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Unconventional Monetary Policy and International Risk Premia*

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Abstract

We assess the relationship between monetary policy, foreign exchange risk premia and term premia at the zero lower bound. We construct carry trade portfolios using daily data from two dozen foreign countries and find that they are significantly related to contemporaneous U.S. monetary policy surprises. We then estimate a structural VAR including U.S. and foreign interest rates and exchange rates, and identify monetary policy shocks through a method that uses these surprises as the crucial "external instrument" that achieves identification without having to use implausible short-run restrictions. This allows us to measure effects of policy shocks on expectations, and hence risk premia. U.S. monetary policy easing shocks significantly lower domestic and foreign bond risk premia, and lead to dollar depreciation. There is some evidence that they lower foreign exchange risk premia.

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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, 2014). Indeed, 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 answers are potentially different at the ZLB.

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. Several papers achieve identification by positing a recursive ordering 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, which we reinforce below, 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).

In this paper, we provide evidence on the relationship between monetary policy and excess returns using two approaches that reflect the existing literature. First, we construct currency carry trade portfolios using daily data from the U.S. and two dozen foreign countries, and estimate the contemporaneous effects of U.S. monetary policy announcements on excess returns. Thus we contribute to the event study literature by examining the high-frequency response of currency carry trade excess

[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. In all cases, identification works through shocks to the target Fed Funds rate in these pre-ZLB papers.

returns to U.S. monetary policy surprises, with a focus on the zero lower bound period. Second, we propose 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 Garadi, 2015; Mertens and Ravn, 2013), where the ordering of the variables does not matter in identification. This structural VAR then allows us to trace out the dynamic effects of a monetary policy shock on domestic and foreign interest rates, as well as exchange rates. As a by-product, we can then compute the effects of the monetary policy shock on financial market risk premia: the domestic term premium, the foreign term premium, and the foreign exchange risk premium. 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. It is clear that foreign exchange risk premia are time-varying (Fama, 1984; Engel, 1996), but 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 revisit this issue in the context of unconventional monetary policy.

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 examine the effects of U.S. monetary policy surprises on carry trade excess returns. In section 4, we describe our VAR methodology and present 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.

For the analysis of carry trade excess returns, we use daily data on U.S. and foreign 3-month Treasury bill yields and daily spot exchange rates, from October 19, 2004 to March 31, 2015 for 20 foreign countries.[2] Observations are recorded at 4 p.m. Eastern

[2]There are a handful of missing values that are interpolated linearly to fill the gaps.

time every day. Because our main objective is to examine event study evidence on the relationship between excess returns and U.S. monetary policy surprises, timing precision is crucial. We flesh this out, including discussing how we deal with the possibility of "stale quotes", in section 3 below, where we relate excess returns to Federal Open Market Committee (FOMC) announcements.

Throughout the paper we use monetary policy shocks at the ZLB as in Rogers et al. (2014). Following their methodology, we measure U.S. monetary policy surprises at the ZLB as the change in yields bracketing FOMC announcements. Specifically, the surprise is the change in five-year Treasury futures from 15 minutes before the time of FOMC announcements to 1 hour 45 minutes afterwards on the days of FOMC announcements. A positive value of the monetary policy surprise is normalized to be an expansionary change, i.e., a drop in the yield.

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 log of U.S. employment and core CPI, and the BAA-Treasury spread (a widely-used credit spread (Christiano et al., 2014)). The zero-coupon bond yields all come from the dataset of Wright (2011), updated to the present. Exchange rates are defined as dollars per unit of foreign currency. We employ a mix of daily data for the zero coupon yields, intradaily data for the foreign exchange rate (again from 15 minutes before to 1 hour and 45 minutes after FOMC announcements), and monthly for the macro variables. We choose the U.K., euro area, and Japan as our foreign countries. The sample period is January 1990 to March 2015 (except January 1999 to March 2015 where the euro area is the foreign country).

3 Carry Trade and U.S. Monetary Policy

Similarly to Lustig and Verdelhan (2007), we construct portfolios that go long foreign bonds on the basis of the foreign less U.S. 3-month interest rate differential. We construct five carry trade portfolios sorted in increasing order of the 3-month interest differential. The first consists of 3-month bills in the four lowest interest rate countries, and so on. Portfolios are rebalanced every quarter (65 business days) in a way that maintains the ascending order of interest differentials throughout the sample period.[3]

We calculate daily excess returns over corresponding-maturity U.S. interest rates on these carry trade portfolios. We compute the unconditional mean of these excess returns. We also investigate the relationship between excess returns and U.S. monetary policy surprises using an event-study approach. This distinguishes our work from the existing literature, which has taken a long-horizon approach to explaining excess returns with factors like aggregate consumption growth.

3.1 Measuring Daily Returns to the Carry Trade

Denote home and foreign continuously compounded interest rates as i_t and i_t^* respectively. The price of an m-year zero coupon home bond with face value F is $Fexp(-i_t m)$. Let $s_t = ln(S_t)$ denote the log exchange rate on date t in dollars per unit of foreign currency, and k equal the fraction of the year over which the bond is held. We consider one-day ($k = 1/260$) holding period excess returns, calculated as follows:

Definition Hold-One-Day Excess Return (H1D) − The excess return for holding an m-year bond for only one day is:

$$H1D_t = (m - (1/260))i_t - mi_{t-1} - [(m - (1/260))i_t^* - mi_{t-1}^*] + s_t - s_{t-1} \tag{1}$$

which is approximately the daily foreign bond return less the daily U.S. bond return plus the exchange rate return $-[m(i_t^* - i_{t-1}^*) - m(i_t - i_{t-1})] + s_t - s_{t-1}$.

Since we are considering three-month bills ($m = 0.25$), these returns are dominated by the exchange rate return.

In practice, this strategy would entail significant transaction costs. Nevertheless, we want as narrow a window as possible around Fed monetary policy announcements, and the hold-one-day excess return ($H1D$) is a suitable way of isolating the effects of FOMC announcements. Lustig et al. (2013) find results that are largely robust across holding periods of one, three, and 12 months.

[3] Sorting into portfolios filters out the currency-specific component of exchange rate changes that is unrelated to changes in the interest rate. This helps isolate the source of variation in excess returns that may be due to monetary policy.

3.2 Portfolio Characteristics

Figure 1 displays details of our portfolio construction. Each colored cell lists the percent of days out of the sample of 2,726 that each country's bond was held in a particular portfolio. There is a reasonable amount of reshuffling. Still, it is noteworthy that low interest rate countries like Switzerland and Japan are exclusively held in portfolios 1 or 2, while high interest rate countries (Brazil, Indonesia, Mexico) remain in the highest portfolios (in darker color).

Of course, UIP implies that when the foreign interest rate is higher than the U.S. interest rate, risk-neutral and rational U.S. investors should expect the foreign currency to depreciate against the dollar by the difference between the two interest rates. This way, borrowing at home and lending abroad, as under our strategy, produces a zero return. Thus the carry trade excess returns should be independent of portfolio ordering and approximately zero.

3.2.1 Excess returns - annual averages

In Figure 2, we depict mean annual carry trade excess returns by portfolio. In each panel, we display results for the full sample as well as pre-ZLB and ZLB sub-periods, up to September 2008 and since October 2008, respectively. A pattern quite similar to that found by Lustig and Verdelhan (2007) is apparent: a general rise in the mean return as we move from the low to high interest rate currencies. Sharpe ratios, not shown, exhibit a broadly similar pattern. Thus, in line with a long literature, we show that UIP is violated in our data (Tryon, 1979; Engel, 1996, 2014). Investors earn low or negative excess returns on the low interest rate currencies because they typically have relatively low rates of appreciation or even depreciate against the dollar. These findings also echo Lustig and Verdelhan (2007), whose sample period (ending in 2002) was generally one of trend dollar appreciation.

