Does a Big Bazooka Matter? Central Bank Balance-Sheet Policies and Exchange Rates*

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Abstract

In this paper we study the effects of unconventional monetary policy (UMP) in the form of increases in central bank balance sheets, focusing on the foreign exchange market as a case study. We explicitly relate the response of the exchange rate and its fundamental determinants to changes in the central bank balance sheets over time, in order to disentangle the workings of different transmission channels. Using announcements of UMP by the ECB and the Federal Reserve predicting future changes in their relative balance sheet, we find that a 1% increase in the ECB balance sheet relative to that of the Fed results in a 1% euro depreciation vis-á-vis the dollar. Since the euro-dollar exchange rate is expected to revert to its baseline after less than a year, central bank signalling about fundamentals over longer horizons (the "signalling" channel) cannot contribute much to the estimated UMP effects on the exchange rate. We find instead that these policies work by impinging on money market conditions, and on frictions in foreign exchange markets, such as failures of covered interest rate parity. Specifically, a UMP shock reduces the short-term euro-dollar interest rate differential, while narrowing the differential between money market euro rates and their "synthetic" counterparts in euro-dollar currency swaps. However, as these two channels offset each other in their effects on the exchange rate, we find that currency risk premia account for the bulk of the euro depreciation.

Keywords: Unconventional monetary policy, exchange rates, covered interest rate parity, limits to arbitrage, financial frictions.
JEL-Classification: F42.

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1 Introduction

Since the onset of the global financial crisis in late 2008, central banks around the world have engaged in a number of unprecedented and unconventional monetary policy interventions (henceforth UMP). Central banks have deployed their balance sheet as a separate policy tool, especially when interest rates reached their lower bound. For instance, the Federal Reserve was early in conducting sizeable purchases of private and government assets, totalling close to 12 percent of GDP, which resulted into a dramatic expansion of the size of its balance sheets. The European Central Bank initially implemented more modest programs of asset purchases, but greatly expanded its provision of liquidity to the banking sector, far beyond standard short-term maturities, especially after the second half of 2011. By March 2012, the nominal size of the Eurosystem balance sheet was similar to that of the Federal Reserve System. And starting from March 2015, the ECB has also embarked on a comprehensive program of private and public asset purchases, which have brought again its nominal balance sheet close to that of the Federal Reserve (see Figure 1).

Against the background of the exceptional scope of UMP measures in recent years, a fast-growing literature has been instrumental in assessing their effectiveness, especially concerning their effects on financial markets. The bulk of this empirical literature, however, has focused on the high-frequency (i.e., daily or intraday) effect of these policies, mostly relying on event studies conducted around the time of the announcements of the policy measures.[1] Although providing invaluable evidence of nontrivial effects of UMP, this approach is less informative regarding the dynamic effects of UMP, and its transmission channels. As a result, there is currently no consensus regarding the transmission channels of UMP measures at frequencies and time horizons that are relevant for policymakers.

A case in point concerns how UMP affects exchange rates, with several studies documenting that currency markets significantly react upon announcement of these policies.[2] Such a response of the exchange rate, however, can be the result of different transmission channels. Pervasive asset market frictions have been suggested to rationalize this evidence, harking back to the portfolio balance model of e.g. Kouri (1976). But as forcefully argued by Woodford (2012), even under frictionless financial markets, announcements about balance sheet policies could affect long-dated assets (such as the nominal exchange rate) through a so-called "signalling" channel. As the current value of the exchange rate depends on market expectations about its future value, announcements will have an immediate effect to the extent that they convey new information

[1]See for instance the early paper by Krishnamurthy and Vissing-Jorgensen (2011) on the Federal Reserve unconventional policies, and Krishnamurthy et al. (2014) on the ECB UMP. An exception is Gambacorta et al. (2014) who use a VAR approach.

[2]See for instance Rogers et al. (2014), Altavilla et al. (2015), Neely (2015), Glick and Leduc (2015), Fratzscher et al. (2016), Georgiadis and Gräb (2016), Weale and Wieladek (2016), as well as Fratzscher et al. (forthcoming).

that results in an update of these expectations. This can be the case even when the information is about the future state of the economy, and the policy measure per se has no impact on the economy. Nevertheless, there is compelling evidence of pervading frictions in foreign exchange markets after 2008, pointing to a failure of basic no-arbitrage conditions such as covered interest parity.[3] Therefore, a crucial question for both economic theory and monetary policy is whether unconventional policies only work through such a signalling channel or whether their effects can be traced back to specific financial markets frictions.

This is the gap we aim to fill with this paper by documenting the dynamic effects and transmission channels of UMP, focusing on the foreign exchange market. By explicitly relating the response of the exchange rate and its fundamental determinants to the actual changes in the central bank balance sheets, we document the workings of different transmission channels. We find that actual UMP measures have large and persistent effects on the exchange rate. They are transmitted by impinging on both money markets conditions throughout the period of their implementation, and frictions in the foreign exchange market, such as deviations from covered interest rate parity. Conversely, the signalling channel contributes very little to UMP effects on exchange rates.

We obtain these findings by proxying UMP shocks with future changes in the size of the central bank's balance sheet, similarly to the approach in Mertens and Ravn (2011). In order to address the endogeneity of the central bank's balance sheet we use announcements of UMP measures as instruments in two-stage least squares regressions, while controlling for conventional interest rate monetary policy (and other contemporaneous influences). We then estimate the effects of UMP on the euro-dollar exchange rate, using local projections (Jorda, 2005). The local projection approach is motivated with the standard asset pricing formulation of exchange rate determination. We focus on the exchange rate of the US dollar against the euro, as the ECB and the Federal Reserve have been carrying out the largest UMP programmes after the global financial crisis, and as this is the world's most liquid currency pair. As the dollar-euro exchange rate is a relative price, in our analysis we consider the size of the ECB's balance sheet *relative* to that of the Federal Reserve as well as UMP announcements by both the ECB and the Federal Reserve. In addition, we estimate the responses of the fundamental determinants of the exchange rate in order to identify the transmission channels of UMP measures.

We find that the euro persistently depreciates against the dollar in nominal terms for a few months, and by around 1%, in response to a 1% expansion of the ECB's balance sheet relative

[3]See for example Du et al. (2017). Covered interest parity requires that the nominally riskless return in a currency (e.g., the US dollar) be equal to the return from investing a unit of the currency into the nominally riskless return in another currency (e.g., the euro) and at the same time entering in a forward currency agreement to convert back the proceeds into a known amount of the original currency. Borio et al. (2016) document that the differential between these two returns in US dollars has been consistently negative vis-à-vis several currencies, including the euro — or consistently positive in euro, see Section 2.

to that of the Federal Reserve. Regarding the transmission channels, because the depreciation is temporary and the exchange rate is expected to revert to its baseline after about 10 months, signalling about future fundamentals, including monetary policy, over longer horizons cannot be an important driver of the estimated effects of balance sheet policies. Moreover, we find that money market rates are also affected by the UMP shock. The reduction in short-term money market rate differentials in response to the UMP shock is consistent with reductions in frictions in money markets (Garcia-de Andoain et al., 2016). We also show that UMP shocks relax limits to arbitrage in foreign currency markets, by persistently reducing the differential between euro money market rates and their synthetic counterpart in euro-dollar currency swap markets. To the extent that deviations from covered interest parity can be ultimately traced back to borrowing constraints in dollar and euro money markets, our results thus suggest that financing frictions play a key role in the transmission of the balance sheet shocks to the exchange rate. However, this channel contributes to dampening the overall euro depreciation, and basically offsets the contribution from the persistent fall in the 3-month euro-dollar differential. As a result, currency risk premia play a prominent role in driving the overall euro depreciation against the US dollar.

The paper is organized as follows. The next section reviews standard exchange rate determination according to asset pricing theory, helping us to distinguish between the different transmission channels of UMP. Section 3 presents our identification strategy and empirical specification. Our main results on the response of the exchange rate and other financial assets, as well as macro variables are described in Section 4. Section 5 reports a few robustness exercises, while Section 6 concludes.

2 Theoretical framework

In this section we motivate the local-projection equation for the exchange rate that we will use in order to estimate the effects of UMP measures. To do so, we draw on textbook asset pricing theory and review exchange rate determination, both in the absence and presence of frictions, such as deviations from CIP. In the presence of frictions, we show that a generalised UIP condition implies that the spot exchange rate is given by the un-discounted sum of future expected fundamentals. The latter include expected interest rate differentials and currency risk premia over a given horizon, the expected exchange rate at the end of the horizon and — when CIP does not hold — the sum of expected CIP deviations. We then show that a theoretically-consistent local-projection equation for the exchange rate can be derived as the difference between generalised UIP conditions for the exchange rate in period $t-1$ and its expected value in period $t+h$. These generalised UIP conditions imply that the spot exchange rate is equal to the un-discounted sum of future expected fundamentals. The latter include expected interest rate differentials and currency risk premia over a given horizon, the expected exchange rate at the end of the period, and, when CIP does not hold, also the sum of expected CIP deviations.

2.1 Exchange rate determination in the absence of frictions

Consider an investor whose relevant nominal discount factor is expressed in US dollars ("American" investor), $\mathcal{D}_t^{\$}$.[4] Under standard conditions, the relation between $\mathcal{D}_t^{\$}$ and the one-period nominally risk-free US dollar nominal interest rate $R_t^{\$}$ is then given by:

$$1 = E_t\left(\mathcal{D}_{t+1}^{\$}\right) R_t^{\$}. \tag{1}$$

The equation says that one dollar today has to be equal to the certain dollar amount $R_t^{\$}$ in period $t+1$, appropriately discounted by the expected marginal value of wealth across the two periods. Similarly, denoting R_t^E the one-period risk-free euro nominal rate, $F_{t,t+1}$ the forward dollar price of one euro (and S_t the spot price, equally expressed in amount of dollars per euro), the investor would price the nominally safe investment of one dollar today into $1/S_t$ euro yielding the safe dollar payoff $F_{t,t+1}R_t^E$ in period $t+1$ as follows:

$$1 = E_t\left(\mathcal{D}_{t+1}^{\$}\right) \frac{F_{t,t+1}R_t^E}{S_t}. \tag{2}$$

CIP is thus implied by the equality of the right-hand sides of Equations (1) and (2) (the law of one price), namely

$$\frac{F_{t,t+1}R_t^E}{S_t} = R_t^{\$}, \tag{3}$$

and in logs

$$r_t^{\$} = f_{t,t+1} + r_t^E - s_t. \tag{4}$$

Intuitively, by enforcing the law of one price arbitrage ensures that the nominally safe dollar return $R_t^{\$}$ is equal to the equally safe "synthetic" dollar return, $\frac{F_{t,t+1}R_t^E}{S_t}$. Put differently, the euro-dollar forward exceeds the spot rate only by an amount equal to the euro-dollar interest rate differential.[5]

Arbitrage forces should also ensure that the one-period risk-adjusted expected return of investing

[4] Under general conditions, the stochastic discount factor is equal to the ratio of Lagrange multipliers on the agent's future and current budget constraint, i.e., her marginal value of wealth (see Lucas, 1978). The nominal discount factor is not necessarily a function of consumption growth only. For instance, with Epstein-Zin-Weil preferences, it is a nontrivial function of wealth growth itself.

[5] Observe that a crucial assumption is that both interest rates are risk-free, e.g. they are not subject to credit risk.

in the dollar-euro forward market or in the dollar-euro spot market are the same, namely:

$$\frac{E_t\left(\mathcal{D}^{\$}_{t+1}\right)F_{t,t+1}}{S_t}R^E_t = \frac{E_t\left(\mathcal{D}^{\$}_{t+1}S_{t+1}\right)}{S_t}R^E_t. \tag{5}$$

Hence, we have the following relation between the forward and the expected spot exchange rates:

$$F_{t,t+1} = E_t\left(S_{t+1}\right) + \frac{Cov_t\left(\mathcal{D}^{\$}_{t+1}, S_{t+1}\right)}{E_t\left(\mathcal{D}^{\$}_{t+1}\right)}. \tag{6}$$

Assuming log-normality and taking logs yields:

$$f_{t,t+1} = E_t\left(s_{t+1}\right) + Cov_t\left(d^{\$}_{t+1}, s_{t+1}\right) + \frac{1}{2}Var_t\left(s_{t+1}\right). \tag{7}$$

Taking into account Jensen's inequality (the term $\frac{1}{2}Var_t\left(s_{t+1}\right)$), the forward exceeds (falls short of) the expected spot rate when the investor is willing to pay a positive (negative) premium. The latter is the case when the spot rate is expected to covary positively (negatively) with the investor's discount factor. Specifically, the premium is positive if dollar depreciation against the euro (a higher S_{t+1}) is expected to go hand in hand with a higher marginal value of wealth (higher $\mathcal{D}^{\$}_{t+1}$). This means that the dollar currency risk of a nominally safe euro investment actually provides a hedge to the investor, who then requires compensation to hold the forward. Conversely, the premium is negative when dollar depreciation is expected to be associated with a lower discount factor of the investor.

