.1
	(-0.72)	(0.32)	(0.69)	(0.79)
CBPP	-0.067	22.5	38.9	50.5
	(-0.00)	(0.64)	(0.88)	(1.28)
SMP	-93.6	102.5	215.7**	198.5***
	(-1.55)	(1.56)	(2.43)	(2.59)
LTRO3	-20.9	29.1	115.0***	227.8***
	(-1.15)	(1.37)	(3.77)	(3.35)
OMT	-2.31	67.8***	232.8***	275.0***
	(-0.55)	(2.91)	(2.92)	(3.34)
PSPP	-19.4**	-45.3***	-56.4**	-62.5*
	(-2.15)	(-2.86)	(-2.42)	(-1.87)
LTRO4	-10.7	-12.7	-31.8	-34.7
	(-0.42)	(-1.01)	(-1.05)	(-0.86)
CSPP	26.3	11.7	-53.1*	-62.6
	(1.60)	(0.74)	(-1.74)	(-1.61)
FG	-24.7**	-48.7**	-47.3	-19.3
	(-1.98)	(-2.11)	(-0.84)	(-0.50)
Constant	2.40***	16.3***	24.4***	26.1***
	(4.73)	(27.26)	(36.34)	(41.76)
R^2	0.006	0.035	0.054	0.065

Table VII. Effect of unconventional policy measures on joint dynamics of stocks and the yield curve: BOE and BOJ

The table summarizes results for UMP by the BOE and BOJ. The regressions are estimated over the sample from 2008 though 2017 for the BOE and from 2003 though 2017 for the BOJ. See caption to Table V for further details.

A. Summary of UMP events

	No. events	First obs.	Last obs.
BOE			
UMP	32	19 Jan 2009	04 Aug 2016
of which: FG	9	04 Jul 2013	16 Sept 2015
Phases:			
USD liquidity (swap lines with the Fed)	17	02 May 2008	17 Jun 2014
APF1 (asset purchase facility phase 1)	12	19 Jan 2009	04 Feb 2010
APF2 (asset purchase facility phase 2)	5	06 Oct 2011	29 Feb 2012
APF3 (asset purchase facility phase 3)	4	05 Jul 2012	26 Feb 2013
APF4 (asset purchase facility phase 4)	1	04 Aug 2016	04 Aug 2016
BOJ			
UMP	39	16 Sept 2003	21 Sep 2016
Phases:			
USD liquidity (swap lines with the Fed)	15	18 Sep 2008	29 Jul 2016
QEP (quantitative easing phase 1)	3	10 Oct 2003	09 Mar 2006
Stocks / REITS	6	16 Sep 2003	29 Jul 2016
QEAPP (quantitative easing phase 2)	18	19 Dec 2008	22 Jan 2013
QQE (quantitative and qualitative easing)	3	04 Apr 2013	19 Nov 2015
QQE with negative rates	2	29 Jan 2016	29 Jul 2016
QQE with yield curve control	1	21 Sep 2016	21 Sep 2016

B. Regression analysis of realized stock-yield covariances

BOE	3m	10y
USD liquidity	-18.2	74.2*
	(-0.88)	(1.84)
APF1	11.4	-1.82
	(1.25)	(-0.10)
APF2	15.2**	-41.2
	(2.03)	(-0.86)
APF3	29.1	8.15
	(1.25)	(0.48)
APF4	-99.5***	-310.5***
	(-98.11)	(-557.01)
FG	-0.34	-21.5***
	(-0.15)	(-3.04)
Constant	0.059	20.4***
	(0.06)	(36.68)
R^2	0.000	0.013

BOJ	10y
USD liquidity	11.2
	(1.50)
QEP	-9.99**
	(-2.38)
Stocks/REITS	37.6*
	(1.65)
QEAPP	-15.8
	(-1.06)
QQE	-80.4***
	(-5.19)
QQE with negative rates	-154.2*
	(-1.76)
QQE with yield curve control	28.4***
	(164.12)
Constant	5.63***
	(32.57)
R^2	0.041

Table VIII. Variance decompositions of yield changes and stock returns around communication events

The table presents variance decompositions of shocks to two- and ten-year yield and to stock returns around scheduled FOMC decision announcements (window -15 to +15 minutes) and ECB press conferences (window -15 to +90 minutes). The numbers in each row report the variance ratio, i.e., the fraction of variance of yield changes (stock returns) explained by each structural shock. The decomposition is obtained by imposing sign and monotonicity restrictions. The results are based on 2000 simulations of rotation matrices that satisfy the restrictions. We report the average variance ratios across simulations. T-statistics in parentheses are obtained by diving the average variance ratio by its standard deviation across simulations.

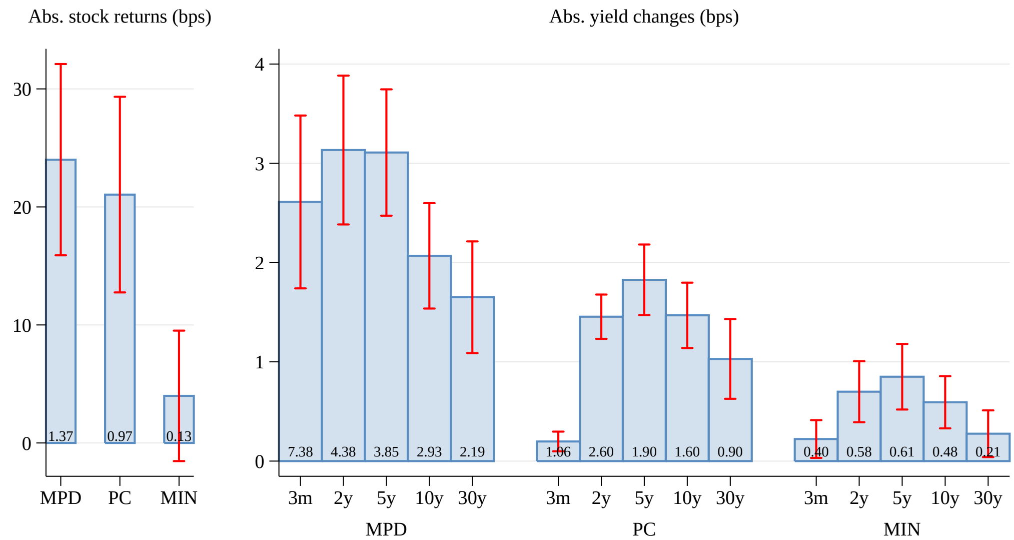
A. Fed: scheduled monetary policy decisions

	growth	monetary policy	risk preferences
2y yield changes	0.49	0.43	0.09
	(2.79)	(2.51)	(1.21)
10y yield changes	0.08	0.35	0.58
	(0.89)	(4.37)	(6.14)
stock returns	0.11	0.87	0.03
	(0.85)	(7.28)	(0.90)

B. ECB: press conferences

	growth	monetary policy	risk preferences
2y yield changes	0.50	0.42	0.09
	(1.82)	(1.66)	(1.02)
10y yield changes	0.12	0.25	0.63
	(0.96)	(1.94)	(4.44)
stock returns	0.31	0.59	0.10
	(1.11)	(2.52)	(0.92)

Panel A. Fed



Panel B. ECB

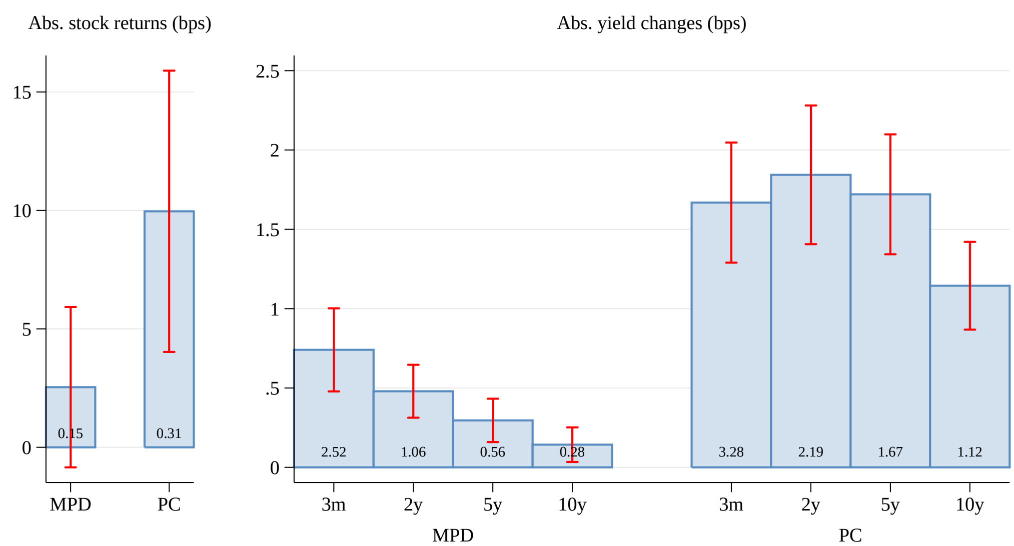
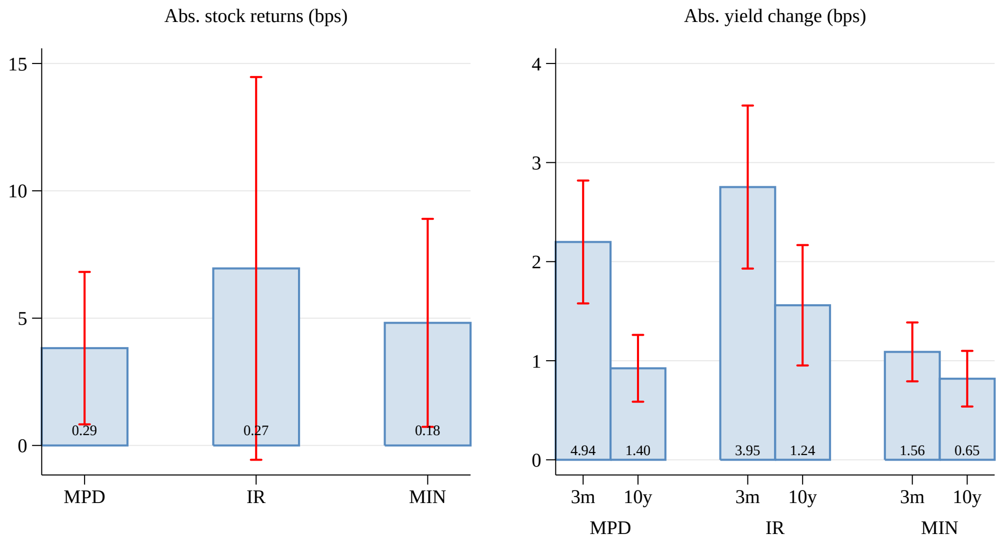


Figure 1. Reactions of stocks and yields to central bank communication events

The figure summarizes the effect of monetary policy communication events on absolute stock market returns and absolute yield changes (in basis points). Bars present slope coefficients from a regression of absolute stock returns (or absolute yield changes) on a constant and a dummy variable indicating a type of communication. Those types are: monetary policy decisions (MPD), press conferences (PC), minutes releases (MIN) and, for the BOE, releases of inflation reports (IR). The height of the bar measures the incremental effect (in bps) of communication events relative to the baseline variation in asset prices absent central bank news. Error bars indicate 95% robust confidence interval. The number superimposed on each bar reports the regression slope coefficient divided by the regression intercept. For example, a ratio of 2 means that absolute returns are 200% higher around an event relative to their baseline variation on other days (over a window of the same length as the event window). The event window is from -15 to +15 minutes around MPDs and from -15 to +90 minutes around other events. Detailed regression estimates are discussed in Internet Appendix A.

Panel C. BOE



Panel D. BOJ

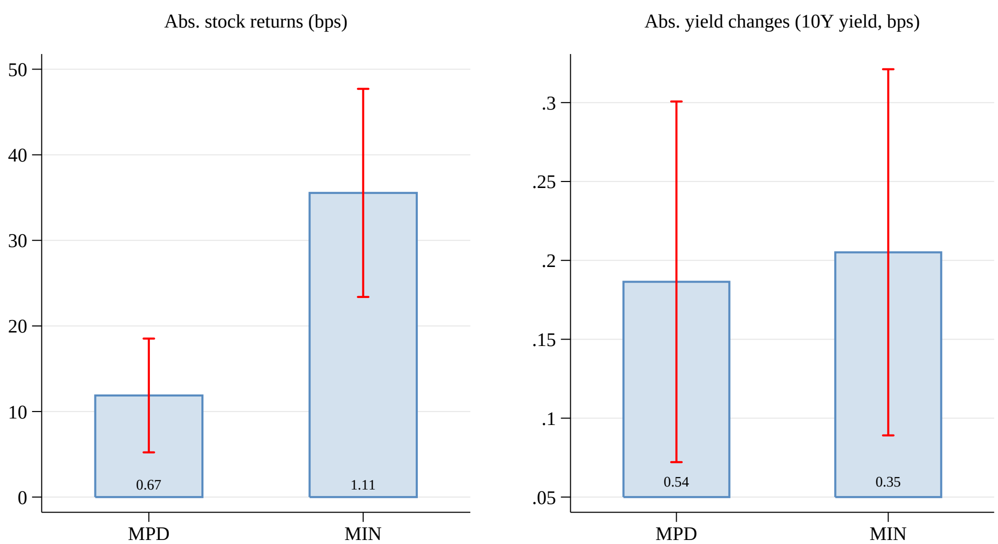


Figure 1. Reactions of stocks and yields to central bank communication events (continued)