3.3 Excess returns and monetary policy surprises

We turn to our main question in this section—the relationship between monetary policy actions and carry-trade portfolio excess returns. We regress excess returns on monetary policy surprises on days of monetary policy announcements. The regression is:

$$H1D_t = b * MPS_t + u_t. \tag{2}$$

where $H1D_t$ is the hold-one-day excess return on a carry trade portfolio on the day of an announcement and MPS_t is the monetary policy surprise on that day.

The top panel of Table 1 shows OLS coefficient estimates, t-statistics and R^2 values from estimating this regression over the ZLB period, with monetary policy surprises measured as minus the intraday change in five-year yields, as discussed above. All the coefficients are highly significantly positive, indicating that easing surprises boost carry trade returns. The effect of the U.S. monetary policy surprise—including statistical significance and amount of variation explained—tends to be smallest for the high interest rate portfolios.

For comparison, we also estimate this equation over the pre-ZLB period for which we have data on carry trade returns (October 2004-September 2008). In this period, however, we measure monetary policy surprises as the change in the fourth eurodollar futures contract from 15 minutes before the time of FOMC announcements to 1 hour 45 minutes afterwards. The results are also shown in panel A of Table 1. The coefficients are also significantly positive, although the R^2 values are lower and the significance is less consistent.

We finally allow for the possibility that some of our quotes are "stale" in the sense that on some days, an emerging market interest rate may not have been recorded/updated after the time of the FOMC announcement. Thus we calculate for robustness a "hold-two-days" excess return:

$$H2D_t = (m - (1/130))i_{t+1} - mi_{t-1} - [(m - (1/130))i^*_{t+1} - mi^*_{t-1}] + s_{t+1} - s_{t-1} \quad (3)$$

The bottom panel of Table 1 estimates the regression of two-day excess returns ($H2D$) onto monetary policy surprises for both ZLB and pre-ZLB subsamples. Comparing results for $H1D$ and $H2D$, we see that the signs are the same, while the latter are less precisely estimated, though somewhat larger, and have smaller R^2 values. This makes sense given that the wider, two-day window leaves the effect of the pure monetary policy surprise confounded with other factors influencing interest rates and exchange rates on a daily basis.

4 VAR Analysis

Existing event study work has shown a strong contemporaneous relationship between unconventional U.S. monetary policy surprises, U.S. and foreign interest rates, and exchange rates (see, for example Rogers et al. (2014)). In the previous section, we documented the influence of monetary policy on the currency carry trade returns at high frequency. The impact of a U.S. monetary policy surprise on a portfolio that is long foreign bonds and short U.S. bonds on the day of the surprise itself is positive. In the remainder of the paper we now turn to estimating structural VARs in U.S. and foreign interest rates and exchange rates, where shocks are identified through the method of external instruments. The external instrument is the monetary policy surprise described above, and the VAR impulse responses allow us to trace out the effects over time. This in turn allows us to measure effects of shocks on various financial market risk premia, which is not possible from the event-study approach alone.

4.1 Methodology

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):

$$A(L)Y_t = \varepsilon_t \tag{4}$$

where ε_t denote the reduced form forecast errors. All variables are linearly detrended. We further assume that these reduced form errors can be related to a set of underlying structural shocks:

$$\varepsilon_t = R\eta_t \tag{5}$$

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 the intraday change in a domestic interest rate in a short window bracketing the time of any monetary policy announcement in month t. Here our external instrument Z_t is the monetary policy surprise MPS_t from section 3: the change in yields on five-year Treasury futures from 15 minutes before the time of FOMC announcements to 1 hour 45 minutes afterwards on the days of FOMC meetings. In the VAR, if there is no monetary policy announcement in that month, then $Z_t = 0$. If there are multiple monetary policy announcements, then it is the sum of the intraday changes bracketing all of those announcements.

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 $E(\eta_{2t}Z_t) = 0$.

We further define X_t as a vector of changes in the elements of Y_t in a daily or intradaily window bracketing the time of any monetary policy announcement in month t.[4] If there is any element of X_t for which these data are not available, set that to the corresponding element of ε_t. 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: $E(Z_t(\varepsilon_t - X_t)) = 0$.

Clearly assumption A2 implies that $E(Z_tX_t) = E(Z_t\varepsilon_t)$.

Our approach proceeds as follows. We first estimate the VAR, selecting the lag order by the Bayes Information Criterion (BIC), and take the residuals e_t. We then construct X_t from daily or intradaily data (and e_t, if necessary). We regress X_t onto Z_t. This identifies the first column of R up to scale and sign.[5] Coupled with the estimate of $A(L)$, this allows us to trace out the effect of the monetary policy shock on $E_t(Y_{t+j})$. This 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 some elements of Y_t. Thus, the methodology also draws on the event study approach, as we use high-frequency data around announcements in both Z_t and X_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.

[4] This window must subsume the entire intraday window used in constructing Z_t.

[5] We could envision multiple instruments, in which the regression of e_t on Z_t involves a reduced rank regression, as described in Olea et al. (2013). But if there is a single monetary policy shock, then it has to be a maintained assumption that $E(\epsilon_t Z_t')$ has rank 1.

[6] The high-frequency data in X_t permits much tighter inference. We could simply regress the full vector of reduced form residuals on Z_t, and this would be the standard external instruments approach, but the resulting confidence intervals for impulse responses would be much wider.

We let Y_t be a vector of 9 variables: three-month, five-year and ten-year US zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year foreign zero-coupon bond yields, and the log of US employment and core CPI, and the BAA-Treasury spread A separate VAR is run for each foreign country: UK, euro area, and Japan. For X_t, we observe daily data on the zero coupon yields and intradaily data on the foreign exchange rate. The sample period is January 1990 to March 2015 (except January 1999 to March 2015 where the euro area is the foreign country). However, because we are interested in the effects of announcements during the era of unconventional monetary policy, for our external instrument Z_t, we only consider announcements since October 2008—that is we run the regression of X_t on Z_t for this subsample alone. As in section 3, the dates of the unconventional monetary policy period correspond to those in Rogers et al. (2014) updated to the present. As the data are persistent, estimation of the VAR and inference is conducted by the bias-adjusted bootstrap of Kilian (1997).

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:

$$TP_t(m) = r_t(m) - E_t(\frac{1}{m/3}\Sigma_{i=0}^{m/3-1} r_{t+3i}(3)) \tag{6}$$

the foreign term premium, defined as:

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

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

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

For 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. He defines the UIP deviation as the hold-to-maturity excess returns on the foreign long bond over the domestic long bond, i.e. $\frac{m}{12}(r_t^*(m) - r_t(m)) + 100(E_{t+m}s_{t+m} - s_t)$. He does not look at portfolios, however. 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. 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 (6)-(8).

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. At the same time, it should be emphasized that the external instruments methodology used in this paper only identifies monetary policy up to a scale factor. Also, we do not separate out the effects of monetary policy operating via forward guidance and asset purchases—rather we are estimating the total effects of monetary policy news.

4.2 Empirical Results

The monetary policy shock is scaled to lower U.S. five-year yields by 25 basis points. As discussed earlier, the monetary policy announcement is only estimated up to scale— that is, given the size of the shock, we estimate the dynamic effects on interest rates and exchange rates.

First, we check instrument relevance. The "first stage" regression is a regression of the daily change in five-year yields onto the instrument. The test statistic is 301—far above the cutoff in the weak instruments literature (Stock and Yogo, 2005; Stock et al., 2002). Weak instruments are not an issue in this application.

Figure 3 shows the estimated effect of the monetary policy shock on the exchange rate at different horizons (in quarters). Bootstrap confidence intervals are also included, constructed as described by Kilian (1997)—here and throughout this paper, all confidence intervals and references to statistical significance are at the 68 percent level. The expansionary U.S. monetary policy shocks cause the dollar to depreciate significantly. The effect tends to wear off over time, but slowly. Unlike Eichenbaum and Evans (1995) (who considered VARs with recursive identification), we find no evidence of delayed overshooting. The exchange rate effect is significantly positive for a few quarters for all three foreign currencies.