Finally, by combining the CIP condition with the pricing of the forward rate we obtain the standard UIP condition:

$$s_t = E_t\left(s_{t+1}\right) + r^E_t - r^{\$}_t + Cov_t\left(d^{\$}_{t+1}, s_{t+1}\right) + \frac{1}{2}Var_t\left(s_{t+1}\right). \tag{8}$$

Expectations of future depreciation, a lower current euro-dollar interest rate differential, and a larger (more positive) risk premium all contribute to depreciating the dollar-euro spot exchange rate. Again, a larger risk premium implies that the dollar is now expected to be weaker relative to the euro when the marginal value of investor's wealth is also higher (S_{t+1} is expected to increase with $D^{\$}_{t+1}$).

We can solve forward Equation (8) for T periods to obtain the following relation:

$$\begin{aligned} s_t =& E_t\left(s_{t+T}\right)+\sum_{j=0}^{T-1} E_t\left(r_{t+j}^E-r_{t+j}^{\$}\right) \\ &+\frac{1}{2} \sum_{j=0}^{T-1} E_t Var_{t+j}\left(s_{t+j+1}\right)+\sum_{j=0}^{T-1} E_t Cov_{t+j}\left(d_{t+j+1}^{\$}, s_{t+j+1}\right). \end{aligned} \tag{9}$$

Equation (9) shows that all information as of period t about future fundamentals — i.e. expected interest rate differentials and currency risk premia — is immediately reflected in the spot exchange rate. Therefore, UMP can impact the spot exchange rate only to the extent that it affects current and expected interest rate differentials and currency risk premia, as well as exchange rate expectations beyond horizon T. Exchange rate expectations may be affected when the UMP measures "signal" changes in future fundamentals or monetary policy *beyond* horizon T; in fact, the latter need even not be related to future UMP measures, but could also be based on a different path of policy rates.

2.2 CIP deviations and exchange rate determination

We now introduce the possibility of deviations from CIP. Specifically, assume that investors are borrowing constrained (or, alternatively, that they face transactions costs).[6,7] In this case the two Euler equations above read as follows:

$$1 \geq 1-\lambda_t^{\$}=E_t\left(\mathcal{D}_{t+1}^{\$}\right) R_t^{\$}, \tag{11}$$

and

$$1 \geq 1-\lambda_t^F=E_t\left(\mathcal{D}_{t+1}^{\$}\right) \frac{F_{t, t+1} R_t^E}{S_t}. \tag{12}$$

Equation (11) holds with equality ($\lambda_t^{\$}=0$) if the investor is not facing a binding borrowing constraint at her desired level of investment in the dollar risk-free rate. This is for sure the case when the desired investment is positive, namely when the investor is saving and is long in $R_t^{\$}$. In this case, both sides of Equation (11) have to hold with equality. Thus, $\lambda_t^{\$} \geq 0$ can be interpreted as the shadow value of borrowing one additional dollar. Intuitively, when $\lambda_t^{\$}>0$

[6] Another possibility to introduce deviations from CIP would be that the dollar or euro interest rates are actually not safe, say because of default risk, and that this risk differs between them. Clearly, in this case the conditions under which CIP was derived above fail, leading to the following condition:

$$1=E_t\left(\mathcal{D}_{t+1}^{\$} R_t^E\right) \frac{F_{t, t+1}}{S_t}=E_t\left(\mathcal{D}_{t+1}^{\$} R_t^{\$}\right). \tag{10}$$

In this case, arbitrage does not ensure anymore that the forward-spot discount is equal to the interest rate differential. However, several contributions have shown that interest rate default risk has not been a key source of CIP deviations recently (see, for example, Du et al., 2017).

[7] In Appendix A we show that CIP deviations cannot arise because of counterparty risk in the forward market.

one dollar in period t is worth more than (the appropriately discounted value of) $R_t^{\$}$ in $t+1$. Similarly, Equation (12) holds with equality ($\lambda_t^F = 0$) if the investor is not borrowing constrained at her desired level of investment in the synthetic risk-free dollar rate $\frac{F_{t,t+1}R_t^E}{S_t}$. Again, this is for sure the case if the investment is positive (the investor has a long position).[8]

Combining the last two equations, it is easy to show that deviations from CIP can only arise if the investor is borrowing constrained in at least one of the investments. In particular, using Equations (11) and (12) we can write the following relation between the spot exchange rate, the forward rate and the interest rate differential:

$$S_t \frac{R_t^{\$}}{R_t^E} = F_{t,t+1} \cdot (1 - \lambda_t), \tag{13}$$

where $\lambda_t = 1 - \frac{1-\lambda_t^{\$}}{1-\lambda_t^F} > 0$ represents CIP deviations under borrowing constraints (or transaction costs). In particular, rearranging Equation (13)

$$R_t^{\$} = (1 - \lambda_t) \cdot \frac{F_{t,t+1}R_t^E}{S_t},$$

we see easily that have that the return on the forward dollar-euro is larger than the safe dollar return if borrowing is more expensive at the synthetic dollar rate $\frac{F_{t,t+1}R_t^E}{S_t}$ than at the cash dollar rate $R_t^{\$}$ (or at the cash euro rate R_t^E than at the synthetic euro rate $\frac{S_t R_t^{\$}}{F_{t,t+1}}$), i.e. when cash dollar borrowing constraints are tighter, $\lambda_t^{\$} > \lambda_t^F \geq 0$ and $\lambda_t > 0$.[9]

Taking logs of Equation (13) yields:

$$f_{t,t+1} - \lambda_t \simeq s_t - \left(r_t^E - r_t^{\$}\right), \tag{14}$$

where we have assumed that CIP deviations λ_t are small. Substituting the latter expression into Equation (7), we can derive the following generalised UIP condition:

$$s_t = E_t(s_{t+1}) + r_t^E - r_t^{\$} - \lambda_t + \frac{1}{2}Var_t(s_{t+1}) + Cov_t\left(d_{t+1}^{\$}, s_{t+1}\right), \tag{15}$$

[8] Observe that we can also interpret $\lambda_t^{\$}$ and λ_t^F as transaction costs. In this case, allocating one US dollar to either strategy only translates into an effective investment of $1 - \lambda_t^i$ US dollars. A key difference under the perspective of transaction costs is that $\lambda_t^i > 0$ even when the investor is long in either position.

[9] Indeed these expressions could be derived for an investor whose relevant nominal discount factor is expressed in euros ("European" investor), $\mathcal{D}_t^E$. In this latter case we would have the following:

$$1 \geq E_t\left(\mathcal{D}_{t+1}^E\right) R_t^E,$$
$$1 \geq E_t\left(\mathcal{D}_{t+1}^E\right) \frac{S_t R_t^{\$}}{F_{t,t+1}},$$

with an inequality when borrowing constraints bind. Therefore, in order to have that $F_{t,t+1}R_t^E/S_t > R_t^{\$}$, for this investor it must be that borrowing is also more restricted, if at all, at the synthetic euro rate $S_t R_t^{\$}/F_{t,t+1}$, than at the the risk-free euro rate R_t^E.

which solved forward for T periods yields:

$$s_t = E_t\left(s_{t+T}\right) + \sum_{j=0}^{T-1} E_t\left(r^E_{t+j} - r^{\$}_{t+j}\right) - \sum_{j=0}^{T-1} E_t\lambda_{t+j} + \frac{1}{2}\sum_{j=0}^{T-1} E_t Var_{t+j}\left(s_{t+j+1}\right) + \sum_{j=0}^{T-1} E_t Cov_{t+j}\left(d^{\$}_{t+j+1}, s_{t+j+1}\right). \quad (16)$$

In the presence of borrowing constraints in the cash and synthetic euro-dollar markets, in addition to expectations about interest rate differentials and currency risk premia the spot exchange rate also reflects expectations about CIP deviations. In particular, expected borrowing-constraint differentials in the cash and synthetic euro-dollar markets, $E_t\lambda_{t+j} > 0$, will imply that the dollar exchange rate is relatively *more* appreciated against the euro than what would be implied by expected interest rate differentials and currency risk premia alone.

2.3 Deriving the local-projection equation for the exchange rate

Consider the generalised UIP condition in Equation (16) and subtract on both sides the corresponding equation lagged by one period:

$$\begin{aligned} s_t - s_{t-1} = &-\left(r^E_{t-1} - r^{\$}_{t-1}\right) + \lambda_{t-1} - \tfrac{1}{2}Var_{t-1}\left(s_t\right) - Cov_{t-1}\left(d^{\$}_t, s_t\right) \\ &+ E_t\left(s_{t+T}\right) - E_{t-1}\left(s_{t+T}\right) + \sum_{j=0}^{T-1}\left[E_t\left(r^E_{t+j} - r^{\$}_{t+j}\right) - E_{t-1}\left(r^E_{t+j} - r^{\$}_{t+j}\right)\right] \\ &+ \sum_{j=0}^{T-1}\left[E_t\left(\lambda_{t+j}\right) - E_{t-1}\left(\lambda_{t+j}\right)\right] \\ &+ \sum_{j=0}^{T-1}\Big\{E_t\left[\tfrac{1}{2}Var_{t+j}\left(s_{t+j+1}\right) + Cov_{t+j}\left(d^{\$}_{t+j+1}, s_{t+j+1}\right)\right] \\ &\quad - E_{t-1}\left[\tfrac{1}{2}Var_{t+j}\left(s_{t+j+1}\right) + Cov_{t+j}\left(d^{\$}_{t+j+1}, s_{t+j+1}\right)\right]\Big\}. \end{aligned} \quad (17)$$

The summations in the second to the last row involve differences between the same terms, but in terms of expectations formed in period t and $t-1$. Hence, the terms in the second to the last row are functions of the structural shocks in period t, i.e. the vector of uncorrelated white noise variables $\boldsymbol{\varepsilon}_t$, $E_{t-1}\left(\boldsymbol{\varepsilon}_t\right) = 0$. Assuming linearity, we can thus re-write Equation (17) as:

$$\begin{aligned} s_t - s_{t-1} &= -\left(r^E_{t-1} - r^{\$}_{t-1}\right) + \lambda_{t-1} - \tfrac{1}{2}Var_{t-1}\left(s_t\right) - Cov_{t-1}\left(d^{\$}_t, s_t\right) + \boldsymbol{a}_0'\boldsymbol{\varepsilon}_t \\ &= \omega_{0,t-1} + \boldsymbol{a}_0'\boldsymbol{\varepsilon}_t, \end{aligned}$$

where

$$\omega_{0,t-1} \equiv -\left(r_{t-1}^{E} - r_{t-1}^{\$}\right) + \lambda_{t-1} - \tfrac{1}{2}Var_{t-1}\left(s_t\right) - Cov_{t-1}\left(d_t^{\$}, s_t\right), \tag{18}$$

$$\begin{aligned}
\boldsymbol{a}_0'\boldsymbol{\varepsilon}_t \equiv & \sum_{j=0}^{T-1}\left[E_t\left(\lambda_{t+j}\right) - E_{t-1}\left(\lambda_{t+j}\right)\right] + \sum_{j=0}^{T-1}\left[E_t\left(r_{t+j}^{E} - r_{t+j}^{\$}\right) - E_{t-1}\left(r_{t+j}^{E} - r_{t+j}^{\$}\right)\right] \\
& + \sum_{j=0}^{T-1}\left\{E_t\left[\tfrac{1}{2}Var_{t+j}\left(s_{t+j+1}\right) + Cov_{t+j}\left(d_{t+j+1}^{\$}, s_{t+j+1}\right)\right]\right. \\
& \left. - E_{t-1}\left[\tfrac{1}{2}Var_{t+j}\left(s_{t+j+1}\right) + Cov_{t+j}\left(d_{t+j+1}^{\$}, s_{t+j+1}\right)\right]\right\} + E_t\left(s_{t+T}\right) - E_{t-1}\left(s_{t+T}\right) \\
& = \boldsymbol{\alpha}_1'\boldsymbol{\varepsilon}_t + \boldsymbol{\alpha}_2'\boldsymbol{\varepsilon}_t + \boldsymbol{\alpha}_3'\boldsymbol{\varepsilon}_t + \boldsymbol{\alpha}_4'\boldsymbol{\varepsilon}_t,
\end{aligned} \tag{19}$$

and the coefficients in the vector $\boldsymbol{a}_0 \equiv (\boldsymbol{\alpha}_1', \boldsymbol{\alpha}_2', \boldsymbol{\alpha}_3', \boldsymbol{\alpha}_4')'$ represent the effects of the structural shocks $\boldsymbol{\varepsilon}_t$ on the dollar-euro exchange rate s_t.

Analogously, for the change in the exchange rate between periods $t+h$ and $t-1$ we have:

$$s_{t+h} - s_{t-1} = \omega_{h,t-1} + \boldsymbol{a}_0'\boldsymbol{\varepsilon}_{t+h} + \boldsymbol{a}_1'\boldsymbol{\varepsilon}_{t+h-1} + \ldots + \boldsymbol{a}_h'\boldsymbol{\varepsilon}_t, \tag{20}$$

where

$$\begin{aligned}
\omega_{h,t-1} = & -\left(r_{t-1}^{E} - r_{t-1}^{\$}\right) - \sum_{j=1}^{h-1} E_{t-1}\left(r_{t+j-1}^{E} - r_{t+j-1}^{\$}\right) + \lambda_{t-1} + \sum_{j=1}^{h-1} E_{t-1}\left(\lambda_{t+j-1}\right) \\
& - \sum_{j=0}^{h-1} E_{t-1}\left[\tfrac{1}{2}Var_{t+j-1}\left(s_{t+j}\right) + Cov_{t+j-1}\left(d_{t+j}^{\$}, s_{t+j}\right)\right].
\end{aligned}$$

Taking expectations as of period t yields:

$$E_t s_{t+h} - s_{t-1} = \omega_{h,t-1} + \boldsymbol{a}_h'\boldsymbol{\varepsilon}_t. \tag{21}$$

The coefficients $\boldsymbol{a}_h$ thus represent the impulse responses of the exchange rate to the structural shocks $\boldsymbol{\varepsilon}_t$ at horizon h. Importantly, notice that Equation (21) is a standard local projection of the exchange rate in period $t+h$ on shocks and controls in period t and earlier.