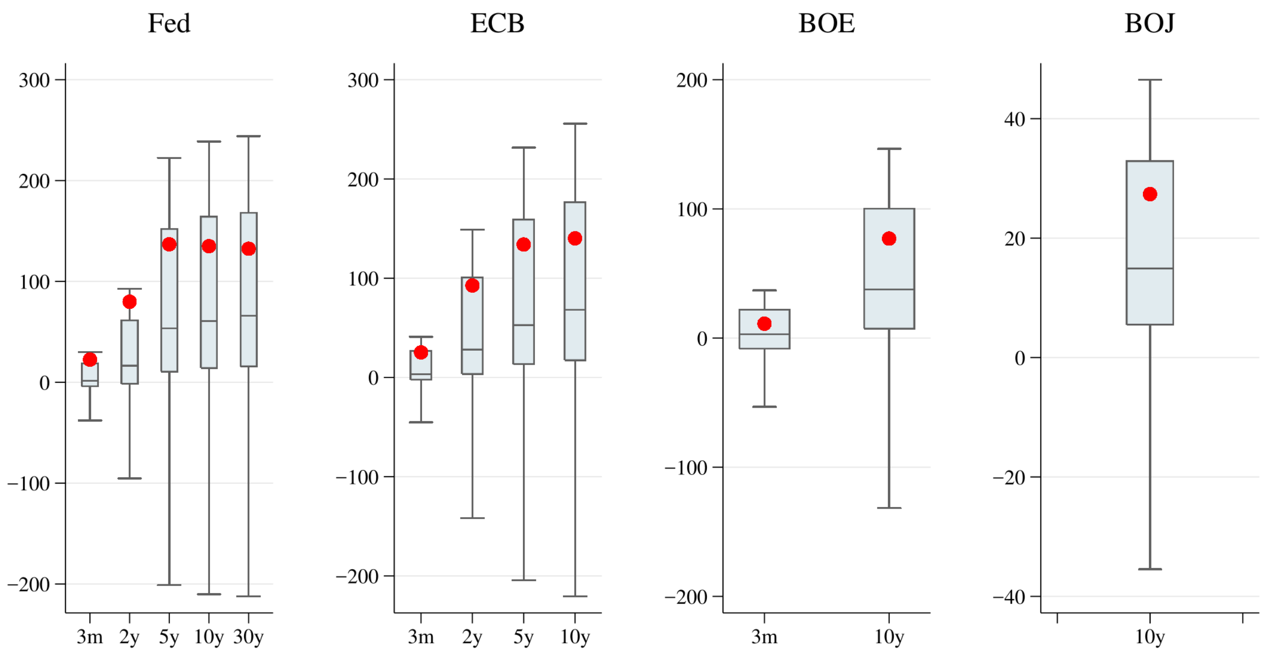


Figure 2. Term structures of realized stock-yield covariances on non-monetary policy days

The figure presents distribution of realized stock-yield covariances across available maturities on non-monetary policy days. Realized covariances are constructed by summing up products of one-minute stock returns with yield changes each day, and are reported in units of basis points squared. Mean covariances are marked with circles. Box borders indicate the upper and lower quartiles, the line within the box is the median. The whiskers identify the largest and smallest adjacent values calculated as upper quartile +1.5×IQR (interquartile range) and lower quartile −1.5×IQR. Extreme values are not shown.

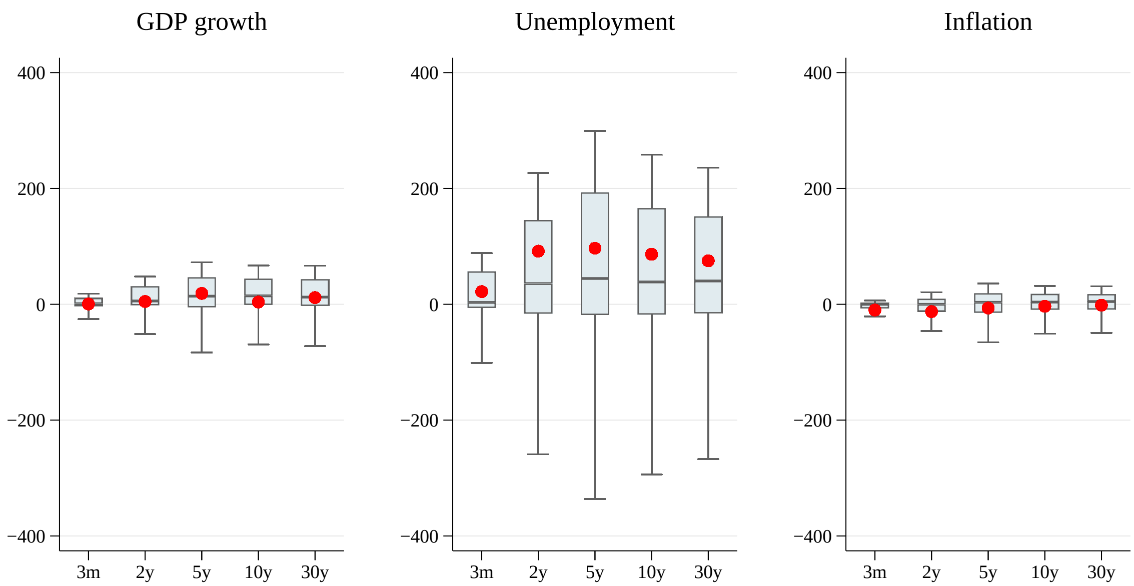


Figure 3. Term structure of stock-yield covariances around US macro announcements

The figure plots the distribution of the realized stock-yield covariances around macroeconomic announcements. The time stamps of macroeconomic announcements are from Bloomberg and we use the following tickers: USURTOT Index for unemployment rate (released together with non-farm payrolls); CPI CHNG Index for CPI inflation rate (other CPI indices are announced at the same time); GDP CQOQ Index for GDP growth (advance announcement). Covariances are constructed over the (-15,+60) minute window around the release. Underlying the plot, there are 243 inflation releases, 243 unemployment releases, and 81 GDP release.

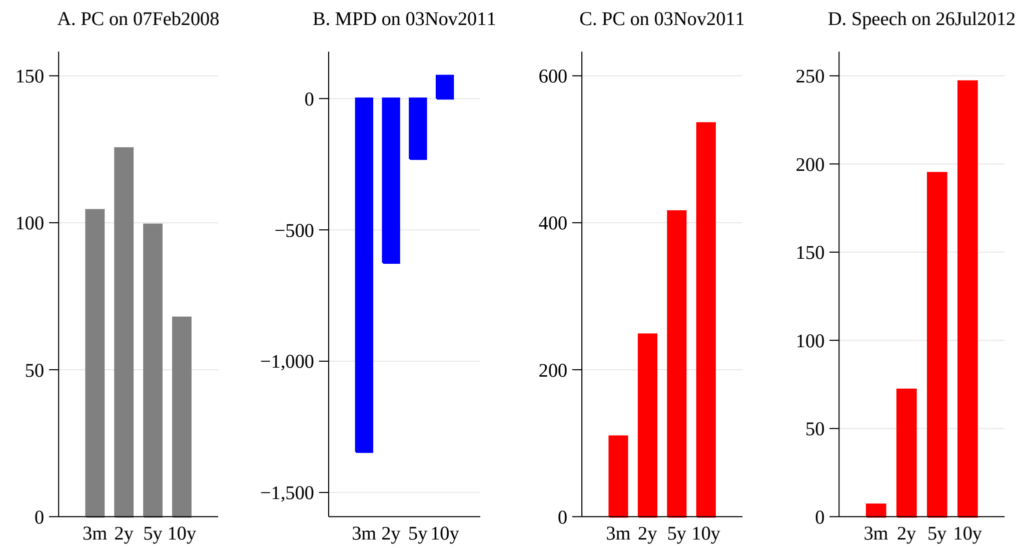


Figure 4. Term structures of stock-yield covariances: selected ECB events

The figure presents the term structure of realized stock-yield covariances around selected ECB communication events: press conference on Feb 7, 2008; monetary policy decision (rate cut) and press conference on Nov 3, 2011 (Draghi's first communications as the President of the ECB), and Draghi's speech on July 26, 2012. Covariances are reported in units of basis points squared.

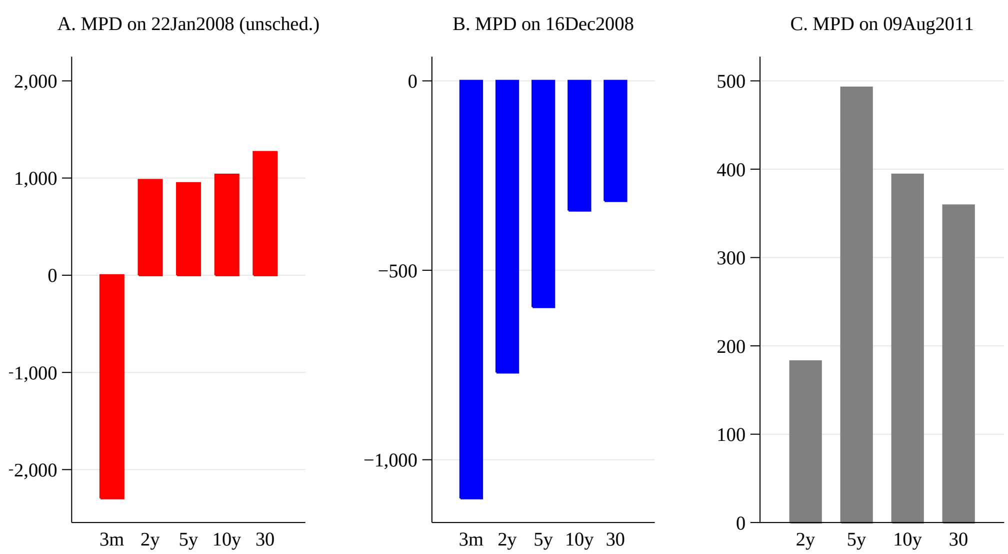


Figure 5. Term structures of stock-yield covariances: selected Fed events

The figure presents the term structure of realized stock-yield covariances around Fed communication events: unscheduled FOMC decision announcement on Jan 22, 2008 and two scheduled FOMC announcements on Dec 16, 2008 and Aug 09, 2011. Covariances are reported in units of basis points squared.

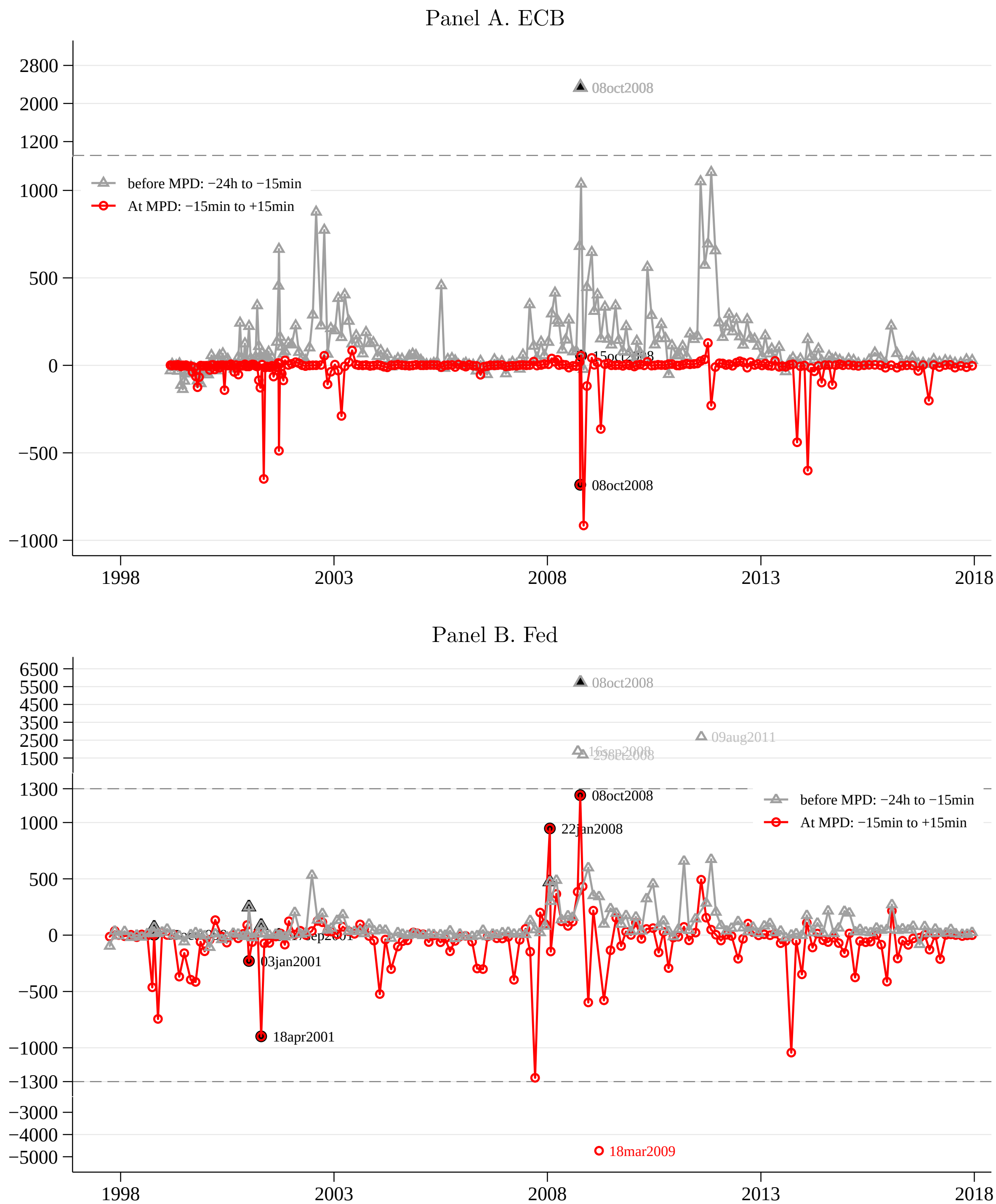


Figure 6. Realized covariances of stocks with 5-year yield 24 hours before and at the monetary policy decision

The figure presents realized covariances of stocks and five-year yields from 24 hours before policy decision to -15 minutes before (gray triangles) and from -15 minutes to +15 minutes around the decision (red circles). The y-axes are broken to accommodate outliers. The realizations at unscheduled MPD announcements are indicated with black-filled markers. Those dates are Oct 8 and Oct 15, 2008 for the ECB and Jan 2, 2001; Apr 18, 2001; Sep 9, 2001; Jan 22, 2008; Oct 8, 2008 for the Fed. The black-filled triangles mark covariances in the 24 hours before an unscheduled announcement.

