Unconventional Monetary Policy and International Risk Premia*

John H. Rogers† Chiara Scotti‡ Jonathan H. Wright§

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†International Finance Division, Federal Reserve Board, Washington DC 20551; john.h.rogers@frb.gov.

‡Division of Financial Stability, Federal Reserve Board, Washington DC 20551; chiara.scotti@frb.gov.

§Department of Economics, Johns Hopkins University, Baltimore MD 21218; wrightj@jhu.edu.

Abstract

We assess the relationship between monetary policy, foreign exchange risk premia and term premia including the period at the zero lower bound (ZLB). We estimate a structural VAR including U.S. and foreign interest rates and exchange rates, and identify monetary policy shocks through a method that uses high-frequency monetary policy surprises as the external instrument that achieves identification without using implausible restrictions. We split out effects of different types of monetary policy surprises that apply at the ZLB, including forward guidance and asset purchases. This allows us to measure the effects of policy shocks on expectations, and hence risk premia.

1 INTRODUCTION

In the wake of the Great Recession, the world's largest central banks set short term nominal interest rates to the effective zero lower bound (ZLB) and began adopting unconventional monetary policies, such as forward guidance and large scale asset purchases. These policies have renewed interest in the role of monetary policy in explaining the dynamics of exchange rates, and domestic and foreign interest rates. By affecting exchange rates and foreign interest rates, monetary policy shifts are a potential source of unintended spillovers onto other countries (Engel, 2013). These issues are old ones in empirical international finance, predating the recent period of unconventional monetary policy (Eichenbaum and Evans, 1995; Kim, 2001; Kim and Roubini, 2000; Faust et al., 2003), but the question is worth revisiting including data from the ZLB era.

A large strand of the literature addresses these questions using a vector autoregression (VAR) in interest rates (domestic and foreign) and exchange rates. The identification of monetary policy shocks is however contentious. Many authors achieve identification by positing a recursive ordering as in the seminal paper of Sims (1980), in which it is assumed that U.S. monetary policy shocks have no immediate effect on foreign interest rates (Eichenbaum and Evans, 1995; Kim and Roubini, 2000).[1] However, there is considerable evidence from the "event-study" literature showing that global interest rates and exchange rates respond immediately and substantively to U.S. monetary policy shocks (Andersen et al., 2003, 2007; Faust et al., 2007; Ehrmann and Fratzscher, 2003, 2005; Bredin et al., 2010; Hausman and Wongswan, 2011; Rogers et al., 2014; Wright, 2012; Kiley, 2013; Gilchrist et al., 2014). Moreover, these methods all measure monetary policy using the target federal funds rate, which is not applicable at the ZLB.

In this paper, we adopt a different and more credible approach to identification of structural monetary policy shocks in a VAR. We use a variant of the method of external instruments (Stock and Watson, 2012; Olea et al., 2013; Gertler and Karadi, 2015; Mertens and Ravn, 2013), where the ordering of the variables does not matter in identification. Our external instruments are high-frequency jumps in the term structure of interest rates around monetary policy announcements. By considering jumps in the whole term structure of interest rates—not just short-term interest rates—we are able to identify unconventional monetary policy surprises, and can separately analyze monetary policy shocks that operate at different points on the term structure, which we interpret as forward guidance and asset purchase surprises. The structural VAR allows us to trace out the dynamic effects of these monetary policy shocks on domestic and foreign interest rates, as well as exchange rates. As a by-product, we can then compute their effects on financial market risk premia: the domestic term premium, the foreign term premium, and the foreign exchange risk premium. While it is clear that foreign exchange risk premia are time-varying (Fama, 1984; Engel, 1996), the existing empirical results on whether monetary policy surprises affect foreign exchange risk premia are more mixed (Kim and Roubini, 2000; Faust and Rogers, 2003; Scholl and Uhlig, 2008; Bjornland, 2009; Bouakez and Normandin, 2010). In other words, it is clear that uncovered interest parity (UIP) does not hold *unconditionally*, but the existing evidence is less clear on whether UIP holds *conditional* on monetary policy surprises. We focus primarily on the effects of U.S. monetary policy shocks, but also include a brief analysis of the impact of Bank of England, European Central Bank, and Bank of Japan monetary policy shocks.

This framework gives us a complete picture of the international effects of unconventional monetary policy on asset prices and risk premia. To preview our main results, we find that U.S. monetary policy easing surprises lead to dollar depreciation and lower domestic and foreign bond risk premia. Our findings on the effects on foreign exchange risk premia differ for forward guidance and asset purchase surprises. We report some evidence that forward guidance easing surprises raise foreign exchange risk premia. But asset purchase easing surprises, if anything, actually lower foreign exchange risk premia.

The plan for the remainder of this paper is as follows. In the next section we describe the data we use in the empirical analysis. In section 3, we describe our VAR methodology. In section 4, we present empirical results. Section 5 concludes.

2 DATA

We use a wide range of financial and macroeconomic data at different frequencies. To the extent possible, we try to incorporate intradaily information into our analysis.

Along the lines of the work of Gürkaynak et al. (2005) and Swanson (2017), and taking account of the special circumstances at the ZLB, we consider three separate measures of U.S. monetary policy surprises:

1. The surprise component of the decision about the target federal funds rate based in the change in yield on the current- or next-month federal funds futures contracts, as proposed by Kuttner (2001), from 15 minutes before the time of a Federal Open Market Committee (FOMC) or other monetary policy announcement to 1 hour and 45 minutes afterwards. We call this a *target surprise*. At the ZLB, there were effectively no target surprises.

2. We take the residual from a regression of the change in the yield for the fourth Eurodollar futures contract from 15 minutes before the time of the announcement to 1 hour 45 minutes afterwards onto the target surprise. The fourth

Eurodollar futures contract is a bet on the level of three month interest rates about one year hence. We call this a *forward guidance surprise*. At the ZLB, this was around the shortest point on the term structure that could be influenced by monetary policy. But, even away from the ZLB, forward guidance surprises have been very important, as the FOMC has long tried to manage expectations of future changes to the target federal funds rate. Decisions about the target federal funds rate have been largely anticipated by markets and have ratified expectations that were already set in place (Kuttner, 2001; Gürkaynak et al., 2005).

3. The residual from a regression of the change in the ten-year Treasury futures yield from 15 minutes before the time of the announcement to 1 hour and 45 minutes afterwards onto the target and forward guidance surprises. This measures the jumps in long-term interest rates that are associated with FOMC announcements related to large-scale asset purchases. We call this an *asset purchase surprise* and compute it only over the period October 2008-December 2015 that we think of as being associated with asset purchases and the ZLB.[2]

Although we include target surprises for completeness, these shocks did not apply at the ZLB, and have been consistently small for a long time, and so they are not our focus in this paper. Instead, we are most interested in the forward guidance and asset purchase surprises that are the tools of unconventional monetary policy. Figure 1 shows the time series of the target and forward guidance surprises from February 1994 (when the FOMC began announcing it's decisions after committee meetings) to December 2015, and of the asset purchase surprises over the ZLB period (October 2008-December 2015). The series are shown monthly. In months with no monetary policy announcements, the surprises are set to zero. In months with more than one monetary policy announcements, the surprises are the sum of those from each announcement in that month. There are 196 monetary policy announcements in this period, which are all statements following scheduled FOMC meetings, statements following the 6 intermeeting changes in the target for the federal funds rate, and 14 other events that are particularly salient to unconventional monetary policy[3]. Of these 196 announcements, 69 are during the ZLB period. As can be seen in Figure 1, forward guidance surprises exist both before and at the ZLB. They diminish in absolute magnitude in 2012-2014 as Federal Reserve communication strategy had convinced investors that liftoff was at least a year off and so the ZLB effectively extended that far out the term structure for a while (Swanson and Williams, 2014).

In the VAR analysis, we use three-month, five-year and ten-year U.S. zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year foreign zero-coupon bond yields, the U.S. unemployment rate and log CPI, and the excess bond premium of Gilchrist and Zakrajšek (2012). The zero-coupon bond yields all come from the dataset of Wright (2011), updated to the end of 2015, augmented with Italian zero-coupon bond yields, obtained from the BIS. Exchange rates are defined throughout as dollars per unit of foreign currency. The VAR is run at the monthly frequency (using end-of-month data for asset prices), but we have daily data on the zero-coupon yields and intradaily data on foreign exchange rates, and we will use these higher-frequency data in identifying our structural VAR, as explained below. We choose the United Kingdom, euro area, and Japan as our foreign countries, and use German zero-coupon yields as euro area interest rates.[4] The sample period is January 1990 to December 2015 (except January 1999 to December 2015 where the euro area is the foreign country).

