Monetary Policy Surprises and Exchange Rate Abnormalities*

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Abstract

Central banks unexpectedly tightening policy rates often observe the exchange value of their currency depreciate, rather than appreciating as predicted by standard models. We document this for Fed and ECB policy days using eventstudies and ask whether an information effect, where the public attributes the policy surprise to an unobserved state of the economy that the central bank is signaling by its policy may explain the abnormality. It turns out that many informational assumptions make a standard two-country New Keynesian model match this behavior. To identify the particular mechanism we condition on reactions of longer term interest rates in the eventstudy and model implications for these. We find that there is heterogeneity in this dimension in the eventstudy and no model with a single regime can match the evidence. Further, even after conditioning on the information effects on longer term interest rates, there may be independent information in the reaction of exchange rates.

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1 Introduction

We have become adept at measuring asset price responses to monetary policy surprises, and indeed, measuring those surprises themselves using changes in asset prices. This is due to increased data availability and conceptual advances that led to better empirical methodology. These monetary policy eventstudies are useful in themselves, helping relate changes in a broad array of financial markets to policy actions and announcements; and are also useful in VAR identification where the surprises are used as instruments.

In a large and expanding literature, a recent strand is focusing on asymmetries in financial market responses to policy surprises, when an asset price moves in an unexpected direction given the policy event. This may be stock prices or breakeven inflation rates increasing when there is a surprise tightening, or long-term forward interest rates decreasing in response to the same. "Unexpected" in this context is based on the canonical model of monetary policy, where tighter policy decreases stock prices and inflation, and leaves long-term forward interest rates unchanged. The observed effects require a deviation from the canonical model, and that is often found in relaxing the informational assumptions. If the central bank has a different information set than market participants, policy surprises may signal this private information, without precluding genuine policy shocks.

Our focus in this paper is on the behavior of exchange rates on policy dates. We first show that similar abnormal behavior is prevalent in exchange rate reactions to monetary policy surprises as well, and then discuss why this may be so. In presenting the discussion we will make use of a standard two country open economy model taking into account implications for yield curves, which allows jointly analyzing policy surprises' effects on the exchange rate and the shapes of the home and foreign yield curves simultaneously.

Our study helps accomplish several goals. We are quickly able to show that looking at one moment, such as the covariance of the shortest end of the yield curve—the policy surprise—and the exchange rate, does not uniquely identify the possible mechanism. There are multiple informational assumptions that are consistent with a single moment condition. Second, we can then argue that bringing in other moments, such as covariances with changes in longer-term points on the yield curve, may narrow down the set of plausible models. We discuss several noteworthy policy dates where this becomes apparent.

Using estimated versions of models with different informational assumptions, we then ask which model fits the observed macro-finance data best, on average. "On average" is very consequential here as information asymmetries inherently include regime switching where in-

formation of one or another kind may be received by the public on any policy date. But fitting a regime switching model to the data is not possible because each period may be in a different regime, this is not a slowly regime switching world. Thus, only the model that fits best on average can be chosen and that is certainly a misspecified model. The exercise we carry out allows us to discuss these issues and relay what we learn from the best fitting model, which is an imperfect information model.

We conclude by observing that given the canonical model we are employing, the two country open economy Clarida et al. (2002) [CGG] model, there exist a policy dates where no variant of the model matches the signs of all asset price changes. In that regard, this paper is a call for action on open economy macro-finance modeling.

2 What We Build On

This paper is motivated by high frequency eventstudies. This methodology studies asset prices, which are forward looking jump variables, at times of arrival of news to achieve identified effects of news on asset prices. This literature goes back to Fama et al. (1969) but the strand we belong to, monetary policy event studies, date to the 1989 paper of Cook and Hahn. A seminal paper is the work of Kuttner (2001) who recognized that conditioning on days of monetary policy announcements and changes in policy rates imparts considerable measurement error as market participants at least partly anticipate policy decisions and therefore these by themselves do not constitute news. Kuttner spearheaded the use of Federal Funds Futures contracts in measuring policy news.

Gürkaynak et al. (2005a) then showed that monetary policy announcements are perceived to be multi-dimensional, with one factor capturing the surprise in the policy action (target) and another the surprise in the policy communication (path). The monetary policy event-study literature took off, with a large number of papers that we will not survey here using these surprise measures as independent variables and studying the responses of a wide variety of asset prices.

More recently, the eventstudy literature, with its measure of policy surprises, met the VAR literature, with its measure of shocks. High frequency eventstudy surprises are innovations in market participants' information sets, whereas lower frequency VAR shocks are innovations conditional on the actual state of the economy. These two measures would overlap under full information (Gürkaynak and Wright, 2013) but even under partial information surprises may be good instrument for identified shocks in VARs, where identification is notoriously

difficult. Faust et al. (2004) took the first step in formally identifying monetary VARs using eventstudy data and Gertler and Karadi (2015) is the first and very influential paper that used the monetary policy surprises as instruments for shocks in a proxy VAR.

As noted by Gertler and Karadi and discussed in detail by Ramey (2016), some of the findings of Gertler and Karadi are consistent with the eventstudy surprise not satisfying the exclusion restriction. For example, if the central bank forecasts output to go down and cuts interest rates for this reason and the forecast is private to the central bank, the rate cut will be surprise in the eventstudy sense but not a shock in the VAR sense. Central banks may indeed have superior information on some aspects of macroeconomic processes, as argued by Romer and Romer (2000) and Peek et al. (1999). This observation has led to a growing literature in central bank information effects.

Eventstudies are again the starting point, as some asset price reaction will look "abnormal" under the presence of asymmetric information. Abnormality is, of course, in the eye of the beholder and the beholder is the model one has in mind. For example, Gürkaynak et al. (2005b) have argued that the reaction of the long-end of the yield curve is not consistent with models of fixed steady states and instead proposed a model where the inflation target is time-varying and unknown to the public, as was the case in the US before 2012. This is a case where the information asymmetry is about the preferences of the central bank, as in the theoretical work of Ellingsen and Soderstrom (2001).

The influential paper of Campbell et al. (2012) provided the nomenclature of information effects, with Delphic forward guidance providing signals about the central bank's forecast and Odyssean forward guidance being about the future path of interest rates given the macroeconomic forecast. More recently, eventstudy papers focusing on the long-end of the yield curve (Nakamura and Steinsson, 2018), stock prices (Jarociński and Karadi, 2020), break-even inflation rates (Andrade and Ferroni, 2016) have found similar abnormal behavior from the perspective of standard models and have proposed central bank information-based explanations. These papers suggest central banks may have superior information on the steady state growth rate of output or the current state of the business cycle and use asset price behavior to disentangle standard monetary policy surprises from information surprises.

Two papers that stand out in this literature are Miranda-Agrippino and Ricco (2017) and Bauer and Swanson (2020). The former paper conditions on Greenbook forecasts of the Fed (which are released with a five year delay) to see whether the contemporaneous market-based surprise correlated with the internal forecast. In essence, this paper asks whether there was actually information the Fed had, rather than the market participants behaving as if

it did. There is evidence of information effects but only a small proportion of the surprise is attributable to Greenbook forecasts. The latter paper asks this question outright in a survey, which finds that market participants do not think the Fed has consistently superior information about cyclical dynamics. Bauer and Swanson note that central bank preferences, as in Gürkaynak et al. (2005b) are likely candidates for information effects.

There is also a large literature on exchange rate reactions to monetary policy. The relevant strand for our purposes goes back to Engel and Frankel (1984) who observed the abnormal behavior of exchange rates in response to monetary policy actions, with the local currency depreciating when policy is tightened. Their explanation rested on policy reversals. As relevant are works that focus on non-monetary policy data releases and exchange rate reactions, relating these to monetary policy rules. In particular, Clarida and Waldman (2008) and Clarida (2009) nicely argue that inflation surprises (inflation higher than expected) may lead to local currency appreciations if inflation is a persistent process and monetary policy is sufficiently attuned to inflation stabilization. Clarida (2009) employs the Clarida et al. (2002) model to make that point and is the rare paper that provides a formal model to make an argument based on eventstudy evidence.

More recently, Stavrakeva and Tang (2018) note the appreciation of the dollar in response to easings in Fed policy during the Great Recession. They propose a combination of information (Delphic forward guidance) and exorbitant duty a la Gourinchas et al. (2018) as an explanation. Taking a similar path in eventstudies, we will show that this behavior was not limited to the dollar and was also not limited to the Great Recession period. Another immediately relevant paper is that of Cieslak and Schrimpf (2019), who do not focus on exchange rates but do take into account multiple moments in the eventstudy, in their case the joint behavior of the stock prices, policy action surprise, and the long-end of the yield curve. We will focus on exchange rates and yield curves in two countries, as well as bringing in a formal model to frame the interpretation.

This overview of the state of the literature helps place our contribution in context. Eventstudies have long been used to inform models and models form the baseline against which eventstudy findings are seen as expected or abnormal. The abnormal findings on monetary policy days are being attributed to central bank information effects. We study the exchange rate behavior on policy days in response to Fed and ECB surprises. From the perspective of the CGG model, abnormal behavior is rampant.

But if monetary policy is informative about some other, unobserved realization in the economy, then asset price reactions to monetary policy in the incomplete information setting

will be the asset price reactions to that realization in the complete information setting. We therefore ask which shock in the full information model generates the abnormal covariance of exchange rate and the short rate. This is when bad news about inflation being good news about the exchange rate become relevant. The answer turns out to be several shocks and combinations of shocks. This lack of identification is important. Abnormal asset price reactions suggest something may be unobserved and signaled by the central bank but they may not uniquely pin down what.

We therefore bring in more asset prices and have a larger set of moment conditions from the eventstudy to discipline the information structure of the model. The main body of the paper is carrying out these exercises. But before we go there an important caveat is in order.

The model is limited to information asymmetries for the variables it employs. We therefore do not speak to the Rogers et al. (2014) "saving the euro" effect where easier than expected monetary policy announcements during the European debt crisis sometimes led to appreciations of the euro as these were seen as signs that ECB is determined to hold the euro area together. This has no counterpart in the model and we cannot analyze its effects, although we believe the effect was present.

Further, the solution algorithm of the model, which uses approximations around a steady state where inflation and output gaps are zero, preclude studying effects of information asymmetries for the weights the central bank has in the policy rule for output and inflation stabilization. This is an important omission, as potentially changing preferences of policymakers is a natural source of information asymmetry. The study of changing preferences other than the inflation target will have to be taken up in further work.

Despite the caveats, we are able to offer the most complete model-based assessment of eventstudy evidence in the presence of potential information effects and speak clearly about the dimensions in which the standard workhorse open economy macroeconomic model does and does not help explain the financial market data we observe.

3 Eventstudy: First pass

We will study the USD/EUR exchange rate reaction to ECB and Fed policy surprises. The exchange rate, e, is always defined as dollars per euro, hence e going up in response to surprise ECB tightening is an appreciation of the euro (as expected) but the same happening in response to a surprise Fed tightening is a depreciation of the dollar (and is abnormal behavior).

Our data comes from the Euro Area Monetary Policy Eventstudy Database (Altavilla et al.,

2019) and an updated version of the data used in Gürkaynak et al. (2005a). The monetary policy surprise measure is the standard one, often called target surprise, backed out using a short dated interest rate contract, Federal Funds Futures for the US, and Overnight Indexed Swap for the euro area.

Using these surprise measures, we run event study regressions for the US and the euro area to identify the effects of monetary policy surprises on the exchange rate. For the US, we use the percentage change in USD/EUR exchange rate in the 30-minute window around the Fed announcements and the target surprises in the same window. For the euro area, we use intraday changes in 1-month OIS as the Target surprise and percentage change in USD/EUR exchange rates around the monetary event window, which covers both the press release by the ECB and the press conference by the ECB governor. Sample periods for the event studies are from 1994-2018 for the US and 1999-2018 for the euro area.

The estimates of basic event study regressions are given in Table 1. Surprise tightening in the US appreciates dollar against euro, whereas surprise tightening in the euro area appreciates euro against the dollar (although the effect is not statistically significant in this sample). This is as expected. However, even when the responses are statistically significant, explanatory power of these regressions are very low. Scatter plots presented in Figures 1 and 2 explain why. In these figures, we plot monetary policy action surprises (target) and the associated percentage change in exchange rates. Green dots show the policy dates with the expected sign derived from the event study regression: surprise tightening causes an appreciation of the domestic currency. Even though most policy dates has this covariance, there are many days with the opposite sign: surprise tightening depreciating the domestic currency, which are depicted by red dots. In particular, 35 out of 83 days for the US and 61 out of 146 days for the euro area are days where the sign of the covariance is the opposite of what event study regressions imply.