2.4 Introducing UMP shocks

In order to see how the local-projection equation in Equation (21) can be used to estimate the effects of UMP, partition the structural shocks $\boldsymbol{\varepsilon}_t$ into two subsets, $\boldsymbol{\varepsilon}_t = (\varepsilon_{1t}, \boldsymbol{\varepsilon}_{2t}')'$, where $\varepsilon_{1t} = \varepsilon_t^{ump}$ is a UMP shock and $\boldsymbol{\varepsilon}_{2t}$ includes all other structural shocks (in particular conventional monetary policy shocks to the policy rate and money demand shocks). Moreover, because

UMP measures are typically carried out over several periods, assume that ε_t^{ump} includes a contemporaneous component that reflects central bank asset purchases within the same period denoted by $\eta_{t|t}$, as well as a component that is anticipated as of period t to be implemented in period $t+1$ denoted by $\eta_{t+1|t}$:

$$\varepsilon_t^{ump} = \eta_{t|t}^{ump} + \phi \cdot \eta_{t+1|t}^{ump}. \tag{22}$$

In other words, while $\eta_{t|t}$ captures unexpected UMP shocks that affect the balance sheet contemporaneously, $\eta_{t+1|t}$ instead captures UMP shocks in t about measures that take place from period $t+1$ onwards. The intuition for including both a contemporaneous and an anticipated future component in the UMP shock ε_t^{ump} is that because the exchange rate is a forward-looking asset price, it will not only respond to UMP measures announced and implemented in period t, $\eta_{t|t}$, but also to those that are announced in t but that will only be — and are anticipated by agents to be — implemented in period $t+1$, $\eta_{t+1|t}$. Moreover, notice that because the dollar-euro exchange rate is a relative price, the term ε_t^{ump} should be interpreted as a *relative* UMP shock, i.e. UMP measures implemented by either the ECB or the Federal Reserve that affect the difference in central bank asset purchases. Partitioning the vector of impulse response coefficients as $\boldsymbol{a}_0 = (a_0^{ump}, \boldsymbol{a}_{0,2}')'$, we can write the local-projection equation for the exchange rate as:

$$s_t - s_{t-1} = \omega_{0,t-1} + a_0^{ump} \left(\eta_{t|t}^{ump} + \phi \eta_{t+1|t}^{ump} \right) + \boldsymbol{a}_{0,2}' \boldsymbol{\varepsilon}_{2t}. \tag{23}$$

The impulse response of the exchange rate to the UMP shock ε_t^{ump} is then given by the coefficients a_h^{ump} for horizons $h = 0, \ldots, H$.

Notice from Equation (20) that $\boldsymbol{a}_{T-1}' \boldsymbol{\varepsilon}_t = E_t(s_{t+T}) - E_{t-1}(s_{t+T})$, which is the revision in the expectation of the exchange rate T periods in the future that occurs between periods t and $t-1$ as a result of shocks in period t. Thus, in case of a UMP shock, the estimate of a_{T-1}^{ump} indicates the importance of the signalling channel through effects of UMP measures on fundamentals and monetary policy beyond period T. Finally, recalling the decomposition of the exchange rate in Equation (16), notice that estimating the impulse responses of the fundamental determinants allows us to quantify the transmission channels of the effects of UMP measures on the exchange rate.

2.5 Proxying UMP shocks by changes in central banks' balance sheets

Estimating the effects of UMP measures in the euro area and the US on the dollar-euro exchange rate represented by $\{a_h^{ump}\}_{h=0,1,\ldots,H}$ in Equation (23) is complicated by the fact that the shocks $\eta_{t|t}^{ump}$ and $\eta_{t+1|t}^{ump}$ are unobserved. However, we can proxy these relative UMP shocks by actual changes in the relative size of central banks' balance sheets that take place after UMP shocks.

Specifically, assume that the relative size of central banks' balance sheets evolves as:

$$\Delta BS_t = \delta_0 + \eta_{t|t}^{ump} + \eta_{t|t-1}^{ump} + \boldsymbol{\rho}'\boldsymbol{X}_{t-1} + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t}, \tag{24}$$

where $\boldsymbol{X}_{t-1}$ includes $s_{t-1}, r_{t-1}^E - r_{t-1}^\$, BS_{t-1}$ and λ_{t-1} as well as other variables. We can substitute the unobserved contemporaneous and future anticipated UMP shocks $\eta_{t|t}^{ump}$ and $\eta_{t+1|t}^{ump}$ in Equation (23) using Equation (24), namely

$$\begin{aligned}
\eta_{t|t}^{ump} &= \Delta BS_t - \left(\delta_0 + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t} + \eta_{t|t-1}^{ump} + \boldsymbol{\rho}'\boldsymbol{X}_{t-1}\right), \\
\eta_{t+1|t}^{ump} &= \Delta BS_{t+1} - \left(\delta_0 + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t+1} + \eta_{t+1|t+1}^{ump} + \boldsymbol{\rho}'\boldsymbol{X}_t\right),
\end{aligned}$$

to obtain:

$$\begin{aligned}
s_t - s_{t-1} =& \omega_{0,t-1} + a_0^{ump}\left(\phi^{-1}\Delta BS_{t+1} + \Delta BS_t\right) + \boldsymbol{a}_{0,2}'\boldsymbol{\varepsilon}_{2t} \\
& - a_0^{ump}\left[\phi^{-1}\left(\delta_0 + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t+1} + \eta_{t+1|t+1}^{ump} + \boldsymbol{\rho}'\boldsymbol{X}_t\right) + \left(\delta_0 + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t} + \eta_{t|t-1}^{ump} + \boldsymbol{\rho}'\boldsymbol{X}_{t-1}\right)\right] \\
=& \omega_{0,t-1} + a_0^{ump}\left(\phi^{-1}\Delta BS_{t+1} + \Delta BS_t\right) - a_0^{ump}\boldsymbol{\rho}'\left(\phi^{-1}\boldsymbol{X}_t + \boldsymbol{X}_{t-1}\right) + \widetilde{\delta}_0 + \zeta_t, \qquad (25)
\end{aligned}$$

where

$$\zeta_t \equiv -a_0^{ump}\left[\phi^{-1}\left(\boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t+1} + \eta_{t+1|t+1}^{ump}\right) + \left(\boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t} + \eta_{t|t-1}^{ump}\right)\right] + \boldsymbol{a}_{0,2}'\boldsymbol{\varepsilon}_{2t}. \tag{26}$$

Of course, in Equation (25) we have that the term $\phi^{-1}\Delta BS_{t+1} + \Delta BS_t$ is endogenous due to its correlation with ζ_t.[10] Intuitively, central banks' balance sheets change not only in response to UMP shocks, but also due to money demand and conventional monetary policy shocks. However, we can use announcements of UMP measures as instruments, while also trying to control for the effects of other structural shocks. Specifically, assume that future anticipated relative UMP shocks can be forecast given announcements by the ECB and the Federal Reserve according to:

$$\eta_{t+1|t}^{ump} = \mu_0 + \mu_1 a_t^{ECB} + \mu_2 a_t^{FED} + u_t. \tag{27}$$

where a_t^{ECB} and a_t^{FED} denote announcements by the ECB and the Federal Reserve, respectively, and where by definition $E\left(u_t \left| a_t^{ECB}, a_t^{FED}\right.\right) = 0$.[11] A large number of studies has used such announcements of UMP measures as indicators of exogenous monetary policy actions, showing that they are largely unanticipated by markets (see, for instance, Rogers et al., 2014; Fratzscher

[10] As we do not have information on the sign of $\boldsymbol{\delta}$ we cannot predict whether the endogeneity bias affecting the estimate of a_0^{ump} in Equation (25) is positive or negative.

[11] We mean here monetary policy news arising from the communication to the public via press releases, press conferences, speeches, testimonies, etc. of quantitative easing measures taken by central banks, in the spirit of the literature on macroeconomic announcements (see e.g. Andersen et al., 2003, for an application to exchange rates).

et al., 2016, forthcoming). Then, consider the sum of Equation (24) over periods t and $t+1$:

$$\begin{aligned}\Delta BS_{t+1} + \Delta BS_t &= \eta^{ump}_{t+1|t+1} + \eta^{ump}_{t+1|t} + \eta^{ump}_{t|t} + \eta^{ump}_{t|t-1} \\ &\quad +2\delta_0 + \boldsymbol{\rho}'(\boldsymbol{X}_t + \boldsymbol{X}_{t-1}) + \boldsymbol{\delta}'(\varepsilon_{2t+1} + \varepsilon_{2t}),\end{aligned}$$

and substitute $\eta^{ump}_{t+1|t}$ based on Equation (27) yielding:

$$\Delta BS_{t+1} + \Delta BS_t = \widetilde{\mu}_0 + \mu_1 a^{ECB}_t + \mu_2 a^{FED}_t + \boldsymbol{\rho}'(\boldsymbol{X}_t + \boldsymbol{X}_{t-1}) + \xi_t, \tag{28}$$

where

$$\xi_t \equiv \eta^{ump}_{t|t} + \eta^{ump}_{t|t-1} + \eta^{ump}_{t+1|t+1} + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t} + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t+1} + u_t. \tag{29}$$

Under the further identifying assumption that $\phi = 1$, we can estimate a^{ump}_0 in Equation (25) by two-stage least squares, with Equation (28) as the first-stage regression in which announcements of UMP measures a^{ECB}_t and a^{FED}_t by the ECB and the Federal Reserve represent instruments for $\Delta BS_{t+1} + \Delta BS_t$.

Three issues are worth pointing out. First, observe that if in Equation (23) we substituted only $\eta^{ump}_{t+1|t}$ by ΔBS_{t+1}, UMP announcements in period t might not be valid instruments for the latter. Specifically, in this case $\eta^{ump}_{t|t}$ would appear in the error of Equation (25). Especially when the frequency of the dataset is not very high — for example monthly, as in our baseline specification — UMP announcements in period t might be correlated with $\eta^{ump}_{t|t}$, because many ECB announcements have taken place at the beginning of the month and purchases could have started later in the same month.[12] Second, a possible problem with our two-stage least squares approach in Equations (25) and (28) is that UMP announcements may actually be responses of the ECB and the Federal Reserve to other structural shocks ε_{2t}. In this case, UMP announcements in period t would not be valid instruments, as they would be correlated with the error in Equation (25). As we explain in more detail in the next section, we address this possibility by including a number of controls to capture the impact of the other structural shocks ε_{2t}, such as an index of macroeconomic news and the US VIX. Finally, since a specific concern in the case of the ECB is that UMP measures may be deployed together with changes in policy rates, in our empirical specification we also control for the differential between the ECB main refinancing operations rate (MRO) and the Federal Funds target rate. Effectively, this implies that we focus on balance sheet changes that are orthogonal to shocks affecting all these contemporaneous variables.

[12] Having said that, as we have two instruments for the relative balance sheet — announcements by the ECB and the Federal Reserve — we can test for the validity of our instruments with a standard test of over-identifying restrictions in which we use only ΔB_{t+1} instead of the sum $\Delta B_{t+1} + \Delta B_t$. We do this in a robustness check in Section 5.

3 Empirical specification

We estimate Equations (25) and (28) by considering the ECB's and the Federal Reserve's balance sheets as well as the nominal bilateral US dollar-euro exchange rate.[13] We specify the relative balance sheet size variable BS_t as the difference between the nominal growth rates of the ECB's and the Federal Reserve's balance sheets in their respective currencies (specifically the differential in the respective log differences between periods $t+1$ and $t-1$).

Since we are interested in the effect of UMP measures introduced in the wake of the global economic and financial crisis and its aftermath, our sample period spans January 2009 to December 2016. In the baseline our analysis is carried out on data sampled at the monthly frequency.[14] We transform the data for financial variables available at higher frequencies to monthly observations by calculating averages over daily or weekly data. The data on the dollar-euro exchange rate as well as the size of the ECB's and the Federal Reserve's balance sheets are obtained from Haver Analytics.