3 VAR ANALYSIS

We start from an assumption that there is an nx1 vector of monthly variables, Y_t including interest rates and exchange rates, that follows a VAR(p):

$$A(L)Y_t = c + \varepsilon_t \tag{1}$$

where ε_t denote the reduced form forecast errors which are $N(0, \Sigma)$. We further assume that these reduced form errors can be related to a set of underlying structural shocks:

$$\varepsilon_t = R\eta_t$$

where η_t is a vector of structural shocks. Partition η_t as $(\eta_{1t}, \eta'_{2t})'$ where η_{1t} is the monetary policy shock and η_{2t} is an $(n-1)$x1 vector of other shocks. The fact that the monetary policy shock is ordered first is for notational convenience only. The ordering of variables is irrelevant as a Choleski decomposition will not be used for identification.

Our approach to identification instead involves the method of external instruments. We define Z_t as either the forward guidance or the asset purchase surprise for month t, constructed from intraday changes in interest rates around FOMC announcements, as described earlier.

We make a number of assumptions. Our first assumption is that Z_t is correlated with the monetary policy shock and uncorrelated with all other structural shocks:

ASSUMPTION A1: $E(\eta_{1t}Z_t) = \alpha$ *and* $E(\eta_{2t}Z_t) = 0$.

Let $\tilde{Y}_t$ be the $\tilde{n}$x1 subvector of elements of Y_t for which higher frequency data are available (asset prices, not macro variables) and define S as the $\tilde{n}$xn selection matrix such that $\tilde{Y}_t = SY_t$. Further define W_t as the $\tilde{n}$x1 vector of changes in the elements of $\tilde{Y}_t$ in daily or intradaily windows bracketing the time of any monetary policy announcement in month t[5]. Our second assumption is that any shocks to Y_t that occur away from the time of the monetary policy announcement cannot be correlated with the jump that is associated with the monetary policy news:

ASSUMPTION A2: $E(Z_t(S\varepsilon_t - W_t)) = 0$.

Clearly assumption A2 implies that $E(Z_t W_t) = E(Z_t S \varepsilon_t)$. In conjunction with assumption A1, it implies that $E(Z_t \varepsilon_t) = \alpha R_1$ and $E(Z_t W_t) = \alpha S R_1$, where R_1 is the first column of R. Essentially this assumption allows us to establish the impact effect of the monetary policy shock on asset prices from event-study regressions of W_t on Z_t, up to a scale factor. If assumption A2 were false, then it would imply that Z_t could either be predicted by previous asset price changes, or could be used to predict future asset price changes within that month. A standard efficient markets view would hold that there should be little predictability in asset returns. Assumption A1 is the standard external instruments assumption, and is sufficient for identification of R_1 up to scale and sign. Assumption A2 gives additional restrictions coming from observing some variables at high frequency, and this improves estimation efficiency of R_1.

But assumptions A1 and A2 identify R_1 only up to scale and sign. For target surprises, we consider a monetary policy shock that is scaled to lower U.S. three-month yields by 25 basis points. For forward guidance and asset purchase surprises, we consider a shock scaled to lower U.S. five-year yields by this same amount. We estimate the VAR by Bayesian methods, similar to those proposed by Caldara and Herbst (2016). Write the VAR in equation (1) in the form $Y_t = B'X_t + \varepsilon_t$ or, in matrix notation, $Y = XB + \varepsilon$ where X is Txk, and B (which contains all the parameters in $A(L)$) is nxk. Using assumptions A1 and A2, and assuming Gaussianity, we can write:

$$\begin{pmatrix} Y_t - B'X_t \\ W_t \\ Z_t \end{pmatrix} = \begin{pmatrix} \varepsilon_t \\ W_t \\ Z_t \end{pmatrix} \sim N(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \multicolumn{2}{c}{\Omega} & \gamma \\ & & S\gamma \\ \gamma' & \gamma'S' & \psi^2 \end{pmatrix})$$

where $\gamma = \alpha R_1$. Hence, from a multivariate conditional normal:

$$Z_t|\varepsilon_t, W_t \sim N(\mu_{Z|\varepsilon,W}, V_{Z|\varepsilon,W}) \tag{2}$$

where

$$\mu_{Z|\varepsilon,W} = \begin{pmatrix} \gamma' & \gamma'S' \end{pmatrix} \Omega^{-1} \begin{pmatrix} \varepsilon_t \\ W_t \end{pmatrix}$$
$$V_{Z|\varepsilon,W} = \tilde{\psi}^2 = \psi^2 - \begin{pmatrix} \gamma' & \gamma'S' \end{pmatrix} \Omega^{-1} \begin{pmatrix} \gamma \\ S\gamma \end{pmatrix}.$$

Our prior for the parameters $\{B, \Omega, R_1, \tilde{\psi}\}$ is diffuse, and proportional to $|\Omega|^{-(l+1)/2}$ where $l = k + \tilde{n}$. The posterior for the parameters is then:

$$\begin{aligned} p(B, \Omega, \gamma, \tilde{\psi}|Y, W, Z) &\propto p(Y, W, Z|B, \Omega, \gamma, \tilde{\psi})|\Omega|^{-(l+1)/2} \\ &= p(Y, W|Z, B, \Omega, \gamma, \tilde{\psi})p(Z|Y, W, B, \Omega, \gamma, \tilde{\psi})|\Omega|^{-(l+1)/2} \\ &= p(Y, W|B, \Omega)p(Z|Y, W, B, \Omega, \gamma, \tilde{\psi})|\Omega|^{-(l+1)/2} \\ &\propto |\Omega|^{-(T+l+1)/2} \exp(-\frac{1}{2}tr(\Omega^{-1}\xi(B)'\xi(B))) \\ &\quad \tilde{\psi}^{-1} \exp(-\frac{1}{2\tilde{\psi}^2}(Z - \mu_{Z|\varepsilon,W})'(Z - \mu_{Z|\varepsilon,W})) \end{aligned} \tag{3}$$

where Z and W denote the available data on Z_t and W_t and $\xi(B) = [Y - XB\ W]$. We take draws from the posterior in equation (3) from the following simulation scheme:

1. Draw a proposal for Ω from an inverse-Wishart distribution with parameters $(\xi(\hat{B})'\xi(\hat{B}), T-l-1)$ where $\hat{B}$ denotes the OLS estimator of B, and a proposal for $vec(B)$ from a $N(vec(\hat{B}), \Sigma \otimes (X'X)^{-1})$ distribution. Let $q(B, \Omega)$ denote the proposal density and let Ω^* and B^* denote the realizations of these proposals. Accept this proposal with probability:

$$min(\frac{p(B^*, \Omega^*, \gamma, \tilde{\psi}|Y, W, Z)}{p(B, \Omega, \gamma, \tilde{\psi}|Y, W, Z)} \frac{q(B, \Omega)}{q(B^*, \Omega^*)}, 1).$$

   Otherwise keep the existing draws of B and Ω.

2. Draw a proposal for $(\gamma, \tilde{\psi})$ from a random walk Metropolis-Hasting step, $(\gamma^*, \tilde{\psi}^*)$, i.e. let the proposed value for each of these parameters be the existing value plus a Gaussian shock. Accept the proposal with probability:

$$\min(\frac{p(Z|Y, W, B, \Omega, \gamma^*, \tilde{\psi}^*)}{p(Z|Y, W, B, \Omega, \gamma, \tilde{\psi})}, 1)$$

   using the posterior in equation (2). The innovation variance of the shocks to the proposal is calibrated to target an acceptance rate of around 35 percent.

3. Let R_1 be γ, normalized to lower U.S. five-year yields by 25 basis points, except for the target surprise where the normalization is to lower U.S. three-month yields by 25 basis points. Positive values of the instruments correspond to unexpected tightenings; but the monetary policy shocks identified in our structural VAR are constructed to be easing surprises.

4. Use R_1 and B to compute a draw from the impulse response.

5. Repeat steps 1-4 to build up the posterior distribution, discarding an initial burnin sample.

This allows us to trace out the effect of any of the types of monetary policy shocks on $E_t(Y_{t+j})$. The methodology essentially involves the external instruments approach, but we extend it by using the fact that data at higher-than-monthly frequency are available for many elements of Y_t.[6] However, because we embed this in an identified VAR, we can trace out the full dynamic effect of the monetary policy shock, not just the instantaneous effect as is standard in the event-study literature.