Figures 1 and 2 show the monetary policy surprises and the exchange rate reactions for the Fed and the ECB in the full sample. Our full sample, also used in the regressions, is still a subset of all policy dates, where we only consider dates where the exchange rate has changed by at least 0.2% and either the immediate policy surprise or the change in year-ahead rates (fourth eurodollar contract-implied rate for the US and one-year OIS rate for the euro area) has changed by at least two basis points. We trim the dates where either the monetary policy surprise or the exchange rate reaction was minuscule because we will count days with "normal" and "abnormal" behavior and do not want to classify dates where nothing really happened. Including these dates would not have changed our analysis but would have cluttered figures

and added noise to the count of days with probable information effects.

The number of abnormal days, where the exchange rate moves in the wrong direction is what motivated Engel and Frankel (1984), and we replicate that finding with 21st century data and using interest rate surprises as the monetary policy stance measure. Figures 3 and 4 display this information in a time series format, making it clear that responses of exchange rates in both directions to the same surprise were present in policy dates before 2009, when the Global Financial Crisis began and policy rates moved to the ELB, and after the crisis was over as well. The abnormal behavior of exchange rates was not an artifact of the crisis and its immediate aftermath.

This is the type of evidence that leads economists to study central bank information effects. Indeed, one can easily think of a setting where inflation is better known by the central bank and policy surprises are informative to the public about that latent variable. Higher than expected policy rates signal higher inflation and depreciation of currency. While the mechanism is plausible, whether it can arise in an internally consistent model requires using such a model.

4 The Model

To study the extent to which exchange rate behavior is abnormal on some days and why this may be so, we will use what is now a standard model in open economy macroeconomics. The Clarida et al. (2002) model is the two country open economy variant of Clarida et al. (1999) and is a well studied, canonical framework. We first provide a very brief overview of the model in its standard full information form, emphasizing the aspects that are important for the discussion to follow.

4.1 Model Under Full Information

This is a two-country open economy New Keynesian model that in contrast to small open economy models such as Gali and Monacelli (2005) countries' decisions have effects on global variables. We use this setting to model the EU and the US, with possible spillover effects of policy decisions.

The model, the way we employ it, has producer currency pricing and complete pass-through of exchange rates to domestic prices. Calvo pricing generates nominal price rigidities in both countries and the law of one price holds, implying purchasing power parity (PPP). On the financial side, there are complete markets (i.e., a complete set of Arrow-Debreu securities), which brings perfect international consumption risk-sharing ($C_t = C_t^*$ for all t where * means

a foreign variable or parameter). Complete markets also make uncovered interest parity (UIP) hold. Labor, which is the sole input for intermediate goods production, is immobile across two countries.

It is useful to remember that this model is built on the closed economy New Keynesian model of Clarida et al. (1999) so insights from that well known closed economy model continue to apply. CGG themselves used this open economy variant to study optimal discretionary monetary policy with and without international cooperation. Our interest is elsewhere and we will not be asking optimal policy questions. We refer to two countries as domestic (US) and foreign (EA) and use the model to study the two economies jointly.

The model, after the optimization problem of households and firms are solved, market clearing conditions are imposed on the first order conditions, and the resulting equations are linearized, consists of two structural equations and a monetary policy rule. Of the structural equations, the IS curve is obtained from the utility maximization of households and the Phillips curve from the profit maximization of firms.

The IS relationship is

$$\tilde{y}_t = \tilde{y}_{t+1} - \frac{1}{\sigma_0}[r_t - E_t\{\pi_{t+1}\} - \bar{rr}_t]$$

where $\tilde{y}$ is output gap, r is the nominal interest rate, π is domestic price inflation, and $\bar{rr}$ is the natural rate of interest given by

$$\bar{rr}_t = \sigma_0 E_t\{\triangle \bar{y}_{t+1}\} + \kappa_0 E_t\{\triangle y^*_{t+1}\},$$

with $\bar{y}$ the natural level of output of the form

$$\bar{y}_t = \frac{1}{\kappa}[(1+\phi)a_t - \kappa_0 y^*_t],$$

and a the aggregate productivity that follows

$$a_t = \rho_a a_{t-1} + \varepsilon^a_t.$$

ε^a is a white noise productivity shock with variance σ^2_a. $\sigma_0 = \sigma - \kappa_0$ where $\kappa_0 = \gamma(\sigma - 1)$, $1/\sigma$ is the intertemporal elasticity of substitution of consumption, and $\gamma \in [0, 1]$ is the country size. We assume that the countries are of equal size ($\gamma = 0.5$). Finally, ϕ is the inverse Frisch elasticity of labor supply and $\kappa = \sigma + \phi - \kappa_0$.

Note that the IS equation has a knife-edge property: if $\sigma = 1$, international spillovers disappear from the equation (because $\kappa_0 = 0$ and $\sigma_0 = \sigma$) and we are back to the closed-economy IS equation.

The New Keynesian Phillips Curve is

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \lambda \tilde{y}_t + \varepsilon_t^{\pi}$$

where ε^{π} is a white noise inflation shock with variance σ_{π}^2, β is the time discount factor, $\lambda = \delta\kappa$ with $\delta = (1-\theta)(1-\beta\theta)/\theta$, and θ is the Calvo pricing parameter. Note that when $\sigma = 1$, the slope is identical to that of the closed economy New Keynesian Phillips curve.

The inspection of these structural equations shows that σ is the parameter that governs international spillovers in the model. The estimate of this parameter informs the existence and the direction of international spillovers in the data, an issue we will turn to below.

The monetary policy rule closes the model. We will introduce partial information to the model by making various subsets of the variables on the right-hand-side of the interest rate rule unobservable. The rule is of the form

$$r_t = \rho_r r_{t-1} + (1-\rho_r)(\bar{rr}_t + \bar{\pi}_t + \phi_{\pi}(\pi_t - \bar{\pi}_t) + \phi_{\tilde{y}}\tilde{y}_t) + \varepsilon_t^r$$

where ε^r is a white noise interest rate shock with variance σ_r^2 and $\bar{\pi}$ is the inflation target that follows

$$\bar{\pi}_t = (1-\rho_{\bar{\pi}})\bar{\pi} + \rho_{\bar{\pi}}\bar{\pi}_{t-1} + \varepsilon_t^{\bar{\pi}}$$

where $\varepsilon^{\bar{\pi}}$ is a white noise inflation target shock with the variance $\sigma_{\bar{\pi}}^2$. We set the long-run inflation target $\bar{\pi} = 0$ to avoid a further complication by trend inflation.

We have an analogous set of equations for the foreign economy whose variables and parameters are indexed by *. They are not shown here in the interest of space. Obviously, given the symmetry, it is irrelevant which country is home and which is foreign.

Because the nominal exchange rate is not stationary under the interest rate rule above, we do not include it as part of the rational expectations system to be solved. It still can be backed out using the consumer price index, the goods market clearing conditions, and the purchasing power parity, which is what we do here. One option for ensuring stationarity of the nominal exchange rate is optimal monetary policy under commitment which links the domestic price inflation to the change in output gap over time. This form of stabilization also makes the domestic price level and the nominal exchange rate stationary but we estimate the policy rule

under asymmetric information and cannot impose the optimal rule. Another option, which is rather trivial, is a fixed exchange rate, which would not have helped the model match the eventstudy evidence had we assumed it.

Note that this is equivalently a model where one state variable (or equivalently a shock in case of exogenous state variable) is not currently observed by the private sector. Because the endogenous variables on the right-hand-side of the interest rate rule are functions of all state variables, it is always possible to back out a single missing state variable by inverting the interest rate rule conditional on the nominal interest rate and the observed state variables. This assumes that the information set of the central bank is at least as large as the the private sector's and contains all relevant variables required for the unique inversion. See Ellingsen and Soderstrom (2001) and Lee (forthcoming) for the exposition of this idea.

We are used to thinking of the unobserved variable as the monetary policy shock, which is "revealed" when the interest rate is observed. Under full information, this is the eventstudy monetary policy surprise, and is also the VAR monetary policy shock. However, one can equivalently think of a world where the monetary policy shock is known (or is known to be zero at all times) but, say, inflation shock is not observed. Then, when monetary policy is announced, we will still observe a surprise in the eventstudy sense, but the information revealed is not ε_t^r but ε_t^π. In the model/VAR interpretation, market participants have learned the realization of the inflation shock and asset prices will respond accordingly.

This concludes the description of the model. Two important notes are in order. The first concerns the nominal exchange rate. It is worth repeating that the exchange rate is non-stationary in this setting. It therefore does not enter the system of equations to be solved but can be backed out using the consumer price index, the goods market clearing conditions, and the purchasing power parity.

The second has to do with the yield curve. We can, and do, also back out long term interest rates and a full yield curve assuming expectations hypothesis. We will be interested in changes in yield curves in response to shocks hence need to assume only a weak form of the expectations hypothesis, allowing maturity-specific term premia but will assume away time-varying prices of risk.

To parameterize the model, we estimate 26 parameters using 27 moments of quarterly EA and US real GDP, short-term interest rate, and CPI from 1998 to 2008 using GMM. All moments we use for estimation can be computed analytically for the perfect (full) information model here as well as the partial (asymmetric) information models below.

Table 2 shows the moments in the data and the estimated moments, as well as the parameter

estimates. Note the difference between the estimates of the elasticity of substitution between the US and the euro area. We will see that these being on either side of unity is a result of the full information assumption we impose on the model and that the best fitting model, with partial information, will have elasticities of substitution that are closer and impulse responses more similarly behaved.

With these parameters in hand, Figure 5 shows the standard set of impulse-response functions to monetary policy surprises by the ECB and the Fed. These are all as expected, importantly with the exchange rate appreciating in response to a positive policy rate shock.

To complement these, we provide yield curve responses on impact (with the horizontal axis being maturity rather than response horizon) and the impulse response function for the nominal exchange rate under different one standard deviation shocks, shown in Figure 6. The yield curves are obtained via expectations hypothesis. The first figure is for the EU shocks and the second for the US ones. We observe asymmetries in the yield curve responses to monetary policy shocks: whereas a positive shock in the EU raises yield curves in both the EU and the US, a positive shock in the US raises only the US yield curve and shifts down the EU yield curve (the third rows). This is also the case for inflation shock (the first rows).

These results are driven by the estimates of the inverse elasticity of intertemporal substitution which determine the coefficients of the structural equations presented above ($\sigma = 3.29$ for the US and $\sigma^* = 0.15$ for the EU), numerically illustrating that the inverse elasticity of intertemporal substitution is the key parameter governing international spillovers.

We will not dwell on the longer horizons in the IRFs, our focus will be on the contemporaneous relationships. Under full information, the eventstudy captures the moment the shock is realized and we observe the contemporaneous covariances of variables that react immediately. Those jump variables are the asset prices, in this model the exchange rate and interest rates at various maturities, including the short (policy) rate. This makes it clear why some exchange rate-policy surprise correlations are abnormal from the lens of the model, where the covariance should always have the same sign, a tightening policy shock should always lead to an exchange rate appreciation. In the data, we have seen many policy days where the covariance has the opposite sign. This is where we ask whether changing the information structure in the model helps pin down the mechanism that generates the data we observed.

4.2 The Model Under Asymmetric Information

The full information model is the proper starting point to think of a particular case of information asymmetry. As discussed above, if only one variable is not observed by the public

and known to the central bank, monetary policy will reveal that variable exactly. Hence, the asset price response on the day of policy announcement will be the response to that variable. If only the monetary policy shock were unknown, the response will be to monetary policy. But if there is no genuine monetary policy shock, the only driver of the policy surprise can be the latent (from the public's perspective) variable, which will enter the public information set by the realization of the policy rate. Thus, studying the contemporaneous responses of the short rate and exchange rate to shocks to *other* variables provide guidance on which variable's unobervability to the public may create the abnormal covariances we find in the eventstudies.

It is important to underline that although the model has many variables, its internal consistency limits the combinations of unobservable variables. If the histories and current values of all eight (four in each country) shocks in the model are observable, other model variables will necessarily be known as these can be expressed as functions of the shocks. And if all model variables are observable, these imply the realizations of the shocks. In the final analysis, it is various combinations of these shocks that may need to be inferred, which require shocks and some variables to be unobservable.

We therefore begin by studying the responses of interest rates in the US and euro area, as well as the exchange rate to model defined shocks. If one of these has the desired contemporaneous covariance, consistent with an information effect, we may then ask which information structure in the model may give rise to inference about that shock as a result of monetary policy announcements. The responses of interest rates and the exchange rate are what were shown in Figure 6, hence we turn there again.

Our quest to find model defined shocks that, when realized produce the abnormal covariances we are after, produces good and bad news. The good news is that the effort is successful, we find in the model contemporaneous correlations that would be abnormal had they taken place on monetary policy days. The bad news is that the answer is not unique, there are several variables that produce this result. We will also find below that the non-uniqueness comes in other flavors as well.