We specify the announcements a_t^{ECB} and a_t^{FED} as indicator variables which equal unity if the ECB or the Federal Reserve announced in period t an asset purchase (see, for instance, Rogers et al., 2014; Fratzscher et al., forthcoming, 2016). The dates of the announcements of UMP measures by the ECB and the Federal Reserve are reported in Tables 1 and 2, respectively.[15] The dates in question are assigned to their respective calendar month.[16] As we are interested in the impact of UMP measures in the form of central bank asset purchases, we only consider announcements that can be assumed to have a tangible impact on the size of central banks' balance sheets. For example, we do not include the announcements of the ECB's intention to do "whatever it takes to preserve the euro" in July 2012 and of the Outright Monetary Transactions programme in September 2012, because these announcements did not result in asset purchases by the time of writing. Furthermore, we do not include the ECB announcement of the Securities Market Programme in May 2010, because the associated asset purchases were sterilised and hence did not increase the ECB's balance sheet.[17] Tables 1 and 2 also include information on the first principal component of the standardised one-day change of the German 2-year and 10-year Bund and US Treasury yields on the day of the announcements. In all cases, the volatility of changes in yields on the announcement days exceeds two standard deviations of the volatility

[13]In a future version of this paper we will also consider other major currency pairs.

[14]In robustness checks we report results based on data sampled at the weekly frequency. Although weekly sample would allow us a more accurate assignment of UMP announcements to the respective periods, we do not use a weekly frequency in our baseline. The reason is that because of fluctuations in banks' short-term liquidity needs, the weekly data are significantly more noisy than the monthly data.

[15]The announcement dates of the UMP measures of the Federal Reserve are taken from Rogers et al. (2014). Those for the ECB are taken from the ECB's website.

[16]The dummies also equal unity when there is more than one announcement in a given month, but this occurs only once in our dataset in the case of Federal Reserve announcements in October 2010.

[17]In robustness checks we added these three measures, however, and obtained similar results.

observed in our sample period, corroborating our assumption that these announcements were surprise monetary policy actions.

In order to decompose the response of the exchange rate to changes in the relative size of the central banks' balance sheets as laid out in Equation (16), we also estimate the responses of US and euro area interest rates, CIP deviations and risk premia by replacing the left-hand side variable in Equation (25) accordingly. For interest rates, we consider three-month money market rates as well as two and ten-year sovereign bond yields obtained from Haver Analytics; we use German Bund yields as measures of euro area sovereign yields. We derive CIP deviations at the three-months maturity or the dollar-euro exchange rate, λ_t, directly from Equation (13). We take data on the three-months dollar-euro forward exchange rate from Bloomberg.

Finally, in the vector of controls $\boldsymbol{X}_t$ we include lagged announcements and lags of the three-month and two-year interest rate differentials, the US dollar-euro exchange rate, the relative balance sheet changes and CIP deviations, as well as lags and contemporaneous values of the Citigroup Economic Surprise Indices for the US and the euro area obtained from Haver Analytics, the VIX, and the differential between the main ECB policy rate, the MRO, and the Federal Reserve Federal Funds target. As explained above, by doing so we effectively control for conventional monetary policy shocks in $\boldsymbol{\varepsilon}_{2t}$ in Equation (26), which could contaminate the estimation of the effects of UMP shocks.

4 Results

4.1 Predictive content of unconventional monetary policy announcements

Table 3 reports the estimates of our first-stage regression in Equation (28) for the relative balance sheet variable $BS_{t+1} - BS_{t-1}$.[18] The estimates indicate that announcements of UMP measures predict changes in central bank balance sheets. Especially ECB announcement dummies are highly statistically significant and have a positive coefficient estimate. Specifically, following an ECB UMP announcement, the ECB's balance sheet expands by almost 4% relative to that of the Federal Reserve. To put these numbers in perspective, recall from Figure 2 that this amounts to an expansion of the ECB's balance sheet relative to that of the Federal Reserve somewhat more than 75 billion euros. Notice that this is roughly equivalent to the amount of monthly asset purchases under the ECB's Expanded Asset Purchase Programme launched in 2015. Conversely, UMP announcements by the Federal Reserve do not seem to be statistically significant in accounting for changes in the relative balance sheet size.

[18] All standard errors in the tables are robust to heteroskedasticity and autocorrelation.

Finally, the results reported in Table 3 suggest that the estimated model passes the over-identification (i.e. Hansen J) and the under-identification (Kleibergen-Paap) tests.[19] In particular, the null of no correlation of the instruments with the relative balance sheet is rejected at the 1% significance level. This means that we can have some confidence in relying on standard asymptotic inference in reporting our results.

4.2 Dynamic effects of monetary policy supply shocks

We now turn to the dynamic responses of the relative size of central banks' balance sheets, of the nominal bilateral US dollar-euro exchange rate and of the variables involved in the decomposition in Equation (16). All figures report asymptotic confidence bands at the 68% and 90% significance levels, corrected to allow for heteroskedasticity and autocorrelation (dotted and dashed lines respectively).

4.2.1 Balance sheet and policy rate responses

The left-hand side panel in Figure 3 shows the evolution of the relative balance sheet after a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point. Specifically, the impulse response in the figure is obtained with our instrumental-variables local projections in which the dependent variable is the (log of the level of the) relative balance sheet, for horizons $h \geq 2$. Specifically, the ECB's balance sheet expands statistically significantly relative to that of the Federal Reserve for around five months after the shock. The persistence of the relative balance sheet expansion is consistent with the fact that UMP measures were typically not one-off instances of asset purchases or liquidity injections, but implemented gradually or repeatedly over time.

It is important to make sure that the monetary policy shocks we measure by instrumenting the relative balance sheet with UMP announcements really reflect *unconventional* monetary policy. Specifically, it may be that UMP announcements are also followed by changes in conventional monetary policy instruments. In this case, our estimates would not only reflect the effects of UMP shocks, but also those from conventional monetary policy actions. As an external validity test, we therefore estimate the responses of the ECB's and Federal Reserve's policy rates to our presumed UMP shocks. We use the Federal Funds target rate for the Federal Reserve as well as both the ECB's main refinancing operations rate (MRO) and deposit facility rate (DFR).

The results are displayed in Figure 4. The differential between the ECB MRO rate and the

[19] The Hansen J-test of over-identification and the Kleibergen-Paap test of under-identification are tests of whether instruments are valid and meaningful, respectively.

Federal Funds target rate (left-hand side panel) barely responds.[20] The point estimates are not statistically significantly different from zero, except after 15 months when they turn negative. The response of the differential between the ECB's DFR and the Federal Funds target rate is very similar to that of the MRO-Federal Funds target rate differential (right-hand side panel). The point estimate is marginally statistically significant at the 68% confidence level between three and four after the shock, but its economic magnitude of one basis point is minuscule. Similarly to the MRO-Federal Funds target rate differential, the response turns negative and statistically significant after 15 months. The finding of a lack of a economically (and, mostly, statistically) significant negative impact of UMP shocks on the policy rate differential is all the more noteworthy insofar as ECB policy rates were changed several times throughout our sample period; for example, the ECB decreased the MRO rate from 2.5% in January 2009 to -0.05% in March 2016, including four instances in which ECB UMP measures were announced alongside conventional measures. Overall, these results suggest that the effects we estimate are related to UMP shocks, and are not confounded with those from conventional monetary policy shocks. In particular, as we show below, the negative interest rate differentials after 15 months do not result in a corresponding response of the exchange rate or of money market interest rates.

4.2.2 Exchange rate response

The right-hand side panel in Figure 3 shows that the euro depreciates persistently in response to a relative UMP shock reflected in an expansion of the ECB's balance sheet relative to that of the Federal Reserve by 1%. The response is statistically significant at the 90% (68%) level after three (one) months and until the ten(twelve)-month horizon, over which the euro's depreciation bottoms at around 1.0%. Compared to the response of the relative balance sheet, the exchange rate response is more persistent, returning to baseline only after around ten to twelve months; importantly, notice that the exchange rate returns to baseline *before* the differential in policy interest rates shown in Figure 4 turns negative. That the exchange rate response to a UMP shock is mean-reverting, i.e. that $E_t\left(s_{t+T}\right) \longrightarrow 0$, implies that we can rule out that it is driven to a large extent by expectations of exchange rate depreciation over horizons beyond twelve months, and thus on account of expectations of future policy actions or changes in fundamentals.

4.2.3 Decomposition of the exchange rate response

We can now shed light on how UMP shocks are transmitted to the exchange rate through changes in interest rate differentials, CIP deviations and currency risk premia.

[20]Recall that differential between the ECB MRO rate and the Federal Funds target rate is restricted not to react to the expected increases in the relative balance sheet on impact due to the inclusion of this variable on the right-hand side of the local projections.

Interest rate differentials The top row in Figure 5 shows the response of the three-month money market rate euro-dollar differential.[21] The figure suggests that euro area money market rates decline statistically significantly relative to those in the US in response to a relative UMP shock in the euro area vis-à-vis the US. The three-month money market rate differential falls statistically significantly at the 90% confidence level by up to around three basis points between three and four months after the shock, when the exchange rate depreciates.[22] At the 68% significance level, the fall in the short-term money market rate differential is statistically significant after two months until at least 15 moths after the UMP shock.

The panels in the bottom row in Figure 5 present the responses of sovereign bond yield differentials at the two and ten-year maturities. The relative UMP shock in the euro area vis-à-vis the US has statistically significant effects on the sovereign bond yield differential only at the shorter end of the yield curve, and only at the 68% level. In particular, in response to a 1% expansion in the ECB's balance sheet relative to that of the Federal Reserve, the two-year interest rate differential falls statistically significantly by almost three basis points after three months, quickly reverting to baseline after six months.[23] In contrast to two-year maturities, the relative UMP shock in the euro area vis-à-vis the US does not affect the ten-year government bond yield differential. The lack of a statistically significant response of ten-year sovereign bond yields may seem counterintuitive against the backdrop of the APP program the ECB launched in January 2015. However, the estimated, relatively short-lived dynamics of the relative balance sheet depicted in Figure 3 seems consistent with the interpretation that our results mainly capture the effects of prior ECB asset purchase programs, which were focused more on providing liquidity to money markets. Thus, it is likely that the ECB asset purchase programs other than the APP did not affect much long-term interest rates. This is consistent with results in Section 5, where we show that excluding announcements related to the ECB APP program does not materially change our results.

Overall, notice that our findings that (i) the exchange rate reverts back to baseline and that (ii) longer-term yield differentials do not change imply that the signalling channel does not play a major role for the transmission of UMP shocks.

CIP deviations The left-hand side panel in Figure 6 presents the response of the CIP deviation at the three-month maturity, defined such that a positive value amounts to a money

[21]Considering short-dated interest rates is important because default risk is less pronounced than for rates of longer maturities, which would otherwise bias our estimates of the importance of the risk premia channel.

[22]Results available upon request show that the widening in short-term interest rate differentials is, in fact, driven almost exclusively by euro area money market rates.

[23]Analogous to the three-month money market differential, the widening in the two-year sovereign yield differential is—as for money market rates—driven by a decline in euro area yields. These estimates are available upon request suggest that.

market euro rate, $R_t^{€}$, larger than the synthetic euro rate, $\frac{S_t R_t^{\$}}{F_{t,t+1}}$ (or a larger synthetic dollar rate, $\frac{F_{t,t+1} R_t^{€}}{S_t}$ than its money market counterpart $R_t^{\$}$). The three-month CIP deviation persistently and statistically significantly falls in response to a relative UMP shock in the euro area vis-à-vis the US, although the response is statistically significant at the 90% only after around 8 months. In particular, in response to a 1% expansion of the ECB's balance sheet relative to that of the Federal Reserve, the three-month CIP deviation falls by around three basis points. Given that over our sample period CIP deviations have been persistently positive (money market euro rates have been larger than synthetic euro rates), our results imply that a relative UMP shock in the euro area vis-à-vis the US led to a narrowing in CIP deviations due to a reduction in borrowing costs in euro money markets relative to those in synthetic funding markets.[24] In order to understand the economic implications of this result, recall the definition of the CIP deviation from Section 2

$$\lambda_t \equiv 1 - \frac{1 - \lambda_t^{\$}}{1 - \lambda_t^F}.$$

Also recall that $\lambda_t^{\$}$ represents the shadow value of borrowing one additional euro in the synthetic market (or one dollar in the cash market), while λ_t^F represents the shadow value of borrowing one additional euro in the cash market (or one dollar in the synthetic market). This equation indicates that a fall in the CIP deviation can result only from a fall in $\lambda_t^{\$}$ relative to λ_t^F. The estimated effect on the CIP deviation is thus consistent with the notion that a relative UMP shock in the euro area vis-à-vis the US lowers the cost of borrowing in euro money markets relative to the cost of borrowing euro synthetically cum forward exchange rate in the dollar money market. However, as we showed in Section 2.2, this reduction has to be associated with a relative loosening of borrowing constraints in the latter relative to the former market.

According to Equation (14), changes in CIP deviations can be further decomposed into movements in interest rate differentials and forward-spot exchange rate differentials (forward discount), namely

$$\lambda_t = r_t^{€} - r_t^{\$} + f_{t,t+1} - s_t. \tag{30}$$

We have already shown that the money market rate differential falls by around three basis points in response to a relative UMP shock in the euro area vis-à-vis the US (see Figure 5). Analogously, the right-hand side panel in Figure 6 shows the response of three-month dollar-euro forward-spot differential. The latter peaks at around one basis point after three months. This is *less* than what would be required to keep CIP deviations constant. The response of the CIP deviation at the three-month maturity is thus mainly driven by the more subdued adjustment in the dollar-euro forward-spot response, relative to the response in the money market rate differential. Recall that according to the decomposition of the exchange rate in Equation (16), a fall in CIP deviations

[24] Notice that the market convention is to denote CIP deviations — the cross-currency basis swap — with the opposite sign compared to our notation.

strengthens the euro relative to the dollar. As we show below, the contribution of the response of CIP deviations is thus to appreciate the euro relative to the US dollar, overall resulting in a more subdued depreciation than what would be warranted by the decline in the interest rate differential and risk premia.