Figure 4 shows the estimated effect of the US monetary policy shock on the foreign interest rates, both three-month and ten-year. For all three countries, the monetary policy shock has no significant effect on three-month yields, but has a significantly negative effect on ten-year interest rates. The finding that monetary policy spillovers are greatest for longer term interest rates seems unsurprising because the ZLB was binding on the UK and Japan for this period, and so no easing action by the Fed can lower their short rates much further, while the European Central Bank was close to the ZLB and reached it near the end of the sample. The estimated instantaneous effect on foreign ten-year interest rates is slightly more than 10 basis points for the UK and Germany and a bit less for Japan.

Figure 5 shows the estimated effect of the monetary policy shock on the expected foreign exchange excess returns ($FP(m)$) at different horizons. The monetary policy shock is estimated to lower the foreign exchange risk premium for all three currencies. But the effect is statistically significant only for the pound and the yen at the very shortest horizons. Overall, the effects of the monetary policy shock on the foreign exchange risk premium do not suggest gross violations of UIP conditional on the monetary policy shock.

It is useful to compare Figure 5 and Table 1. Figure 5 shows the effect of the U.S. monetary policy shock on the expected excess return on a foreign (U.K., euro area or Japanese) 3-month bill over a U.S. 3-month bill from h to h+1 quarters in the future. Table 1 is showing something different. It is the initial impact of the monetary policy surprise on the carry trade portfolios, but is not saying anything about expected future returns. The U.S. easing surprise is good news for investors in foreign bills on the announcement day, but may lower their expected future returns.

Table 2 shows the estimated instantaneous effect of the monetary policy shock on the ten-year term premium in the UK, Germany and Japan. The point estimates of the effects on term premia are roughly the same as the effects on the ten-year yield—the effect on foreign long bond yields is estimated to be largely due to term premia. The confidence intervals are wide, but do not bracket zero.

From the VAR results so far, we conclude that U.S. monetary policy easing shocks both depreciate the dollar and lower foreign term premia, and may lower foreign exchange risk premia.

4.2.1 Analysis of Foreign Exchange Risk Premia

To the extent that we find evidence against conditional UIP, it is that an easing monetary policy surprise lowers the foreign exchange risk premium. This is the opposite sign from what has been found in earlier VAR work (e.g. Eichenbaum and Evans (1995)).

A recent study (International Monetary Fund, 2013) finds that with unconventional monetary policy, surprise easings of US policy shift foreign exchange *risk-reversals* in the direction of dollar depreciation. A risk-reversal is an options position which is long an out-of-the-money call option and short an equivalently out-of-the-money put option. It is quoted as the annualized implied volatility on the call option less that on the put option. It is a measure of options-implied skewness.

Motivated by this finding, on all U.S. monetary policy announcement days, we regressed the change in foreign exchange risk-reversals at various maturities onto our measure of the U.S. monetary policy surprise. The results are shown in Table 3. The coefficients are significantly positive (at the 5 percent level) for almost all currency-maturity pairs. Recall that throughout this paper the foreign exchange rate is defined as dollars per unit foreign currency. This means that, like International Monetary

Fund (2013), we find that monetary policy easings cause the options market to view the prospects for future exchange rate changes as being more skewed in the direction of dollar depreciation. If investors are risk-averse, this in turn might make them want to shift from dollar-denominated to foreign-currency-denominated assets. As investors cannot all do so, in equilibrium the expected return on foreign-currency assets must fall. In other words, investors may demand a bigger risk premium to hold currencies that are more likely to depreciate sharply than to appreciate sharply. If so, and if unconventional monetary policy easings shift skewness in the direction of sharp dollar depreciations, it would reduce the foreign currency risk premium. This is at least consistent with our finding that unconventional easing monetary policy surprises lower the foreign exchange risk premium. Note that International Monetary Fund (2013) found this pattern of monetary policy surprise easings leading to options-implied skewness only for unconventional monetary policy.

This potential explanation for the evidence that we find against UIP *conditional* on monetary policy shocks is related to several recent papers that have proposed a skewness-related interpretation of the *unconditional* failure of UIP. Brunnermeier et al. (2009) and Farhi and Gabaix (2014) find that risk-reversals imply that the distribution of future exchange rate returns is skewed in the direction of depreciation of high interest currencies. They argue that, as compensation for this risk, investors demand positive expected returns to induce them to hold high interest currencies, explaining the unconditional failure of UIP. We are using a similar argument to explain the failure of UIP conditional on unconventional monetary policy surprises. Other recent theoretical explanations of the UIP puzzle include Engel (forthcoming) and Backus et al. (2013). Engel argues that it is unlikely that a foreign exchange risk premium could explain the pattern of excess returns that he documents in a (mostly pre-ZLB) sample period ending in October 2009, and offers a model based on liquidity returns. Backus et al. (2013) investigate how different specifications of domestic and foreign Taylor rules for monetary policy can resolve the UIP puzzle.

4.2.2 Effects of Monetary Policy on Domestic Term Premia

Our main focus in this paper is on the effects of monetary policy surprises on international risk premia, but our methodology also gives estimates of the effects of monetary policy surprises on domestic term premia. We estimated the effects of monetary policy surprises on U.S. term premia in the VARs of the previous section. 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 term premia, we report results from a VAR in US three-month, five-year and ten-year interest rates, the log of employment and core CPI, and the BAA-Treasury spread.

The results are shown in Table 4. The monetary policy shock that lowers the five-year yield by 25 basis points is estimated to lower the term premium by 22 basis points, essentially explaining the full drop in yields. The confidence interval is wide, but there is clear evidence of a meaningful negative effect on term premia. Results for the ten-year term premium are similar.

4.2.3 Effects of Monetary Policy on Carry Trade Returns

We also considered a VAR in US three-month, five-year and ten-year interest rates, the log of employment and core CPI, the BAA-Treasury spread, and cumulative carry trade returns for one of the five portfolios based on three-month interest rates discussed in section 3. A separate VAR is run for each of these carry trade portfolios. The sample period for estimating these VARs is shorter than for the other structural VARs that we consider in this paper, on account of the later start date for carry trade returns. These VARs are estimated over the period from October 2004 to March 2015.

Figure 6 shows the estimated effect of the unconventional monetary policy shock on the carry trade returns at different horizons. The surprise easing in the US significantly and persistently boosts excess returns on the carry trade portfolios. The initial effects are larger for the low interest portfolios than for the high interest portfolios, consistent with what we found from event study analysis.

4.2.4 Comparison with pre-ZLB era

The methodology that we propose applies in principle to the pre-ZLB era as well. Indeed, monetary policy in the pre-ZLB and ZLB eras have much in common. Kuttner (2001) and Gürkaynak et al. (2005) both show that over the past twenty years, FOMC announcements concerning the target federal funds rate have been largely anticipated by the market. Instead, FOMC announcements and communications have been important mainly because of information that they contain about the future path of monetary policy. But this is just a form of forward-guidance, although less explicit than during the ZLB era.

In Figures 7, 8 and 9, we show the estimated effects of the monetary policy shock on the exchange rate, foreign interest rates, and expected foreign exchange returns, where the VAR is estimated as before, but the external instrument is the change in the fourth eurodollar futures contract from 15 minutes before the time of FOMC announcements to 1 hour 45 minutes afterwards, and the VAR residuals are regressed on this external instrument over the period from February 1994 to September 2008.

The effects of monetary policy surprises over the pre-ZLB era estimated in Figures 7-9 are generally similar to those in Figures 3-5. A 25 basis point reduction in five-year yields that is driven by monetary policy leads to dollar depreciation and lower interest rates abroad. But there are some differences. The point estimates of the exchange rate effects are smaller in the pre-ZLB sample. Also, in the pre-ZLB sample, three-month UK and Japanese interest rates are significantly lowered (unlike the post-October 2008 sample). The point estimates of the effects on foreign ten-year rates are smaller in the pre-ZLB sample. Also, there is no statistically significant effect on the foreign exchange risk premium in the pre-ZLB sample for any of the currencies, although the point estimates indicate that monetary policy easings *raise* the foreign exchange risk premia.