This observation is salient. We find that inflation and inflation target are both candidates to match the abnormal behavior of exchange rates in their own right. The contemporaneous covariance produces one moment condition and matching that in a reasonably rich model is possible with a variety mechanisms; the model is under identified given the data. This is an issue for a large part of the literature on central bank information effects, most of which is concerned with a particular contemporaneous covariance, based on eventstudies.

4.3 Estimated asymmetric information models

Estimated parameters of a model with asymmetric information are not the same as the parameters estimated assuming full information and then changing the information structure. Hence, we re-estimate the model under different assumptions about the information structure. This exercise is interesting when multiple variables are unobserved so that there is an inference problem to be solved by the public.

Solving and estimating DSGE models with asymmetric information is a nontrivial task. To solve the model under partial information, we use the solution method of Pearlman et al. (1986). The method adopts the Kalman filter to model expectations formation under partial information. As Svensson and Woodford (2003, 2004) note, the signal extraction problem in a forward-looking model like ours is complicated by the circularity where current forward-looking variables depend on their future expectations, which in turn depend on the estimates of unobservables. But the estimates are dependent on the current forward-looking variables whether they are observed or not. For a linear(ized) model, it is possible to overcome this issue and obtain a unique stable solution. Because we use a Taylor rule to model monetary policy, Pearlman et al.'s method is readily applicable to our setting where the central bank has a larger information set than the private sector (Lee (2019) provides details).

Table 3 gives the fit of various partial information models relative to the perfect information benchmark. We classify the models by which model defined variables are observable, with the other variables and the eight shocks unobservable. Moments and estimated parameter values for the best fitting model and some of the close competitors are presented in Tables 4 and 5. We find that the best-fitting partial information model (where r, π, and $\bar{\pi}$ are observed) fits better than the best-fitting perfect information model.

Using this model, we first ask whether the monetary policy shock alone delivers the abnormal correlation between the nominal interest rate and the nominal exchange rate that we take to be an indication of information effect. It does not, as Figure 7 shows. That is, even in the best fitting partial information model, the monetary policy surprise is informative primarily of the monetary policy shock, not of other latent model variables.

We can still ask whether there is any shock that delivers the abnormal exchange rate behavior. The answer is affirmative. The Figures 8 and 9 show that the inflation shock does indeed produce that behavior, as well as the inflation target shock. In this model, inflation and inflation target shocks both generate the exchange rate and short rate covariance we are after. We learn that if the monetary policy shock were informative about either of these, we

would have seen the abnormal exchange rate behavior generated by the model. One is then tempted to conclude that days of monetary policy announcements where the exchange rate moved in the "wrong" direction must have led the market participants to update their beliefs about something related to inflation, either inflation itself or its target. That conclusion would be premature.

Market participants need not be inferring information about a single shock or variable. Figure 10 shows that joint interest rate and productivity shocks also do the trick. As long as shocks have differential effects on the short rate and the exchange rate, regardless of the direction, there exist combinations of shocks that generate any covariance of the short rate and exchange rate, including the abnormal behavior we are studying. Hence, within the best-fitting model with asymmetric information, there is a wide set of belief updating by the public that can generate the same exchange rate behavior in response to policy surprises.

Two notes are in order. First is that this model, based on estimated parameters, suggests that market participants are *not* updating their beliefs about unobservables in response to monetary policy realizations to an extent that the abnormal behavior arises. This model, with these parameters, does not explain the data we are focusing on. In the model, there is a single type of policy realization and the response to it is always the same.

Second, even if one allows for different signals to be inferred from the same policy surprise over time, lack of identification on what that information is about runs deeper than the discussion above suggests. We have shown that different shocks and shock combinations deliver the same sign of exchange rate response within the best fitting model. That is lack of identification within the model.

There is also lack of identification across models. Models with different information structures also imply similar contemporaneous covariances between the short rate and the exchange rate. Figure 11 shows this for a set of models. Models that are similar to the best fitting one but having information asymmetries for different variables produce the abnormal effects we observe in the data.

We therefore conclude that (a) no model in this family generates the information effect in response to the monetary policy surprise but perhaps they should not anyway as these are the average effects and the standard monetary policy shock may well dominate on average, and (b) neither within nor across models is there identification of the information structure or the shocks that may be generating the abnormal behavior.

The former point has to do with having models with a single regime. Monetary policy cannot sometimes generate one effect and sometimes another in these. But estimating a

regime switching model across regimes that are not smoothly transitioning is likely unfeasible. Thus, we may have to be satisfied with asking whether there is any shock in an asymmetric information model that may be generating the abnormal behavior. In that case we are faced with lack of identification. One moment (one stylized fact) is too easy for these models to match and several models, as well as several (combinations of) shocks within models, indeed do so.

We therefore ask whether we can bring in further moments to discipline the model.

5 Eventstudies: A Deeper Look

This time, rather than only studying the covariance of the policy rate surprise with the exchange rate, we pay attention to covariances of some other asset price reactions as well. In particular, we study the behavior of longer-term interest rates. It is, of course, conceivable to study other asset prices, such as multiple exchange rates, indexed-bonds, stock prices, options, etc. But these do not have ready model counterparts. Note that the model implies a pricing kernel and a law of motion of model variables. Thus, all other asset prices are implied by the model (the model prices a complete set of Arrow-Debreu securities on all dates) but explicitly introducing these into the model and solving and estimating a model with those features has not yet been done. That would be a most welcome exercise.

In the eventstudy, along with the exchange rate, we now focus on the behavior of the policy setting surprise (target) and the forward guidance (Path) surprise, measured by orthogonalizing the one-year rate with target and taking the residual. We also have data and model implications on five-year and ten-year interest rates but the mapping between the data and the model here should be taken with a handful of salt, as the model prices longer-term securities with expectations hypothesis and at those maturities term premia variance is not negligible.

The exercise we are now doing is in the spirit of Cieslak and Schrimpf (2019), who in a paper written for the International Seminar on Macroeconomics, classify policy surprises by the behavior of short rates, long rates, and stock prices. That is a rare paper using multiple asset prices. The multi-asset structure is similar but here we focus on a different set of assets, bringing in the exchange rate and, importantly, try to reconcile the eventstudy with structural model implications.

The variety of monetary policy responses may be due to intrinsic multi-dimensionality in monetary policy announcements. We therefore use the simple target-path decomposition and condition on both types of policy surprises. Table 6 and Figures 12 and 13 show the result

and make it clear that the path surprise is responsible for most of the policy-related signals in this sample, as well as driving the exchange rate responses. The binding ELB and associated forward guidance is one reason but even before that, policy makers had become skilled at signaling the forthcoming policy action and genuine target surprises were few and far between. Path surprises were always prevalent in this period, as shown by Figures 14 and 15.

An important finding is that most of the abnormal rates flagged based on the target surprise are no longer abnormal for the US when conditioning on the path surprise. The number of abnormal exchange rate reaction dates decline by a half and the remaining ones are days of smaller asset price movements. In the euro area, the number of abnormal reaction dates decline a little. We note the difference between the euro area and the US in this regard but leave proper study of the reason to further work. An interesting observation is the presence of days when neither the target nor the path surprise correlate with the exchange rate reaction in the normal way, both in the US and in the euro area. Whatever information effects there may be, they do not manifest themselves completely in the perceived forward guidance. This is consistent with Cieslak and Schrimpf (2019), who found a separate role for stock prices after controlling for the short and long-ends of the yield curve.

We will look more carefully into a few selected dates to give a sense of the policy communication and financial press interpretation but before doing so should highlight an important point. From an information asymmetry perspective, path surprises themselves are likely results of central bank information revelation (Delphic surprises) and finding exchange rate correlations with these that accord with standard full information models do not constitute evidence against asymmetric information. That finding perhaps puts more discipline on the nature of the information structure and the source of shocks, as the year-out interest rates and exchange rates should be moved in opposite directions (for the US), as in the data. We will return to this issue below.

5.1 Selected days of abnormal exchange rate behavior

Some of the dates with abnormal exchange rate reactions stand out in the figures we have displayed so far. We look at a few of those closely and relay the market commentary associated with the observed exchange rate reactions. We choose days that are abnormal when the surprise is measured by the target factor and discuss dates when the path factor "explains" the exchange rate (although path itself may be an artifact of information revelation) and dates when the exchange rate movement is abnormal regardless of which measure of policy surprise is used. Note that such dates are actually very rare in the US.

5.1.1 Discussion of Selected US Information Days

- May 17, 1994 (Target Surprise = 11 bps, Path Surprise = - 10.9 bps, US Dollar depreciates):

  Fed increased policy rates by 50 basis points. In the monetary policy statement, the FOMC wrote "These actions, combined with the three adjustments initiated earlier this year by the FOMC, substantially remove the degree of monetary accommodation which prevailed throughout 1993" and "it has achieved a 'neutral' interest-rate policy with this latest action." The statement was interpreted as "not a finality but a pause" in rate hikes by Stephen Axilrod, vice Chairman of Nikko Securities and Co. and a former Fed staffer (Fed Raises Discount and Funds Rates; Stops for Now (Update2), Bloomberg, May 17, 1994). "A bolder move would let investors to think that the Fed is getting even more determined to preempt inflation Michael Link [a fund manager] said. 'I think people will say, this is putting a spike in the heart of the vampire."' (US Bonds Surge After the Fed Raises Rates by 1/2 Point, Bloomberg May 17, 1994).

  Note that the exchange rate depreciation on this policy date, given the commentary, can be explained by the path surprise. (Although path itself is likely due to an information effect.) Investors are surprised by the action, since they were expecting further tightening in the future. Fed's statement about achieving "neutral" interest rate, resulted with a negative path surprise, which leads depreciation in the US dollar because i) investors think that this increase is not enough to preempt inflation and ii) lower interest rates imply depreciation in local currency through uncovered interest parity.

- June 30, 1999 (Target Surprise = -3 bps, Path Surprise = -9.45, Dollar appreciates)

  Note that this is a different policy date than the one discussed previously (and is different from the ones that will follow). All other dates in this subsection are the policy dates where the exchange movements can be reconciled with the path surprise but not with the target surprise. However, this policy date cannot be reconciled by either.

  On June 30, 1999, the Fed raised interest rates by 25 basis points, which was largely expected by the market participants (small target surprise). "But the central bank indicated its tiny quarter point increase may be all that is needed to keep inflation under control... The Fed said in a statement that it felt the need to be 'especially alert to the emergence, or potential emergence, of inflationary forces that could undermine economic growth.' But at the same time, the Fed indicated that it was moving its policy directive,

which signals the future course of interest rates, back to neutral...'The message from the Fed is that they are not in any big hurry nor particularly worried that quick action is necessary on inflation front. The markets are relieved that because the central bank could have been a lot tougher', said Allen Sinai, chief economist at Primark Global Economics in New York." (Fed. Reserve Raises Interest Rates, Bloomberg, June 30, 1999).

Fed's statement about neutral rates implied a negative path surprise, since the investors were expecting higher interest rates in the future due to inflationary forces. According to the commentary "[Fed] removed its tilt, or bias, toward higher rates. That bias change was a surprise to most investors and 'gives the market room to rally," said David Brownlee, head of fixed income at Sentinel Advisor Co." (U.S. Bonds Surge as Fed Hints at Limited Rate Rises (Update1), Bloomberg, June 30, 1999).

- March 20, 2001 (Target surprise = 7 bps, Path Surprise = -11 bps, Dollar depreciates)

  The Fed cuts policy rates by 50 basis points and signaled another rate cut could come in an intermeeting move (U.S. Bonds Rise After Fed Cuts Rates a Half-Point to 5 Percent, Bloomberg, March 20, 2001). In the statement, "policy makers cited falling stocks, a slump in manufacturing and 'weakness in global economic conditions' as the reasons for their decisions to lower rates by 50 basis points." Fed adds in it's statement that "In these circumstances, when the economic situation could be evolving rapidly, the Federal Reserve will need to monitor developments closely." The last comment made analysts forecast another cut in the next meeting, or even before then, if need be. "This reads like they are more scared than they have been willing to admit, and that they are ready to cut rates further – maybe soon." said Ian Shepherson, chief US economist at High Frequency Economics Ltd. in Valhalla, New York. (U.S. Bonds Rise After Fed Cuts Rates a Half-Point to 5 Percent, Bloomberg, March 20, 2001)

  Given the interpretation, depreciation in dollar is consistent with weakening in future economic fundamentals as well as lower interest rates this weakening warrants. Even though the Fed should have cut rates more according to the market participants (positive target surprise), Fed being more cautious then what is expected from analysts implies a negative path surprise with the following depreciation.