As noted above, we have three different (mutually orthogonal) instruments that we use to identify three different monetary policy shocks. We identify each monetary policy shock separately. In principle, we could identify all three jointly as a system assuming that each instrument is correlated with just one structural shock. But we leave this extension for future work.

We let Y_t be a vector of 9 variables: three-month, five-year and ten-year U.S. zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year foreign zero-coupon bond yields, the U.S. unemployment and log CPI, and the excess bond premium of Gilchrist and Zakrajšek (2012). Log CPI is linearly detrended.[7] A separate VAR is run for each foreign country: United Kingdom, euro area, and Japan. For W_t, we observe daily data on the zero-coupon yields and intradaily data on the foreign exchange rate, and we construct the variable W_t as described in footnote 2. The sample period is January 1990 to December 2015 (except January 1999 to December 2015 where the euro area is the foreign country). For our external instruments, we use data from February 1994 to December 2015 for target and forward guidance surprises and from October 2008 to December 2015 for asset purchase surprises, setting the external instruments to zero where they are not available.

The VAR immediately allows us to trace out the effects of the monetary policy shock on future values of Y_t. But, because expectations can be measured from the VAR, it also allows us to work out the effects of the monetary policy shock on various financial market risk premia. These include the domestic term premium, defined as:

$$TP_t(m) = r_t(m) - E_t(\frac{1}{m/3}\Sigma_{i=0}^{m/3-1} r_{t+3i}(3)), \tag{4}$$

the foreign term premium, defined similarly as:

$$TP_t^*(m) = r_t^*(m) - E_t(\frac{1}{m/3}\Sigma_{i=0}^{m/3-1} r_{t+3i}^*(3)), \tag{5}$$

and the average annualized foreign exchange risk premium over the next m months, defined as:

$$FP(m) = \frac{1}{m/3}\Sigma_{i=0}^{m/3-1}[E_t r_{t+3i}^*(3) - E_t r_{t+3i}(3) + 400(E_t s_{t+3i+3} - E_t s_{t+3i})]. \tag{6}$$

In these definitions, the short rate is a three-month interest rate but the time subscripts refer to months, consistent with the VAR. Examining the dynamic effect of the monetary policy shock on each of these risk premia gives us additional insight into the channels by which monetary policy may be effective.

Our paper is related to the large and fast-growing literature on the effects of unconventional monetary policy. Authors such as Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgenson (2011) and Christensen and Rudebusch (2012) have examined the change in government bond yields and term premia—as estimated by affine term structure models—on the days of specific unconventional monetary policy announcements. Wright (2012) and Rogers et al. (2014) used a methodology based on identification through heteroskedasticity to trace out the effects of monetary policy surprises on interest rates. Kiley (2013) estimates the *one-day* effects of monetary policy surprises on foreign and domestic long-term interest rates and on exchange rates.[8] The present paper is however the first to use a vector autoregression identified with external instruments to measure the full dynamic effects of unconventional monetary policy surprises on foreign and domestic interest rates, and exchange rates. As a by-product, this then gives us estimates of the effects of monetary policy surprises on the full set of financial market risk premia given by equations (4)-(6).

It should also be emphasized that several papers, including Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgenson (2011) and Christensen and Rudebusch (2012), have analyzed the effects of specific unconventional monetary policy announcements, assuming that they were entirely unanticipated by the markets. This is a reasonable assumption in relation to some announcements, for example during the first phase of quantitative easing in the United States (QE1). But many other unconventional monetary policy announcements have been partially anticipated by markets. This is not a problem for our methodology, as long as there is some news coming out in monetary policy announcements.

Forward guidance surprises exist both at and away from the ZLB. Asset purchase surprises only apply at the ZLB and target surprises are effectively nonexistent at the ZLB. One might wonder if the effects of forward guidance surprises are different in the pre-ZLB and ZLB subsamples. This can be assessed using the forward guidance surprises only over the ZLB period. Results are shown in the appendix of supplementary materials but are quite similar to those using forward guidance surprises over the entire sample. We therefore conclude that the impact of forward guidance surprises does not depend much on whether the economy is at the ZLB or not.

4 EMPIRICAL RESULTS

We consider the effects of the three different monetary policy surprises on a number of variables, showing impulse responses out to 60 months. Results for the effects on the exchange rate are shown in Figure 2. The figure shows the posterior median and 68 percent Bayesian posterior intervals, which we henceforth refer to as the estimates and confidence intervals.[9] All three expansionary U.S. monetary policy shocks cause the dollar to depreciate significantly. Unlike Eichenbaum and Evans (1995) (who considered VARs with recursive identification) and several other more recent papers, we find little evidence of delayed overshooting. The exchange rate effect is significantly positive for at least a few quarters for all three surprises and for all three currencies.[10] Recall that the target surprise is normalized to lower three-month yields by 25 basis points, while the forward guidance and asset purchase surprises are normalized to lower five-year yields by this same amount. In a few cases, such as the effects of forward guidance shocks on the pound and euro exchange rates, there is a little evidence of delayed overshooting.

Figure 3 shows the effect of the U.S. monetary policy surprises on foreign three-month interest rates. The easing target surprise initially significantly lowers foreign short rates, but the effect is not very long lasting. The forward guidance and asset purchase easing shocks have little effect on foreign short-term interest rates, except for forward guidance shocks and U.K. short term interest rates. While U.S. forward guidance easing shocks initially lead U.K. short rates to fall very slightly, but significantly, at longer horizons they cause U.K. short rates to rise. An FOMC signal that it will keep rates low for a long time does not directly bind the Bank of England, and should lead to a strengthening of the global economy. In this way, it is not unreasonable to suppose that the Bank of England might respond by adopting a tighter monetary policy in due course.

Figure 4 shows the effect of the U.S. monetary policy surprises on foreign ten-year interest rates. Forward guidance surprises lower foreign ten-year interest rates, but the effect is short-lived. Asset purchase surprises lower foreign ten-year interest rates and the effect is sizeable and quite persistent. The fact that U.S. easing surprises are more effective in lowering foreign ten-year yields than in lowering foreign three-month yields likely owes to the fact that these countries were stuck at the ZLB for part of the sample period.

Figure 5 shows the effect of the monetary policy surprises on the expected foreign exchange excess returns, $FP(m)$, at different horizons. The forward guidance shocks generally raise the foreign exchange risk premium, and significantly so at short horizons for the pound and euro. These are cases in which the foreign exchange rate showed some sign of delayed overshooting (Figure 2). This failure of conditional UIP is consistent with earlier VAR work on the effects of monetary policy shocks (e.g. Eichenbaum and Evans (1995); Faust and Rogers (2003); Scholl and Uhlig (2008) who find positive responses to easing shocks, albeit with wide confidence bands). Several authors have proposed explanations for this delayed overshooting phenomenon. Bruno and Shin (2015) argue that it occurs because U.S. easing monetary policy shocks increase the leverage of cross-border banks and hence raise the foreign exchange risk premium. Bruno and Shin (2015) attribute it to investors having distorted beliefs about interest rates, ascribing too much variation in interest rates to transitory as opposed to permanent shocks. Kim (2005) instead ascribes it to foreign exchange intervention policy, although that has not been a factor for major currency exchange rates in recent years.

Figure 5 also shows the effects of asset purchase easing shocks. These tend to lower foreign exchange risk premia, significantly so for the pound and yen. This is also a failure of conditional UIP, but one of the opposite sign. To shed some light on the finding that asset purchases surprises tend to lower foreign exchange risk premia, we examined the effects of different monetary policy surprises on capital flows in a simple event-study analysis. In Table 1, we report the results of event-study regressions of changes in equity capital flows on monetary policy surprises. The capital flows data are at the weekly frequency and provided by Emerging Portfolio Fund Research.[11] Fund holdings represent between 5 and 25 percent of the float-adjusted market capitalization of individual equity markets. We measure the capital flows as either dollar-denominated funds investing in advanced foreign economies' equities and, in the right column, the active component of this, i.e., flows where valuation changes from the previous period are abstracted from.

In Table 1, we see that asset purchase shocks have an impact on dollar-denominated flows of funds investing in advanced foreign economies' equities, whereas forward guidance shocks do not significantly affect capital flows. This is consistent with our finding in Figure 5. Forward guidance easing shocks don't affect capital flows and the foreign exchange risk premium goes up. We don't take a stand on the mechanism by which this happens, but we reviewed some potential explanations earlier. In contrast, the coefficient on asset purchase shocks is negative. This means that an asset purchase easing shock (negative value of the asset purchase surprise) leads US fund investors to acquire more foreign equities. This may drive down the expected excess returns for holding foreign currency and hence explain the drop in the foreign exchange risk premium for the pound and yen.