Table 5 shows the estimated effect of the US monetary policy shock on the ten-year term premium in the United Kingdom, Germany and Japan in the pre-ZLB sample. The effect is not statistically significant for Japan, but is significantly negative for the UK and Germany. Overall the evidence that U.S. monetary policy shocks affect foreign term premia seems a little weaker over the pre-ZLB sample.

4.2.5 Foreign Monetary Policy Surprises

We applied precisely the same methodology to the case where the home country is the UK, the euro area or Japan. For the UK and Japan, the variables in the VAR, Y_t, consist of three-month, five-year and ten-year UK/Japanese zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year US zero-coupon bond yields, and UK/Japanese unemployment and log CPI. The external instruments are now intraday changes in UK or Japanese ten-year government bond yields on monetary policy announcement days. The monetary policy surprise is normalized to lower UK/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 Germany zero-coupon bond yields, the log foreign exchange rate, the three-month and ten-year US zero-coupon bond yields, German unemployment and log CPI, and five-year zero-coupon Italian bond yields.[7] 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 in Italy (and other countries whose sovereign bond markets were coming under significant pressure) rather than German bond yields. As in the US framework, the sample period is January 1990 to present for the VAR estimation of the residuals. For our external instrument Z_t, we only consider announcements during the unconventional monetary policy period—the dates of UK, euro-area and Japanese unconventional monetary policy announcements correspond to those in Rogers et al. (2014) updated to the present.[8]

Figure 10 shows the estimated effects of UK, euro-area, and Japanese monetary policy shocks on their respective exchange rates. The Bank of England monetary policy easing that lowers five-year UK yields by 25 basis points is estimated to lead to pound depreciation viz-a-viz the dollar that is significant for a few quarters. The ECB monetary policy easing that lowers Italian five-year yields by 25 basis points leads to significant appreciation of the euro, while the corresponding Bank of Japan monetary policy easing has no significant exchange rate effect. The finding that ECB monetary policy easing leads the euro to *appreciate* may seem surprising, 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 at the tail end of our sample when concerns about the viability of the euro had ebbed. We conjecture that going forward ECB monetary

[7]The Italian zero-coupon bond yields were obtained from the BIS.

[8]Since January 2000 for Japan, since August 2007 for the euro area, and since October 2008 for the UK.

policy easing surprises will lead to euro depreciation, unless substantial concerns of a disintegration of European monetary union resume.

Figure 11 shows the estimated effects of UK, euro-area and Japanese monetary policy shocks on US interest rates. The UK and Japanese monetary policy shocks significantly lower US ten-year yields for a few quarters. The euro area easing shock actually raises US yields. 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 12 shows the estimated effects of UK, euro area, and Japanese monetary policy shocks on the foreign exchange risk premium. Foreign monetary policy easings are estimated to significantly raise the euro and yen foreign exchange risk premia. These foreign exchange risk premia are defined from the perspective of the foreign country. For example, in Figure 11, the euro area panel shows the effect of the ECB monetary policy easing on expected future US short rates less expected future German short rates, adjusted for expected changes in the euro-dollar exchange rate. From this and our earlier results on the effects of US monetary policy easings, we can conclude that to the extent that conditional UIP fails, it is that monetary policy easing shocks anywhere shifts the foreign exchange risk premium in favor of US interest rates.

Finally, the UK monetary policy shock is estimated to lower the ten-year UK term premium by 30 basis points (confidence interval: -41 to -19 basis points). The ECB monetary policy surprise lowers the ten-year German term premium by 8 basis points (confidence interval: -14 to -2). The Japanese monetary policy shock is estimated to lower the ten-year Japanese term premium by 35 basis points (confidence interval: -54 to -9 basis points).

5 Conclusion

We assess the relationship between monetary policy and foreign exchange risk premia and term premia at the zero lower bound, taking two different approaches that allow us to look at these inveterate questions with some novelty. We first estimate the effects of monetary policy surprises on excess returns to currency carry trade portfolios at high frequency. We also employ a dynamic, structural VAR analysis, using those surprises as the external instrument that is key to identifying monetary policy shocks in our method.

Despite our focusing narrowly on monetary policy and our use of best-practice identification, we have not found irreproachable evidence on how these shocks affect foreign exchange risk premia, although monetary policy surprise easings tend to lower foreign exchange risk premia during the ZLB. On the other hand, there is consistent evidence that unconventional U.S. monetary policy easing shocks significantly lower domestic and foreign bond term premia and lead to dollar depreciation.

Table 1: Regression of carry trade excess returns on U.S. monetary policy surprises

Portfolio	1	2	3	4	5	All Ctrs
	Panel A: One-Day Excess Returns (H1D)					
ZLB	0.067***	0.071***	0.037***	0.040***	0.038***	0.051***
	(8.79)	(6.41)	(5.56)	(3.83)	(3.50)	(8.41)
	[0.51]	[0.50]	[0.24]	[0.21]	[0.21]	[0.43]
Pre-ZLB	0.026***	0.025***	0.023***	0.028**	0.025	0.025***
	(3.24)	(4.40)	(2.73)	(2.44)	(1.51)	(3.61)
	[0.24]	[0.24]	[0.20]	[0.19]	[0.08]	[0.26]
	Panel B: Two-Day Excess Returns (H2D)					
ZLB	0.087***	0.095***	0.063***	0.077***	0.038	0.072***
	(5.89)	(3.69)	(4.91)	(3.80)	(2.27)	(5.09)
	[0.46]	[0.38]	[0.27]	[0.21]	[0.08]	[0.34]
Pre-ZLB	0.026	0.023	0.022*	0.038***	0.057***	0.033***
	(1.62)	(1.63)	(1.72)	(3.75)	(2.87)	(3.26)
	[0.08]	[0.07]	[0.09]	[0.26]	[0.23]	[0.20]

Notes: t-statistics are in parentheses and R^2 values in brackets * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The regression coefficient indicates the effect of a U.S. monetary policy surprise on the daily excess return. A positive coefficient indicates that an expansionary monetary policy surprise raises the excess return. The number of observations is 63 (36) for the ZLB (pre-ZLB) sample periods.

Table 2: Effects of US Monetary Policy Shock on Foreign Ten-Year Term Premia (in basis points)

	Point Estimate	Confidence Interval
UK	-13.6	(-22.6,-7.1)
Germany	-10.3	(-13.8,-7.1)
Japan	-5.4	(-10.0,-1.0)

Notes: The table reports the point estimates and 68% bootstrap confidence intervals for the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on the ten-year term premium in the UK, Germany and Japan.

Table 3: Effects of US Monetary Policy Shock on Foreign Exchange Risk Reversals

Risk Reversal Maturity	Euro	Pound	Yen
1 month	1.18***	0.80**	1.60**
	(0.32)	(0.34)	(0.69)
3 months	1.07***	0.64**	1.52**
	(0.30)	(0.28)	(0.72)
6 months	0.85***	0.54**	1.07**
	(0.23)	(0.24)	(0.51)
1 year	0.70***	0.47**	0.83*
	(0.20)	(0.24)	(0.44)

Notes: We measure monetary policy surprises as minus the intraday changes in the five-year Treasury futures yield from 15 minutes before FOMC announcements to 1 hour and 45 minutes afterwards—positive values reflect easing surprises. We then regress the two-day change in 25 delta risk reversals for each currency (viz-a-viz the dollar) and each maturity on these monetary policy surprises. Monetary policy surprises are measured in percentage points, while risk-reversals represent the differences in annualized volatility, also in percentage points, implied by out-of-the-money call and put options. The regression is run over all the FOMC announcements from October 2008 to March 2015. The regressions are run without constants. Robust standard errors are in parentheses. All currencies are defined as dollars per unit foreign currency, so that a positive coefficient means that a monetary policy easing changes the options-implied skewness in the direction of dollar depreciation. One, two and three asterisks denote significance at 10, 5 and 1 percent levels, respectively.