- January 27, 2010 (Target Surprise = -0.5 bps, Path Surprise = 7.39 bps, US Dollar appreciates)

  This is a policy date with a very low target surprise, but large path surprise. The Fed did

not change policy rate, with one member of the committee dissenting on the decision. The Fed statement said "With substantial resource slack continuing to restrain cost pressures with long-term inflation expectations stable, inflation is likely to be subdued for some time." Kansas City Fed President Hoeing "believed that economic and financial conditions had changed sufficiently that the expectation of exceptionally low levels of the federal funds rate for an extended period was no longer warranted." The dissent was of particular interest to the market participants. "The dissent from Hoeing was a big boost for dollar. There is a good chance there are other officials who are less dovish as well." said Kathy Lien, director of currency research at the online currency GFT Forex in New York (Dollar Climbs to Six-Month High Against Euro on Fed Dissent, Bloomberg, January 27, 2010).

5.1.2 Discussion of Selected Euro Area Information Days

- October 7, 1999 (Target surprise = -17 bps, Path Surprise = 5 bps, Euro appreciates)

  The ECB kept the policy rate unchanged, however Euro appreciated on speculation the ECB might raise its benchmark lending soon. ECB president said at a news conference that with the economic outlook improving "we have to adopt and to have a monetary policy stance which is conducive to sustainable, non-inflationary growth." Stephen Gallagher, an economist at Societe Generale said, "People are more optimistic on European growth prospects going into 2000. Eventually the ECB is going to push to start raising rates. The euro has found and held support." (Euro Gains on Speculation ECB May Raise Rates in Months Ahead, Bloomberg, October 7, 1999).

- December 6, 2001 (Target Surprise = -1.25 bps, Path Surprise = 6.24, Euro appreciates)

  The ECB left its benchmark interest rate unchanged, which was a move largely expected by the market (small target surprise). "The central bank has been trying to bring inflation below its 2 percent ceiling, and the failure to cut may be taken by some investors as evidence the ECB isn't doing enough to bolster the region's economy. 'The euro may come off as the ECB will be perceived as being anti-growth,' said Michael Turner from Edinburgh Fund Managers. Stefan Bergheim, an economist at J.P. Morgan said 'The press conference did not give the impression a new rate cut is just around the corner.' " (Euro Little Changed After ECB Leaves Benchmark Rate Unchanged, Bloomberg, December 6, 2001).

  Even though there is a small target surprise, the large path surprise indicate that the

European economy is recovering implying higher inflation in the future. Higher expected interest rates due to higher expected inflation appreciates euro against dollar.

- April 11, 2001 (Target Surprise = 17 bps, Path surprise = 5.27 bps, Euro depreciates)

  This is an example for a policy date where the exchange rate movements cannot be reconciled either with target surprise nor with the path surprise.

  On April 11, 2001, the ECB left interest rates unchanged, which depreciated the euro. "Even though the ECB was projecting itself for a no change, some people were positioning themselves for a cut and when it didn't go through, the euro had a pretty sharp reaction. I think the market is pretty bearish in the short term as every one wanted ECB to cut, which would have helped (the euro)" said Andrew Delano, currency analyst at IDEAglobal (Euro Falls Then Recovers, Bloomberg, April 11, 2001). The reason why the analysts were expecting a cut was because of a global slowdown. "For them to not even cut rates amid this global slowdown is seen as disappointing," said Tim Mazanec, chief currency strategist at Investors Bank and Trust in Boston. "The ECB once again disappointed the markets, so the euro went down. Right now, the market favors those currencies whose central banks have shown a willingness to cut rates and spur growth," said Ben Strauss, a trader at Julius Baer. The ECB point to the risk of inflation to defend their position. (Euro Falls vs Dollar, Yen After ECB Leaves Key Rate Unchanged, Bloomberg, April 11, 2001).

- June 5, 2008 (Target Surprise = -0.1 bps, Path Surprise = 20 bps, Euro appreciates)

  The ECB left interest rates unchanged, but Trichet said an "interest rate increase in the next meeting is 'possible' ". He said policy makers are in a state of "hightened alertness" over inflation. " 'Trichet's comments were interpreted as more hawkish than expected. We don't expect the Fed to hike anytime soon, so there's still a substantial interest-rate advantage for the euro.' said Marcus Hettinger, a currency strategist in Zurich at Credit Suisse Group. The ECB has cited accelerating inflation as a reason for not cutting rates as the US economic slowdown spread to Europe."

- October 8, 2008 (Target surprise = -20 bps, Path Surprise = 11 bps, Euro appreciates)

  The ECB cut interest rates by 50 basis points, in a coordinated move with other countries. Trichet did not signal more rate cuts, but did not rule them out either. He said "I have no particular signal on that. I don't say that this was a one off cut. I say that we will always do whatever is necessary." ECB Council member Ewald Nowotny said "today's

> move should not be seen as a first step in possible series. The new level of rates will ensure that inflation expectations remain anchored and the situation has to be assessed as we go along." While inflation slowed to 3.6 percent,... it remains above the ECB's 2 percent limit. (ECB Cuts Rates in Coordinated Battle Against Crunch (Update5), Bloomberg, October 8, 2008)

This in depth look at some of the events, the central bank statements and associated financial press write ups, shows that there are many shades of possible information effects. It is particularly difficult to distinguish between Delphic and Odyssean forward guidance by reading the central bank statements and the financial press mostly focuses on rationalizing the asset price reactions. Nonetheless, it is clear that, when it comes to asset price movements that are not explained by the target surprise, a significant share of of these are "explained" by the path surprise, which suggests the same information revelation by the central bank affects different markets similarly. But path by itself is still not sufficient to capture all the different ways exchange rates move in response to monetary policy surprises, especially in the euro area.

6 Back to the Model

The broad contours of the asset price responses reported above do not conform to any of the models we studied so far. Neither the full information model nor any model with a single unobserved variable (as well as the monetary policy shock) produced the contemporaneous covariances that we so often see. Looking at multiple moments, those created by target, path, and the exchange rate, we find that there are even more types of reactions in the data. Replicating the variety of covariances is impossible for a model with a single covariance structure by construction.

The effort in estimating these models with rich information structures is not in vain, however. Although the monetary policy surprise does not generate the responses seen in the eventstudies, different shocks in that model do generate various aspects of the responses. For example, an inflation target shock moves the long end of the local yield curve while an output shock moves the exchange rate in many of the models. This suggests that joint inference about these variables may help explain some of the eventstudy findings.

In the figures we have seen so far, the impulse response of the short rate never changes sign strongly with in the year. That is what target and path surprises having opposite signs is, and the model does not have much of that behavior. That is, in the data path surprises may help explain the exchange rate behavior but in the model, getting the path surprise

to move in the opposite direction of the target surprise is not easy. This would obviously happen with Odyssean forward guidance shocks, which are not present in this model but those put the information story aside, and do not help address the dates when the exchange rate movement is abnormal when policy is judged by both target and path surprises. Although the central bank information literature is built on our theoretical understanding of how asset prices should respond to monetary policy and other shocks, the family of models we employed neither uniquely nor completely fit the eventstudies we have looked at.

In making this assessment, it is important to remember that a particularly pertinent type of information asymmetry is not present here, that of central bank preferences (other than the inflation target). The only preference that can be unobserved by the public and would have repercussions on asset prices in the model is the inflation target. This is an artifact of the solution algorithm that uses local approximations at the steady state, which makes the policy smoothing parameter and relative weights of inflation versus output gap stabilization vanish. Bringing those in for open economy models is clearly a fruitful avenue of further research.

We do not see our findings as negative results. No one will be surprised that we are having difficulty understanding exchange rate movements, in any window, conditional on any event. We also know that the world is more complicated than any model can and should be. But the model we employed, a canonical open economy model, helped us put exchange rate responses to monetary policy in perspective and see which lines of argument are internally consistent, which are identified, where we are falling short.

The literature on central bank information effects offer information-based explanations with reference to standard models, often without specifying those models, seldom asking whether the information story being presented is the only one that is consistent with the data even within a particular model, and even more seldom asking what the implications of other asset prices may be. Macroeconomic models are helpful when they are properly specified and confronted with ample moments in the data. The literature has moved in that direction for the purpose of analyzing real macroeconomic variables–with the CGG model analyzed here a great example of that–it is time that we do the same for financial ones.

7 Conclusion

We find that asset price anomalies, from the perspective of standard models, that arise in eventstudies and motivate the literature on central bank information effects are present in exchange rates as well. These exchange rate abnormalities are common. They are also easy to

explain with asymmetric information models, where the public infers the realization of some variables from the central bank's policy decision. In fact, fitting that one moment, the "wrong" covariance of exchange rate changes and monetary policy surprises turns out to be too easy, with many information structures producing the same effect.

Bringing in more moments from eventstudies, we find that target and path surprises and exchange rate responses to these surprises are heterogeneous, and no model with a single regime can match the data. The responses are not temporally smoothly transitioning either, so regime switching models will require high regime transition parameters and will not be very amenable to estimation.

The best fitting model to the macro data is an asymmetric information model. But the model implied asset price responses to monetary policy surprises in the open economy are not those that are observed in the eventstudies. Estimating a two country open economy model with information asymmetries that helps analyze exchange rates and yield curves is a major undertaking. Having done this, we find that with a single moment from the eventstudy to match, the model is under-identified and with multiple moments finding a model that fits all moments simultaneously is not easy. We do have a way to go in reconciling eventstudy data in monetary policy release windows with model-based mechanisms of asset pricing based on macroeconomic dynamics.

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Tables and Figures

	USD/EUR	USD/EUR
Target Surp. (US)	-0.02^{***}	
	(0.007)	
Target Surp. (EA)		0.01
		(0.01)
R^2	0.1	0.01
N	83	146

Table 1: Event study regressions for the US and the euro area. Robust standard errors are in the parenthesis. Sample for the US is 1994-2018 and for the euro area is 1999-2018.

Moments	Data Moments	Model Moments	Parameters	Explanations	Values
SD of Interest Rate (EA)	0.009	0.003	β	Discount Factor (US)	0.999
SD of Interest Rate (US)	0.018	0.001	σ	Inv. Elast. of Sub. (US)	3.291
SD of RGDP (EA)	0.009	0.009	ϕ	Inv. Frisch Elast. (US)	5.000
SD of RGDP (US)	0.009	0.011	θ	Calvo Pricing Fric. (US)	0.698
SD of Inflation (EA)	0.004	0.004	ρ_a	Pers. of TFP (US)	0.999
SD of Inflation (US)	0.008	0.009	ρ_r	Coef. on Lagged Int. (US)	0.841
Corr of EA and US Interest Rate	0.519	0.136	ϕ_π	Coef. on Inf. (US)	2.500
Corr of EU Interest Rate and RGDP	0.764	-0.073	$\phi_{\tilde{y}}$	Coef. on OG (US)	0.788
Corr of EA Interest Rate and US RGDP	0.140	0.096	$\rho_{\bar{\pi}}$	Pers. of Inf. Targ. (US)	0.602
Corr of EA Interest Rate and Inflation	0.347	0.355	β^*	Discount Factor (EA)	0.988
Corr of EA Interest Rate and US Inflation	0.173	0.170	σ^*	Inv. Elast. of Sub. (EA)	0.150
Corr of US Interest Rate and EU RGDP	0.439	-0.054	ϕ^*	Inv. Frisch Elast. (EA)	1.272
Corr of US Interest Rate and RGDP	0.681	0.075	θ^*	Calvo Pricing Fric. (EA)	0.479
Corr of US Interest Rate and EU Inflation	-0.198	-0.182	ρ_{a^*}	Pers. of TFP (EA)	0.999
Corr of US Interest Rate and Inflation	0.223	0.281	ρ_{r^*}	Coef. on Lagged Int. (EA)	0.136
Corr of EA and US RGDP	0.391	0.146	ϕ_{π^*}	Coef. on Inf. (EA)	2.266
Corr of EA RGDP and Inflation	0.176	0.190	$\phi_{\tilde{y}^*}$	Coef. on OG (EA)	1.493
Corr of EA RGDP and US Inflation	0.087	0.112	$\rho_{\bar{\pi}^*}$	Pers. of Inf. Targ. (EA)	0.908
Corr of US RGDP and EA Inflation	-0.104	-0.045	σ_π	SD of PC Shock (US)	1.138×10^{-6}
Corr of US RGDP and Inflation	0.365	0.396	σ_a	SD of TFP Shock (US)	6.590×10^{-4}
Corr of EA and US Inflation	0.612	-0.001	σ_r	SD of Int. Shock (US)	1.854×10^{-3}
First Order Autocorr of EA Interest Rate	0.944	0.693	$\sigma_{\bar{\pi}}$	SD of Inf. Targ. Shock (US)	0.013
First Order Autocorr of US Interest Rate	0.952	0.527	$\sigma_{\pi*}$	SD of PC Shock (EA)	2.188×10^{-4}
First Order Autocorr of EA RGDP	0.884	0.931	σ_{a*}	SD of TFP Shock (EA)	1.624×10^{-4}
First Order Autocorr of US RGDP	0.825	0.920	σ_{r*}	SD of Int. Shock (EA)	9.679×10^{-3}
First Order Autocorr of EA Inflation	0.669	0.541	$\sigma_{\bar{\pi}*}$	SD of Inf. Targ. Shock (EA)	1.585×10^{-3}
First Order Autocorr of US Inflation	0.485	0.553	γ	Relative Country Size	0.5
			$\bar{\pi}$	Long-run Inf. Target (US)	0
			$\bar{\pi}^*$	Long-run Inf. Target (EA)	0

Table 2: Data moments and perfect information model moments and parameters. The last three parameters are fixed.

	r	r, π	r, π, $\bar{\pi}$	r, π, $\bar{rr}$	r, π, $\bar{\pi}$, $\bar{rr}$	r, π, $\bar{rr}$, $\tilde{y}$	Perfect Info
Ratio	1.18	0.98	0.88	0.96	1.06	1.03	1

Table 3: Fit of the model to the data (relative to the perfect information model). The variables in the columns of the first row (from the second to the last one) apply to both the euro area and the US. For instance, the second column is an information structure where both r and r^* are observed by the private sectors in both economies.