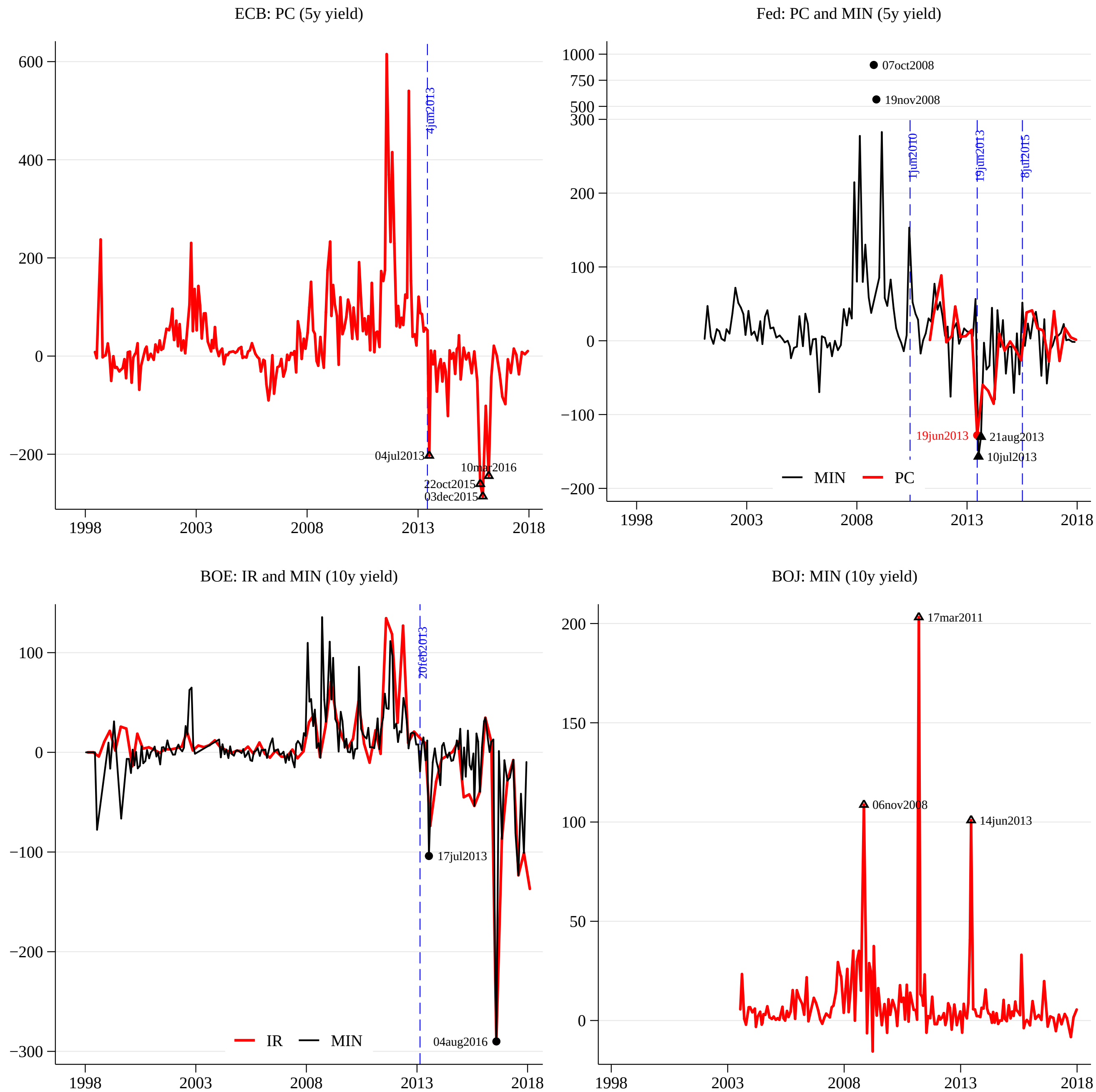


Figure 7. Realized stock-yield covariances around communication events

The figure presents the realized covariances of stocks and yields around central bank communication events. We consider the following events: press conferences for the ECB, minutes' released and press conferences for the Fed, minutes' releases and inflation report releases for the BOE, and minutes releases for the BOJ. Covariances are computed using a window from -15 to +90 minutes of the time-stamp of the event. Vertical lines indicate break dates in average covariances identified with Bai and Perron (1998) test (see Table III for details).

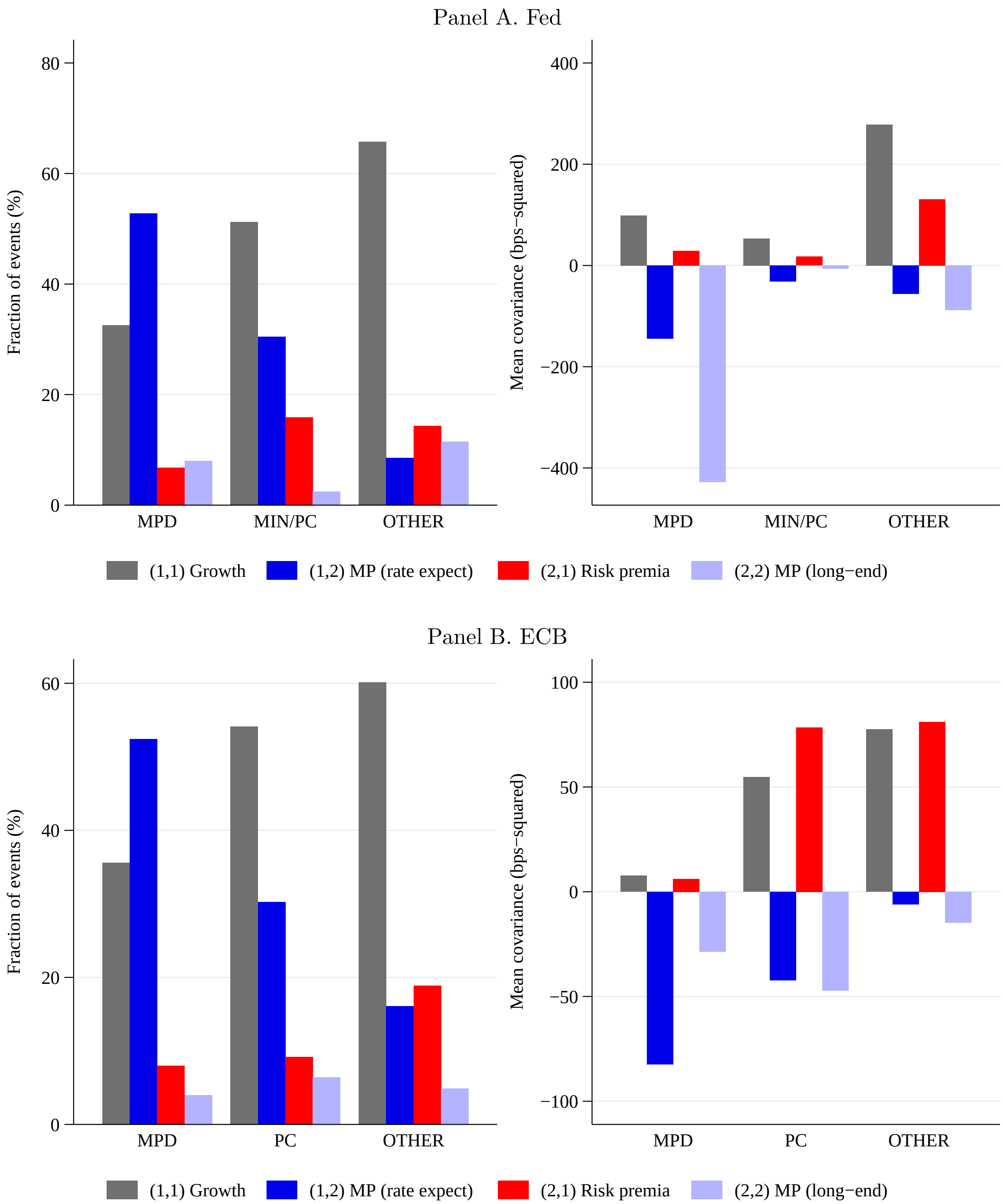


Figure 8. Classification of central bank communication events

The figure accompanies the results reported in Table IV, and displays frequencies of events and mean covariance by news type.

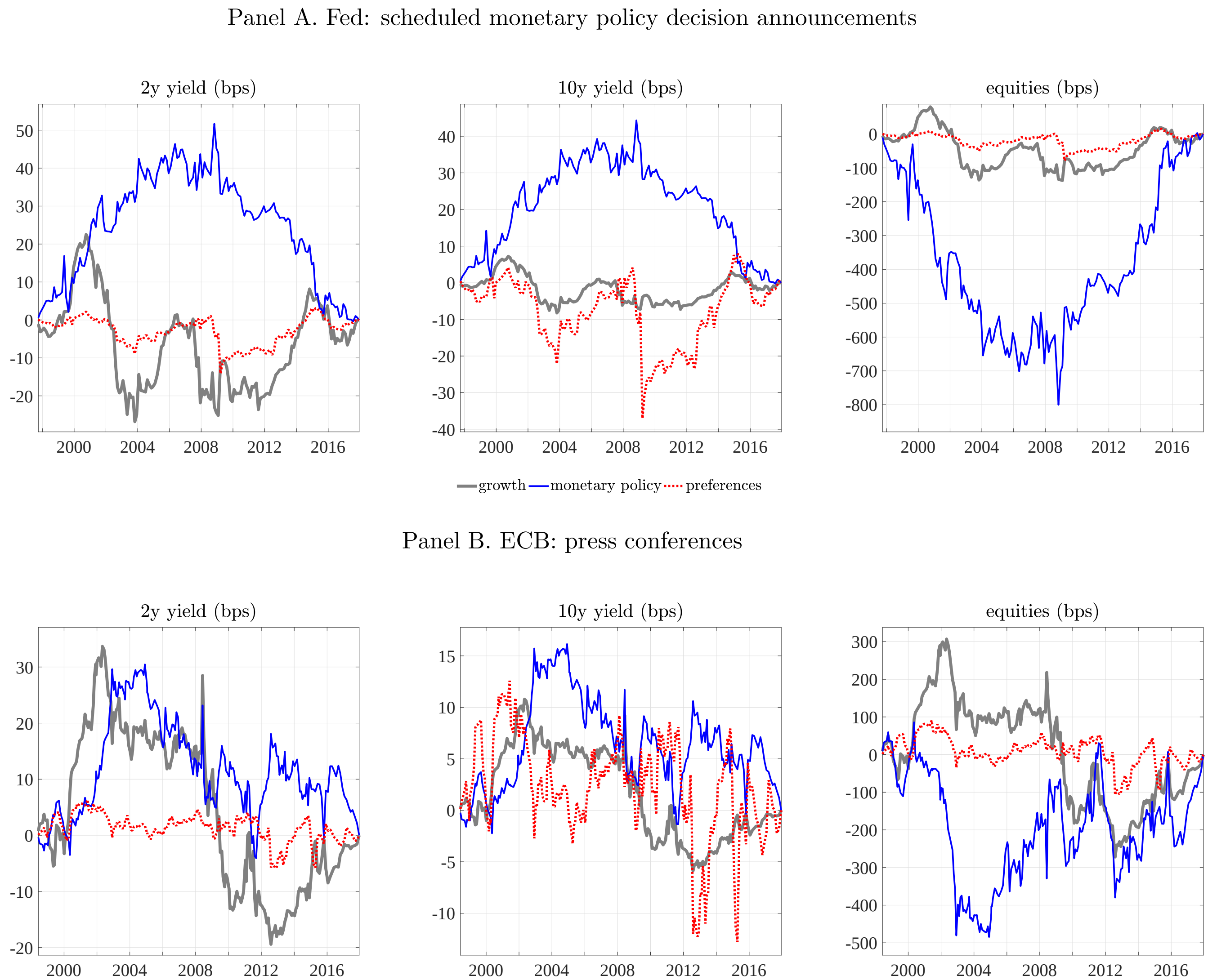


Figure 9. Historical decompositions of yields changes and stock returns

The figure presents historical decompositions of shocks to two- and ten-year yields and stock returns around scheduled FOMC decision announcements (window -15 to +15 minutes) and ECB press conferences (window -15 to +90 minutes). Shocks are normalized to have zero mean and are cumulated over time. The decomposition is obtained by imposing sign and monotonicity restrictions.

Appendix

Illustrative model

To formalize the intuition underlying Section I and our interpretation of the empirical results, we present a stylized model for the joint dynamics of stocks and nominal yields in this Appendix.