Decomposing the exchange rate response Based on the estimated responses of the interest rate differentials, the expected future exchange rate and the CIP deviations and Equation (16)

$$\begin{aligned} s_t - E_t\left(s_{t+T}\right) = \Bigg\{ & \sum_{j=0}^{T-1} E_t\left(r^{€}_{t+j} - r^{\$}_{t+j}\right) - \sum_{j=0}^{T-1} E_t\left(\lambda_{t+j}\right) \\ & + \sum_{j=0}^{T-1} E_t\left[\frac{1}{2} Var_{t+j}\left(s_{t+j+1}\right) + Cov_{t+j}\left(d^{\$}_{t+j+1}, s_{t+j+1}\right)\right] \Bigg\}, \end{aligned}$$

we can determine which transmission channel contributes by how much at different horizons to the overall exchange rate response. Figure 7 presents the cumulated responses of the fundamental determinants of the exchange rate shown on the right-hand side of Equation (16) and based on the estimates shown in Figures 3 to 6; the implied contribution of the currency risk premia is obtained as the residual given the estimated responses of the exchange rate, the three-month money market differential and the CIP deviations. Specifically, the decomposition shows that on impact, falling current and expected future interest rate differentials and risk premia depreciate the euro relative to the US dollar; however, the expected appreciation at the 15 month horizon and the fall in CIP deviations almost completely offsets this. Both the depreciating effect of the decline in interest rate differentials, and the countervailing CIP deviations fade over time due to their mean reversion, while the contribution of the expected end-of period appreciation is constant over all periods. Therefore, the bulk of the estimated depreciation of the euro against the US dollar must be driven by a fall in dollar-euro currency risk premia. Recall from Section 2.1 that a smaller risk premium implies that the euro is now expected to be weaker relative to the dollar when the marginal value of a US investor's US dollar wealth is higher (S_{t+1} is expected to be less positively — or even negatively — related to $D^{\$}_{t+1}$ in Equation (7)).

4.3 Impact of unconventional monetary policy shocks on the real economy and stock markets

The responses of the long-term yield differentials discussed above raises the question of whether the UMP shock might not affect much other financial markets and economic activity. Looking first at US and euro area stock markets, the impulse responses of the Eurostoxx 300 and the

S&P500 shown in Figure 8 suggest that both indexes increase, especially in the euro area. However, only the rise in the Eurostoxx 300 by 1% after six to eight months is statistically significant at the 90% level.

Conversely, when we look at the UMP effects on economic activity in the euro area and the US, we find little evidence of strong effects. While the euro-dollar nominal depreciation translates into a real depreciation, though smaller and a bit less precisely estimated, the responses of industrial production growth and HICP inflation in the euro area are small and not statistically significant, as shown in Figure 10. However, industrial production and especially inflation decrease in the US, the latter briefly even at the 90% level after four to five months, as shown in Figure 11. Our evidence thus suggests that the impact of the relative UMP shock is mostly confined to exchange rate and money markets.

5 Robustness

We now explore the sensitivity of our baseline results to the following: (i) substituting only the anticipated relative UMP shock in Equation (23); (ii) relying on OLS estimates with no instruments; (iii) using higher-frequency, weekly data; (iv) dropping the ECB UMP announcements related to the APP program from the set of indicator variables.

5.1 Purely anticipated relative balance sheet shock

Our first sensitivity check is to explore how our results are affected if we only substitute the anticipated shock $\eta^{MS}_{t+1|t}$ by ΔBS_{t+1}. The local-projection equation is then given by:

$$\begin{aligned} s_t - s_{t-1} =& \omega_{0,t-1} + a_0^{ump}\phi^{-1}\Delta BS_{t+1} + \boldsymbol{a}'_{0,2}\boldsymbol{\varepsilon}_{2t} \\ & - a_0^{ump}\phi^{-1}\left(\delta_0 + \boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t+1} + \eta^{ump}_{t+1|t+1} + \boldsymbol{\rho}'\boldsymbol{X}_t\right) + a_0^{ump}\eta^{MS}_{t|t} \\ =& \omega_{0,t-1} + a_0^{ump}\phi^{-1}\Delta BS_{t+1} - a_0^{ump}\boldsymbol{\rho}'\phi^{-1}\boldsymbol{X}_t + \widetilde{\delta}_0 \\ & + \boldsymbol{a}'_{0,2}\boldsymbol{\varepsilon}_{2t} - a_0^{ump}\phi^{-1}\left(\boldsymbol{\delta}'\boldsymbol{\varepsilon}_{2t+1} + \eta^{ump}_{t+1|t+1}\right) + a_0^{ump}\eta^{MS}_{t|t}, \end{aligned} \tag{31}$$

where we include the same contemporaneous and lagged controls as in the baseline specification. Observe that now the contemporaneous balance sheet shock $\eta_{t|t}$ is in the error term, which amounts to assuming that announcements are not correlated with it. Evidence against this assumption can be provided by the standard Hansen J-test of instrument validity. However, as shown by the estimation results reported in Table 4 for the first stage regression, this specification also passes the tests of instrument validity and relevance.[25] As shown in Figure 12, the impulse responses of the relative balance sheet, the dollar-euro exchange rate, of the differential between the ECB's MRO rate and the Federal Funds target rate, and the three-month rate differential are broadly consistent with those from our baseline results. Moreover, the relative balance sheet does not increase statistically significant on impact. These results thus suggest that the UMP announcements we consider mainly convey information about future central bank asset purchases *beyond* period t.

5.2 OLS estimates

Given the endogeneity of central banks' balance sheets, the error term in Equation (26) is likely to be correlated with the variable of interest $\Delta BS_{t+1} + \Delta BS_t$ in our local-projection equation. As we do not have information on the sign of $\boldsymbol{\delta}$ in Equation (24), we cannot predict whether the endogeneity bias affecting the estimate of a_0^{ump} in Equation (25) is positive or negative. However, it is still useful to assess how severe the endogeneity bias ultimately is. To do so, we can estimate Equation (26) by OLS. Figure 13 displays the results, suggesting that the endogeneity bias is quantitatively significant. Specifically, according to the OLS estimates, the euro depreciates only by up to 0.4% against the US dollar, substantially less than the 1% in the baseline in Figure 3. Moreover, according to the OLS estimates the relative balance sheet increases statistically significantly even on impact, which is consistent with endogeneity bias due to the correlation between the difference in the relative balance sheet griwth rates $\Delta BS_{t+1} + \Delta BS_t$ and the error term ζ_t in Equation (26).

5.3 Weekly data

Our baseline estimates are based on monthly data, which we obtain from averaging weekly data. We consider the monthly frequency because fluctuations in banks' short-term liquidity needs cause substantial noise in weekly data, which inflates the estimation error. In principle, however, exploring the weekly frequency has the advantage that it allows us to assign more accurately the UMP announcements to the respective periods, and thereby improve the power of our instruments. Figure 14 displays the results from our estimations when they are carried out using weekly data.[26] As expected, the results are less precisely estimated, but, more importantly, our baseline findings are largely confirmed. A relative UMP shock in the euro area vis-à-vis the

[25] The main difference with the benchmark specification is that Fed announcements now have — implausibly — a statistically significant and positive coefficient, implying that they are associated with an increase in the ECB's balance sheet relative to that of the Federal Reserve.

[26] Similarly with the first robustness exercise, we proxy the UMP shocks with relative balance sheet growth in the four weeks after that of the announcement.

US gradually and statistically significantly increases the relative balance sheet over around 20 weeks, resulting in a delayed euro depreciation lasting for a similar period, and in a decline of the three-month money market rate differential. Quantitatively, the maximum depreciation of 1% and fall in the interest rate differential by four-basis points are quite similar to our baseline results based on monthly data.

5.4 Excluding APP announcements from the set of instruments

The announcements of the UMP measures of the ECB and the Federal Reserve we consider as instruments are coded as binary dummy variables in our baseline specification. This is potentially an issue as we are treating potentially different UMP measures as the same. This concern is relevant for the ECB, whose APP program, geared towards asset purchases, was different from prior measures mainly targeting bank liquidity demand. In this subsection we thus investigate whether our results are sensitive to excluding announcements about the ECB APP program. The results are displayed in Figure 15, and are very similar to our baseline findings. This is consistent with the view that in our sample we are mainly capturing the effects of the ECB and Feder Reserve UMP measures prior to 2015.

6 Concluding remarks

[To be written.]

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A Can CIP deviations arise due to counterparty risk?

Under the maintained assumption that R_t^E is risk free, a simple way of thinking of counterparty risk in the forward exchange rate market is the following. Rather than at the contracted, known exchange rate $F_{t,t+1}$, the conversion into dollars of the one-period euro payoff R_t^E may be risky if there is a probability that it has to take place on the spot market at the uncertain (risky) exchange rate S_{t+1} because the counterparty cannot deliver dollars anymore. Assuming the (conditional) probability of the latter event is π_t, we have that no-arbitrage under no borrowing constraints implies the following:[27]

$$\frac{(1-\pi_t)\, E_t\left(\mathcal{D}_{t+1}^{\$}\right) F_{t,t+1} + \pi_t E_t\left(S_{t+1}\mathcal{D}_{t+1}^{\$}\right)}{S_t} R_t€ = E_t\left(\mathcal{D}_{t+1}^{\$}\right) R_t^{\$} = 1$$

$$\frac{F_{t,t+1} R_t€}{S_t} > R_t^{\$} <=> \left(E_t\left(S_{t+1}\right) - F_{t,t+1}\right) - Cov_t\left(\mathcal{D}_{t+1}^{\$}, S_{t+1}\right) R_t^{\$} > 0.$$

Thus a sufficient condition for positive CIP deviations ($\frac{F_{t,t+1}R_t€}{S_t} > R_t^{\$}$) is that the expression $\left[\left(E_t\left(S_{t+1}\right) - F_{t,t+1}\right) - Cov_t\left(\mathcal{D}_{t+1}^{\$}, S_{t+1}\right) R_t^{\$}\right]$ is different from zero. However, it is possible to show that this expression is always zero, as it corresponds to the expected forward premium (see e.g. Engel 1999). For our investor, it should be the case that the one period risk-adjusted expected return of investing in the dollar euro forward market or in the dollar euro spot market should be the same, namely

$$\frac{\pi_t E_t\left(S_{t+1}\mathcal{D}_{t+1}^{\$}\right) + (1-\pi_t)\, E_t\left(\mathcal{D}_{t+1}^{\$}\right) F_{t,t+1}}{S_t} R_t€ = \frac{E_t\left(\mathcal{D}_{t+1}^{\$} S_{t+1}\right)}{S_t} R_t€$$

$$(1-\pi_t)\frac{E_t\left(\mathcal{D}_{t+1}^{\$}\right) F_{t,t+1}}{S_t} R_t€ = (1-\pi_t)\frac{E_t\left(\mathcal{D}_{t+1}^{\$} S_{t+1}\right)}{S_t} R_t€.$$

$$F_{t,t+1} = E_t\left(S_{t+1}\right) - \frac{Cov_t\left(\mathcal{D}_{t+1}^{\$}, S_{t+1}\right)}{E_t\left(\mathcal{D}_{t+1}^{\$}\right)} \tag{A.1}$$

Notably, these returns are equalized also if they are subject to the same borrowing constraints and transaction costs. But then it is immediate that deviations from CIP cannot arise from counterparty forward market risks that are perfectly correlated with future spot market risks.The

27

$$\frac{E_t\left(\mathcal{D}_{t+1}^{\$}\right) F_{t,t+1} + \pi_t\left[E_t\left(\mathcal{D}_{t+1}^{\$}\right)\left(E_t\left(S_{t+1}\right) - F_{t,t+1}\right) - Cov_t\left(\mathcal{D}_{t+1}^{\$}, S_{t+1}\right)\right]}{S_t} R_t€ = E_t\left(\mathcal{D}_{t+1}^{\$}\right) R_t^{\$}$$

$$\frac{F_{t,t+1}R_t€}{S_t}\left[1 + \pi_t\frac{\left(E_t\left(S_{t+1}\right) - F_{t,t+1}\right) - R_t^{\$} Cov_t\left(\mathcal{D}_{t+1}^{\$}, F_{t,t+1}\right)}{F_{t,t+1}}\right] = R_t^{\$}$$

same relation for the “European” investor would read

$$F_{t,t+1} = \left[E_t \left(1/S_{t+1} \right) - \frac{Cov_t \left(\mathcal{D}_{t+1}€, 1/S_{t+1} \right)}{E_t \left(\mathcal{D}_{t+1}€ \right)} \right]^{-1}.$$

B Tables

Table 1: ECB announcements of unconventional monetary policy measures

Date	Event	Bond market response
07/05/2009	12-month SLTROs and other measures	8.37
04/08/2011	SLTROs and other measures	-7.27
06/10/2011	12/13-month SLTROs	4.11
08/12/2011	36-month VLTROs and other measures	-3.43
05/06/2014	Targeted longer term refinancing operations (TLTROs)	-4.26
04/09/2014	Announcement of ABSPP and CBPP3	1.02
02/10/2014	Details for the ABSPP and CBPP3	-.40
22/01/2015	Expanded Asset purchase programme (APP)	-7.19
05/03/2015	Implementation details of APP	-2.97
03/09/2015	Increase of PSPP's issue share limit	-5.81
10/03/2016	CSPP announcement	3.85
21/04/2016	CSPP starting date announcement and details	2.49
02/06/2016	CSPP Implementation details	-2.28
08/12/2016	Extension of APP	-2.02

Note: The bond market response is based on the first principal component of the standardized one-day change of the German 2-year and 10-year bund yields on the day of the announcements. Values are standardized with mean equal to zero and standard deviation equal to unity.