Param	Explanation	Perfect	r	r, π	$r, \pi, \bar{\pi}$	$r, \pi, \bar{rr}$	$r, \pi, \bar{\pi}, \bar{rr}$	$r, \pi, \bar{rr}, \tilde{y}$
β	Discount Factor (US)	0.999	0.980	0.980	0.980	0.999	0.980	0.999
σ	Inv. Elast. of Sub. (US)	3.291	2.136	3.273	0.747	0.200	3.321	2.496
ϕ	Inv. Frisch Elast. (US)	5.000	5.000	5.000	5.000	0.200	5.000	5.000
θ	Calvo Pricing Fric. (US)	0.698	0.159	0.650	0.858	0.380	0.662	0.686
ρ_a	Pers. of TFP (US)	0.999	0.955	0.999	0.999	0.999	0.999	0.999
ρ_r	Coef. on Lagged Int. (US)	0.841	0.846	0.873	0.996	0.984	0.906	0.938
ϕ_π	Coef. on Inf. (US)	2.500	1.091	2.500	1.554	1.876	2.500	2.400
$\phi_{\tilde{y}}$	Coef. on OG (US)	0.788	1.063	0.015	1.500	8.956×10^{-3}	1.492	0.676
$\rho_{\bar{\pi}}$	Pers. of Inf. Targ. (US)	0.602	0.978	0.781	0.869	0.902	0.813	0.817
β^*	Discount Factor (EA)	0.988	0.999	0.981	0.988	0.980	0.991	0.999
σ^*	Inv. Elast. of Sub. (EA)	0.150	1.056	0.150	0.183	0.357	0.153	0.154
ϕ^*	Inv. Frisch Elast. (EA)	1.272	5.000	0.746	2.450	4.989	0.871	1.026
θ^*	Calvo Pricing Fric. (EA)	0.479	0.773	0.483	0.565	0.493	0.481	0.536
ρ_{a^*}	Pers. of TFP (EA)	0.999	0.998	0.998	0.977	0.975	0.993	0.992
ρ_{r^*}	Coef. on Lagged Int. (EA)	0.136	0.813	0.192	0.687	0.941	0.014	0.614
ϕ_{π^*}	Coef. on Inf. (EA)	2.266	2.500	2.496	1.000	1.054	2.320	1.530
$\phi_{\tilde{y}^*}$	Coef. on OG (EA)	1.493	0.091	1.499	0.667	0.992	0.099	1.500
$\rho_{\bar{\pi}^*}$	Pers. of Inf. Targ. (EA)	0.908	0.794	0.968	0.999	0.963	0.848	0.949
σ_π	SD of PC Shock (US)	1.138×10^{-6}	2.166×10^{-4}	4.854×10^{-5}	5.958×10^{-3}	1.466×10^{-5}	5.031×10^{-9}	7.887×10^{-8}
σ_a	SD of TFP Shock (US)	6.590×10^{-4}	2.606×10^{-3}	9.805×10^{-5}	2.766×10^{-4}	1.046×10^{-4}	4.169×10^{-7}	3.030×10^{-4}
σ_r	SD of Int. Shock (US)	1.854×10^{-3}	9.043×10^{-4}	2.194×10^{-3}	5.139×10^{-5}	4.332×10^{-5}	2.784×10^{-3}	1.021×10^{-3}
$\sigma_{\bar{\pi}}$	SD of Inf. Targ. Shock (US)	0.013	5.223×10^{-3}	6.001×10^{-3}	0.012	2.642×10^{-3}	5.737×10^{-3}	5.441×10^{-3}
$\sigma_{\pi*}$	SD of PC Shock (EA)	2.188×10^{-4}	3.204×10^{-3}	6.203×10^{-4}	1.069×10^{-3}	8.430×10^{-5}	2.593×10^{-8}	8.559×10^{-6}
σ_{a*}	SD of TFP Shock (EA)	1.624×10^{-4}	6.991×10^{-4}	3.729×10^{-4}	1.414×10^{-3}	1.392×10^{-3}	7.670×10^{-4}	1.003×10^{-3}
σ_{r*}	SD of Int. Shock (EA)	9.679×10^{-3}	6.500×10^{-4}	9.588×10^{-3}	1.799×10^{-3}	1.996×10^{-5}	7.140×10^{-3}	3.903×10^{-3}
$\sigma_{\bar{\pi}*}$	SD of Inf. Targ. Shock (EA)	1.585×10^{-3}	3.061×10^{-3}	9.723×10^{-4}	1.246×10^{-3}	3.610×10^{-3}	2.070×10^{-3}	1.825×10^{-3}
γ	Relative Country Size	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$\bar{\pi}$	Long-run Inf. Target (US)	0	0	0	0	0	0	0
$\bar{\pi}^*$	Long-run Inf. Target (EA)	0	0	0	0	0	0	0

Table 4: Estimated parameters. The top row indicates observables corresponding to different models. The last three parameters are fixed.

Moment	Data	Perfect	r	r, π	$r, \pi, \bar{\pi}$	$r, \pi, \bar{rr}$	$r, \pi, \bar{\pi}, \bar{rr}$	$r, \pi, \bar{rr}, \tilde{y}$
SD of Interest Rate (EA)	0.009	0.003	0.001	0.003	0.002	7.099×10^{-4}	0.003	0.002
SD of Interest Rate (US)	0.018	0.001	0.001	0.002	3.392×10^{-4}	4.923×10^{-4}	0.003	0.001
SD of RGDP (EA)	0.009	0.009	0.012	0.009	0.008	0.007	0.009	0.011
SD of RGDP (US)	0.009	0.011	0.008	0.010	0.013	0.012	0.010	0.010
SD of Inflation (EA)	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.004
SD of Inflation (US)	0.008	0.009	0.006	0.010	0.007	0.008	0.009	0.009
Corr of EA and US Interest Rate	0.519	0.136	0.004	0.072	0.048	0.065	0.024	0.020
Corr of EA Interest Rate and RGDP	0.764	-0.073	-0.046	-0.082	-0.073	0.089	-0.096	-0.058
Corr of EA Interest Rate and US RGDP	0.140	0.096	0.086	0.088	0.170	0.144	0.085	0.089
Corr of EA Interest Rate and Inflation	0.347	0.355	0.386	0.359	0.417	0.410	0.371	0.376
Corr of EA Interest Rate and US Inflation	0.173	0.170	0.175	0.169	0.120	0.171	0.143	0.190
Corr of US Interest Rate and EA RGDP	0.439	-0.054	0.217	-0.037	0.343	0.261	-0.020	0.001
Corr of US Interest Rate and RGDP	0.681	0.075	0.328	0.070	0.331	0.205	0.020	0.074
Corr of US Interest Rate and EA Inflation	-0.198	-0.182	-0.158	-1.161	-0.071	-0.115	-0.071	-0.118
Corr of US Interest Rate and Inflation	0.223	0.281	0.260	0.271	0.324	0.294	0.264	0.277
Corr of EA and US RGDP	0.391	0.146	-0.166	0.181	0.280	0.394	0.176	0.145
Corr of EA RGDP and Inflation	0.176	0.190	0.254	0.213	0.179	0.142	0.219	0.236
Corr of EA RGDP and US Inflation	0.087	0.112	0.092	0.110	0.085	0.092	0.104	0.112
Corr of US RGDP and EA Inflation	-0.104	-0.045	-0.013	-0.055	-0.106	-0.074	-0.057	-0.056
Corr of US RGDP and Inflation	0.365	0.396	0.202	0.335	0.473	0.556	0.331	0.399
Corr of EA and US Inflation	0.612	-0.001	0.161	0.001	-0.093	-0.237	-0.006	-0.011
First Order Autocorr of EA Interest Rate	0.944	0.693	0.513	0.734	0.929	0.957	0.586	0.835
First Order Autocorr of US Interest Rate	0.952	0.527	0.916	0.651	0.967	0.899	0.757	0.712
First Order Autocorr of EA RGDP	0.884	0.931	0.924	0.919	0.908	0.955	0.910	0.926
First Order Autocorr of US RGDP	0.825	0.920	0.954	0.931	0.759	0.788	0.930	0.917
First Order Autocorr of EA Inflation	0.669	0.541	0.534	0.591	0.528	0.341	0.575	0.569
First Order Autocorr of US Inflation	0.485	0.553	0.291	0.523	0.265	0.360	0.547	0.540

Table 5: Moments. The top row indicates observables corresponding to different models.

	USD/EUR	USD/EUR
Target Surp. (US)	-0.02^{***}	
	(0.004)	
Target Surp. (EA)		0.01
		(0.008)
Path Surp. (US)	-0.05^{***}	
	(0.005)	
Path Surp. (EA)		0.06^{***}
		(0.009)
R^2	0.43	0.19
N	83	146

Table 6: Event study regressions with target and path surprises for the US and euro area. Robust standard errors are in the parenthesis. Sample for the US is 1994-2018 and for the euro area is 1999-2018. Construction of path surprises are described in the text.

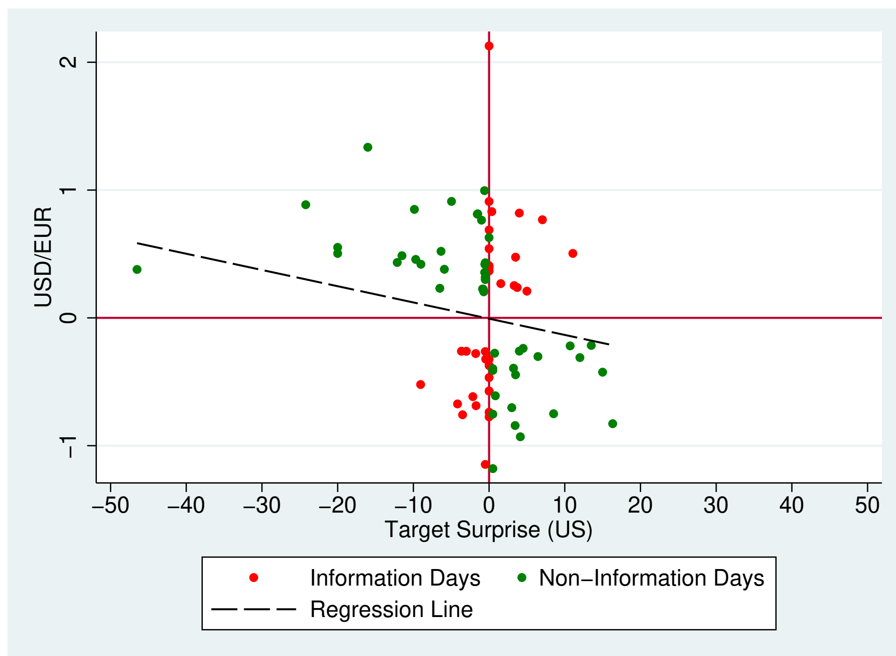

Figure 1: Scatter plot of target surprises and associated changes in USD/EUR exchange rate for the US. The dashed line is the regression line fitted to the data presented in the scatter plot. Sample is from 1994-2018.