We assume there are four state variables that describe the economy: expected inflation τ_t, expected growth g_t, a monetary policy factor f_t, and a price-of-risk factor x_t. All state variables follow AR(1) processes with independent shocks. Written compactly $F_t = (\tau_t, g_t, f_t, x_t)'$,

$$F_{t+1} = \mu + \Phi F_t + \Sigma \varepsilon_{t+1}, \tag{A.1}$$

where Φ, Σ are diagonal matrices with elements ϕ_k, and σ_k on the diagonal, $k = \{\tau, g, f, x\}$, and $\varepsilon_{t+1} = (\varepsilon^{\tau}_{t+1}, \varepsilon^{g}_{t+1}, \varepsilon^{f}_{t+1}, \varepsilon^{x}_{t+1})'$. We assume that F_t is stationary with elements $0 < \phi_k < 1$. To keep the model simple, the conditional covariance matrix of shocks $\Sigma\Sigma'$ is constant.[27] The nominal short rate $i_t := y^{(1)}_t$ is:

$$i_t = \delta_0 + \delta_\tau \tau_t + \delta_g g_t + \delta_f f_t. \tag{A.2}$$

The nominal log SDF which prices nominal assets is $m_{t+1} = -i_t - 0.5\Lambda_t'\Lambda_t - \Lambda_t'\varepsilon_{t+1}$, where Λ_t is a linear function of F_t (made more specific below). Realized inflation equals expected inflation plus an orthogonal shock $\pi_{t+1} = \tau_t + \varepsilon^{\pi}_{t+1}$, thus $\tau_t = E_t(\pi_{t+1})$. Similarly, the real dividend growth rate evolves as expected growth plus an orthogonal shock $\Delta d_{t+1} = g_t + \varepsilon^{d}_{t+1}$, thus $g_t = E_t(\Delta d_{t+1})$. Shocks ε^{π}_{t+1} and ε^{d}_{t+1} are uncorrelated with other shocks in the economy. The real log SDF which prices real assets is $m^r_{t+1} = m_{t+1} + \pi_{t+1}$.

We assume that investors require compensation for facing shocks to expected growth ε^{g}_{t+1} and to expected inflation ε^{τ}_{t+1} (shocks to realizations, ε^{π}_{t+1} and ε^{d}_{t+1}, are not priced), and that risk premia move on a single price-of-risk factor x_t. Specifically, shocks to the nominal log-SDF have the form:

$$-\left(m_{t+1} - E_t(m_{t+1})\right) = \left(\frac{1}{\sigma_\tau}\lambda_{\tau x}\varepsilon^{\tau}_{t+1} + \frac{1}{\sigma_g}\lambda_{gx}\varepsilon^{g}_{t+1}\right) x_t. \tag{A.3}$$

Several comments are in order. The short rate equation (A.2) captures the intuition of forward looking Taylor rules. The variable f_t is a reduced-form way of summarizing the effect of monetary policy on interest rates beyond just iid monetary policy shocks.[28] The ex-ante real rate, $r_t = i_t - E_t\pi_{t+1}$, is $r_t = \delta_0 + (\delta_\tau - 1)\tau_t + \delta_g g_t + \delta_f f_t$. Note that when $\delta_\tau = 1$, the ex-ante real rate only depends on expected growth and the monetary policy factor, but not expected inflation. If $\delta_\tau > 1$, the ex-ante real rate is affected by expected inflation, introducing inflation non-neutrality.

[27] While there is clear evidence of time-varying volatility of stock returns and the yield curve, the link between volatility and risk premia remains debated. Using a rich model with time-varying volatility, Cieslak and Povala (2016) show that the cross-section of yields is well modelled with purely Gaussian dynamics, and factors driving volatility of yields have a minimal impact on the cross-section of yields.

[28] For example, Cieslak (2018) shows that monetary policy affects short rate expectations in a persistent fashion beyond the systematic policy response to macroeconomic factors. Modeling the short rate with a monetary policy shock and a smoothing component would not qualitatively change the intuition arising from this setting.

The price-of-risk factor x_t determines the variation of risk premia in the model. Its shocks can be viewed as shocks to preferences that are not related to fundamentals.[29] This specification is grounded by the empirical facts. There is ample evidence by now that conditional risk premia on stocks and bonds move on a higher frequency than the typical business cycle frequency and are therefore hard to explain with macroeconomic fundamentals.[30] The price-of-risk factor x_t does not affect the short rate, i.e. $\delta_x = 0$, which implies that the central bank does not directly respond to variation in risk premia.

Nominal yield curve

Bond yields have the well-known affine form: $y_t^{(n)} = \mathcal{A}_n + \mathcal{B}_n' F_t$, with $\mathcal{A}_1 = \delta_0$ and $\mathcal{B}_1 = \delta_1$. The model decomposes shocks to yields in equation (2) as

$$y_{t+1}^{(n)} - E_t(y_{t+1}^{(n)}) = \mathcal{B}_n' \Sigma \varepsilon_{t+1} = \mathcal{B}_n^\tau \sigma_\tau \varepsilon_{t+1}^\tau + \mathcal{B}_n^g \sigma_g \varepsilon_{t+1}^g + \mathcal{B}_n^f \sigma_f \varepsilon_{t+1}^f + \mathcal{B}_n^x \sigma_x \varepsilon_{t+1}^x. \tag{A.4}$$

To understand how shocks affect the cross-section of yields, we analyze $\mathcal{B}_n$ coefficients as function of maturity n. Equations (A.1), (A.2) and (A.3) together lead to the following loadings of yields on the state variables:

$$\mathcal{B}_n^k = \frac{\delta_k}{n} \frac{1 - \phi_k^n}{1 - \phi_k} \quad \text{for} \quad k = \{\tau, g, f\} \tag{A.5}$$

$$\mathcal{B}_n^x = \frac{n-1}{n} (-\mathcal{B}_{n-1}^\tau \lambda_{\tau x} - \mathcal{B}_{n-1}^g \lambda_{gx} + \mathcal{B}_{n-1}^x \phi_x), \tag{A.6}$$

Equation (A.5) shows that as long as the state variables have a positive effect on the short rate ($\delta_k > 0$) and are persistent but stationary ($0 < \phi_k < 1$), $\mathcal{B}_n^k$ loadings are also positive. In this case, yields covary positively with expected inflation, expected growth and with the monetary policy factor. The positive loadings δ_τ and δ_g are consistent with Taylor rule estimates. These estimates also suggest that $0 < \delta_g < \delta_\tau$, and $\delta_g < 1$, whereas δ_τ could be above unity (akin to the so-called Taylor principle), depending on the monetary policy regime. Coefficient δ_f is a reduced-form way of modeling the strength with which the central bank can affect the yield curve.

The persistence of state variables determines their effects across maturities. With high persistence (ϕ_τ close to 1), expected inflation has a "level" effect on the term structure, i.e. $\mathcal{B}_n^\tau$ is nearly flat across maturities. Less persistent variables that are the main driver of the real rate (g_t and f_t) vary at a higher, business-cycle, frequency. Accordingly their $\mathcal{B}_n$-loadings decline faster across maturities than $\mathcal{B}_n^\tau$.[31]

The price-of-risk factor x_t determines the variation in bond risk premia (and yield term premia):

[29] Models with a single source of variation in the price of risk and only a subset of shocks that are priced have been studied by Lettau and Wachter (2011), Campbell et al. (2017), Ang et al. (2008), among others. In these models, the price of risk is assumed to follow a univariate process that is independent of other state variables. The role of independent preference shocks for explaining stock market valuations has been also highlighted by Albuquerque et al. (2016).

[30] See Kelly and Pruitt (2013) and Martin (2017) for evidence on equity market risk premia and Cieslak and Povala (2015) for evidence on bond risk premia. In particular, Cieslak and Povala (2015) find that risk premium dynamics in bonds are orthogonal to both real rate and inflation expectations.

[31] This intuition is confirmed by the calibration in Cieslak and Povala (2015).

$$E_t(ex_{t+1}^{(n)}) + \frac{1}{2}Var_t(ex_{t+1}^{(n)}) = -(n-1)(\mathcal{B}_{n-1}^{\tau}\lambda_{\tau x} + \mathcal{B}_{n-1}^{g}\lambda_{gx})x_t. \tag{A.7}$$

Intuitively, positive shocks to x_t lead to a decline in the bond risk premium if coefficients $\lambda_{\tau x}$ and λ_{gx} are positive (as both $\mathcal{B}_n^{\tau} > 0$ and $\mathcal{B}_n^{g} > 0$). Positive signs of $\lambda_{\tau x}$ and λ_{gx} capture the notion of expected growth and expected inflation being procyclical, and bonds providing insurance in bad times.[32] In that case, positive shocks to the price-of-risk factor x_t decrease yields more at longer maturities ($\mathcal{B}_n^{x}$ decreases with maturity). In general, this effect survives, albeit weakens, if only shocks to expected growth are priced with $\lambda_{gx} > 0$, as in a regime when inflation expectations are very stable.[33]

Stocks

Under model assumptions, the log price-dividend ratio is also affine in the state vector, $pd_t = A_s + B_s' F_t$. Using log-linearized returns, unexpected stock returns can be decomposed as:

$$r_{s,t+1} - E_t(r_{s,t+1}) = \kappa_1 B_s' \Sigma \varepsilon_{t+1} + \varepsilon_{t+1}^{d} \tag{A.8}$$

$$= \kappa_1(B_s^{\tau}\sigma_{\tau}\varepsilon_{t+1}^{\tau} + B_s^{g}\sigma_{g}\varepsilon_{t+1}^{g} + B_s^{f}\sigma_{f}\varepsilon_{t+1}^{f} + B_s^{x}\sigma_{x}\varepsilon_{t+1}^{x}) + \varepsilon_{t+1}^{d}, \tag{A.9}$$

with loadings

$$B_s^{\tau} = \frac{1-\delta_{\tau}}{1-\kappa_1\phi_{\tau}}, \quad B_s^{g} = \frac{1-\delta_{g}}{1-\kappa_1\phi_{g}}, \quad B_s^{f} = -\frac{\delta_{f}}{1-\kappa_1\phi_{f}}, \tag{A.10}$$

$$B_s^{x} = \frac{-\kappa_1(B_s^{\tau}\lambda_{\tau x} + B_s^{g}\lambda_{gx})}{1-\kappa_1\phi_{x}}, \tag{A.11}$$

where the linearization constant κ_1 is slightly less than one and depends only on the unconditional average of pd_t.

Stocks are unaffected by expected inflation ($B_s^{\tau} = 0$) if $\delta_{\tau} = 1$. If $\delta_{\tau} > 1$ positive shocks to expected inflation decrease stock prices ($B_s^{\tau} < 0$) via the discount rate channel as they raise the real short rate. Shocks to growth expectations raise stock prices ($B_s^{g} > 0$) if $0 < \delta_g < 1$, i.e. the real short rate increases less than one for one with growth expectations. Monetary policy shocks decrease stock prices as $B_s^{f} < 0$ if $\delta_f > 0$. Similar to bond risk premia, stock risk premia vary with x_t:

$$E_t(ex_{t+1}^{s}) + \frac{1}{2}Var_t(ex_{t+1}^{s}) = \kappa_1(B_s^{\tau}\lambda_{\tau x} + B_s^{g}\lambda_{gx})x_t. \tag{A.12}$$

With market price of risk parameters $\lambda_{\tau x} > 0$ and $\lambda_{gx} > 0$, positive price-of-risk shocks lower stock prices ($B_s^{x} < 0$) and increase stock risk premia ($(B_s^{\tau}\lambda_{\tau x} + B_s^{g}\lambda_{gx}) > 0$) if the pricing of growth shock dominates the inflation effect (as with $\delta_{\tau} \leq 1$). In this case, stocks are risky assets and bonds are

[32] With procyclical inflation, inflation is low when marginal utility is high and $cov_t(\sigma_{\tau}\varepsilon_{t+1}^{\tau}, m_{t+1} - E_t(m_{t+1})) = -\lambda_{\tau x}x_t < 0$. This means $\lambda_{\tau x} > 0$ assuming that x_t, the volatility of the SDF, is a positive process. Similar logic applies to the pricing of growth shocks.

[33] The result is overturned with countercyclical inflation (when $\lambda_{\tau x} < 0$), such as in the US in the 1970s and 80s. However, data from late 1990s, the period we analyze, support the assumption of procylical inflation (e.g., Burkhardt and Hasseltoft, 2012; ?). Given the high correlation of inflation dynamics across advanced economies in this period (Jotikasthira et al., 2015), the evidence extends to other countries in our sample outside the US.

safe; thus, upon a positive price-of-risk shock, negative stock returns are coupled with lower yields (and higher bond prices).

Internet Appendix for:

Non-Monetary News in Central Bank Communication

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Table IA-1. Summary of high-frequency data

Futures type	Futures name	Exchange	Time zone	TickData symbol	BBG symbol
A. Federal Reserve; sample start: Sep 30, 1997					
Equity	S&P 500 E-Mini Futures	CME Group	America – Chicago	ES	ES1 Index
Interest rate	Eurodollar Futures CME	CME Group	America – Chicago	ED	ED1 Comdty
Interest rate	US 5-Year T-Note Futures	Chicago Board of Trade	America – Chicago	FV	FV1 Comdty
Interest rate	US 2-Year T-Note Futures	Chicago Board of Trade	America – Chicago	TU	TU1 Comdty
Interest rate	US 10-Year T-Note Futures	Chicago Board of Trade	America – Chicago	TY	TY1 Comdty
Interest rate	US 30-Year T-Bond Futures	Chicago Board of Trade	America – Chicago	US	US1 Comdty
B. ECB; sample start: Jun 9, 1997					
Equity	DAX Index Futures	Eurex	Europe – Berlin	DA	GX1 Index
Interest rate	Euribor 3-Month Futures	ICE Futures Europe Financials	Europe – London	UR	ER1 Comdty
Interest rate	Euro-Schatz 2-Year Futures	Eurex	Europe – Berlin	BZ	DU1 Comdty
Interest rate	Euro-Bobl 5-Year Futures	Eurex	Europe – Berlin	BL	OE1 Comdty
Interest rate	Euro-Bund 10-Year Futures	Eurex	Europe – Berlin	BN	RX1 Comdty
C. BOE; sample start: Jul 9, 1998					
Equity	FTSE 100 Index Futures	ICE Futures Europe Financials	Europe – London	FT	Z 1 Index
Interest rate	Sterling 3-Month Futures	ICE Futures Europe Financials	Europe – London	ST	L 1 Comdty
Interest rate	Long Gilt Futures	ICE Futures Europe Financials	Europe – London	GL	G 1 Comdty
D. BOJ; sample start: Jul 15, 2003					
Equity	TOPIX Futures JPX	Osaka Exchange	Asia – Tokyo	TP	TP1 Index
Interest rate	Japanese 10-Year Bond Futures JPX	Osaka Exchange	Asia – Tokyo	JB	JB1 Comdty

A. Asset price responses to central bank communication: Details

This appendix provides details about the estimates discussed in Section III in the body of the paper.