Table 2: Fed announcements of unconventional monetary policy measures

Date	Event	Bond market response
28/01/2009	Fed stands ready to expand QE and buy Treasuries	2.40
18/03/2009	LSAPs expanded	-15.32
27/08/2010	Bernanke suggest role for additional QE	3.93
12/10/2010	FOMC members 'sense' 'additional accommodation appropriate'	1.09
15/10/2010	Bernanke reiterates Fed stands ready to further ease policy	1.24
03/11/2010	QE2 announced: Fed will purchase $600 bn in Treasuries	-.11
21/09/2011	Maturity Extension Program announced	.14
20/06/2012	Maturity Extension Program extended	.73
22/08/2012	FOMC members 'judge additional accommodation likely warranted'	-2.68
13/09/2012	QE3 announced: Fed will purchase $40 bn of MBS per month	-1.17
12/12/2012	QE3 expanded	1.07

Note: The bond market response is based on the first principal component of the standardized one-day change of the US 2-year and 10-year Treasury yields on the day of the announcements. Values are standardized with mean equal to zero and standard deviation equal to unity.

Table 3: Regression results - First stage—Baseline ($BS_{t+1} - BS_{t-1}$)

	(1) First stage
VIX	0.001
	(0.55)
L.VIX	-0.003^{+}
	(-1.52)
L.2-year interest rate diff	-6.027
	(-1.26)
D.CESI EA	0.000
	(0.57)
D.CESI US	0.000
	(0.60)
L.CIP deviation (3-months)	17.854
	(1.40)
L.3-months interest rate diff	1.832
	(0.16)
L.Log Exchange rate	-0.247^{+}
	(-1.60)
Policy rate diff (MRO-FFR)	10.265
	(1.11)
L.Policy rate diff (MRO-FFR)	-16.462**
	(-2.05)
L.Change in Relative balance sheet growth	0.221
	(1.03)
L.ECB QE announcement	0.040**
	(2.24)
L.Fed QE announcement	0.009
	(0.53)
ECB QE announcement	0.038***
	(2.65)
Fed QE announcement	0.021
	(1.35)
Observations	95
Hansen-J (p-value)	0.42
Kleibergen-Paap-Test (p-value)	0.01
R-squared	0.49

t statistics in parentheses
Robust standard errors
$^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes:

Table 4: Regression results - First stage—Robustness 2 ($BS_{t+1} - BS_t$)

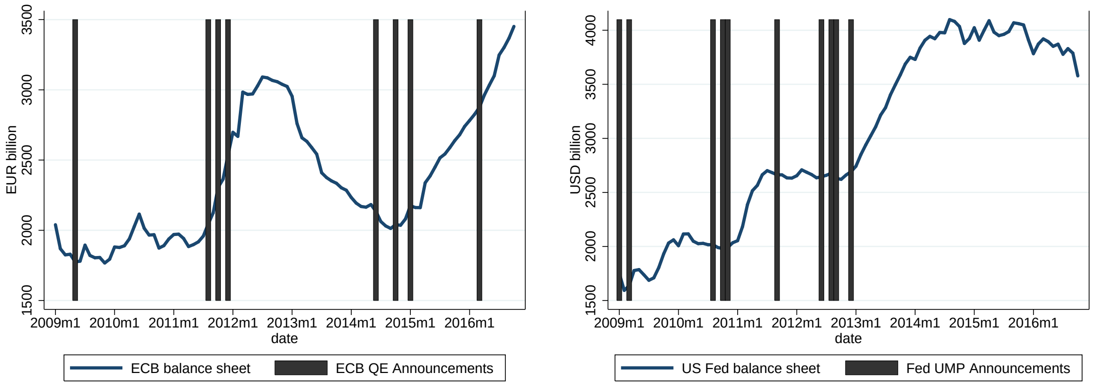
	(1) First stage
VIX	0.001
	(0.42)
L.VIX	-0.001
	(-0.63)
L.2-year interest rate diff	-1.526
	(-0.50)
D.CESI EA	0.000
	(0.73)
D.CESI US	0.000
	(0.71)
L.CIP deviation (3-months)	10.684
	(1.22)
L.3-months interest rate diff	-1.464
	(-0.18)
L.Log Exchange rate	-0.128
	(-1.31)
Policy rate diff (MRO-FFR)	7.336
	(1.27)
L.Policy rate diff (MRO-FFR)	-11.238**
	(-2.14)
L.Change in Relative balance sheet growth	0.014
	(0.12)
L.ECB QE announcement	0.012
	(0.90)
L.Fed QE announcement	-0.014
	(-1.06)
ECB QE announcement	0.029***
	(3.17)
Fed QE announcement	0.018*
	(1.74)
Observations	95
Hansen-J (p-value)	0.40
Kleibergen-Paap-Test (p-value)	0.01
R-squared	0.35

t statistics in parentheses
Robust standard errors
$^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes:

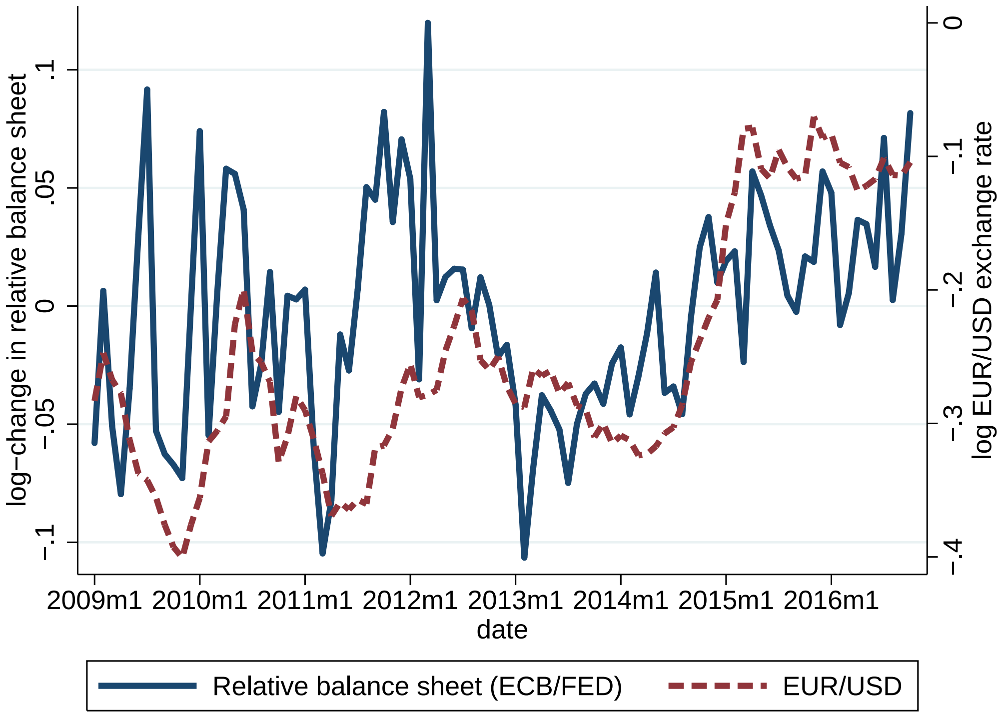
C Figures

Figure 1: Absolute balance sheet movements and UMP announcements



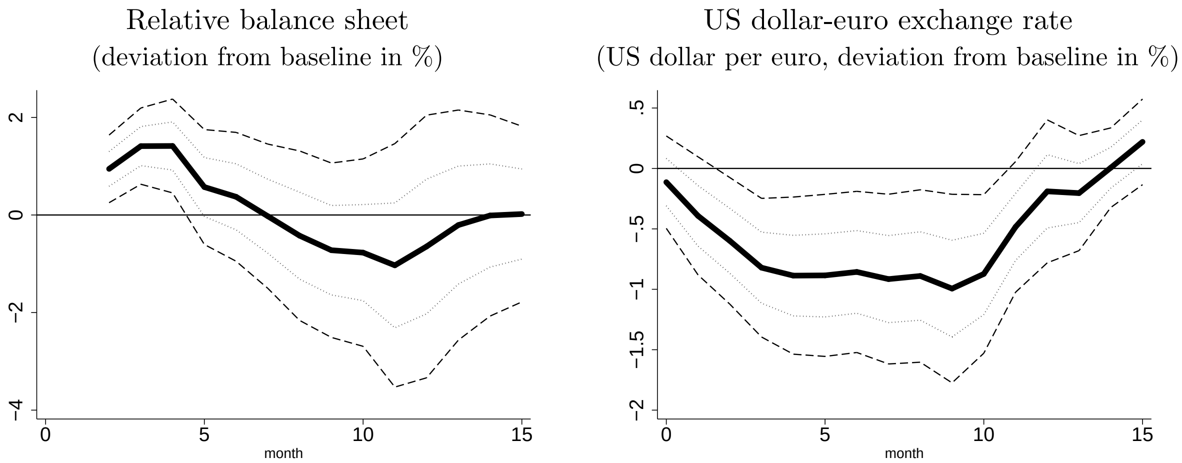
Notes: The figure shows the evolution of the ECB's (left-hand side panel) and the Federal Reserve's (right-hand side panel) balance sheets. In both panels, the vertical lines indicate the dates of UMP announcements by the respective central bank.

Figure 2: Relative balance sheet movements and the EUR/USD exchange rate



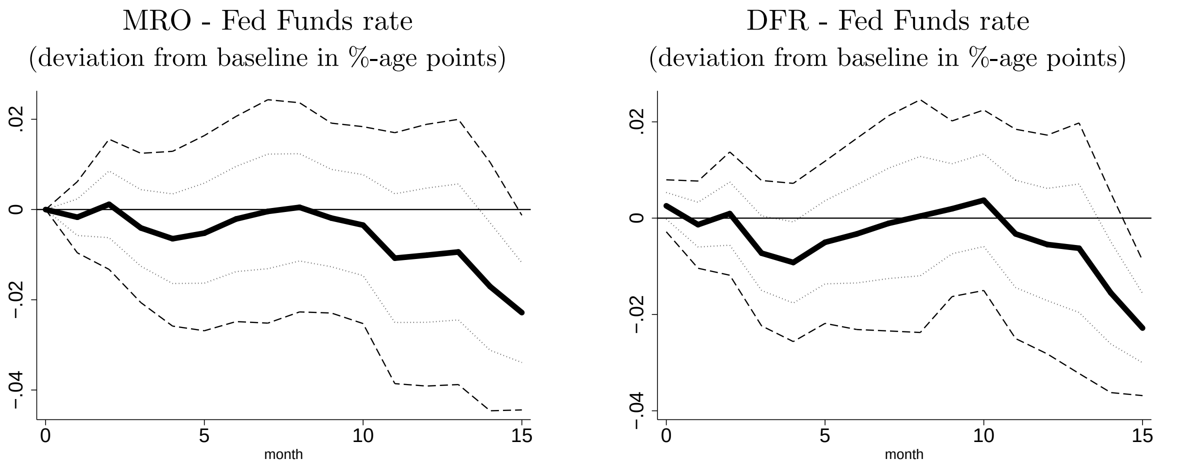
Notes: The figure shows the evolution of the logarithm of the nominal euro-US dollar exchange rate (dashed red line) and the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets (solid blue line).