Table 4: Effects of US Monetary Policy Shock on Domestic Term Premia (in basis points)

	Point Estimate	Confidence Interval
Five-year	-21.5	(-27.0,-12.6)
Ten-year	-20.5	(-25.8,-10.8)

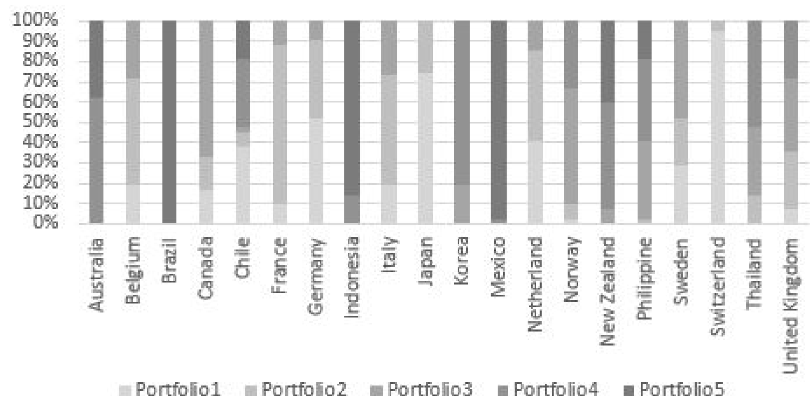
Notes: The table reports the point estimates and 68% bootstrap confidence intervals for the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on the five- and ten-year US term premium.

Table 5: Effects of US Monetary Policy Shock on Foreign Ten-Year Term Premia in the pre-ZLB era (in basis points)

	Point Estimate	Confidence Interval
UK	-13.9	(-24.7,-5.4)
Germany	-7.5	(-14.3,-1.4)
Japan	-0.3	(-4.4,3.1)

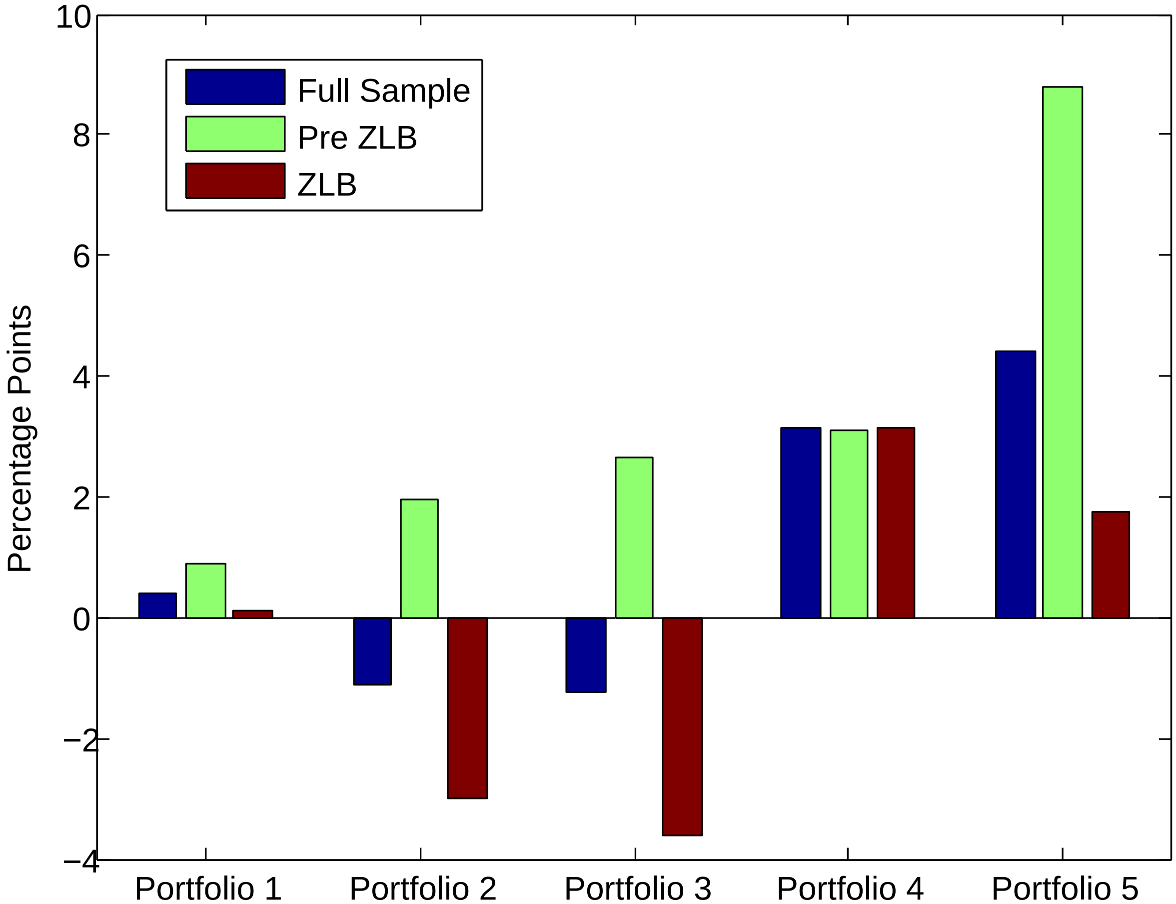
Notes: As for Table 2, except over the pre-ZLB period.

Figure 1: Portfolio allocation by country



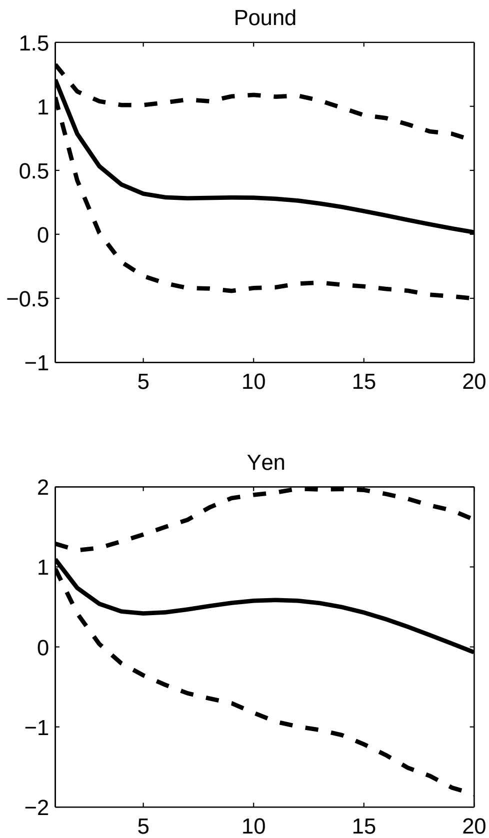
NOTE: The figure reports the number of days each countrys currency spent in each portfolio. Portfolios are rebalanced every quarter based on the nominal interest rate differential with the U.S. rate. Portfolio 1 contains currencies with the lowest interest rates and portfolio 5 contains currencies with the highest rates.