We estimate the following regressions:

$$|x_{\tau-m,\tau+k}| = \gamma_{j,\text{CB}} + \beta_{j,\text{CB}}\mathbf{1}_{\tau,j,\text{CB}} + \varepsilon_{\tau-m,\tau+k}, \qquad \text{(IA.1)}$$

where $|x_{\tau-m,\tau+k}|$ denotes the absolute stock return or absolute yield change (both in basis points) computed over a window from m minutes before the event to k minutes after; $\mathbf{1}_{j,\text{CB}}$ is a dummy variable equal to one for a communication event of type j, $j = \{\text{MPD}, \text{PC}, \text{MIN}, \text{IR}\}$. The regressions are estimated separately by asset, event type j, and for each central bank.

The $\beta_{j,\text{CB}}$ coefficient measures the average change in $|x_{\tau-m,\tau+k}|$ due to news released at event j *relative* to the average absolute return on other days. The average return on other days is reflected in the constant $\gamma_{j,\text{CB}}$. For monetary policy decision announcements, returns are computed from -15 to +15 minutes around the event. For press conferences, minutes and inflation report releases, they are computed over a longer window, from -15 to +90 minutes around the event, given that these communications tend to contain information that is broader than the in the decision announcements, and hence may take longer for the markets to process. To control for the baseline variation on days without central bank news, returns and yield changes on those non-event days are constructed for the same window length as the event returns. To avoid dependence of the results on a particular time of day, control returns are sampled three times per day at 10am, 12pm and 2pm local time. These are the conventions that we also follow elsewhere in the paper, unless otherwise noted. The control group excludes all local cental bank announcements contained in our event database. Using the US as an example, we exclude days with announcements by the Fed but not by other central banks. We have verified that excluding days with announcements by all central banks does not significantly alter the results.

Figure 1 in the main text summarizes the estimates of the above regressions. Bars in each graph present $\beta_{j,\text{CB}}$ coefficients (along with 95% robust confidence interval), showing the *incremental* effect of communication events relative to the baseline variation in asset prices absent central bank news. The number displayed on each bar reports the slope coefficient divided by the intercept in regression (IA.1), $\beta_{j,\text{CB}}/\gamma_{j,\text{CB}}$. This ratio measures an increase in absolute returns (or yield changes) around a given communication event relative to the average absolute return on other days (e.g., a ratio of 2 means that average absolute returns are 200% higher at an event than the baseline). Detailed regression estimates are presented in Appendix Table IA-2.

Table IA-2. Reactions of stocks and yields to central bank communication events

This table accompanies Figure 1 in the body of the paper.

Panel A. Fed

	(1) eq	(2) 3m	(3) 2y	(4) 5y	(5) 10y	(6) 30y
Monetary policy decisions (MPD)						
β	24.0	2.61	3.13	3.11	2.07	1.65
	(5.81)	(5.88)	(8.19)	(9.57)	(7.64)	(5.75)
γ	17.5	0.35	0.72	0.81	0.70	0.75
	(106.80)	(64.83)	(88.71)	(102.46)	(107.98)	(116.45)
ratio β/γ	1.37	7.38	4.38	3.85	2.93	2.19
R^2	0.016	0.089	0.086	0.093	0.062	0.040
Press conferences (PC)						
β	21.0	0.20	1.45	1.83	1.47	1.03
	(4.98)	(3.91)	(12.78)	(10.06)	(8.74)	(5.02)
γ	21.7	0.19	0.56	0.96	0.92	1.15
	(68.24)	(48.99)	(65.23)	(70.25)	(72.53)	(74.45)
ratio β/γ	0.97	1.06	2.60	1.90	1.60	0.90
R^2	0.005	0.003	0.032	0.020	0.015	0.005
Minutes of FOMC meetings (MIN)						
β	3.99	0.22	0.70	0.85	0.59	0.28
	(1.42)	(2.29)	(4.46)	(5.04)	(4.42)	(2.30)
γ	31.2	0.56	1.20	1.40	1.23	1.34
	(106.60)	(69.98)	(97.23)	(110.73)	(114.73)	(120.44)
ratio β/γ	0.13	0.40	0.58	0.61	0.48	0.21
R^2	0.000	0.001	0.002	0.003	0.002	0.000

Panel B. ECB

	(1) eq	(2) 3m	(3) 2y	(4) 5y	(5) 10y
Monetary policy decisions (MPD)					
β	2.54	0.74	0.48	0.30	0.14
	(1.47)	(5.54)	(5.63)	(4.24)	(2.56)
γ	17.3	0.29	0.45	0.52	0.51
	(98.21)	(70.22)	(95.04)	(108.57)	(115.57)
ratio β/γ	0.15	2.52	1.06	0.56	0.28
R^2	0.000	0.031	0.012	0.005	0.001
Press conferences (PC)					
β	9.96	1.67	1.84	1.72	1.14
	(3.29)	(8.64)	(8.27)	(8.93)	(8.11)
γ	32.0	0.51	0.84	1.03	1.02
	(101.82)	(74.77)	(96.06)	(107.09)	(115.60)
ratio β/γ	0.31	3.28	2.19	1.67	1.12
R^2	0.001	0.056	0.042	0.032	0.018

Table IA-2. Reactions of stocks and yields to central bank communication events (continued)

This table accompanies Figure 1 in the body of the paper.

Panel C. BOE

	(1) eq	(2) 3m	(3) 10y
Monetary policy decisions (MPD)			
β	3.82	2.20	0.92
	(2.50)	(6.95)	(5.37)
γ	13.3	0.45	0.66
	(102.69)	(76.33)	(116.73)
ratio β/γ	0.29	4.94	1.40
R^2	0.001	0.089	0.026
Inflation reports (IR)			
β	6.95	2.75	1.56
	(1.81)	(6.56)	(5.03)
γ	26.2	0.70	1.26
	(103.54)	(81.64)	(120.95)
ratio β/γ	0.27	3.95	1.24
R^2	0.000	0.041	0.010
Minutes of MPC meetings (MIN)			
β	4.82	1.09	0.82
	(2.31)	(7.18)	(5.71)
γ	26.2	0.70	1.26
	(103.54)	(81.64)	(120.95)
ratio β/γ	0.18	1.56	0.65
R^2	0.000	0.017	0.007

Panel D. BOJ

	(1) eq	(2) 10y
Monetary policy decision (MPD)		
β	11.9	0.19
	(3.50)	(3.20)
γ	17.7	0.34
	(71.39)	(66.59)
ratio β/γ	0.67	0.54
R^2	0.009	0.006
Minutes of monetary policy meetings (MIN)		
β	35.5	0.21
	(5.73)	(3.47)
γ	32.1	0.59
	(70.78)	(65.87)
ratio β/γ	1.11	0.35
R^2	0.022	0.002

B. Robustness of the results to the event window size

For robustness, we compare realized stock-yield covariances constructed over different window sizes. We also discuss selected events which require special attention.

In Figure IA-1, we first present scatter plots of realized covariances around the Fed's monetary policy decisions (MPD). For the moment, we focus only on MPDs for transparency of the plots, and present analysis covering other event types below. In contrast to MPD announcements by the ECB, MPD announcements made by the Fed are accompanied by a statement providing background information on the decision. Such information may take some time for markets to process. Therefore, the sample of the Fed's MPDs serves as a good laboratory for assessing the sensitivity of our results to the choice of the window size. We compare covariances over the (-15,+15) minute window—our baseline window for MPD announcements—with alternative window sizes: (-10,+20) minutes (as used by Gürkaynak et al. (2005a, GSS)), and for longer windows of (-15, +30/+60/+90) minutes. We report the results for the covariances of stock returns with the two- and ten-year yield changes.

Several observations from Figure IA-1 are worth highlighting. First, the covariances are effectively identical if we use the (-15,+15) or GSS's (-10,+20) minutes' window. Second, while the correlation between the narrow- and longer-window covariances decreases as we extend the window (which is to be expected), it still remains very high, with most observations located along a 45-degree line. One visible exception to this is the datapoint on Sep 16, 2008, which we explore in more detail below. Notice that even in the case of deviations from the 45-degree line, the sign of the covariances stays unchanged. Therefore, changing the window would not lead us to classify more events as being dominated by the non-monetary component.

In addition to scatter plots in Figure IA-1, in Table IA-3 we report regression-based comparisons for all Fed events in our data set. We regress realized covariances computed over different windows on covariances computed over the baseline (-15,15) minute window:

$$\mathrm{RCov}_{\tau}^{(n)}(\tau^-,\tau^+) = \alpha + \beta \times \mathrm{RCov}_{\tau}^{(n)}(-15,+15) + \varepsilon_{\tau}. \tag{IA.2}$$

We estimate this equation with OLS and quantile regression (for the median) which is more robust to outliers, and present result for both. The R^2 from the OLS regression is essentially equal to one for the (-10,+20)-minute window and it drops to the minimum of 0.73 for the two-year yield covariance and the longest window (-15,+90) minutes. The slope coefficients across specifications are close to unity, suggesting that covariances of different window size move one for one: one bps-squared increase in the (-15,+15) minute window covariance corresponds to roughly one bps-squared increase in the longer-window covariance. There is a level difference (visible in the constant) as the longer-window covariances are generally higher than the narrow-window ones. However, comparing the OLS and quantile regression estimates, we see that these level differences are driven by a few influential observations. The constant in the quintile regression shows that the longer-window covariances are slightly higher, which suggests that by extending the window we allow other types of news to affect the covariances.

Note that covariances around Fed's MPDs are generally negative, which we show in the paper (Table II). So the positive constant in the regression in Table IA-3 means that longer-window covariances dampen the initial effect of monetary policy news. This can happen due to non-monetary news revealed by the statement as both growth and risk premium shocks should move stocks and yields in the positive direction. But it could also stem from news not directly related to the Fed: We know that absent monetary policy news (on non-monetary days) stock-yield covariances are generally positive (see discussion in Section IV.B of the paper). To keep our identification consistent with the literature following GSS, we use the narrow window identification for the MPDs, and a longer window for the press conferences and minutes. When we focus on the unconventional monetary policy, we also follow the convention of using longer windows (+90 minutes post announcements). However, going beyond 90 minutes risks inducing too much contamination from other news that may not be due to central bank communication. Importantly, the narrow-window approach seems to be appropriate given our paper's purpose to quantify the amount of non-monetary news in central bank communication as it provides a conservative assessment of the importance of such news.[34]

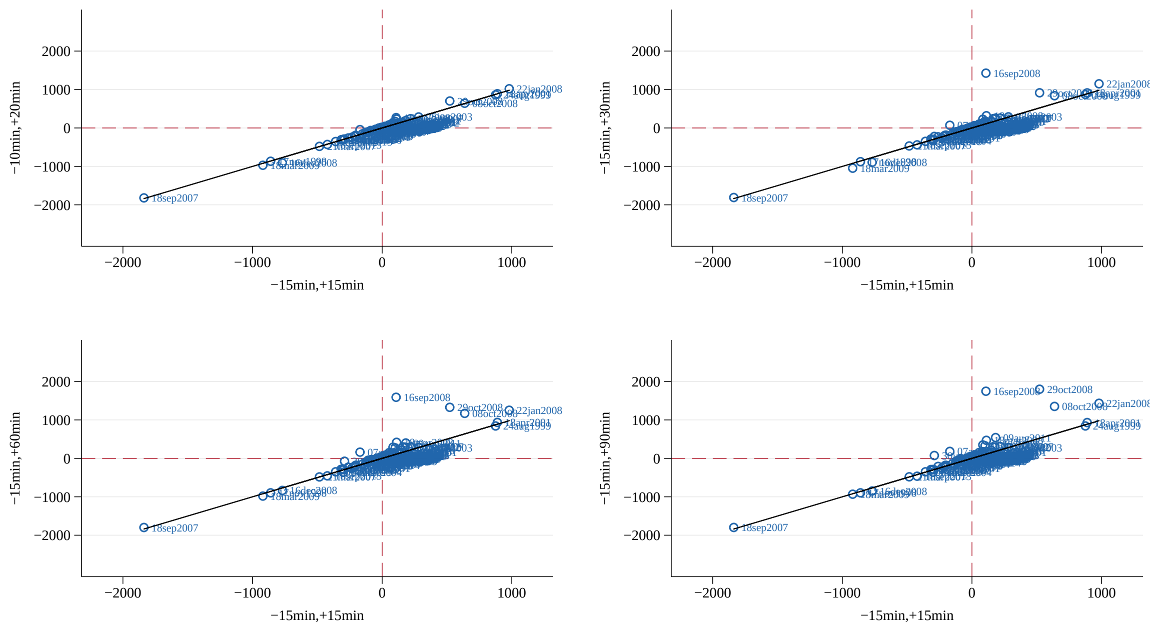
The data point for which the narrow- and longer-window covariances differ the most is the MPD on September 16, 2008, and the differences are particularly visible in the 2-year covariances. Figure IA-2 shows the dynamics of stocks and yields on that day. The Fed decided to keep rates unchanged which led to the initial drop in the stock market on impact, and a small drop in yields. This initial reaction to the announcement is captured by the -15,+15 minute window quite well. After a while, however, the stock market rebounded and yields started to increase. This case illustrates the ambiguity associated with the choice of the window. Fortunately, for our purposes, it is also the most extreme case we see in our sample (Figure IA-1). The media commentary on that day indeed suggested that the market took time to arrive at an interpretation of the statement and of the Fed's move. For the sake of being conservative in our news classification (and for consistent treatment of all MPD events), we rely on the narrow window identification when estimating various regression specifications.