The effects of monetary policy surprises on foreign exchange risk premia can be decomposed into two pieces: the effect on future interest differentials (carry), and the effect on future exchange rate returns. Figure 5 also includes the point estimate of the effect on future interest differentials, which is relatively small. This means while carry is an important part of the foreign exchange risk premium (Koijen et al., 2016), the effect of monetary policy surprises on the foreign exchange risk premium is working mainly through its impact on future currency appreciation.

Table 2 shows the estimated instantaneous effect of the three monetary policy surprises on the ten-year term premium in the United Kingdom, euro area and Japan. Target surprises are estimated to slightly raise foreign term premia, though this is significant only for Japan. Turning to forward guidance and asset purchase surprises, for all three foreign countries, term premia fall significantly and the point estimates of the effects on term premia are roughly comparable to the effects on the ten-year yield. Thus, the initial effect on foreign long bond yields is estimated to be mainly due to term premia. The effects on foreign yields and term premia are smaller for Japan than for the United Kingdom and euro area.

We can use our impulse responses to trace out the full dynamic effect of the monetary policy surprises on ten-year term premia. We include the point estimate of the dynamic effect on foreign term premia in Figure 4—the dynamic effect on foreign long bond yields is also estimated to be mainly due to term premia.

4.1 *Effects of Monetary Policy on Domestic Variables*

Our main focus in this paper is on the effects of monetary policy shocks on international risk premia, but our methodology also gives estimates of the effects of monetary policy shocks on domestic macroeconomic variables and term premia. The precise results of course depend on which foreign country is included, but are qualitatively similar to each other, and to the results in a VAR that includes no foreign variables. Consequently, for the purpose of estimating effects on domestic macroeconomic variables and term premia, we report results from a VAR in U.S. three-month, five-year and ten-year interest rates, unemployment rate, CPI, and the excess bond premium.

Figure 6 shows the effects of all three monetary policy shocks on unemployment, the price level and the excess bond premium. The easing target surprise is slightly inflationary, but has no significant effect on unemployment. The forward guidance easing surprise significantly lowers unemployment and the excess bond premium, but initially lowers the price level. The drop in the price level reverses after a while. These results could be interpreted as evidence that the monetary policy easing causes economic agents to lose confidence in the economy (as in Campbell et al. (2012)), and/or risks trapping the economy in a low inflation equilibrium (Benhabib et al., 2001; Bullard, 2010). A similar unexpected impact on the price level is found in much of the VAR literature, and is commonly referred to as the price puzzle (Sims, 1992).[12] Easing asset purchase shocks raise prices and lower unemployment with both effects being on the borderline of statistical significance.

Table 3 shows the effects on the US term premium. The forward guidance and asset purchase monetary policy shocks that lower the five-year yield by 25 basis points are both estimated to lower the corresponding term premium by about the same amount, fully explaining the drop in yields. The term premium declines are statistically significant. Results for the ten-year term premium are similar.

4.2 *Foreign Monetary Policy Shocks*

We applied our methodology to the case where the home country is the United Kingdom, the euro area or Japan. For the United Kingdom and Japan, the variables in the VAR, Y_t, consist of three-month, five-year and ten-year U.K./Japanese zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year U.S. zero-coupon bond yields, and U.K./Japanese unemployment and log CPI. We do not attempt to disentangle the monetary policy surprises into different types of announcements, as we did for the U.S.. Rather, the external instruments are now simply intraday changes in U.K. or Japanese ten-year government bond yields on monetary policy announcement days. The monetary policy surprise is normalized to lower U.K./Japanese five-year bond yields by 25 basis points. For the euro area, the variables in the VAR consist of three-month, five-year and ten-year German zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year U.S. zero-coupon bond yields, euro area unemployment and log CPI, and five-year zero-coupon Italian bond yields. The external instrument is the spread between Italian and German yields, and the monetary policy shock is normalized to lower five-year Italian yields by 25 basis points. The somewhat different treatment of euro area monetary policy surprises is because, over this unusual period, accommodative actions of the ECB were clearly aimed at lowering government bond yields such as Italy and other countries whose sovereign bond markets were coming under significant pressure, rather than German bond yields.

As in the U.S. framework, the sample period is January 1990 to December 2015 for the VAR estimation of the residuals (except January 1999 to December 2015 for the euro area). For our external instrument Z_t, we only consider announcements during the unconventional monetary policy period—the dates of U.K., euro-area and Japanese unconventional monetary policy announcements correspond to those in Rogers et al. (2014) updated to the end of 2015.[13]

Figure 7 shows the estimated effects of U.K., euro-area, and Japanese monetary policy shocks on their respective exchange rates. The Bank of England monetary policy easing that lowers five-year U.K. yields by 25 basis points is estimated to lead to pound depreciation viz-a-viz the dollar that is significant at horizons out to about three years. Similarly, the corresponding Bank of Japan monetary policy easing leads to yen depreciation that is significant after a short lag. The ECB monetary policy easing that lowers Italian five-year yields by 25 basis points leads to a statistically significant *appreciation* of the euro. This finding may seem anomalous, but recall that the euro was in danger of falling apart for most of our sample period. This is presumably the reason why actions that lowered Italian-German spreads, which we interpret as monetary policy easings, led to euro appreciation. Note that the January 2015 ECB announcement of larger-than-expected quantitative easing was accompanied by euro depreciation, and commentary attributed much of the depreciation of the euro in late 2014 to building expectations that the ECB would embark on a full-blown quantitative easing program. This however came near the end of our sample when concerns about the viability of the euro had ebbed. We conjecture that going forward ECB monetary policy easing surprises will lead to euro depreciation, unless substantial concerns of a disintegration of European monetary union resume.[14]

Figure 8 shows the estimated effects of U.K., euro-area and Japanese monetary policy shocks on U.S. interest rates. The U.K. and Japanese monetary easings significantly lower U.S. ten-year yields. The euro area easing shock actually raises U.S. yields at short horizons. Again this is probably because ECB easing shocks raised the chances of the survival of the euro and reduced safe-haven flows into Treasuries.

Figure 9 shows the estimated effects of U.K., euro area, and Japanese monetary policy shocks on the foreign exchange risk premium. Foreign monetary policy easings are estimated to raise the foreign exchange risk premia at short horizons for the yen. They have no significant effect on the foreign exchange risk premia for the pound. But they significantly lower the foreign exchange risk premia for the euro. These foreign exchange risk premia are defined from the perspective of the foreign country. For example, the U.K. panel shows the effect of the Bank of England monetary policy easing on expected future U.S. short rates less expected future U.K. short rates, adjusted for expected changes in the pound-dollar exchange rate. The different results for the euro could again owe to the special nature of ECB monetary policy surprises over this period. The foreign exchange risk premium is defined as expected future U.S. short rates less expected future German short rates, adjusted for expected changes in the euro-dollar exchange rate. Concerns about possible breakup of European monetary union drove short-term German interest rates down. ECB monetary policy easings, as we have defined them, made that breakup less likely, and so pushed German short term interest rates up, hence lower the foreign exchange risk premium.

4.3 *Shadow Rates*

In this paper, we have used a linear VAR including short-term interest rates even though the ZLB binds for part of the sample period. An alternative is to use a shadow rate estimated from a term structure model (Black, 1995; Krippner, 2015; Wu and Xia, 2016) in which the term structure of interest rates is used to infer what short rates would have been in the absence of a lower bound. Of course, the shadow rates are not observed data but rather are estimated from a model. We repeated our analysis replacing the three-month interest rate with the shadow rate of Wu and Xia (2016) for the U.S., U.K. and euro area.[15] Letting rs_t and rs_t^* denote the domestic and foreign shadow rates, the domestic term premium is:

$$TP_t(m) = r_t(m) - E_t(\frac{1}{m/3}\Sigma_{i=0}^{m/3-1}\max(rs_{t+3i}, 0)), \tag{7}$$

the foreign term premium is defined similarly, and the foreign exchange risk premium is:

$$FP(m) = \frac{1}{m/3}\Sigma_{i=0}^{m/3-1}[E_t\max(rs^*_{t+3i}, 0) - E_t\max(rs_{t+3i}, 0) + 400(E_t s_{t+3i+3} - E_t s_{t+3i})]. \tag{8}$$

Because these are no longer linear functions of the variables in the VAR, impulse responses of foreign exchange risk premia and term premia are nonlinear and depend on the current level of Y_t, but can still be obtained by simulation. The web appendix reports some results for this shadow rate model, but they are generally similar to those obtained without using the shadow rate.[16] One exception is that the effects of a U.S. monetary policy easing surprise on U.K. and euro area interest rates at the end of the sample are muted for about the first year in the model with shadow rates because the U.K. and euro area were still at the zero lower bound. The shock affects foreign shadow rates, but not foreign three month interest rates. However, after the first year, the effects are similar to those from the model without shadow rates.