Figure 2: Excess returns



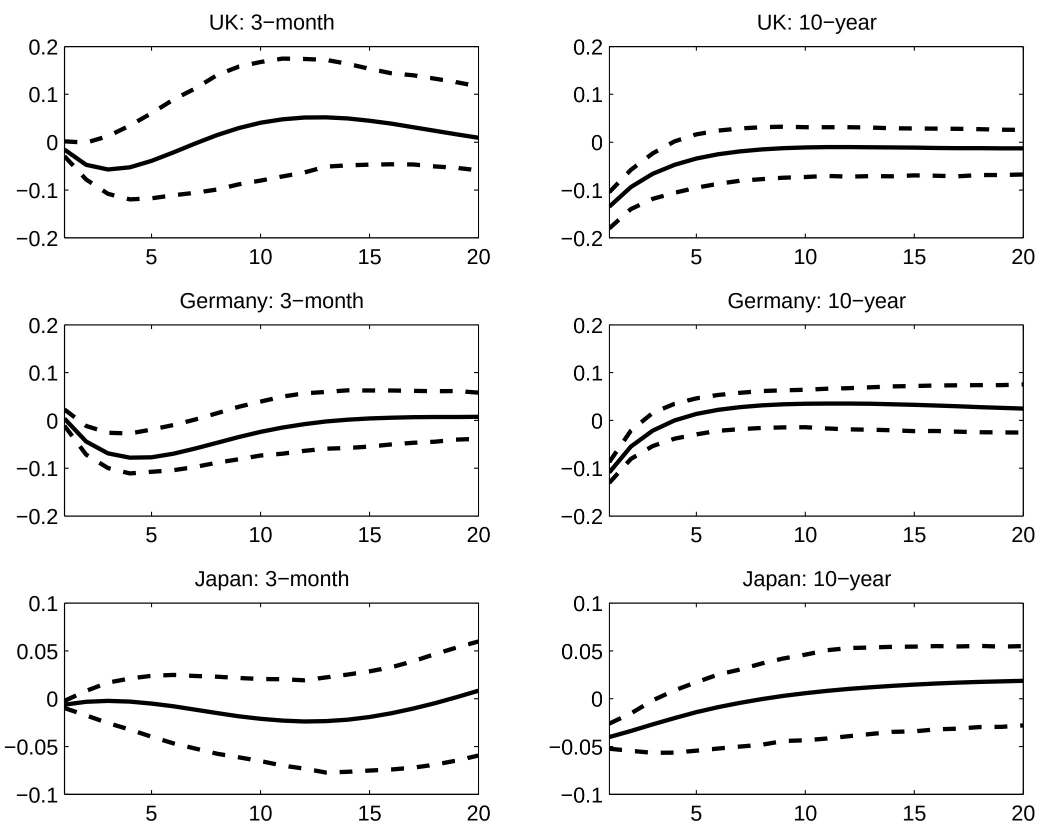
NOTE: The figure presents annual means of excess returns on portfolios for a U.S. investor going long on the foreign bond and short the U.S. bond. Results are presented for the full sample and 2 sub-periods: up to September 2008 (pre-ZLB) and since October 2008 (ZLB). Portfolios are rebalanced every quarter based on the nominal interest rate differential with the U.S. Portfolio 1 contains currencies with the lowest interest rates and portfolio 5 contains currencies with the highest rates.

Figure 3: Effects of U.S. Monetary Policy Shock on Exchange Rates



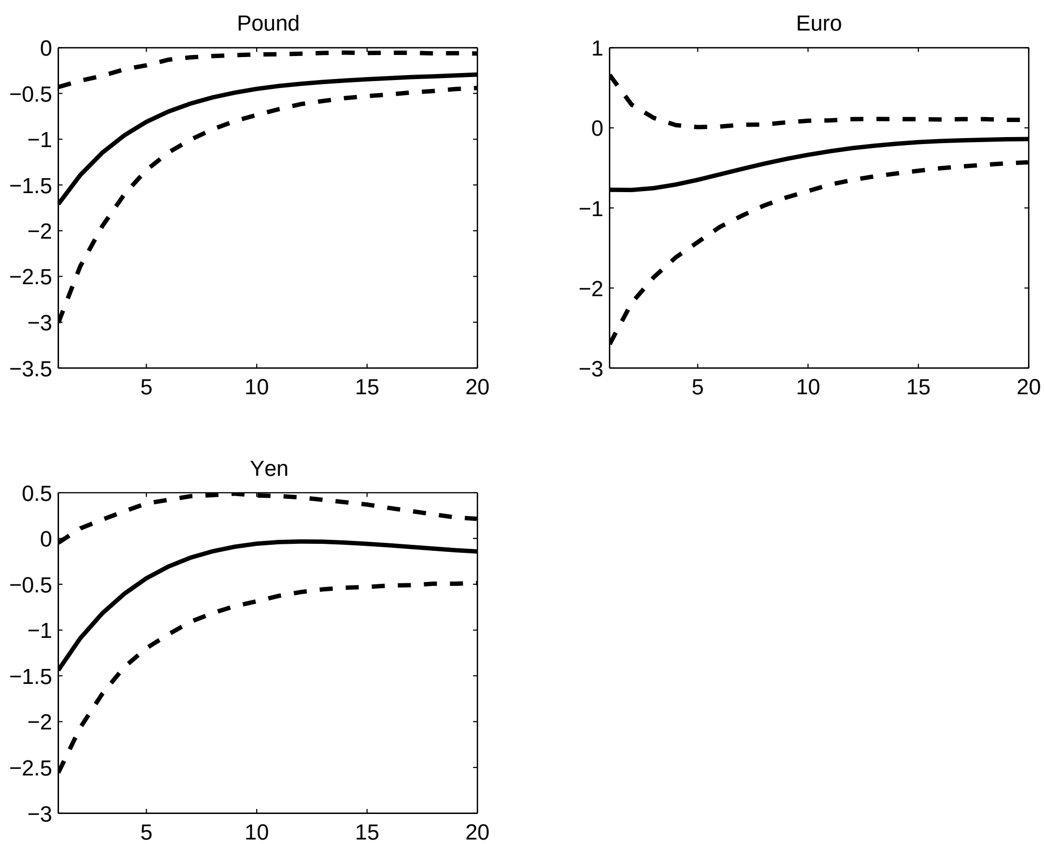
NOTE: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on exchange rates (in percentage points, measured as dollars per unit of foreign currency) over the subsequent 20 quarters. The dashed lines are 68 percent confidence intervals.

Figure 4: Effects of U.S. Monetary Policy Shock on Foreign Interest Rates



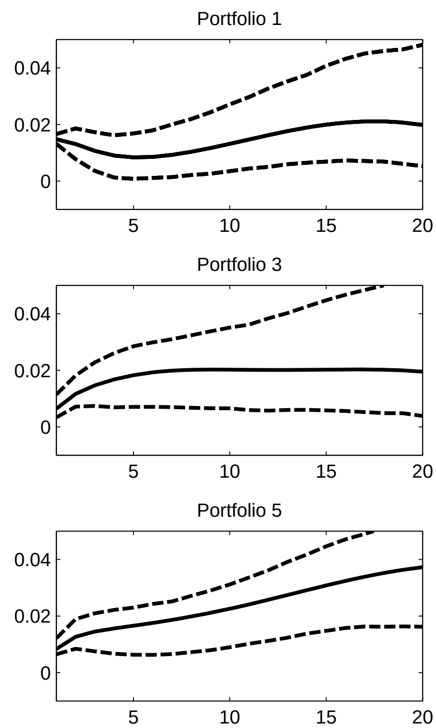
NOTE: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on foreign interest rates (in percentage points) over the subsequent 20 quarters. The dashed lines are 68 percent confidence intervals.

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



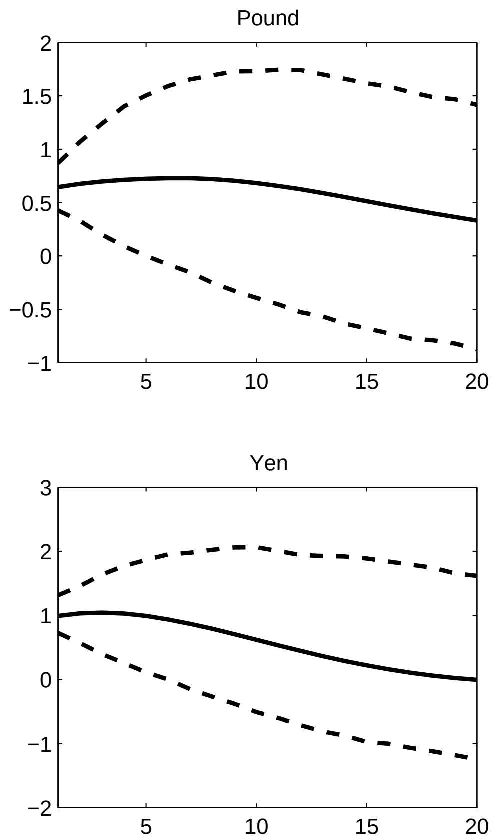
Note: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on the foreign exchange risk premium (as defined in equation (8) in the text, and measured in percentage points) over the subsequent 20 quarters. The dashed lines are 68 percent confidence intervals.