To illustrate how quickly markets usually absorb information in central bank communication, it is useful to look at the behavior of stocks and bonds on July 26, 2012, surrounding Mario Draghi's famous "whatever it takes" speech. This speech was not a formal program announcement, and it covered several topics.[35] One could argue that both of these facts made the message complex. Figure IA-3 shows that the (-15, +90) minute windows is sufficient to capture the market's reaction to the speech.

[34]Note that GSS consider both the narrow window of (-10,+20) minutes and a longer window of (-15,+45) minutes. They very well discuss the tradeoff involved in the selection of the window size. The goal of the GSS is to distinguish between the shocks due to Fed's actions versus shocks due to Fed's "words" revealed in the statement. While complex statements may take more time to process by the market, they emphasize the use of the narrow window, writing: "(...) we continue to emphasize our tight window responses in the analysis below because most of the policy information is incorporated within that window and having a narrower window reduces the amount of noise in our left-hand-side variables, increasing the precision of our estimates."

[35]The 'whatever it takes' speech is commonly regarded as foreshadowing the introduction of the ECB's program of Outright Monetary Transactions (OMT)— a point of inflection of the European sovereign debt crisis.

Panel A. Realized covariance of equity returns and two-year yield changes



Panel B. Realized covariance of equity returns and ten-year yield changes

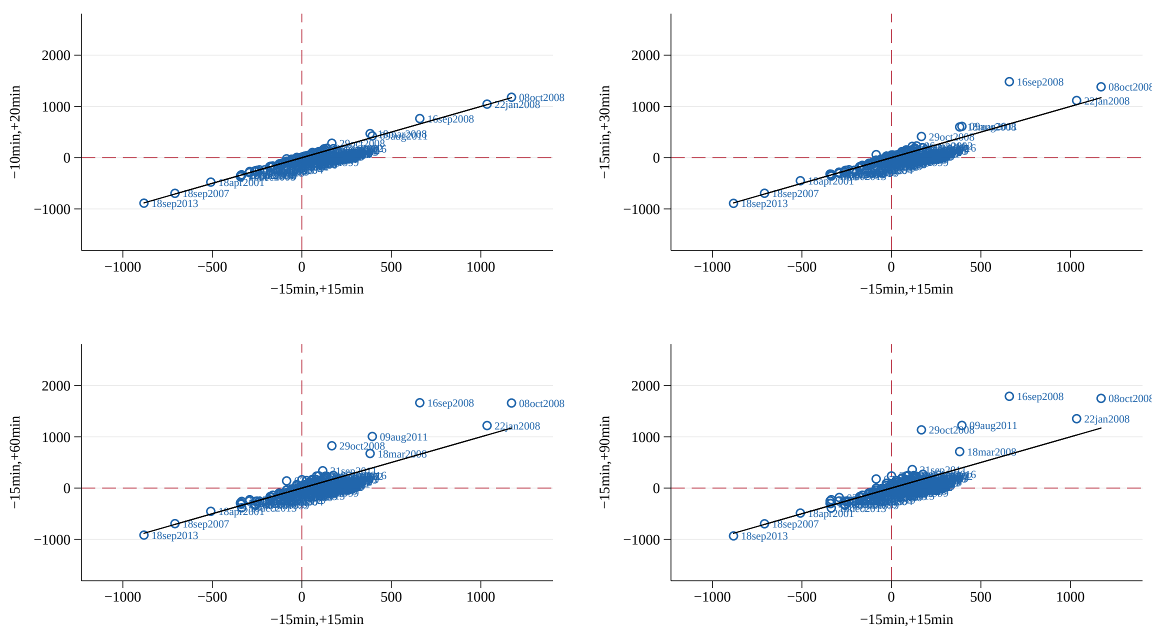


Figure IA-1. Comparison of realized stock-yield covariances for different event windows around Fed's MPD announcements

The figure compares the realized covariances between the equity returns and two- and ten-year yield changes for different window sizes. The realized covariances are defined in equation (5) of the paper, and are reported in bps-squared. The plot is based on the Fed's monetary policy decision announcements only for better readability. Panel B of the figure omits one data point, an outlier on Mar 18, 2009, which distorted the figure's readability. (On that day, however, the covariances across different window specification were similar ranging from -5111 to -4840.) Regressions in Table IA-3 use all Fed events in our database.

Table IA-3. Comparison of realized covariances with different window sizes

This table compares realized covariances constructed around Fed events over different window sizes. We regress realized covariances computed over different windows on covariances computed over the (-15,15) minute window: $\text{RCov}_{\tau}^{(n)}(\tau^{-},\tau^{+}) = \alpha + \beta \times \text{RCov}_{\tau}^{(n)}(-15,+15) + \varepsilon$. The different window specifications for the dependent variables are reported in columns of the table, e.g. (-10,+20) denotes a window from -10 minutes before to +20 minutes after the event. The regressions are estimated for all events included in our sample (Figure IA-1 compares these covariances only for monetary policy decision announcements). Columns (1) through (4) are estimated using OLS (with robust standard errors); columns (5) though (8) are estimated with quantile (median) regressions (with bootstrapped standard errors).

	OLS regressions				Quantile regression			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(-10,+20)	(-15,+30)	(-15,+60)	(-15,+90)	(-10,+20)	(-15,+30)	(-15,+60)	(-15,+90)
A. Realized covariance of equity returns with two-year yield								
$\text{RCov}_{\tau}^{(2Y)}$ (-15,+15)	1.02	1.09	1.15	1.21	1.00	1.02	1.05	1.04
	(63.34)	(27.52)	(16.48)	(12.09)	(138.38)	(34.58)	(31.38)	(21.94)
Constant	1.58	11.7	22.6	30.8	0.0039	1.85	3.45	3.84
	(1.30)	(2.77)	(3.98)	(4.32)	(0.12)	(4.00)	(3.19)	(4.62)
R^2	0.98	0.86	0.79	0.73	–	–	–	–
B. Realized covariance of equity returns with ten-year yield								
$\text{RCov}_{\tau}^{(10Y)}$ (-15,+15)	0.99	1.01	1.03	1.05	1.00	1.02	1.09	1.09
	(133.17)	(25.93)	(15.36)	(12.72)	(84.16)	(21.01)	(11.07)	(8.06)
Constant	1.85	12.4	27.1	36.4	0.59	3.62	9.75	13.2
	(2.01)	(4.06)	(5.61)	(6.08)	(2.70)	(4.70)	(11.27)	(6.20)
R^2	1.00	0.97	0.93	0.89	–	–	–	–

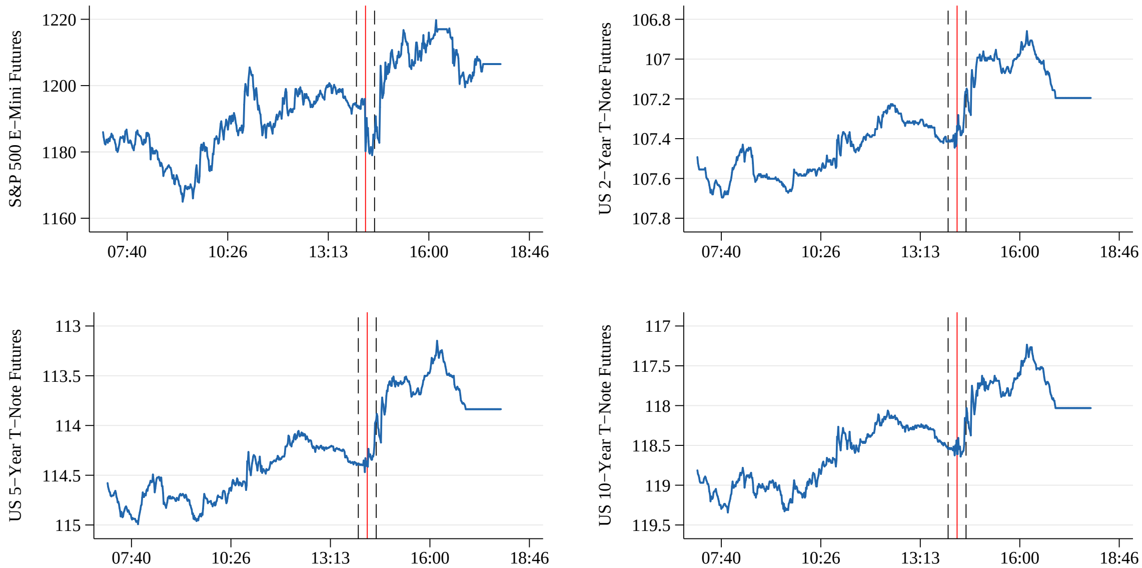


Figure IA-2. US equity and bond futures prices on Sep 16, 2008

The figure presents the evolution of prices for S&P500 stock futures and US bond futures in the US on Sep 16, 2008. In all plots, the first solid (red) line marks the time of the monetary policy decision (08:20am and 14:15pm, respectively). The dashed (black) lines indicate the time interval from -15 to +15 minutes of the policy decision. For bond prices, the y-axis is reversed to be consistent with the direction of the movement in yields. All times are reported in New York time.

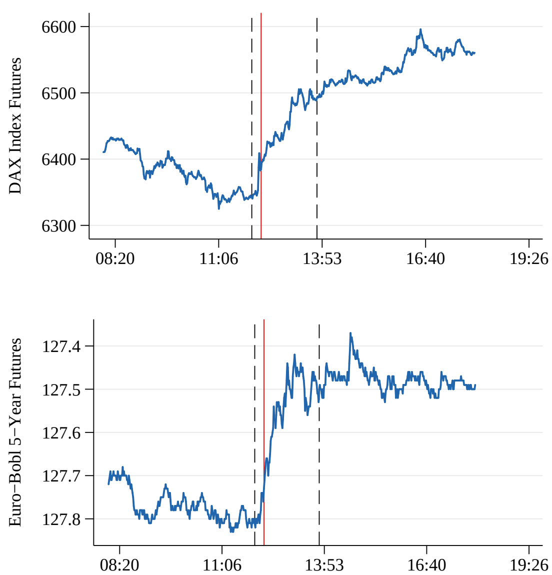


Figure IA-3. German equity and bond futures prices on Jul 26, 2012

The figure presents evolution of prices for DAX stock futures and German five-year bond futures on Jul 26, 2012. The solid (red) line marks the time of the beginning of the speech as reported by Bloomberg (12:15pm), while the dashed (black) lines mark the time 15 minutes before to 90 minutes after the beginning of the talk. For bond futures prices, the y-axis is reversed to be consistent with the direction of the movement in yields. All times are reported in Berlin time.

C. Comovement of stocks and yields around macroeconomic announcements

This appendix provides additional results about the effects of macro releases on variances of stocks and yields and on stock-yield comovement. Regression of variances and covariances on the dummy for macro announcements are summarized in Table IA-4. These regressions present the incremental effect of macro news on the second moments of asset prices, relative to the baseline variation on days without macro or monetary policy news. Figure IA-4 presents the average realized variances of yields around macroeconomic announcements.

Table IA-4. Variances and covariances around US macroeconomic releases

The table accompanies Figure 3 in the body of the paper. The table presents the regressions of realized covariances and variances on a macroeconomic announcement dummy. The time stamps of macroeconomic announcements are from Bloomberg and we use the following tickers: USURTOT Index for unemployment rate (released together with non-farm payrolls); CPI CHNG Index for CPI inflation rate (other CPI indices are announced at the same time); GDP CQOQ Index for GDP growth (advance announcement). The event window spans from -15 minutes before to +60 minutes after macro release. The sample of control covariances is constructed over the same window for days without local monetary policy news and macro news, in analogy to the approach to constructing control returns described in Section III. Realized (co)variances are reported in units of basis points squared. Robust standard errors are reported in parentheses.