4.4 *Using a Shorter Announcement Window*

In constructing the monetary policy surprises, we considered interest rate changes from 15 minutes before each announcement to 1 hour and 45 minutes afterwards. This represents a trade-off. On the one hand, we want the windows to be sufficiently small that non-policy news is negligible. But we want the windows to be sufficiently large to allow for the full effects of the policy announcement to be incorporated. This includes the press conferences that are now a feature of central bank announcements.

As a robustness check, we re-did Figures 2-9 using a tighter window from 15 minutes before each announcement to 15 minutes afterwards. We report these results in the web appendix. The effects of U.S. monetary policy surprises are similar with the tight window. For ECB and Bank of Japan surprises, the impulse response confidence intervals are a good bit wider. The estimated effect of the Bank of Japan easing on the exchange value of the yen is nonetheless significantly negative with the tight window, which was not the case with the wide window.

5 CONCLUSION

We assess the relationship between monetary policy and foreign exchange risk premia and term premia at the zero lower bound, employing a structural VAR analysis, using changes in yields in short windows bracketing monetary policy announcements as an external instrument. This represents a different and more credible approach to identification of structural monetary policy shocks, one that is well-suited to analyzing policy at the ZLB. We separate out monetary policy shocks that operate at different points on the term structure: target surprises, forward guidance surprises and asset purchase surprises. We find that all three kinds of easing monetary policy surprises lead to dollar depreciation. Forward guidance and asset purchase surprises, that were central at the ZLB, lower domestic and foreign bond risk premia. We report some evidence that forward guidance easing surprises raise foreign exchange risk premia. But asset purchase easing surprises, if anything, actually lower foreign exchange risk premia.

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Notes

[1]There are of course exceptions (Faust and Rogers, 2003; Scholl and Uhlig, 2008; Bjornland, 2009; Bouakez and Normandin, 2010). Faust and Rogers (2003) first studied these issues using a technique that allowed a relaxation of such dubious assumptions, Scholl and Uhlig (2008) use a related sign restrictions procedure, while Bjornland (2009) and Bouakez and Normandin (2010) use long run zero restrictions and identification through heteroskedasticity, respectively.

[2]The jumps in long-term yields, orthogonalized with respect to jumps in the fourth Eurodollar contract, can of course equally be computed before the ZLB. But they are smaller in absolute magnitude, and do not have an interpretation as representing the effects of asset purchases.

[3]These are crisis-era FOMC announcements on 8/7/2007, 8/10/2007, 3/11/2008, 10/8/2008 and 11/25/2008 and 12/1/2008, Jackson Hole speeches on 8/27/2010, 8/26/2011, 8/31/2012 and 8/22/2014, Bernanke's speech at the Boston Fed on 10/15/2010, Bernanke's testimony on tapering on 5/22/2013 and the monetary policy reports on 7/15/2014 and 2/25/2015.

[4]The ECB also provides a euro-area yield curve that is fitted to all sovereign euro-area bonds where the issuer has a AAA rating. The issuers included in the yield curve vary over time in line with credit ratings. The data for this yield curve only go back to 2004. We repeated our anyalsis replacing German yields by this yield curve since 2004, splicing on to German yields for earlier periods, but found that it did not change our results materially. Results are included in an appendix of supplementary materials.

[5]We use intradaily changes from 15 minutes before the monetary policy announcement to 1 hour 45 minutes afterwards, summed over all announcement days in the month, where these are available. Otherwise, we use daily changes, summed over all the announcement days in the month. If there is no FOMC or other policy announcement in a given month, the elements of W_t corresponding to any asset prices are all set to zero. The fact that we aggregate daily data to the monthly frequency means that we are assuming that shocks early and late in the month are equivalent to each other.

[6]The high-frequency data in W_t permits much tighter inference. We could simply use the standard external instruments approach, but the resulting confidence intervals for impulse responses would be much wider.

[7]We detrend CPI because the price level has a clear and very consistent upward trend—inflation is on average positive. The other variables do not have such clear trends. However, the results are

little changed if we instead detrend all of the series. Results for this case are shown in the appendix of supplementary materials.

[8]He defines the UIP deviation as the hold-to-maturity excess returns on the foreign long bond over the domestic long bond, i.e. $\frac{m}{12}(r_t^*(m) - r_t(m)) + 100(E_{t+m}s_{t+m} - s_t)$. Under the assumption that m is sufficiently large that the monetary policy surprise has no effect on $E_{t+m}s_{t+m}$, Kiley (2013) finds that monetary policy surprises do not significantly affect the UIP deviation defined in this way.

[9]Our use of 68 percent intervals is common in closely related papers (Eichenbaum and Evans, 1995; Kim, 2001; Kim and Roubini, 2000; Faust and Rogers, 2003; Scholl and Uhlig, 2008) and in the VAR literature more broadly (Sims and Zha, 1999). Identification of dynamic effects of monetary policy shocks in structural VARs is important but difficult, and 95 percent intervals are in many cases so wide as to be useless.

[10]Here and henceforth we refer to effects as significantly positive/negative if the Bayesian confidence interval covers only positive/negative values.

[11]Data at the daily frequency as in Curcuru et al. (2015) are only available to us till September 2014. Results on the daily subsample are consistent with the weekly results.

[12]We can, of course, also impose a sign restriction on impact by simply discarding any draw from the posterior for which the initial effect of the monetary policy easing shock raises unemployment or lowers the price level. However, the results on the interest rate and exchange rate effects of the monetary policy shock are mostly similar regardless of whether we impose the sign restriction or not.

[13]The unconventional monetary policy announcements are defined as all monetary policy announcements since October 2008, August 2007 and January 2000 for the Bank of England, ECB and Bank of Japan, respectively.

[14]Rogers et al. (2014) also found that euro-area expansionary monetary policy shocks led to euro appreciation.

[15]These were obtained from the website https://sites.google.com/site/jingcynthiawu/home/wu-xia-shadow-rates.

[16]We would also note that shadow rate models have drawbacks, including surprising sensitivity to the precise lower bound (Krippner, 2015). The lower bound is typically treated as exactly zero, but the Bank of England has at times viewed the lower bound as being greater than zero, while the

ECB and Bank of Japan have adopted negative interest rates.

Table 1: Effects of U.S. Monetary Policy Shocks on International Capital Flows

	AFE Equity Flows (change)	AFE Equity Active Flows (change)
Target Shock	-0.24	0.47
Forward Guidance Shock	0.36	2.36
Asset Purchase Shock	-2.12***	-2.95***
Constant	-0.12*	-0.10
Observations	69	69

Notes: The table reports results of regressions where weekly changes in capital flows are regressed on different monetary policy shocks and a constant over the sample starting in October 2008. The monetary policy shocks are as described in the text and positive values correspond to tightenings—a negative coefficient means that an easing surprise (negative shock) leads to an increase in US fund investors purchases of foreign assets. The two columns show results for changes in flows of USD-denominated funds investing in advanced foreign economies (AFE) equities, with the right column displaying results for active flows, that is flows where changes in value from the previous period are isolated. Flows data are described in Curcuru et al. (2015). One, two and three asterisks denote significance at the 10, 5 and 1 percent levels respectively.