Figure 6: Effects of U.S. Monetary Policy Shock on Carry Trade Returns



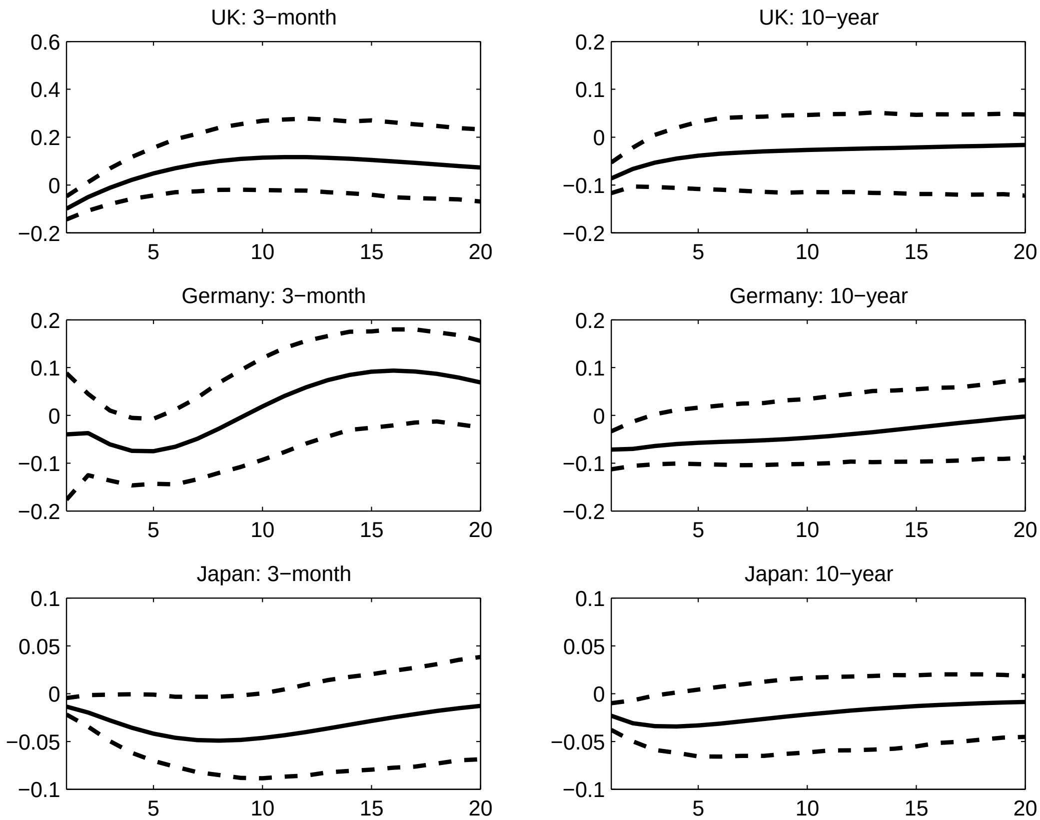
NOTE: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on carry trade returns for 5 portfolios over the subsequent 20 quarters. The dashed lines are 68 percent confidence intervals.

Figure 7: Effects of U.S. Monetary Policy Shock on Exchange Rates: Pre-ZLB Era



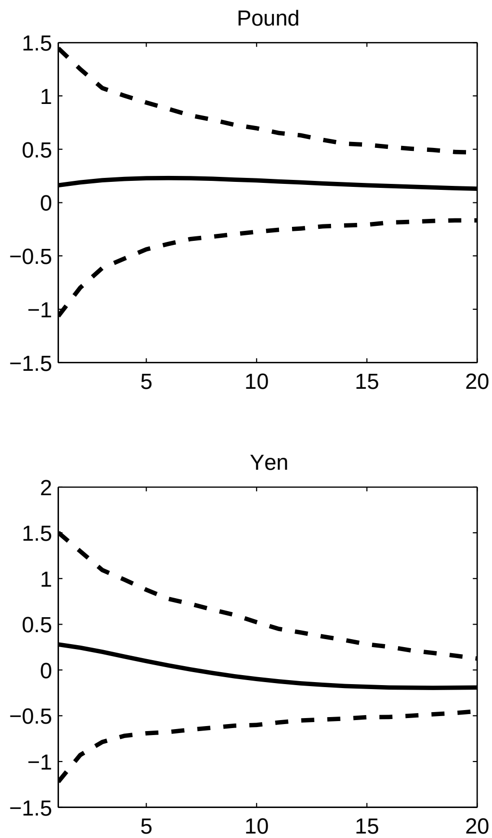
NOTE: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on exchange rates (in percentage points, measured as dollars per unit of foreign currency) over the subsequent 20 quarters. The monetary policy shock is identified over the pre-ZLB period using FOMC-day intraday changes in the fourth eurodollar futures contract as the external instrument. The dashed lines are 68 percent confidence intervals.

Figure 8: Effects of U.S. Monetary Policy Shock on Foreign Interest Rates: Pre-ZLB Era



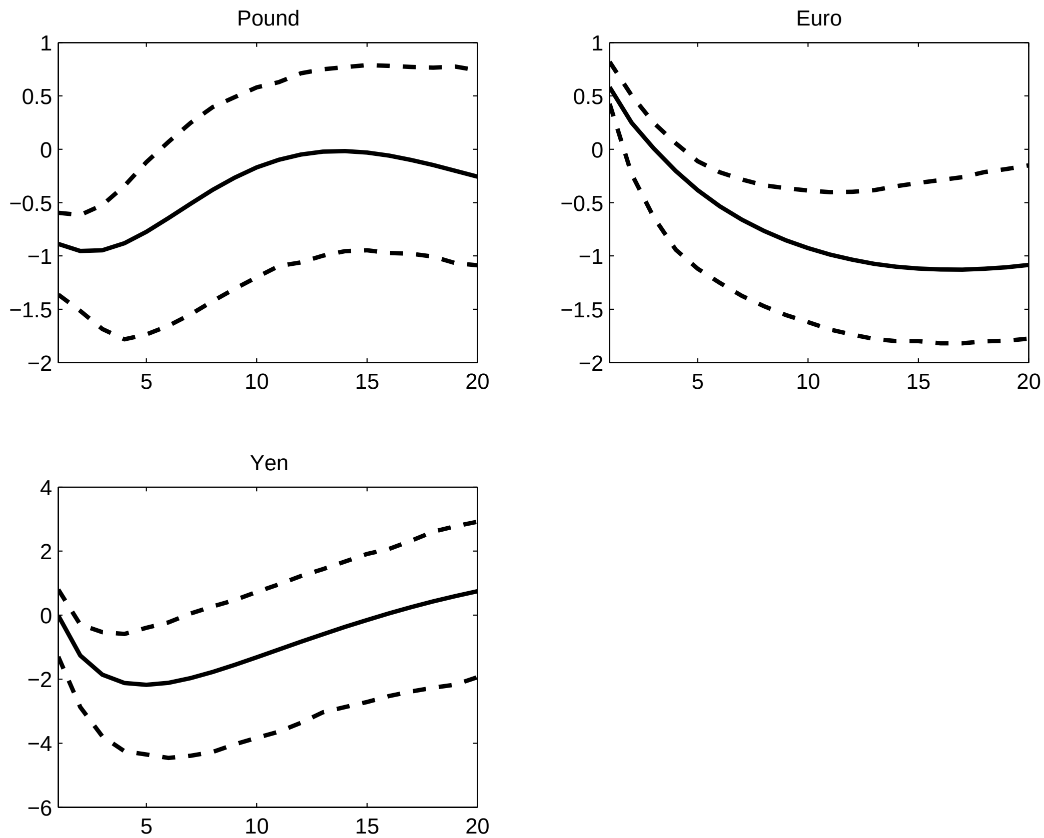
NOTE: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on foreign interest rates (in percentage points) over the subsequent 20 quarters. The monetary policy shock is identified over the pre-ZLB period using FOMC-day intraday changes in the fourth eurodollar futures contract as the external instrument. The dashed lines are 68 percent confidence intervals.