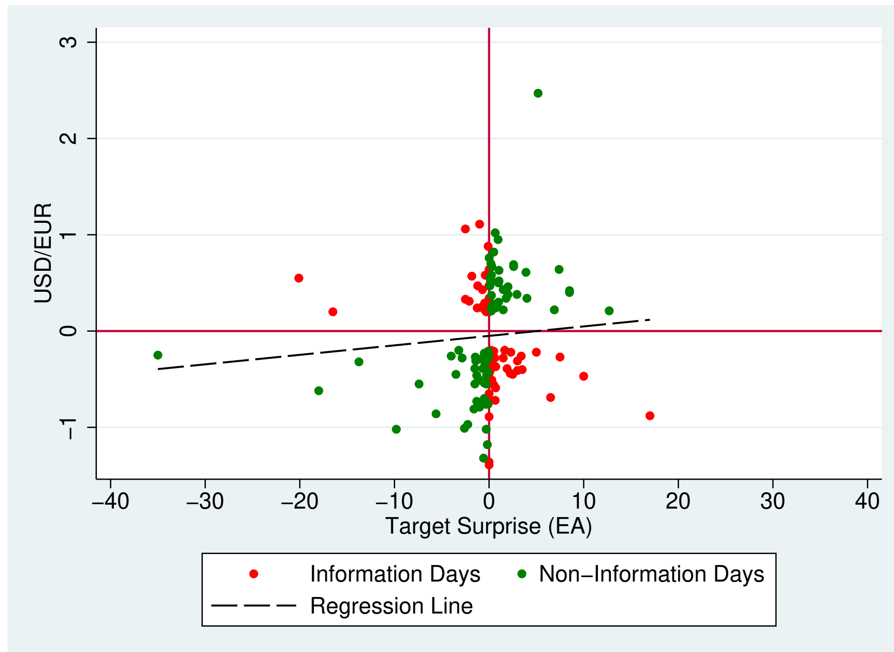

Figure 2: Scatter plot of target surprises and associated changes in USD/EUR exchange rate for the euro area. The dashed line is the regression line fitted to the data presented in the scatter plot. Sample is from 1999-2018.

Figure 3: Bar plot for target surprises and associated changes in USD/EUR exchange rate for the US. Upper panel is for the sample 1994-2007 and the bottom panel is for the sample 2008-2018.

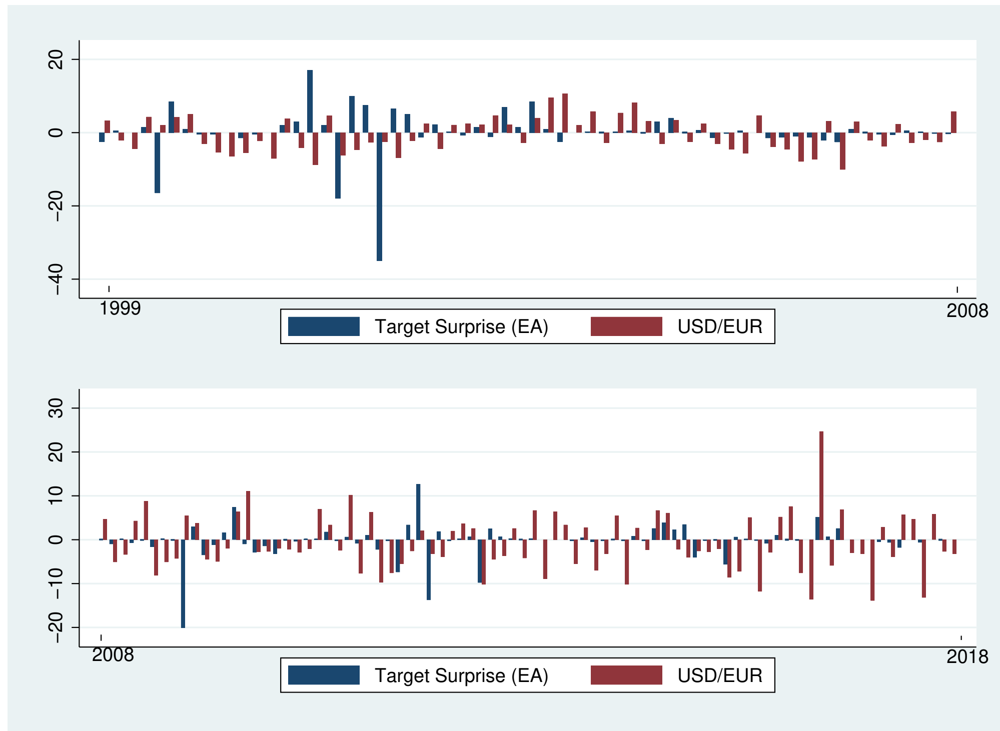

Figure 4: Bar plot for target surprises and associated changes in USD/EUR exchange rate for the euro area. Upper panel is for the sample 1999-2007 and the bottom panel is for the sample 2008-2018.

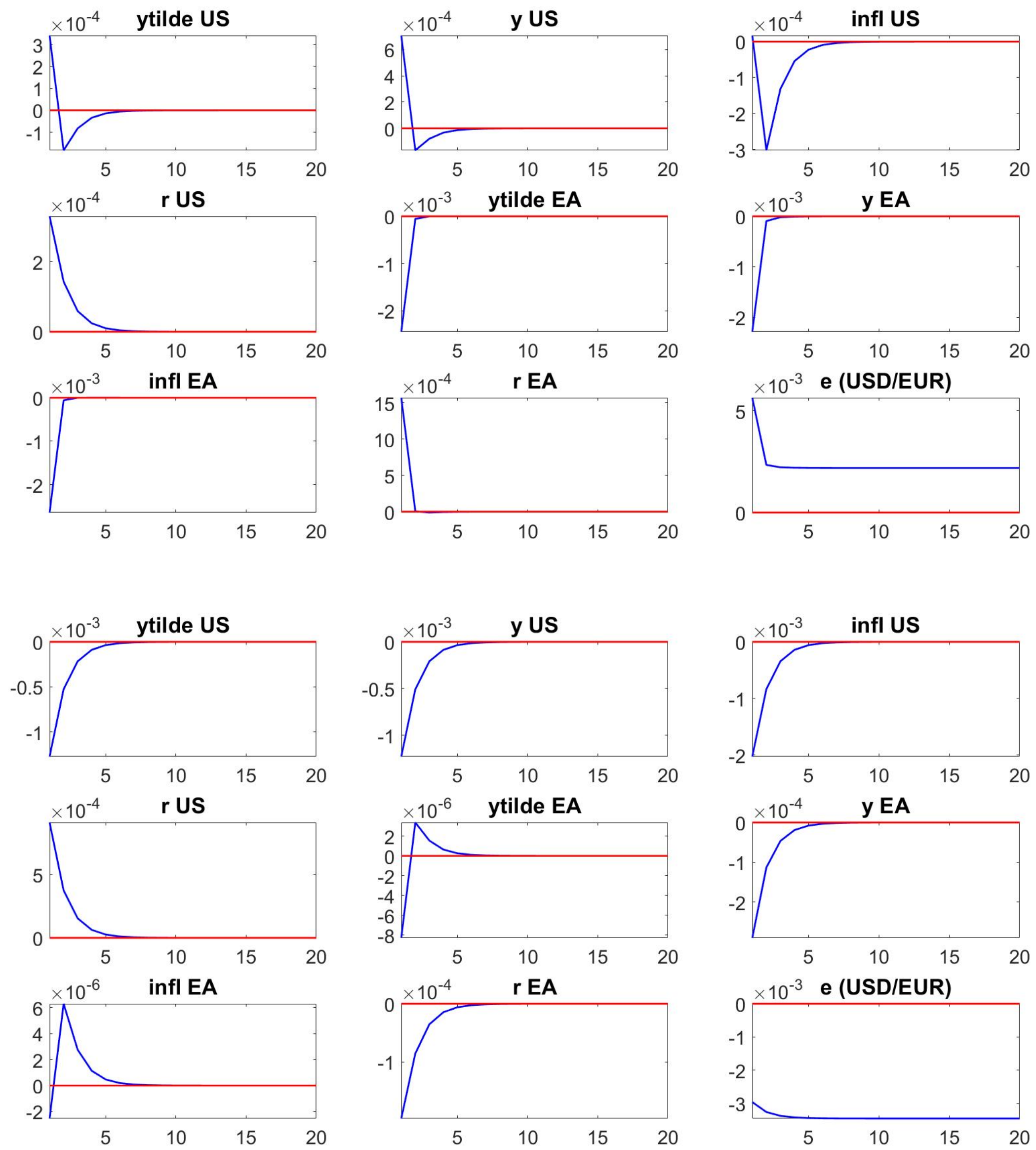

Figure 5: IRFs for one standard deviation monetary policy shock in the EA (upper) and the US (lower)

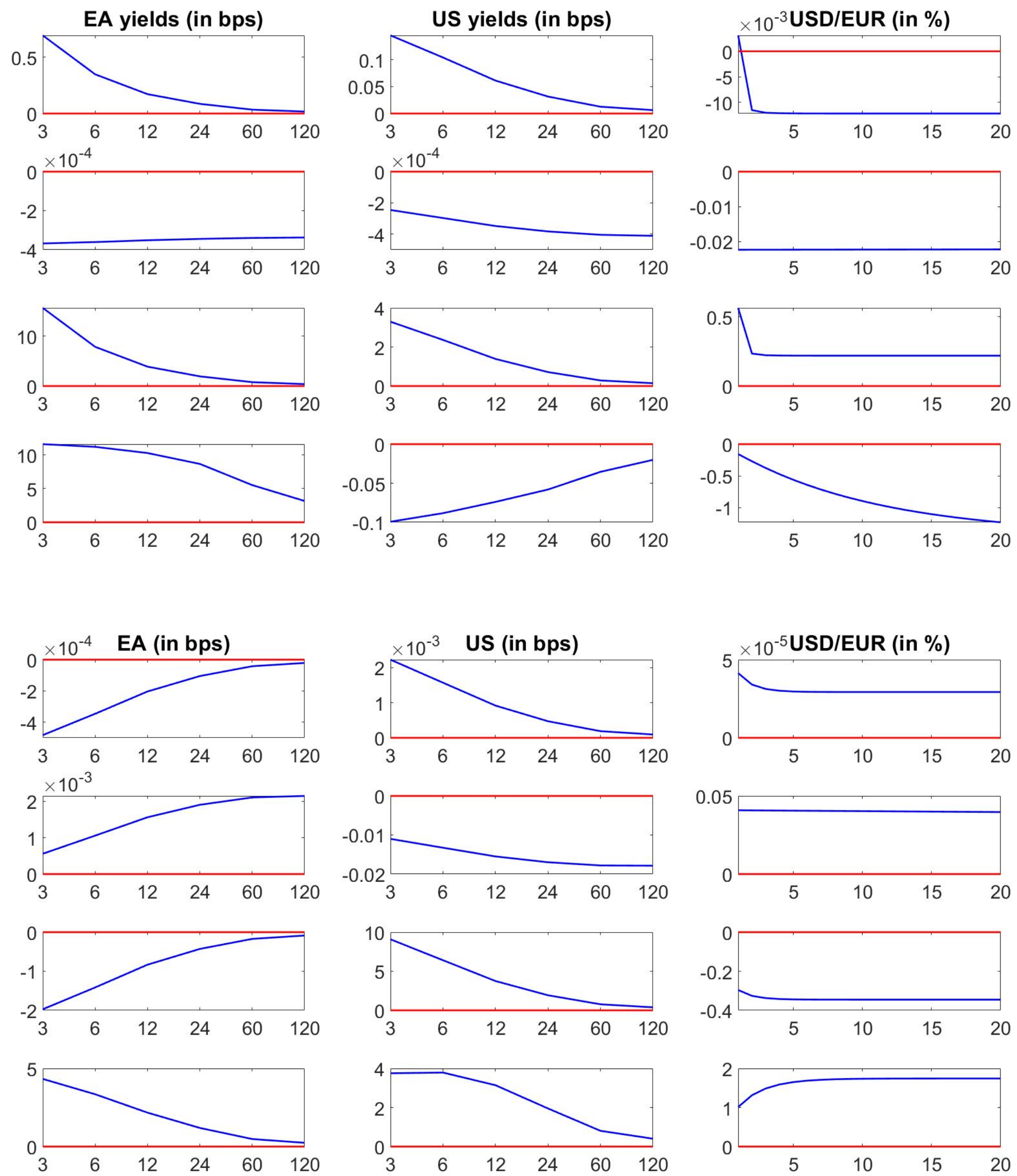

Figure 6: Yield curve responses on impact and IRFs for nominal exchange rate. Upper: first row - EA inflation; second row - EA productivity; third row - EA interest rate; fourth row - EA inflation target. Lower: first row - US inflation; second row - US productivity; third row - US interest rate; fourth row - US inflation target. The horizontal axis for the first two columns gives bond maturities in months. The horizontal axis for the third column gives time periods.