Figure 3: Relative balance sheet and exchange rate responses



Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

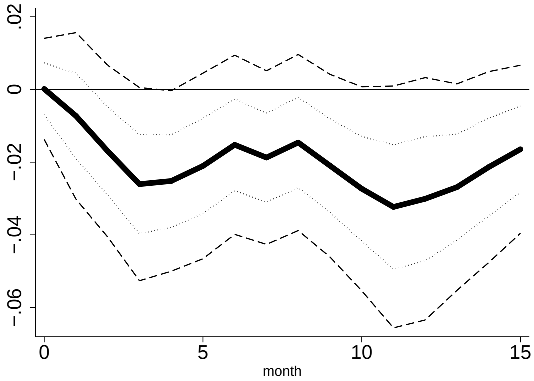
Figure 4: Policy rate differential



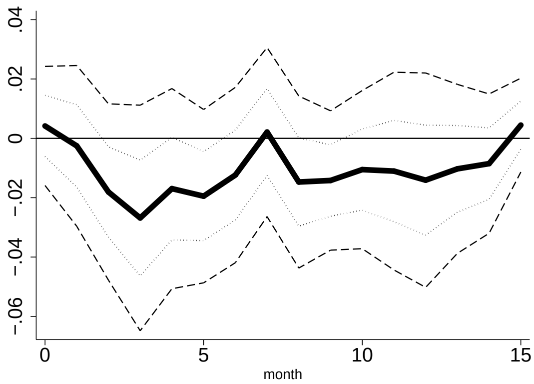
Notes: The panels show the responses to a relative UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 5: Interest rate responses

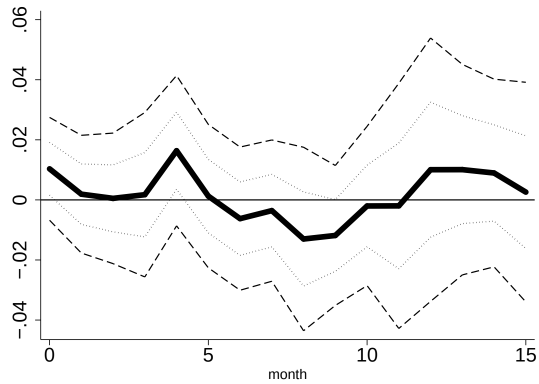
Three-month money market rate differential ($r^{€,3m} - r^{\$,3m}$)
(deviation from baseline in %-age points)



Two-year sov. yield differential ($r^{€,2y} - r^{\$,2y}$)
(deviation from baseline in %-age points)

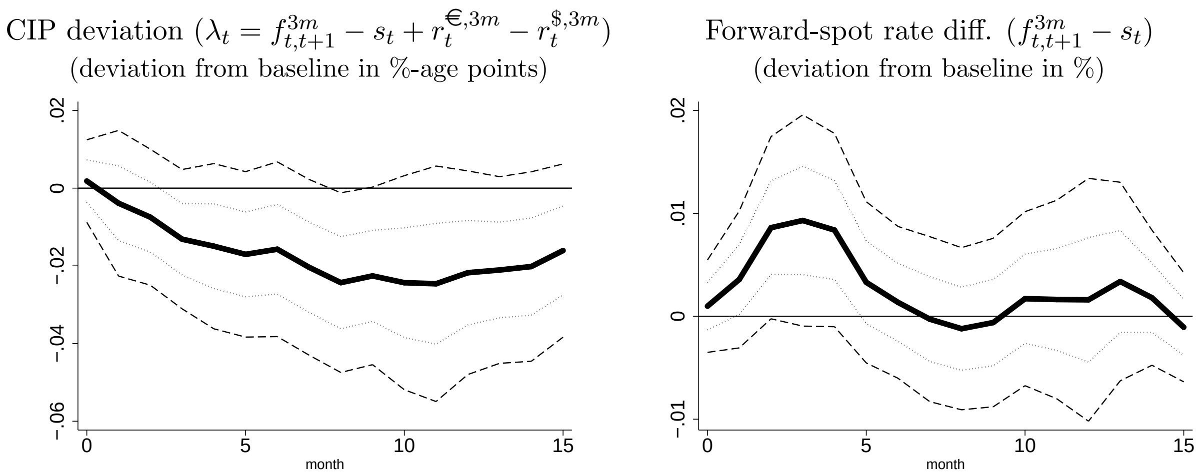


Ten-year sov. yield differential ($r^{€,10y} - r^{\$,10y}$)
(deviation from baseline in %-age points)



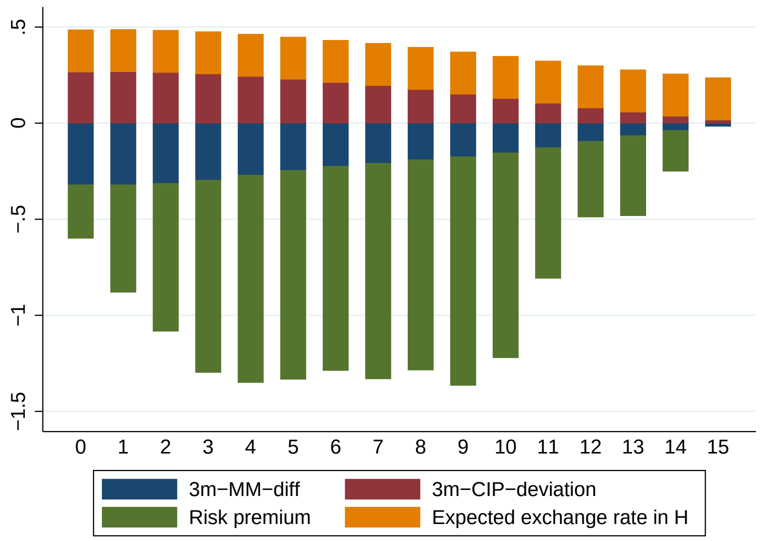
Notes: The panels show the responses to a relative UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 6: Three-month CIP deviation and forward-spot rate differential



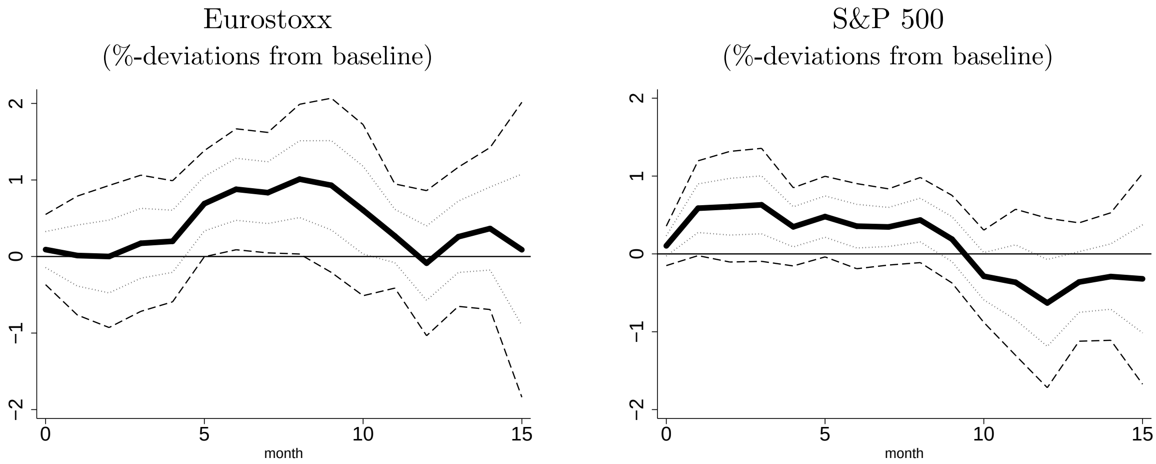
Notes: The panels show the responses to a relative UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 7: Decomposition of exchange rate response to UMP shocks



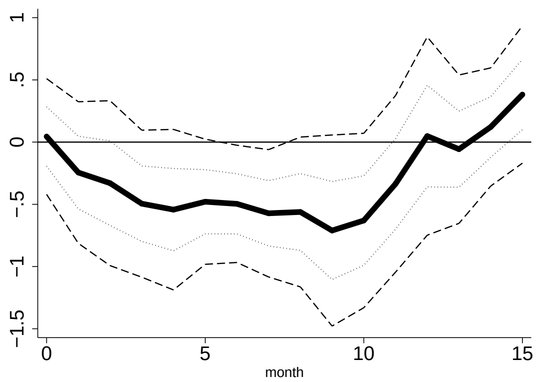
Notes: The figure shows the decomposition of the exchange rate effect of a relative UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point into the transmission channels according to Equation (16).

Figure 8: Equity prices



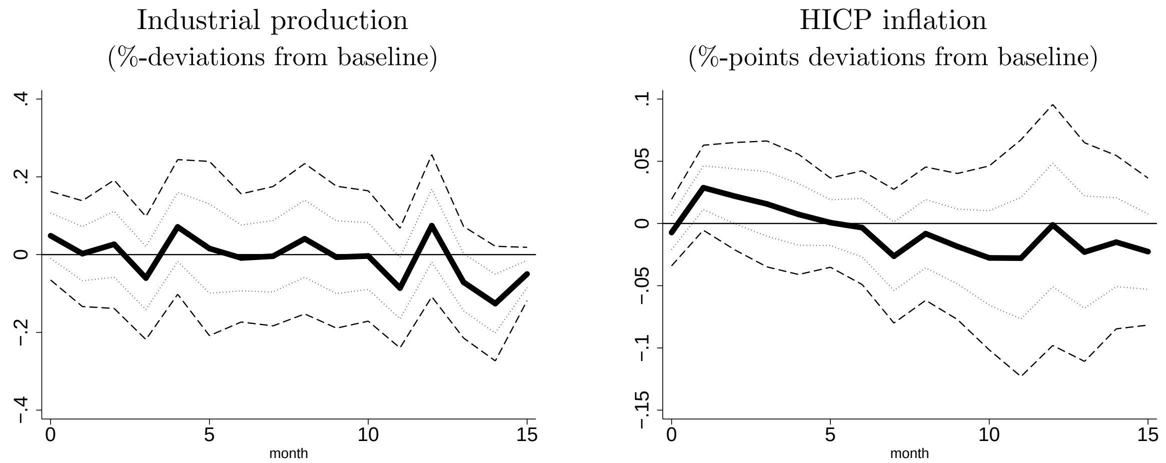
Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 9: US dollar-euro real exchange rate in levels r_t (US dollar per euro deflated with CPI, %-deviations from baseline)



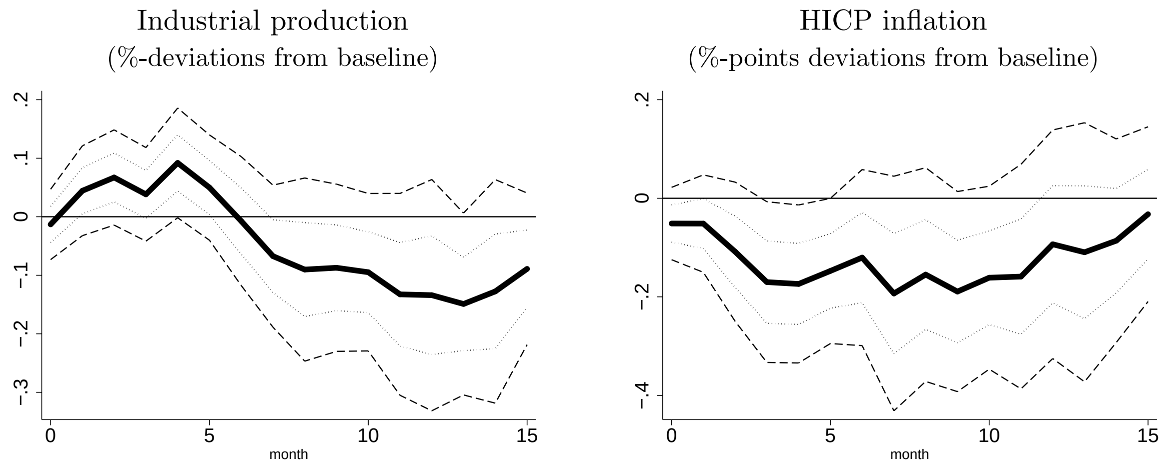
Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 10: Euro area real variables



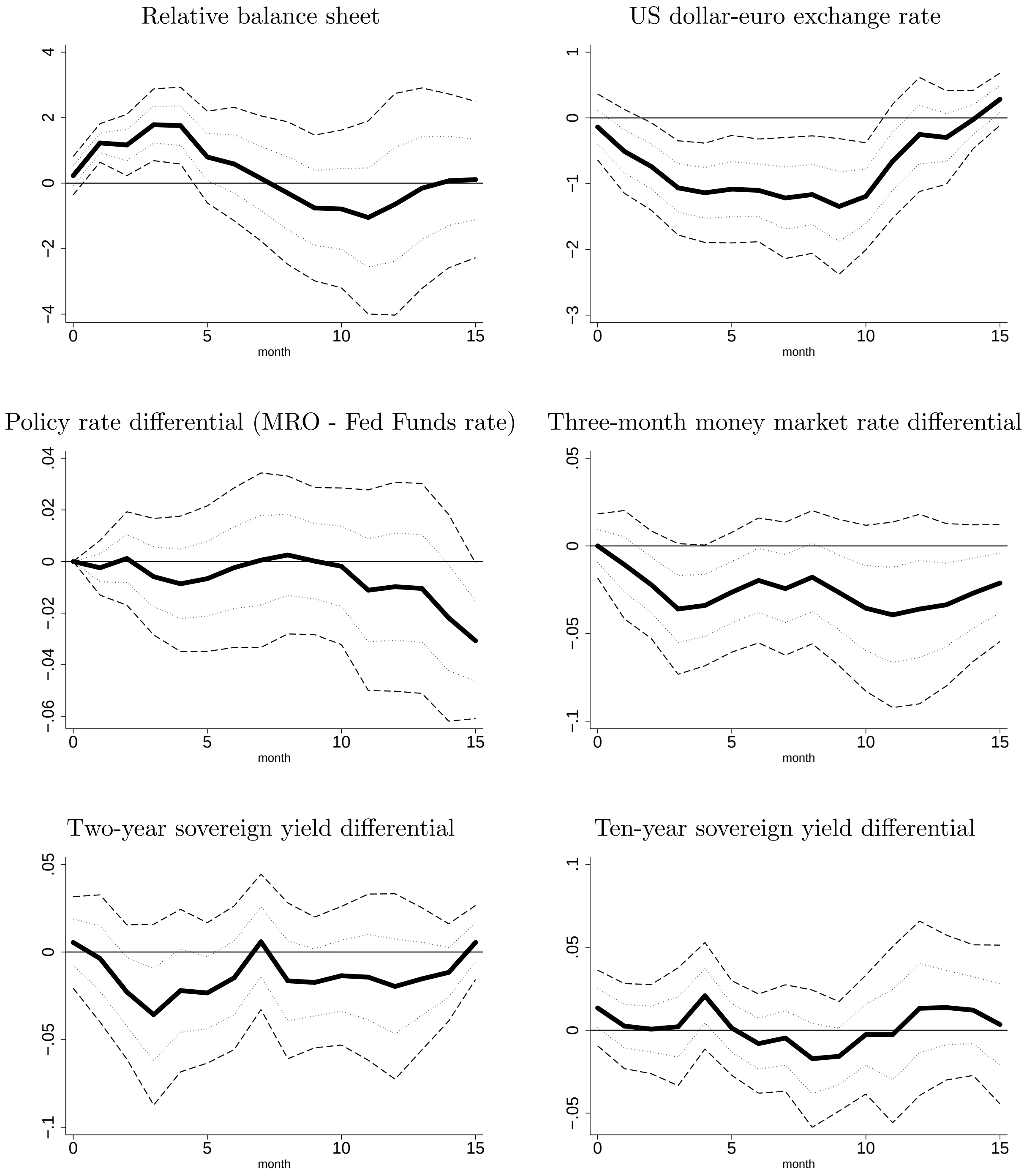
Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 11: US real variables