Table 2: Effects of U.S. Monetary Policy Shocks on Foreign Ten-Year Term Premia (in basis points)

	Target	Forward Guidance	Asset Purchase
United Kingdom	-1.0	-13.3	-3.6
	(-8.6,5.7)	(-23.5,-4.3)	(-9.8,4.0)
Euro Area	-2.3	-13.3	-10.7
	(-8.6,2.7)	(-21.2,-6.2)	(-16.9,-4.4)
Japan	4.0	-4.3	-6.5
	(0.5,7.4)	(-9.5,0)	(-12.0,-2.9)

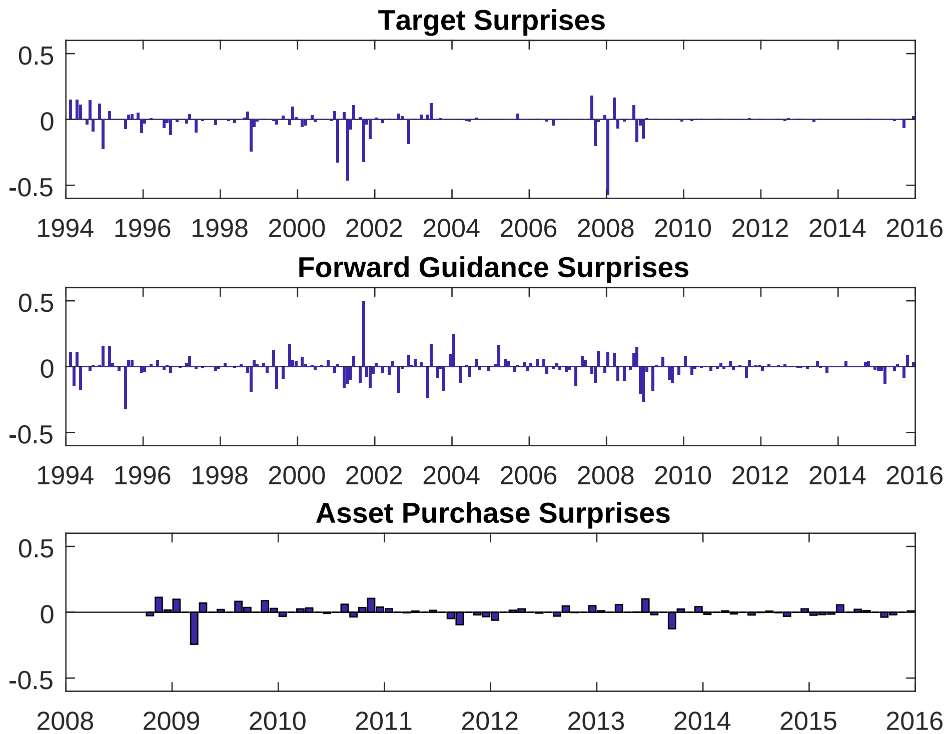
Notes: The table reports the posterior median and 68% Bayesian confidence intervals for the effects of the three U.S. monetary policy surprises on the ten-year term premium in the United Kingdom, Germany and Japan. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points.

Table 3: Effects of U.S. Monetary Policy Shocks on Domestic Term Premia (in basis points)

	Target	Forward Guidance	Asset Purchase
Five year	0.3	-35.0	-19.8
	(-5.7,5.8)	(-44.3,-27.0)	(-28.1,-12.1)
Ten year	3.2	-24.2	-24.4
	(-2.3,8.3)	(-33.1,-17.0)	(-32.1,-16.9)

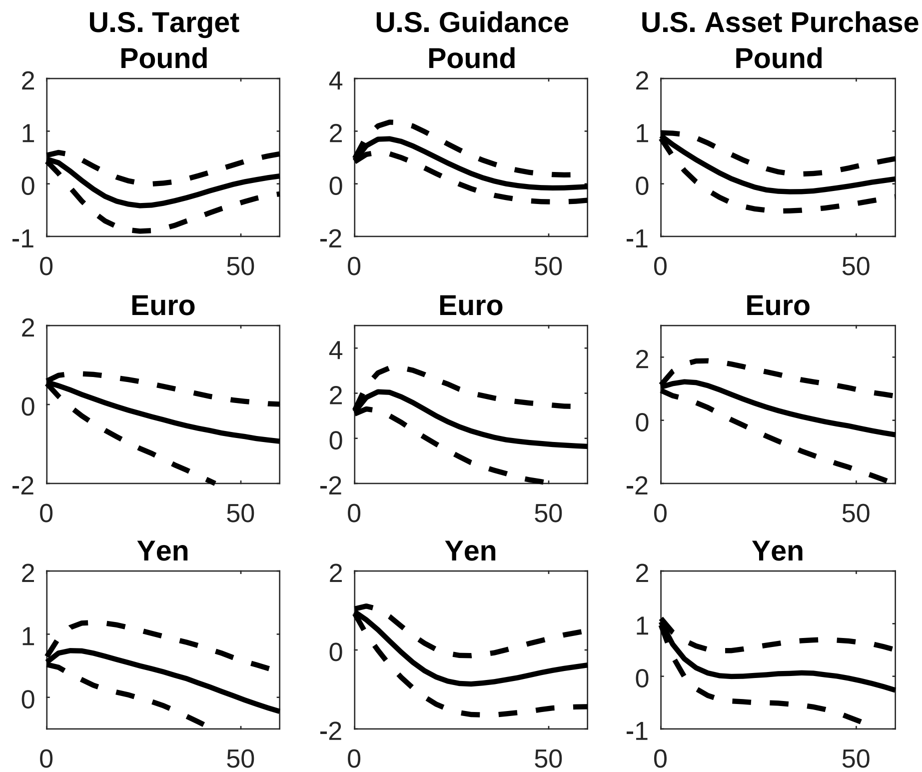
Notes: The table reports the posterior median and 68% Bayesian confidence intervals for the effects of the three U.S. monetary policy surprises on the five- and ten-year U.S. term premium. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points.

Figure 1: U.S. Monetary Policy shocks



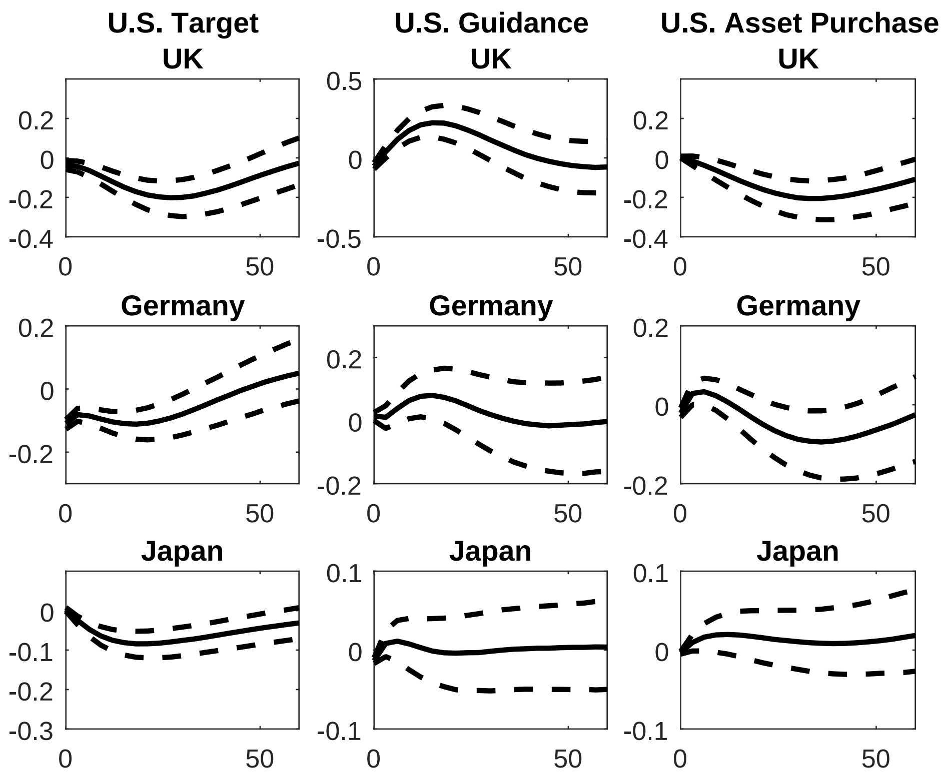
NOTE: This figure plots the time series of the three U.S. monetary policy surprises considered in this paper: target, forward guidance shocks and asset purchase shocks. Target surprises use changes in federal funds futures contracts as described in Kuttner (2001). Forward guidance shocks are changes in the fourth Eurodollar futures rate orthogonalized with respect to target surprises. Asset purchase shocks are changes in ten-year yields orthogonalized with respect to target and forward guidance surprises. All changes are in windows from 15 minutes before FOMC announcements to 1 hour and 45 minutes afterwards. Data are aggregated to the monthly frequency. In any month with no announcement, the shock is zero. In any month with multiple announcements, the shocks are added up within that month.