Panel A. Dependent variable: realized variance (bps-squared)

	(1) eq	(2) 3m	(3) 2y	(4) 5y	(5) 10y	(6) 30y
CPI Inflation						
Inflation release dummy	31.5	1.96	5.25	5.45	3.36	2.91
	(0.29)	(4.48)	(6.16)	(6.94)	(8.20)	(8.09)
Constant	853.7	1.76	3.08	2.94	2.12	2.16
	(46.64)	(28.04)	(21.15)	(22.04)	(24.78)	(22.42)
GDP (advance)						
GDP release dummy	841.3	2.91	9.30	11.9	6.58	5.96
	(2.01)	(4.64)	(4.17)	(3.32)	(4.48)	(3.95)
Constant	849.4	1.78	3.12	2.96	2.14	2.18
	(47.15)	(28.49)	(21.63)	(22.68)	(25.36)	(22.91)
Unemployment report						
Unemployment release dummy	2411.0	19.0	52.1	54.5	34.0	29.1
	(7.65)	(6.35)	(7.20)	(8.65)	(8.14)	(5.78)
Constant	812.4	1.46	2.27	2.08	1.58	1.71
	(46.88)	(54.23)	(55.28)	(49.39)	(74.86)	(89.22)

Panel B. Dependent variable: realized covariance (bps-squared)

	(1) 3m	(2) 2y	(3) 5y	(4) 10y	(5) 30y
CPI Inflation					
Inflation release dummy	-13.4	-25.3	-25.5	-22.1	-19.7
	(-4.79)	(-4.93)	(-6.43)	(-5.76)	(-6.40)
Constant	2.28	7.10	10.9	10.4	10.1
	(9.11)	(15.94)	(22.60)	(26.74)	(29.17)
GDP (advance)					
GDP release dummy	-3.03	-5.03	2.72	-12.4	-2.99
	(-0.47)	(-0.31)	(0.21)	(-0.70)	(-0.36)
Constant	2.07	6.69	10.4	10.1	9.74
	(8.27)	(15.20)	(21.90)	(26.78)	(28.44)
Unemployment report					
Unemployment release dummy	17.6	79.7	77.0	66.2	55.6
	(1.47)	(4.09)	(3.38)	(3.80)	(3.44)
Constant	1.75	5.28	9.12	8.86	8.76
	(12.19)	(18.57)	(34.70)	(37.49)	(45.53)

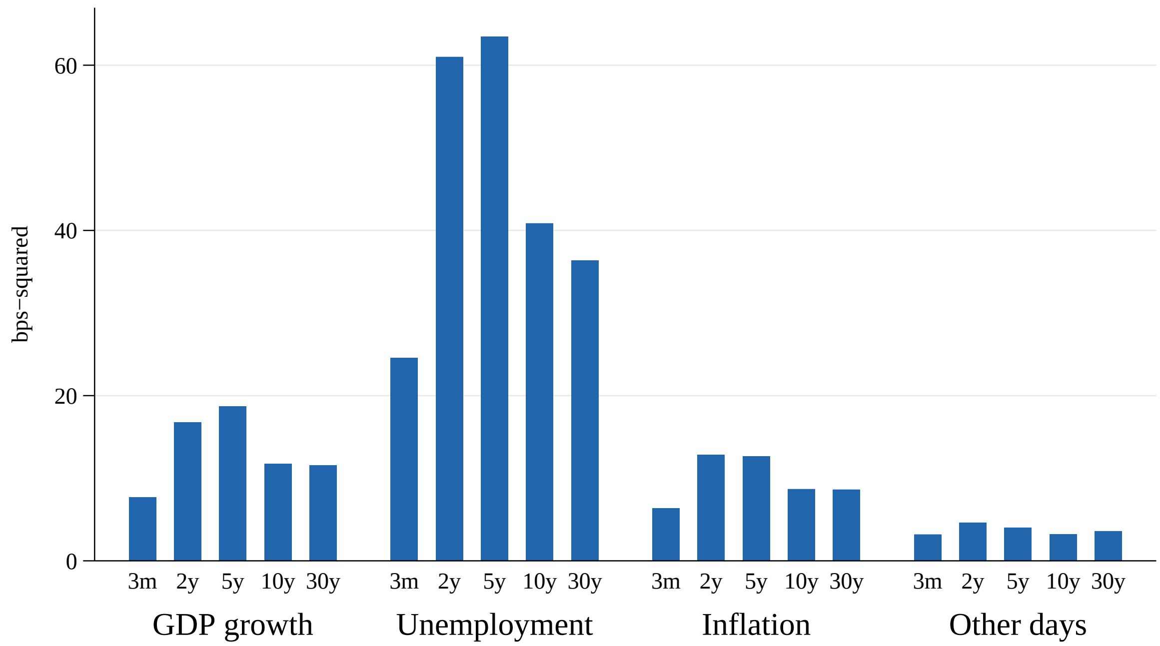


Figure IA-4. Average realized variances of yields around macro announcements

The figure plots the average realized variances of yields around macroeconomic announcements (same announcement as in Figure 3. For comparison, the last panel in the figure ("Other days") presents the average realized variances on days without those three macro announcements and without monetary policy news. The event window is (-15,+60) minutes around announcements.

D. Classification of unconventional monetary policy events

This appendix presents an overview of the types of UMP measures introduced by the Fed, ECB, BOE and BOJ during our sample, and accompanies Section V of the paper.

In the case of the Fed, in Table V, we distinguish the well-known rounds of Quantitative Easing (QE, referred to as QE1, QE2, QE3) as well as the maturity extension program (MEP, also called "Operation Twist"). We also account for early announcements related to the possible removal of monetary stimulus, denoted as "early exit" in Table V, even though the eventual exit from monetary accommodation was repeatedly postponed against the backdrop of a sluggish recovery. The analysis further accounts for exit announcements in the post 2013 period ("late exit"). Among those, we separately treat the taper tantrum in mid-2013, as well as announcements related to the wind-down of the Fed balance sheet in late 2017.

Table VI is based on the classification of the ECB's UMP announcements. A key component of the ECB's UMP toolkit during the crisis were longer-term refinancing operations (LTRO) geared towards proving liquidity to the banking sector. In our analysis, we distinguish four main LTRO phases. The first two phases, rolled out during the course of the sub-prime crisis period, were still fairly limited in terms of the maturity of the operations. The third round of LTROs was launched at the height of the euro area sovereign debt crisis in December 2011 and February 2012, and provided banks with funding at attractive rates for three years. After the sovereign debt crisis abated, another round of so-called targeted long-term refinancing operations (TLTRO) was initiated in June 2014, which we classify as phase four. The TLTROs provided term funding to euro area banks at attractive rates conditional upon fulfilment of certain criteria (regarding bank lending to the real economy).

Besides those liquidity provision measures, we also account for announcements related to asset purchases, including the launch of the ECB's covered bond purchase programme (CBPP), the securities markets programme (SMP) as well as outright monetary transactions (OMT). In terms of sequencing, the CBPP was already introduced prior to the sovereign debt crisis, mainly to alleviate banks' elevated funding costs. The SMP was launched later, in May 2010, at a time when tensions during the European sovereign debt crisis escalated. It involved purchases of government and corporate fixed income securities from euro area peripheral countries, and purchases were conducted with an aim to repair the broken transmission process of monetary policy. The OMT programme, allowing for (in principle) unlimited asset purchases of sovereign debt (subject to conditionality), had a similar focus. Even though never activated, the OMT is generally thought to have significantly alleviated the euro area sovereign debt crisis. The main goal of these crisis-related policies, which involved purchases of sovereign debt of countries affected by the crisis, was to repair the broken transmission mechanism of monetary policy and to combat intra-euro area spread widening. With its decision in January 2015 to purchase public sector debt securities (PSPP) on a large scale, the ECB Governing Council formally embarked on QE policies, aimed at fulfilling its price stability mandate. The asset purchase programme, which is still ongoing at the time of writing, was complemented in early 2016 with purchases of corporate bonds via the corporate sector purchase program (CSPP).

Table VII gives an overview of UMP programs by the BOE and the BOJ. In case of the former, we capture the dates when the BOE (in coordination with the UK Treasury) first created its asset purchase facility (APF) and then expanded the amounts held in the facility. Overall, we distinguish four QE phases by the BOE (APF1-APF4), corresponding to distinct phases when holdings of gilts in the APF were significantly expanded.

In light of persistently deflationary environment in Japan and issues related to the zero lower bound, the BOJ actually started to embrace unconventional policies already in the early-2000s. We classify the early phase of the BOJ's QE from 2002 to 2006 as QEP. At the height of the sub-prime crisis, the BOJ introduced further round of bond purchases which we refer to as QEAPP. A major shift, however, occurred in April 2013 when the BOJ launched quantitative and qualitative easing (QQE), a program aimed at expanding the monetary base via purchases of Japanese government bonds. To prop up asset prices, the BOJ also began purchasing local equities (via ETFs) and real estate investment trusts (REITS), and we classify these announcements separately. QQE was then modified with the introduction of negative interest rates (QQE Neg Rates) and the introduction of yield curve control (YCC).

E. Implementation of sign and monotonicity restrictions

This appendix accompanies Section VI of the paper and describes the details of the sign and monotonicity restrictions algorithm.

Our main goal is to decompose reduced-form shocks u_t into structural shocks ϵ_t. Start from the variance-covariance matrix of reduced-form shocks,

$$\Sigma_u = Var(u_t) = PP', \quad \text{(IA.3)}$$

where P is the lower triangular matrix from a Cholesky decomposition of Σ_u and

$$u_t = P\epsilon_t^{Chol}. \quad \text{(IA.4)}$$

We use the notation ϵ_t^{Chol} to denote candidate ϵ_t shocks obtained using Cholesky decomposition. While P orthogonalizes u_t ensuring that ϵ_t shocks are uncorrelated, $Var(\epsilon_t^{Chol}) = I$, it does not have a particular economic interpretation. Specifically, one can obtain an observationally identical set of reduced-form shocks by finding an orthogonal (rotation) Q matrix such that $QQ' = Q'Q = I$,

$$u_t = PQ'Q\epsilon_t = P^Q\epsilon_t^Q, \quad \text{(IA.5)}$$

where ϵ_t^Q is another candidate set of shocks corresponding to matrix Q.

We want to select a rotation matrix Q that satisfies the restrictions on contemporaneous responses discussed in Section VI:

$$PQ' = A^{-1}. \quad \text{(IA.6)}$$

The restrictions are imposed using the Householder algorithm (see Kilian and Lütkepohl (2017), Chapter 13) in the following way:

1. Generate 3×3 matrix M with elements drawn from the standard normal distribution $N(0,1)$.
2. Perform a QR decomposition of M, obtain upper triangular matrix R and orthogonal matrix Q. If the (i,i) element on the diagonal of R is negative ($diag(R)_{ii} < 0$), switch the sign of the i-th column of the Q matrix as $Q(:,i) = -Q(:,i)$. The last step ensures that the Q matrix is drawn from a uniform distribution over the space of orthogonal matrices.
3. Check whether PQ' satisfies the restrictions.
4. Repeat until N Q matrices satisfy the restrictions, where we set $N = 2000$.

F. Additional figures

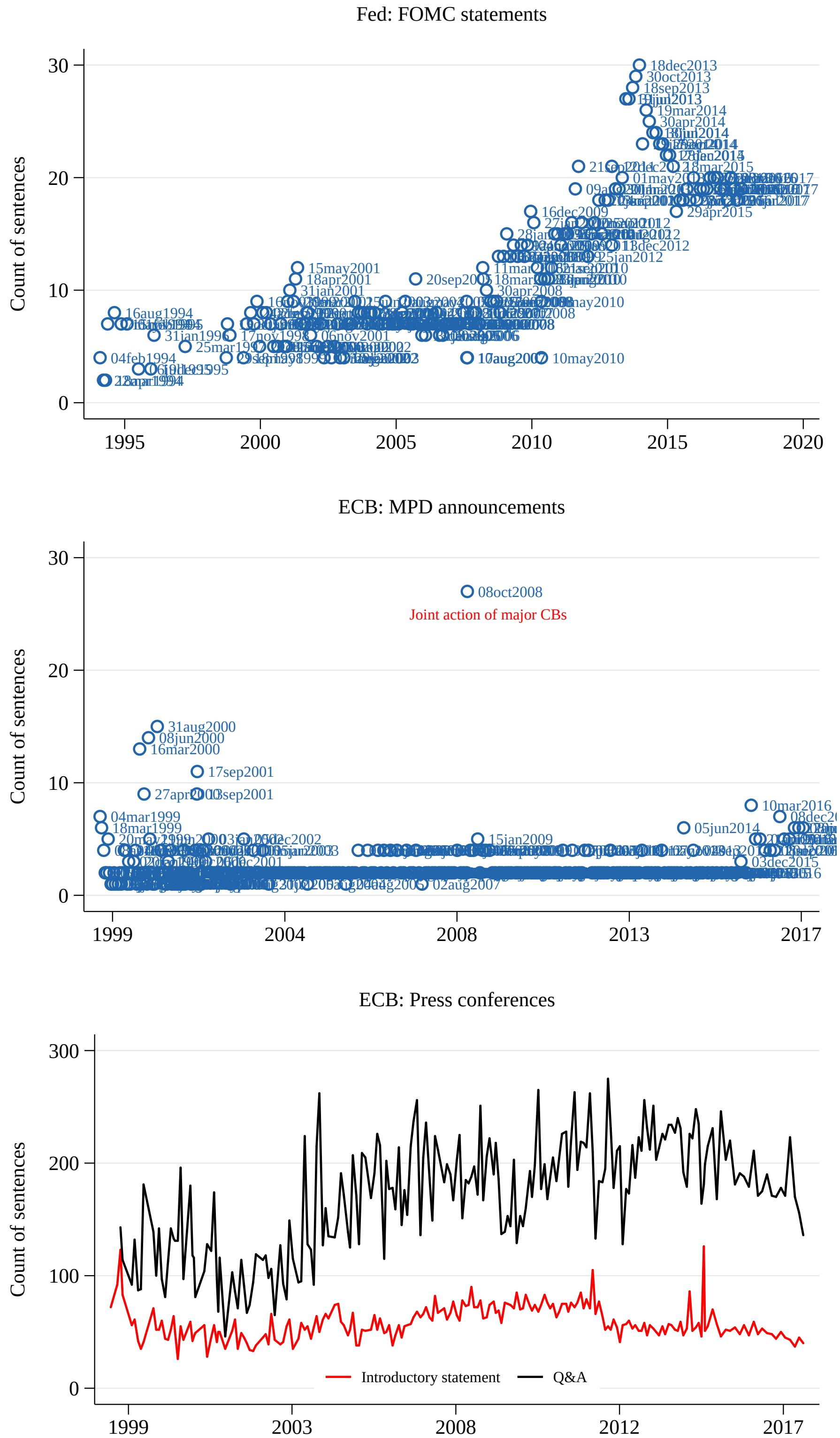


Figure IA-5. Variation in the length of monetary policy decision announcements and press conferences over time

The figure presents the count of sentences included in FOMC statements of policy decisions, ECB's monetary policy decisions and ECB's press conferences.