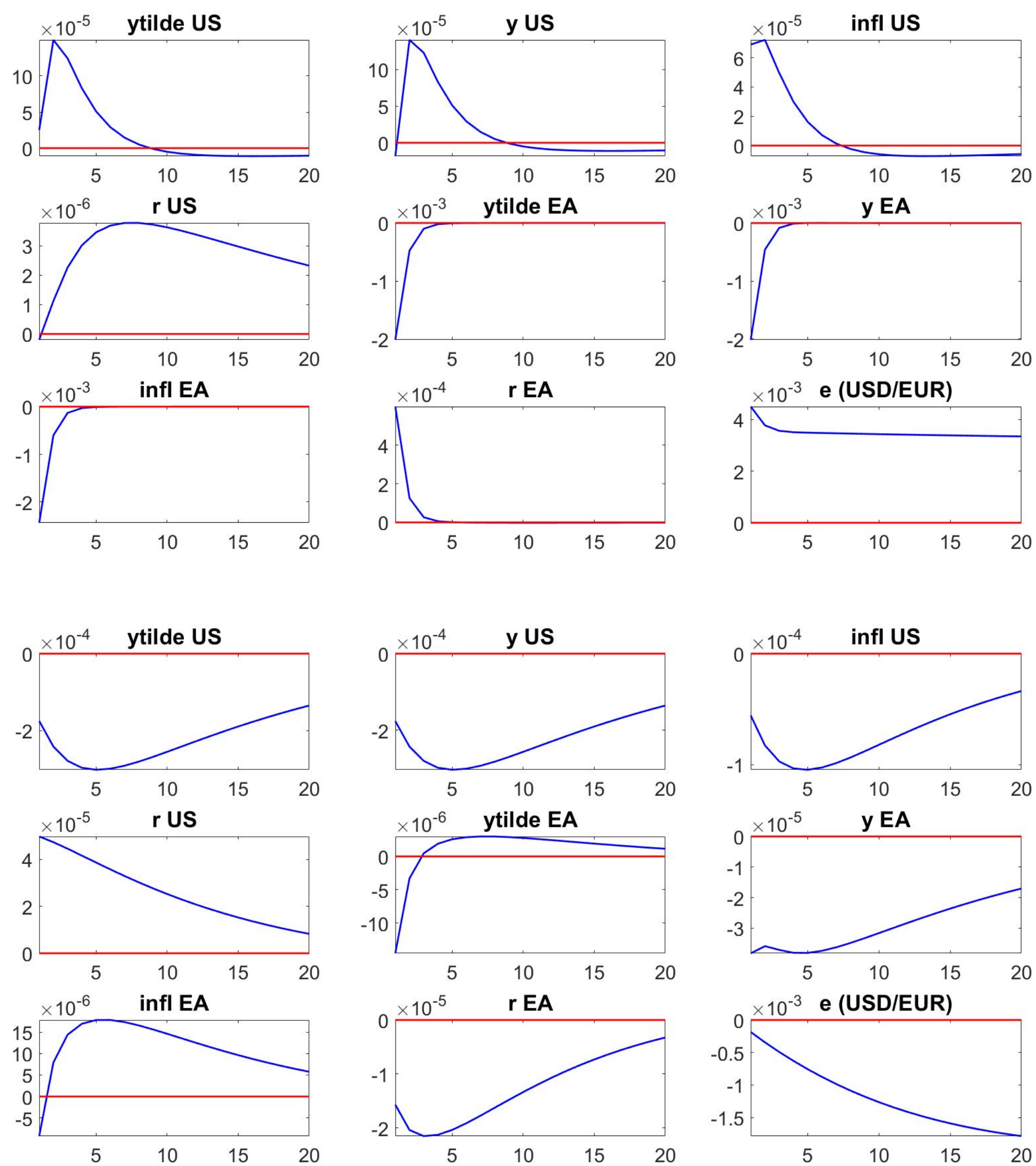

Figure 7: IRFs for one standard deviation monetary policy shock in the EA (upper)

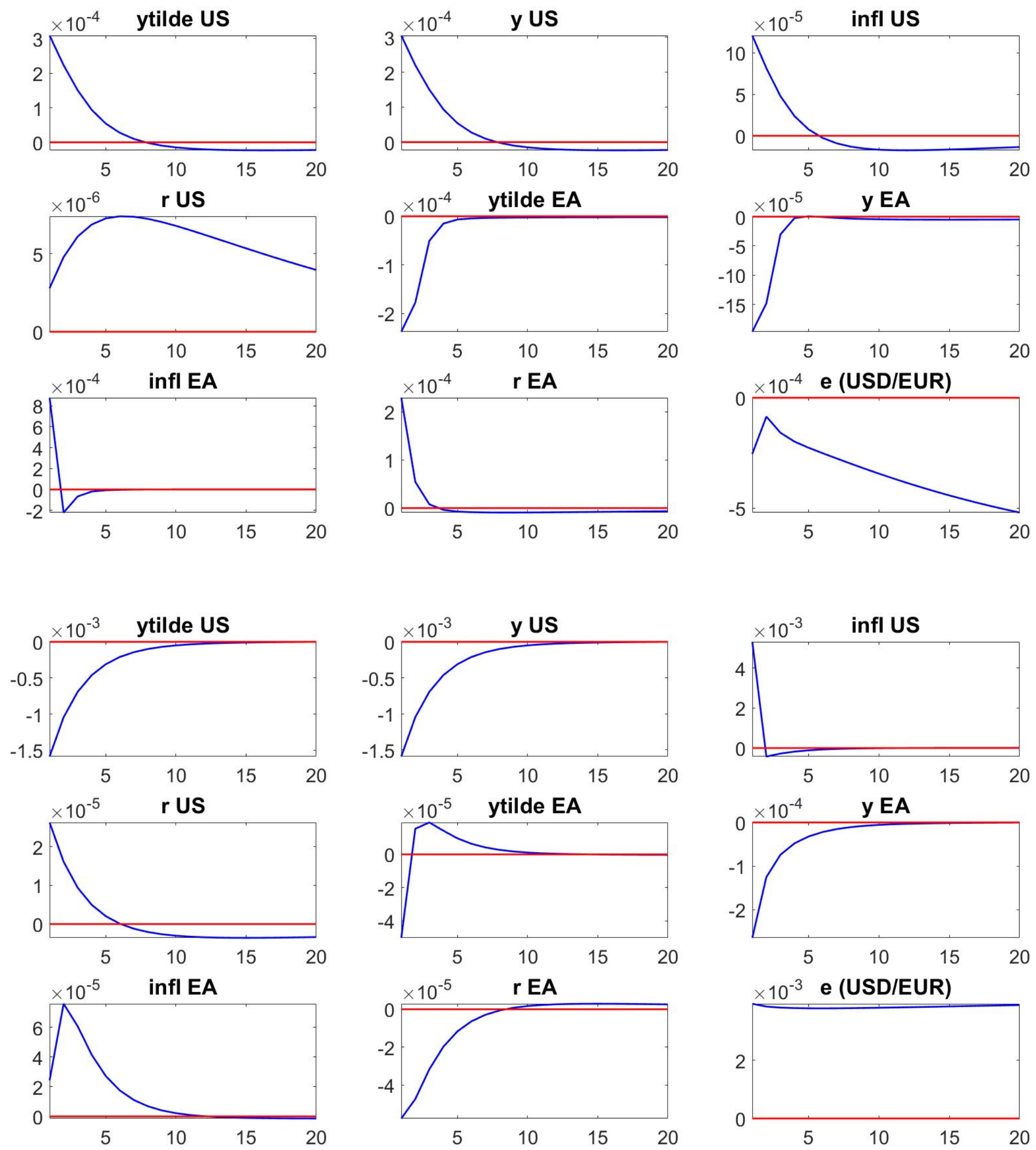

Figure 8: IRFs for one standard deviation inflation shock in the EA (upper) and in the US (lower).

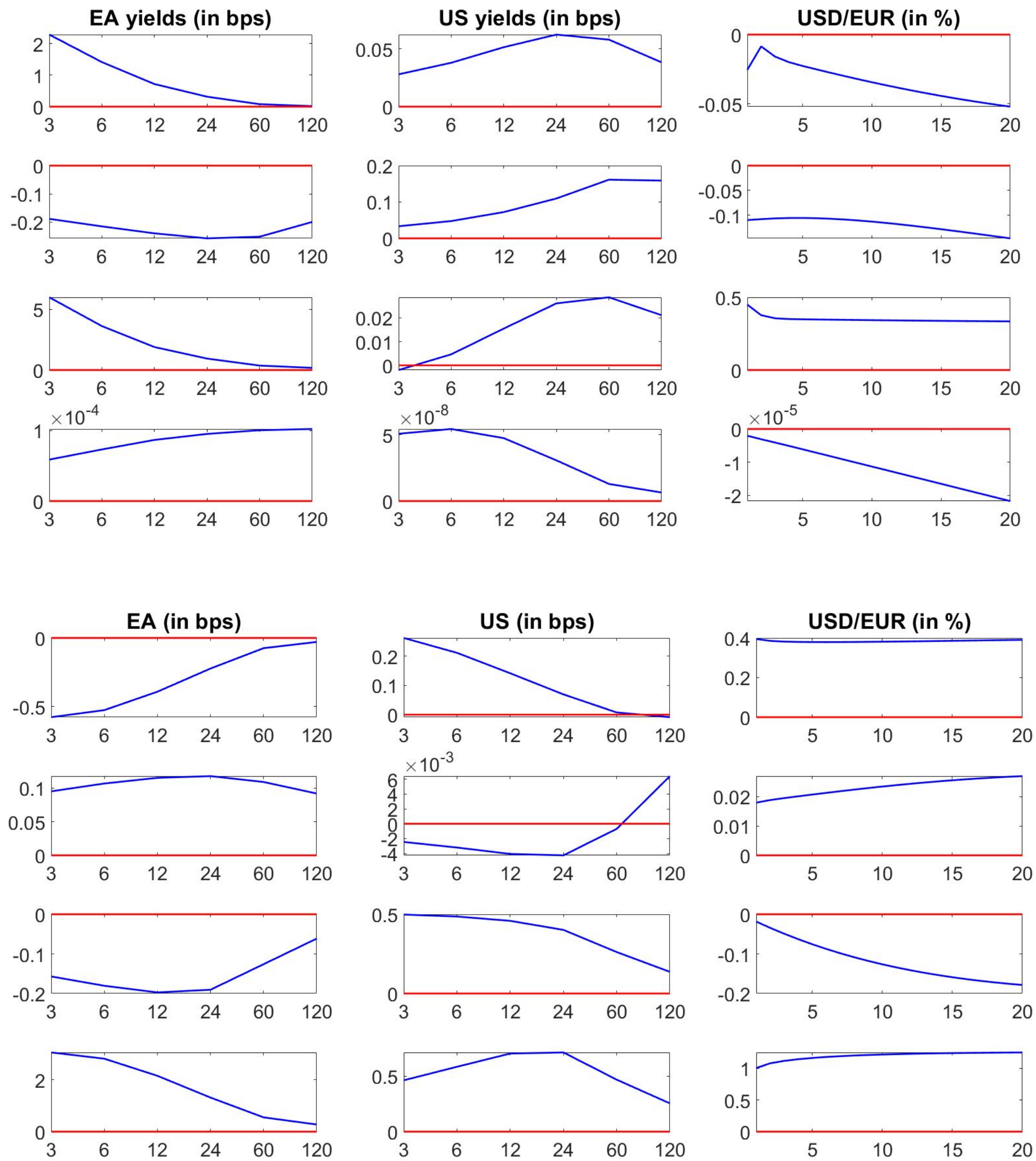

Figure 9: Yield curve responses on impact and IRFs for nominal exchange rate. Upper: first row - EA inflation; second row - EA productivity; third row - EA interest rate; fourth row - EA inflation target. Lower: first row - US inflation; second row - US productivity; third row - US interest rate; fourth row - US inflation target. The horizontal axis for the first two columns gives bond maturities in months. The horizontal axis for the third column gives time periods.