Figure 2: Effects of U.S. Monetary Policy Surprises and Exchange Rates



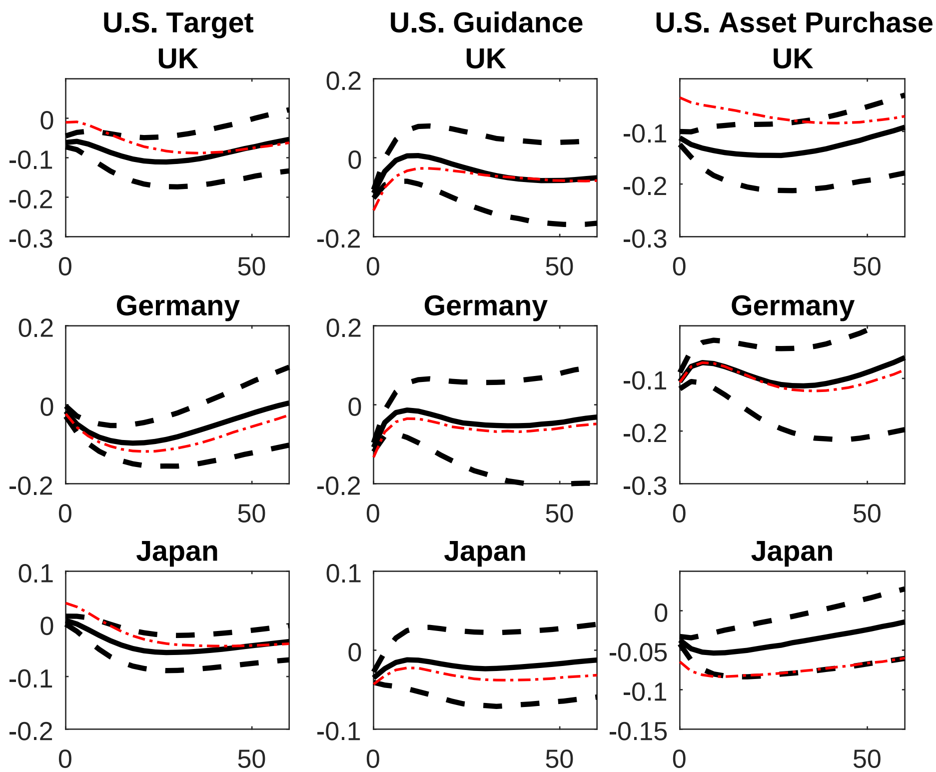
NOTE: This figure plots the posterior median effects of the three U.S. monetary policy surprises on exchange rates (in percentage points, measured as dollars per unit of foreign currency) over the subsequent 60 months. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points. The dashed lines are Bayesian 68 percent confidence intervals.

Figure 3: Effects of U.S. Monetary Policy Surprises on Three-Month Rates



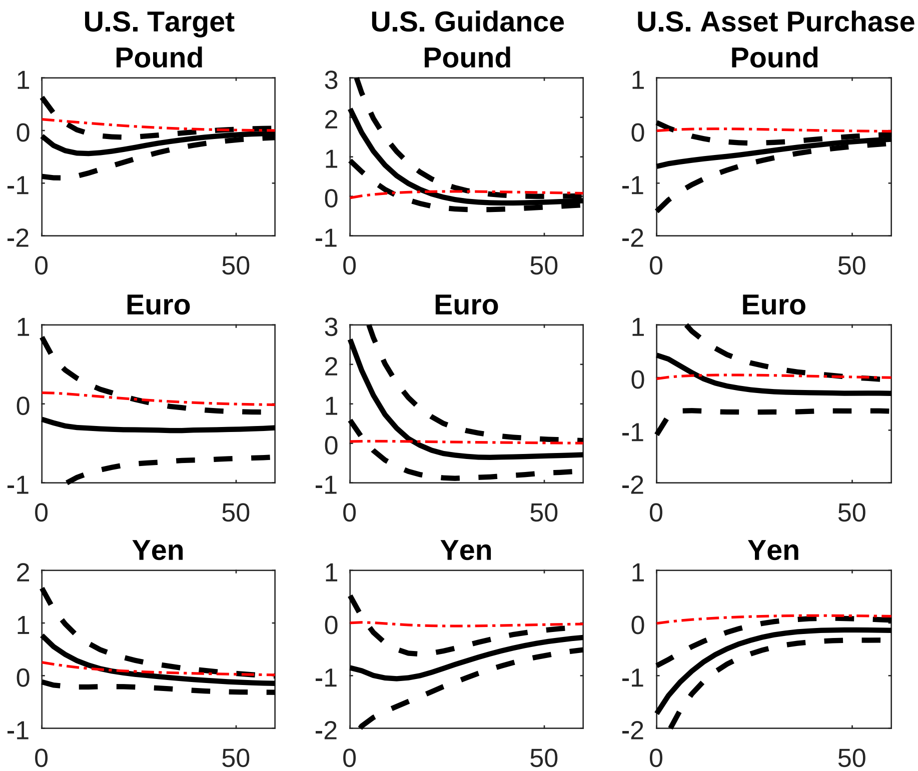
NOTE: This figure plots the posterior median effects of the three U.S. monetary policy surprises on foreign three-month interest rates over the subsequent 60 months. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points. The dashed lines are Bayesian 68 percent confidence intervals.

Figure 4: Effects of U.S. Monetary Policy Surprises on Ten-Year Rates



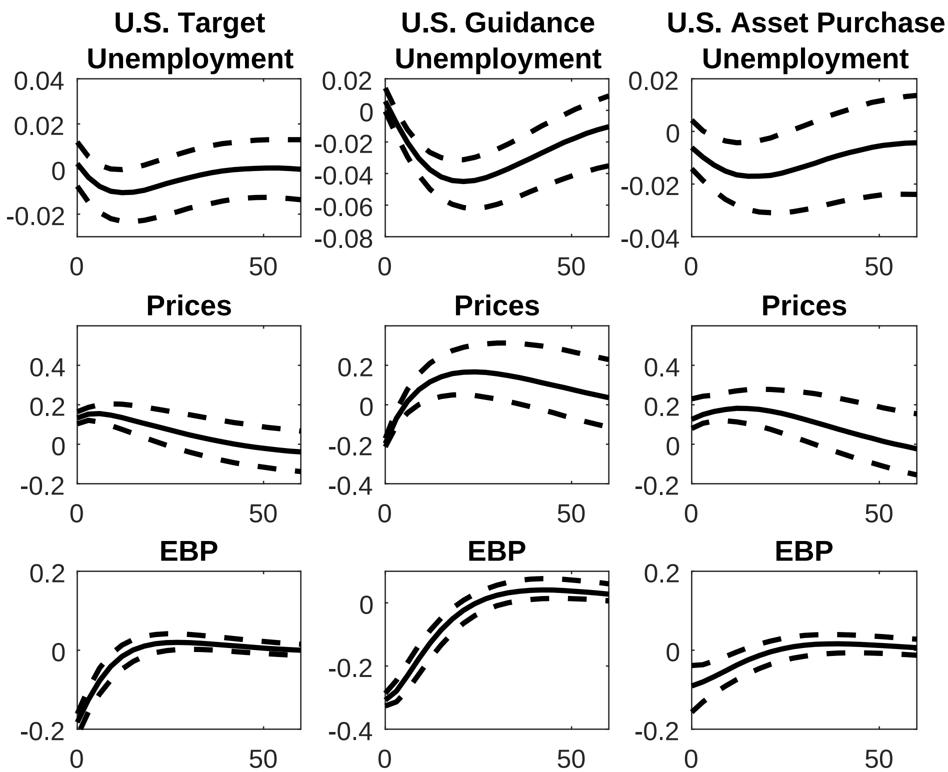
Note: This figure plots the posterior median effects of the three U.S. monetary policy surprises on foreign ten-year interest rates over the subsequent 60 months. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points. The dashed lines are Bayesian 68 percent confidence intervals. Dashed and dotted red lines also show the point estimates of the effects of the monetary policy surprises on foreign term premia: the dynamic version of the impulse responses reported in Table 2.