Figure 9: Effects of U.S. Monetary Policy Shock on Foreign Exchange Risk Premium: Pre-ZLB Era



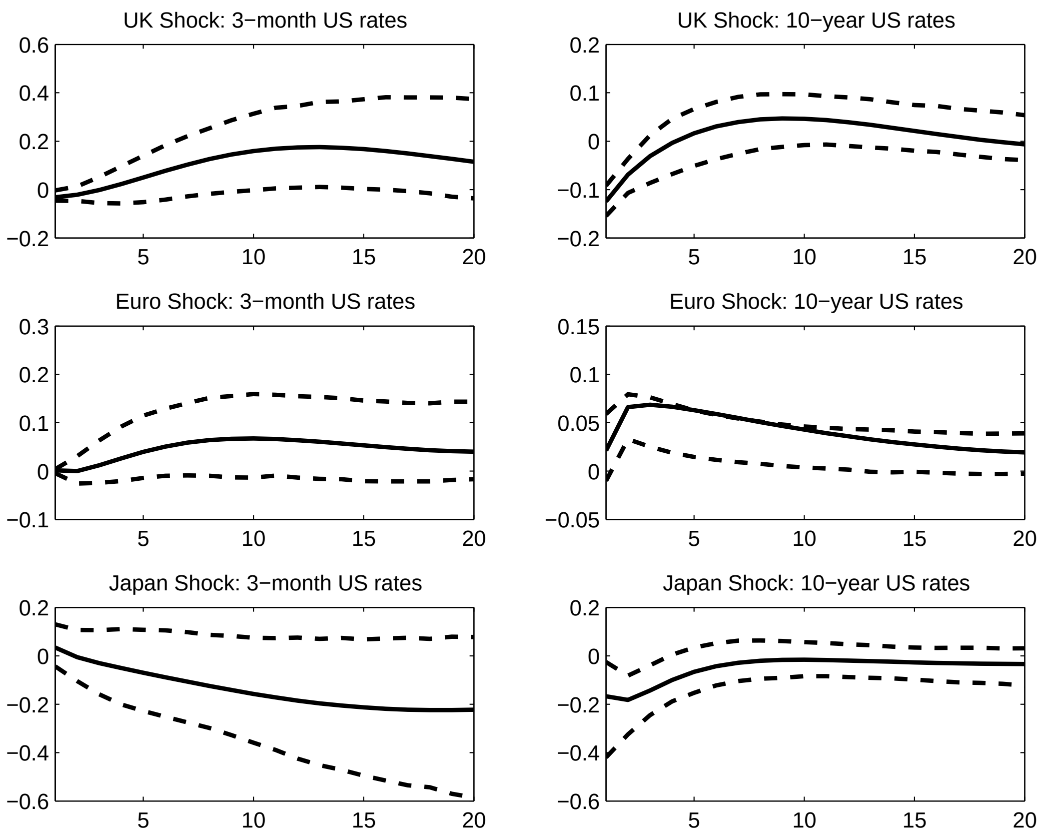
NOTE: This figure plots the effects of a monetary policy shock that lowers the US five-year yield by 25 basis points on the foreign exchange risk premium (as defined in the text, and measured in percentage points) over the subsequent 20 quarters. The monetary policy shock is identified over the pre-ZLB period using FOMC-day intraday changes in the fourth eurodollar futures contract as the external instrument. The dashed lines are 68 percent confidence intervals.

Figure 10: Effects of Non-U.S. Monetary Policy Shocks on Exchange Rates



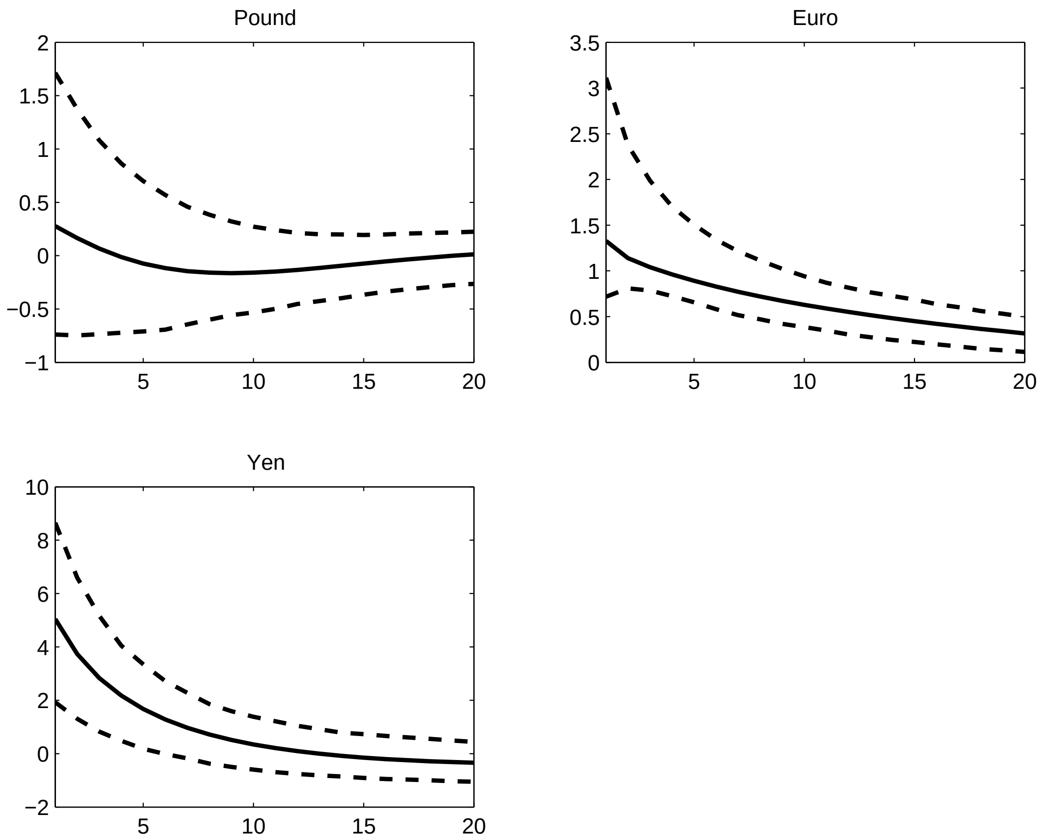
NOTE: This figure plots the effects of a monetary policy shock that lowers the UK, Italian or Japanese five-year yield by 25 basis points on the respective exchange rates (in percentage points, measured as unit of foreign currency per dollar) over the subsequent 20 quarters. The dashed lines are 68 percent confidence intervals.

Figure 11: Effects of Non-U.S. Monetary Policy Shocks on US Interest Rates



NOTE: This figure plots the effects of a monetary policy shock that lowers the UK, Italian or Japanese five-year yield by 25 basis points on US interest rates over the subsequent 20 quarters. The dashed lines are 68 percent confidence intervals.

Figure 12: Effects of Non-U.S. Monetary Policy Shocks on Foreign Exchange Risk Premium



NOTE: This figure plots the effects of a monetary policy shock that lowers the UK, 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 20 quarters. The foreign exchange risk premium is defined from the perspective of the UK, euro area or Japan. The dashed lines are 68 percent confidence intervals.

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