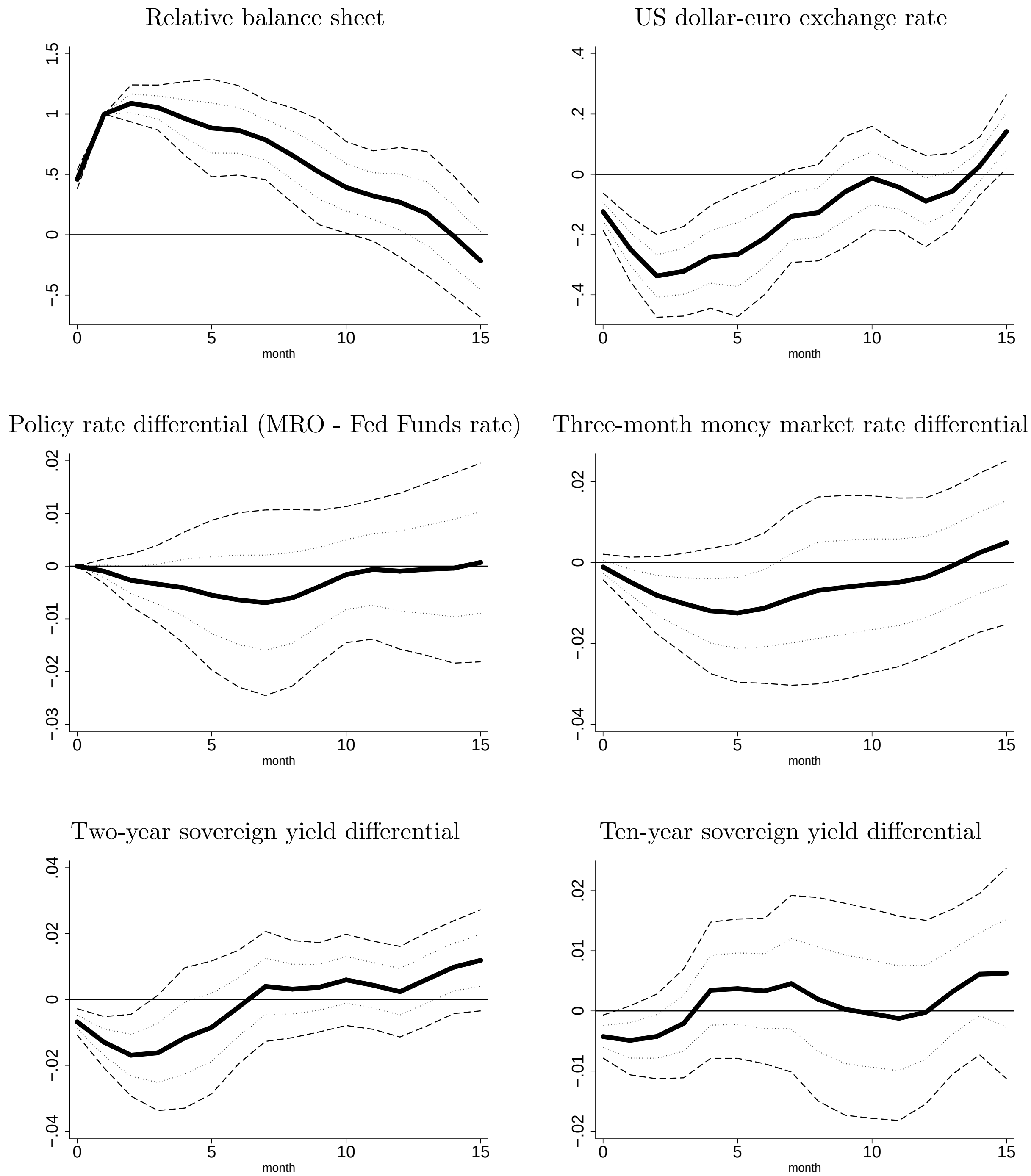
Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 12: Substituting only the anticipated UMP shock $\eta_{t+1|t}$



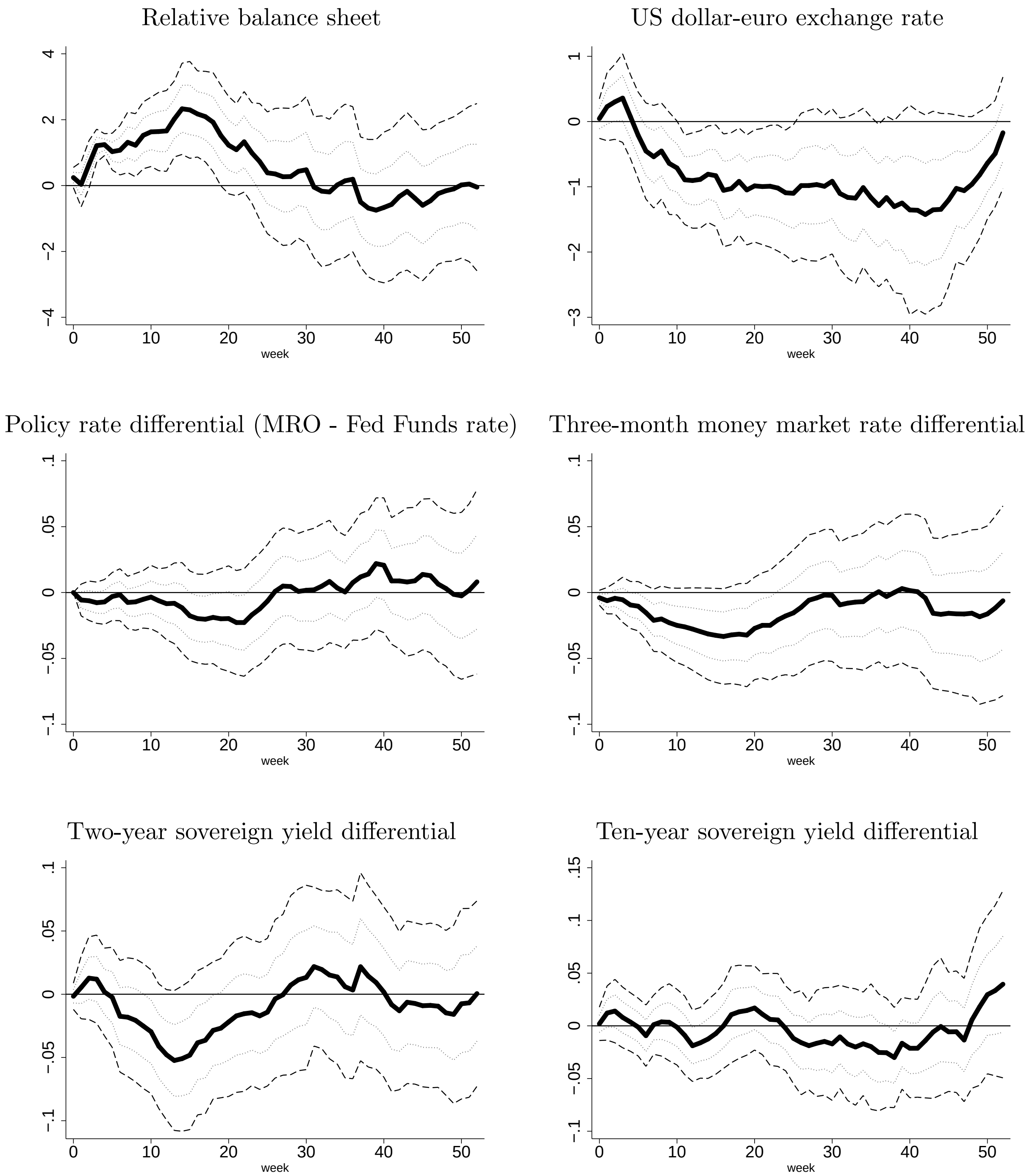
Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 13: OLS results



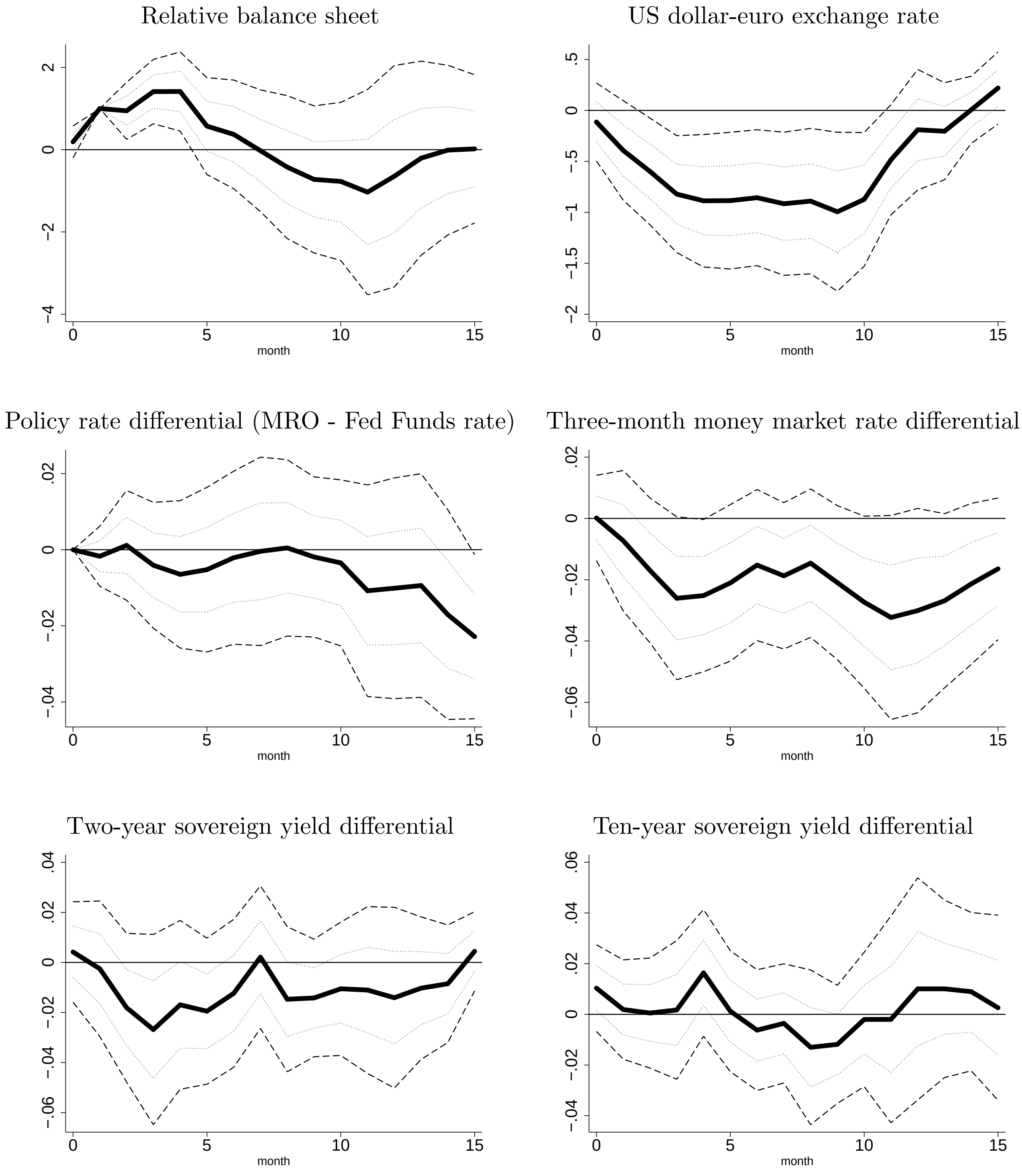
Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 14: Weekly frequency



Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.

Figure 15: Excluding APP announcements



Notes: The panels show the responses to a UMP shock that increases the difference between the growth rates of the ECB's and the Federal Reserve's balance sheets by one percentage point.