Figure 5: Effects of U.S. Monetary Policy Surprises on Foreign Exchange Risk Premium



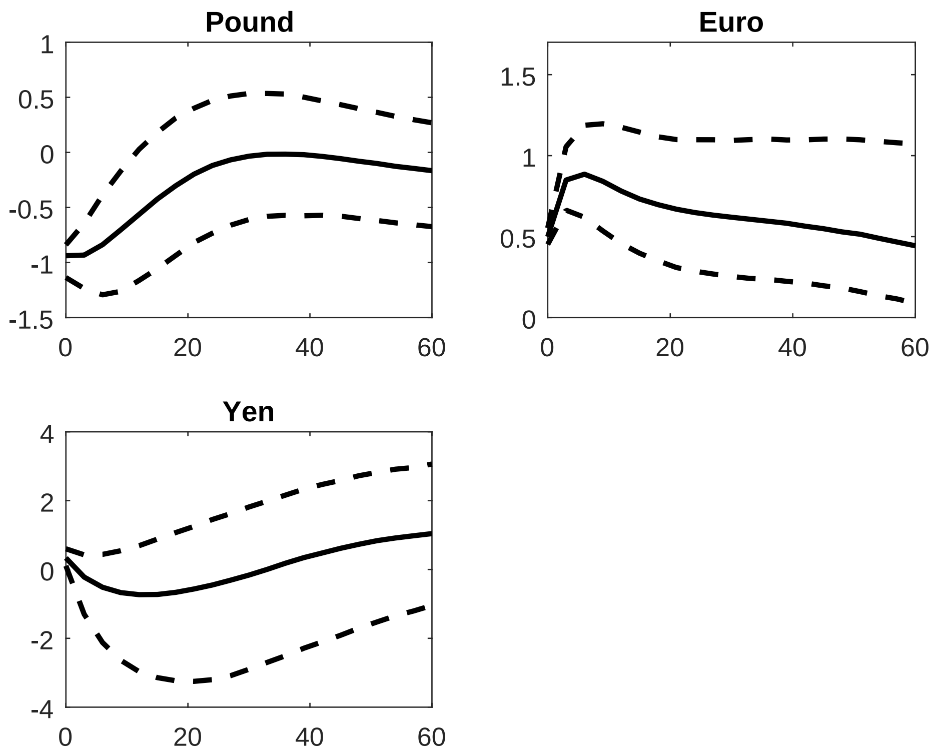
NOTE: This figure plots the posterior median effects of the three U.S. monetary policy surprises on the foreign exchange risk premium (as defined in equation (6) in the text, and measured in percentage points) over the subsequent 60 months. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points. The dashed lines are Bayesian 68 percent confidence intervals. Dashed and dotted red lines also show the point estimates of the effects of the monetary policy surprises on the carry term (excluding exchange rate changes) in equation (6).

Figure 6: Effects of U.S. Monetary Policy Surprises on Macroeconomic Variables



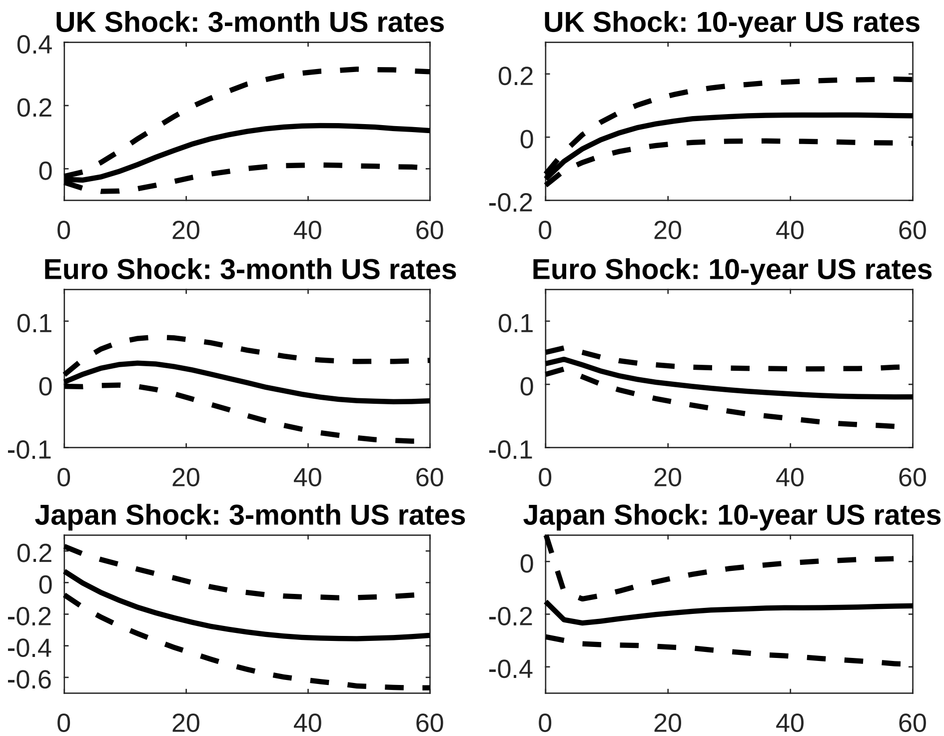
Note: This figure plots the posterior median effects of the three U.S. monetary policy surprises on the unemployment rate, 100 times the log CPI, and the excess bond premium over the subsequent 60 months. These are computed from the VAR using domestic variables only. Target surprises are normalized to lower three-month yields by 25 basis points; forward guidance and asset purchase surprises are normalized to lower five-year yields by 25 basis points. The dashed lines are Bayesian 68 percent confidence intervals.

Figure 7: Effects of Non-U.S. Monetary Policy Shocks on Exchange Rates



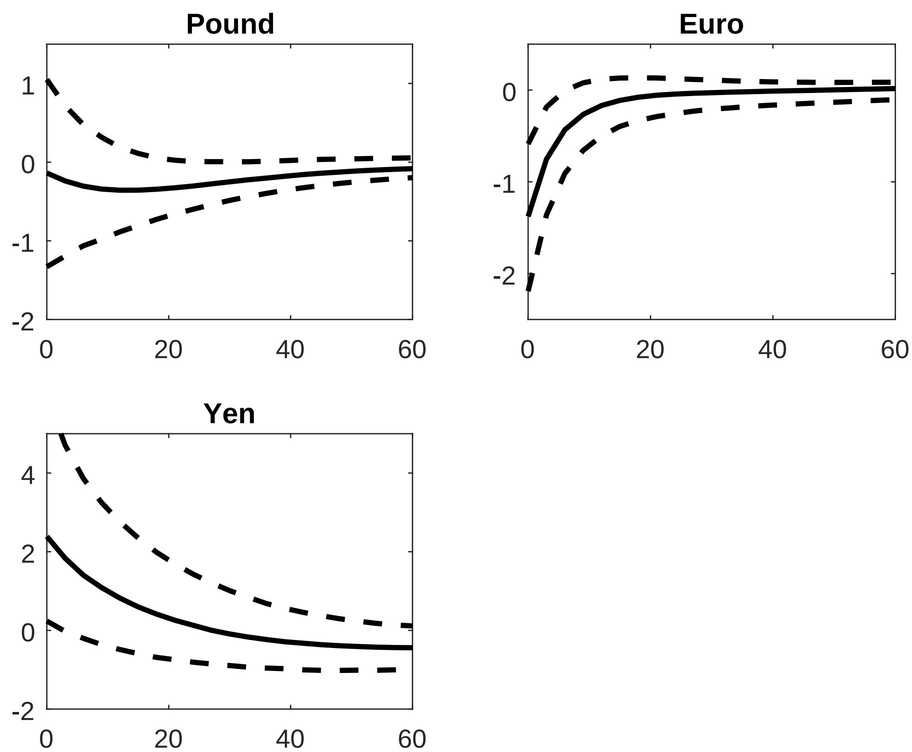
Note: This figure plots the posterior median effects of a monetary policy shock that lowers the U.K., Italian or Japanese five-year yield by 25 basis points on the respective exchange rates (in percentage points, measured as unit of foreign currency per dollar) over the subsequent 60 months. The dashed lines are Bayesian 68 percent confidence intervals.

Figure 8: Effects of Non-U.S. Monetary Policy Shocks on U.S. Interest Rates



Note: This figure plots the posterior median effects of a monetary policy shock that lowers the U.K., Italian or Japanese five-year yield by 25 basis points on U.S. interest rates over the subsequent 60 months. The dashed lines are Bayesian 68 percent confidence intervals.

Figure 9: Effects of Non-U.S. Monetary Policy Shocks on Foreign Exchange Risk Premium



NOTE: This figure plots the posterior median effects of a monetary policy shock that lowers the U.K., Italian or Japanese five-year yield by 25 basis points on the respective foreign exchange risk premia (as defined in the text, and measured in percentage points) over the subsequent 60 months. The foreign exchange risk premium is defined from the perspective of the United Kingdom, euro area or Japan. The dashed lines are Bayesian 68 percent confidence intervals.