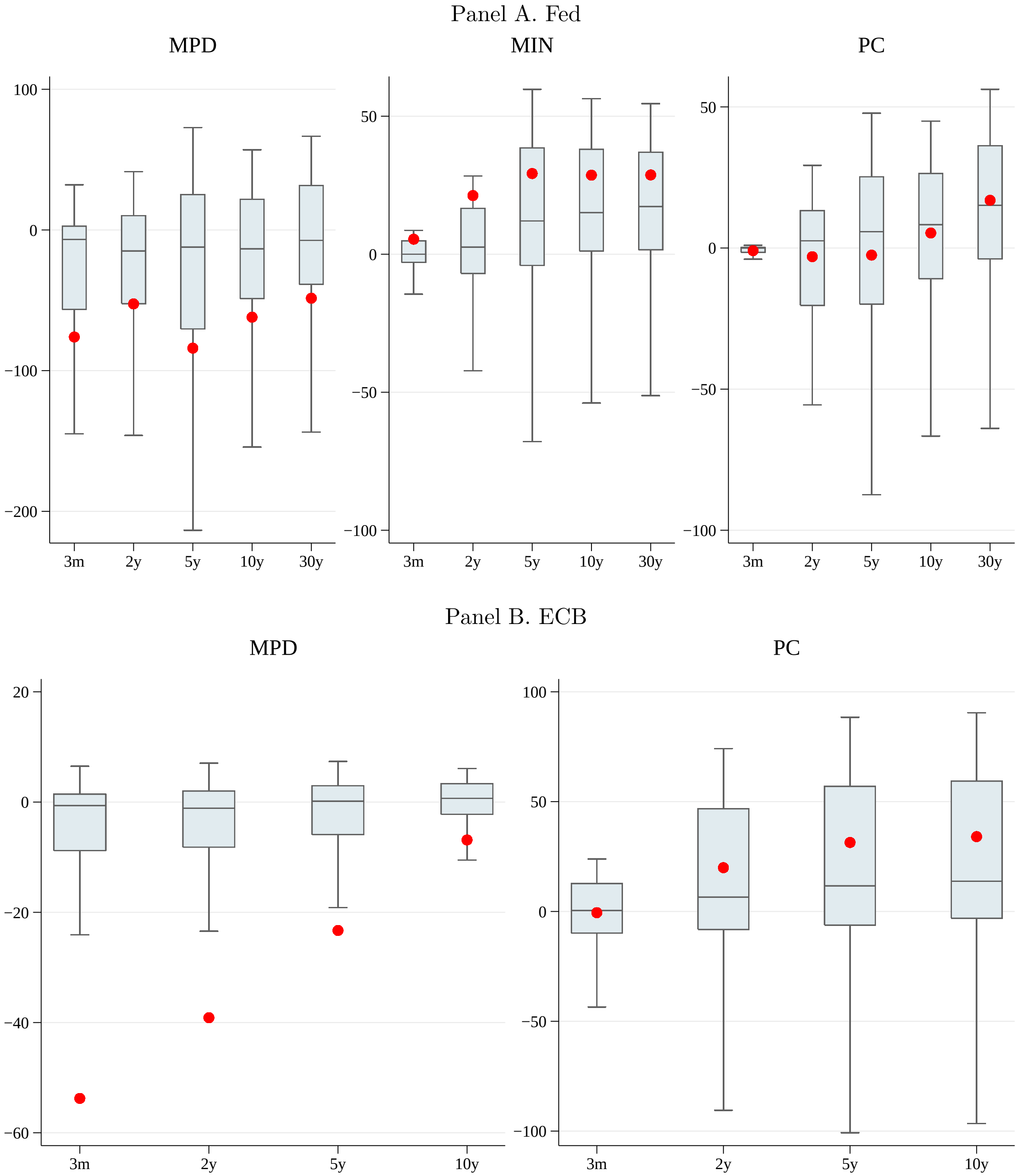
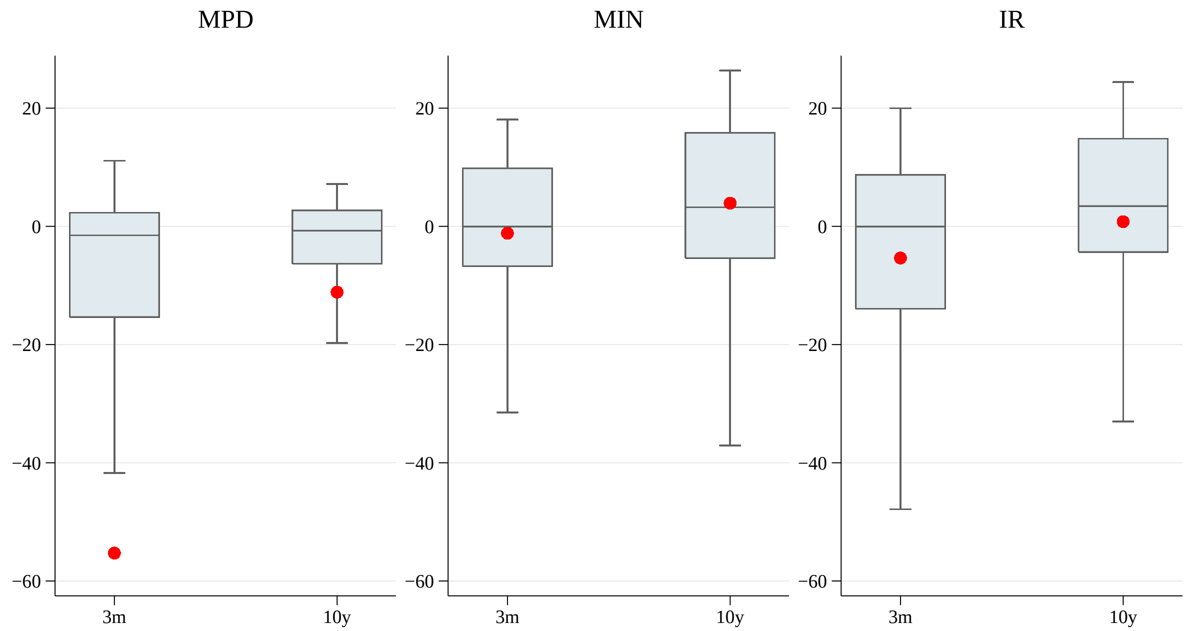


Figure IA-6. Term structures of stock-yield covariances (full sample)

The figure presents the distributions of realized covariances. Covariances are reported in bps-squared. We consider monetary policy decision (MPD) announcements and press conferences (PC) for the ECB, minutes releases (MIN) for the Fed, the BOE and the BOJ, and inflation report (IR) releases for the BOE. Covariances are constructed over a (-15,+15) minute window for MPDs, and over (-15,+90) minute window around other communication events. Mean covariances are indicated with dots. The box borders indicate the upper and lower quartiles and the line within the box marks the median. The whiskers identify the largest and smallest adjacent values calculated as upper quartile +1.5×IQR (interquartile range) and lower quartile −1.5×IQR. Extreme values are not shown.

Panel C. BOE



Panel D. BOJ

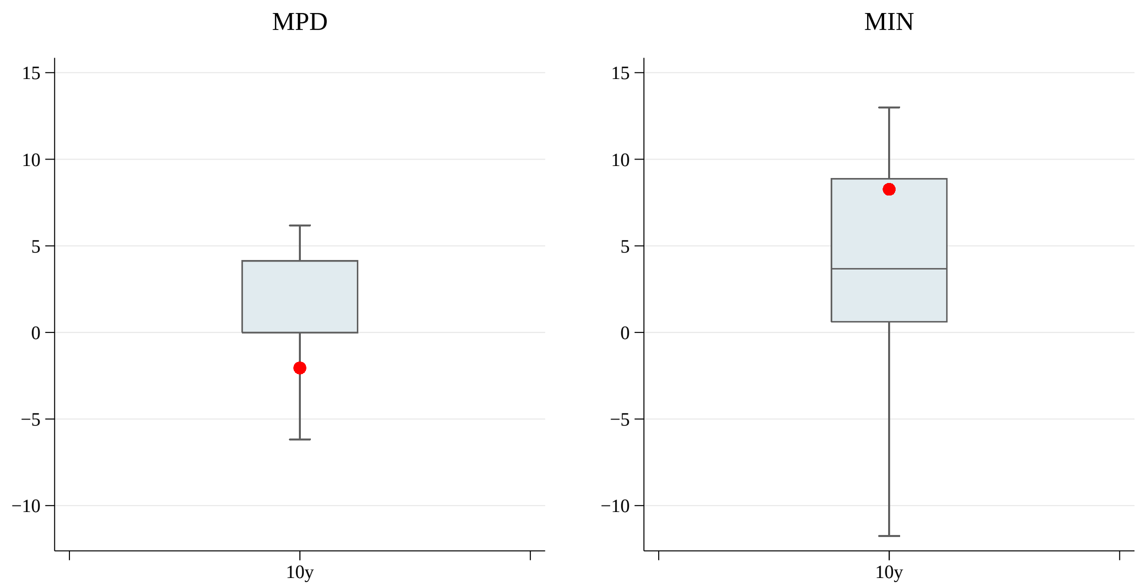


Figure IA-6. Term structure of stock-yield covariances around CB communication events (continued)

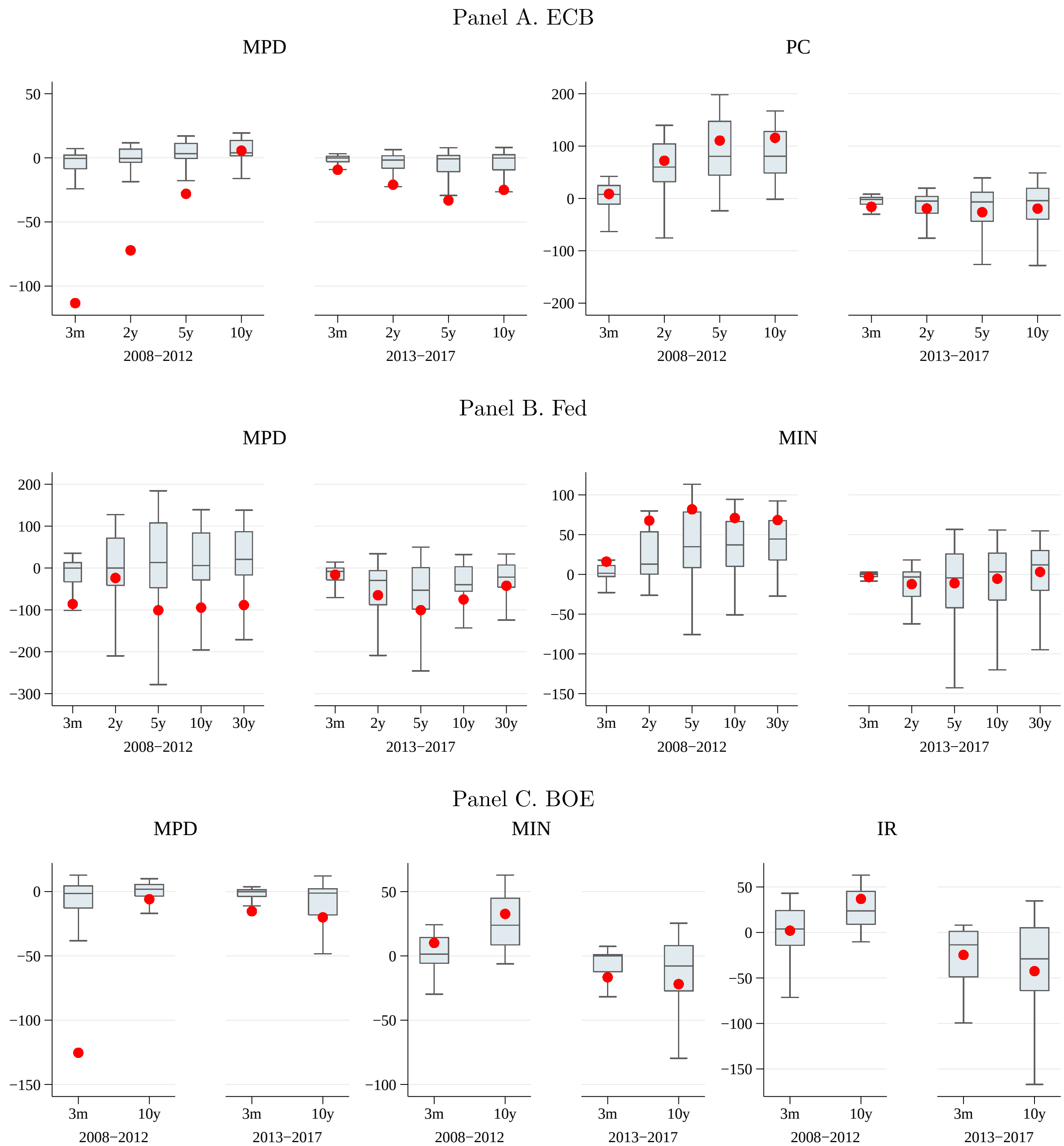


Figure IA-7. Term structures of realized covariances pre- and post-2013

The figure presents distributions of realized stock-yield covariances across available maturities around central bank communication events, for two subperiods: 2008–2012 and 2013–2017. Covariances are reported in bps-squared. We consider monetary policy decision (MPD) announcements and press conferences (PC) for the ECB, minutes releases (MIN) for the Fed and the BOE, and inflation report (IR) releases for the BOE. Covariances are constructed over a (-15,+15) minute window for MPDs, and over (-15,+90) minute window around other communication events. Mean covariances are indicated with dots. The box borders indicate the upper and lower quartiles and the line within the box marks the median. The whiskers identify the largest and smallest adjacent values calculated as upper quartile $+1.5\times$IQR (interquartile range) and lower quartile $-1.5\times$IQR. Extreme values are not shown.