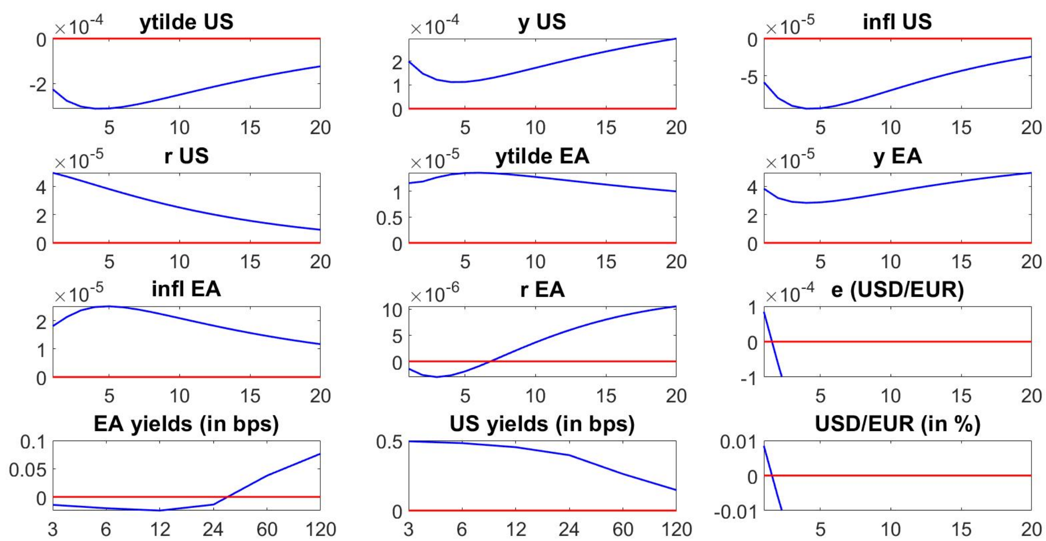

Figure 10: Positive productivity and monetary policy shocks in the US. First three rows: IRFs for positive productivity and interest rate shocks. Last row: Yield curve responses on impact and IRF for nominal exchange rate. The sub-figures for the nominal exchange rate are magnified.

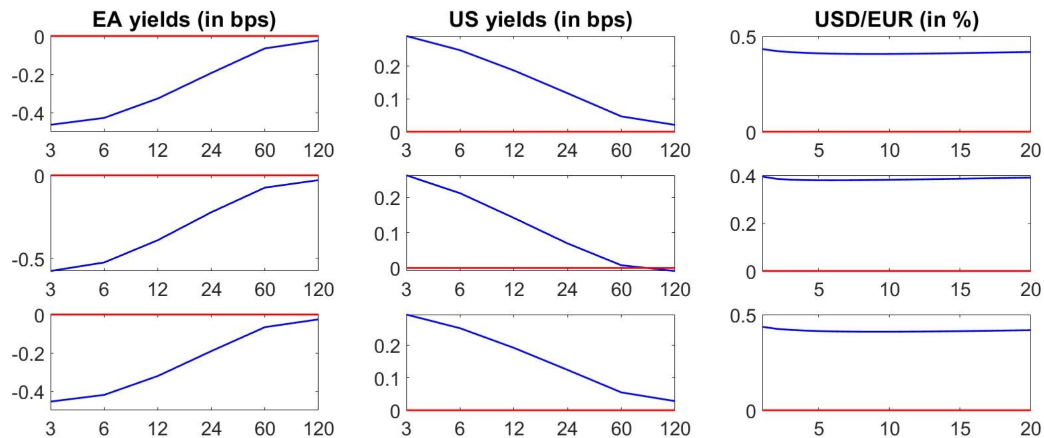

Figure 11: Yield curve responses on impact and IRF for nominal exchange rate. Shock: US inflation. Models: first row - r and π observable; second row - r, π, and $\bar{\pi}$ observable; third row - $\bar{r}r$, r, and π observable. The horizontal axis for the first two columns is bond maturities in months. The horizontal axis for the third column gives time periods. To preserve comparability, the models are evaluated at the parameter values of the best-fitting partial information model (the second row), but the implications are the same if we use the best-fitting parameter values for the respective models.

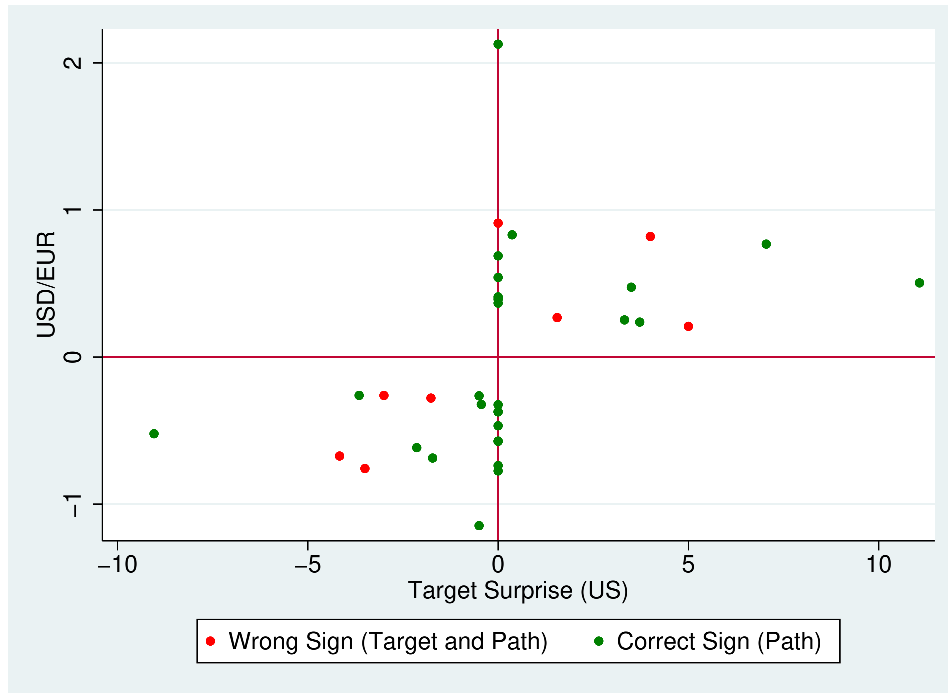

Figure 12: Scatter plot of information days conditional on the target surprise for the US. Green dots are the policy dates where the exchange rates movements can be explained by the path surprise. Red dots are the policy dates where the exchange rate movements cannot be explained by neither by the target surprise nor with the path surprise. The sample is from 1994-2018.

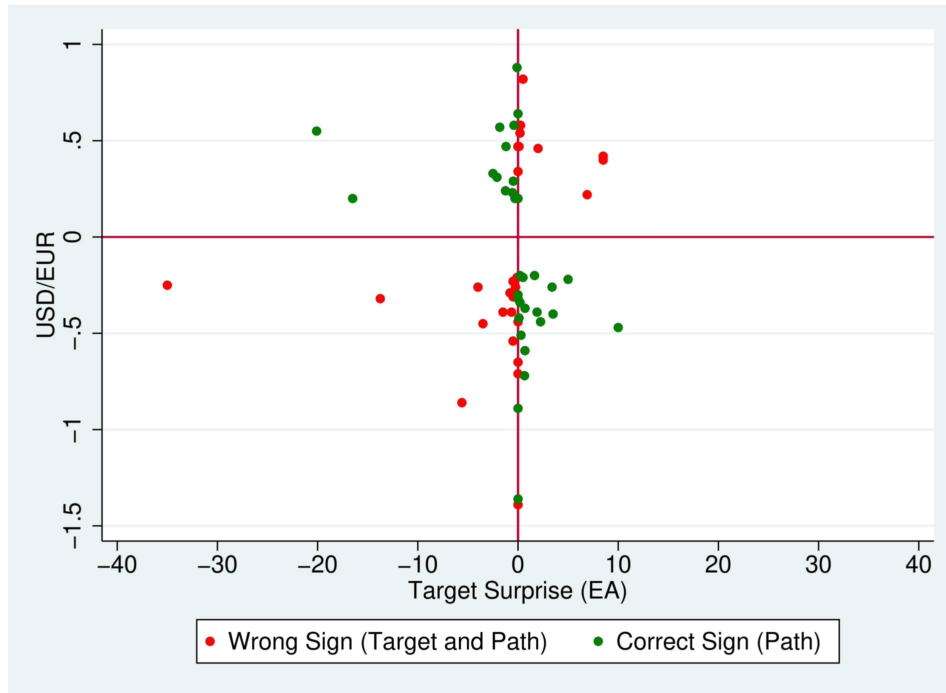

Figure 13: Scatter plot of information days conditional on the target surprise for the euro area. Green dots are the policy dates where the exchange rates movements can be explained by the path surprise. Red dots are the policy dates where the exchange rate movements cannot be explained by neither by the target surprise nor with the path surprise. The sample is from 1999-2018.

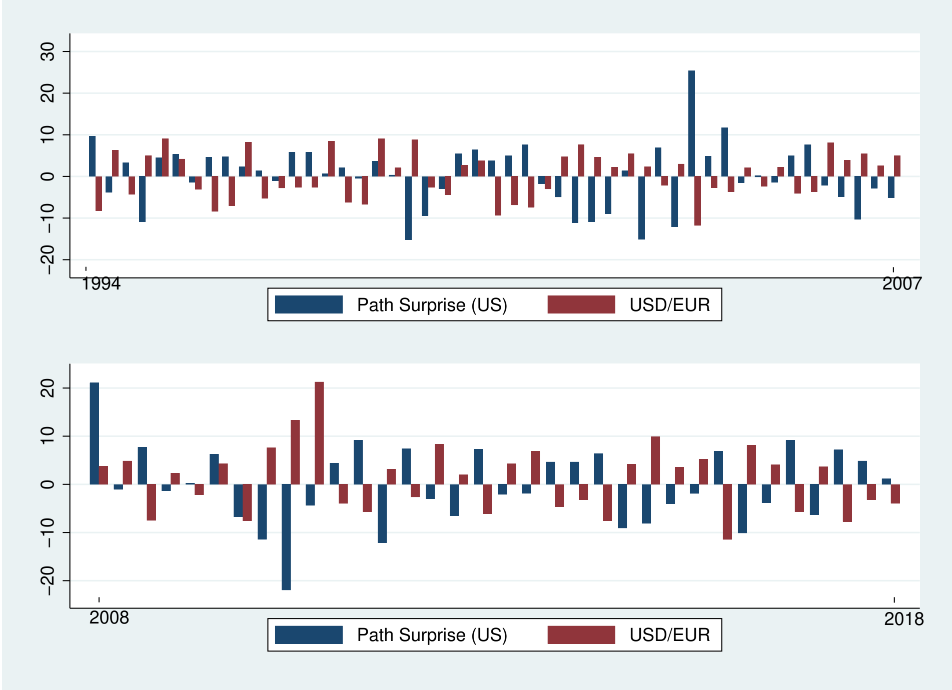

Figure 14: Bar plot for path surprises and associated changes in USD/EUR exchange rate for the euro area. Upper panel is for the sample 1999-2007 and the bottom panel is for the sample 2008-2018.

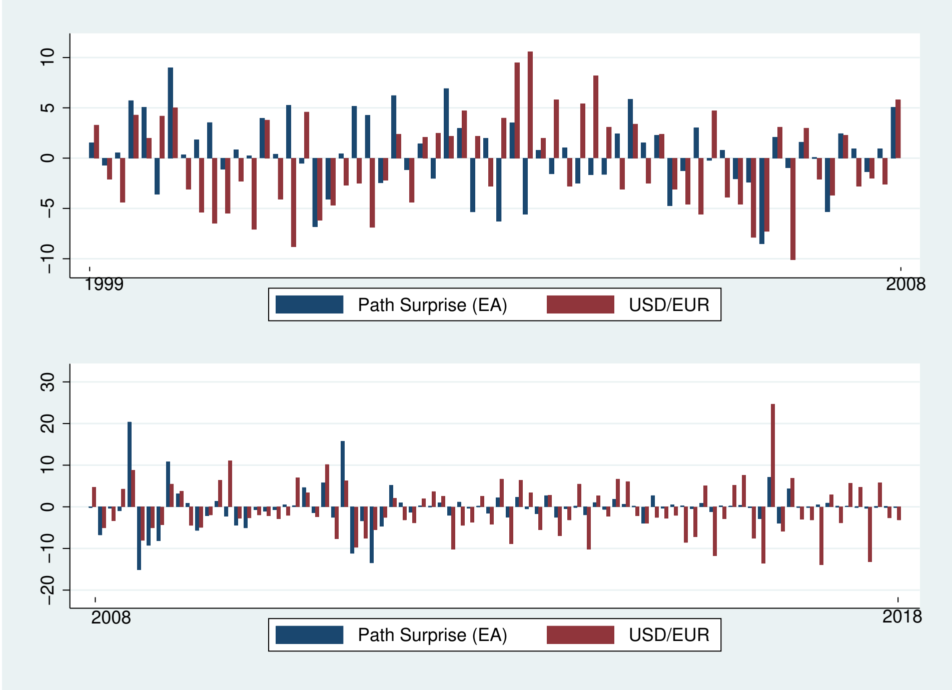

Figure 15: Bar plot for path surprises and associated changes in USD/EUR exchange rate for the euro area. Upper panel is for the sample 1999-2007 and the bottom panel is for the sample 2008-2018.