The European Central Bank's Monetary Policy Announcement Effect on the Exchange Rate in the Effective Lower Bound Era

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***Abstract*— Using a high-frequency event study of the European Central Bank's (ECB) monetary policy announcements for both the "Press Release" event window and "Press Conference" event window, this paper observes an increasing sensitivity of exchange rate response to monetary policy announcements windows over the period of 2002 to 2019. This supports the view that the ECB has growing influence on the exchange rate in the Effective Lower Bound era. The multi-dimensional surprises identified in both conventional and unconventional monetary policy announcements have all resulted in exchange rate appreciations across all currency pairs by successfully increasing the market's expectations of future monetary policy via driving up inflation expectations. Overall, the ECB's communication of monetary policy decisions may be negating the intended effects of its monetary policy implementation to stimulate inflation, therefore impairing it from achieving its central mandate of maintaining price stability.**

I. Introduction

From the viewpoint of monetary policymakers, understanding the extent to which central banks can influence exchange rates is important for gauging the effectiveness of monetary policy transmission mechanisms in open economies. Adding to that, central banks are changing the financial market environment by cutting interest rates to zero and negative rates and entering the "Effective Lower Bound" (ELB) era. They have also been increasingly utilizing a variety of unconventional monetary policy tools since the 2009 financial crisis (Ferrari et al., 2017).

This paper investigates the extent to which the European Central Bank (ECB) influences Euro exchange rates in such an environment. In particular, the paper aims to investigate the following in the sample period of 2002-2019: (i) the dimension of the ECB monetary policy announcement with the strongest response on exchange rates, (ii) whether the response has changed over time, and (iii) if there is any heterogeneity of responses across exchange rates. In this paper, monetary policy is defined as actions of the central bank that affect the term structure of Euro Overnight Index Swap (OIS) rates and bond yields. This paper extends and improves upon the investigation by Altavilla et al. (2019) of ECB monetary policy announcement effects on the nominal spot EUR/USD exchange rate by also including two of the highest traded Euro cross-currency pairs; that is, EUR/GBP and the EUR/JPY exchange rates (BIS, 2019).

In carrying out this investigation, the paper looks at the narrow high-frequency response of OIS rates, bond yields and nominal exchange rates across two event windows of ECB monetary policy announcements; the "Press Release" Window and the "Press Conference" Window. Assuming monetary policy is set endogenously through a Taylor rule, this paper uses a yield factor model regressing on exchange rates to untangle the multidimensional effects of conventional and unconventional monetary policy announcements changing inflation expectations on the exchange rate.

The different components of the "Press Release" window and the "Press Conference" window are as identified by Altavilla et al. (2019). Specifically, they have identified 1 dimension in the "Press Release" window; that is, the market reaction to the change or lack of change on the key policy interest rate named a "Target" surprise. In the "Press Conference" window, they have identified 3 dimensions capturing 3 other aspects of ECB monetary policy. One dimension of the monetary policy announcement corresponds to the adjustment of policy expectations in a way that leaves unchanged longer-term expectations (the "Timing" surprise), another corresponds to changes in the expectations of the medium run future short rates (the "Forward Guidance" surprise), and another corresponding to the changes in long term interest rates (the "Quantitative Easing" or "QE" surprise).

Following the multi-dimensional monetary policy identification by Altavilla et al. (2019), this paper estimates the exchange rate response to the money market rates using a recursive OLS regression across 3 sub-samples. The sub-samples are the pre-financial crisis period (2002-2007), the financial crisis period (2008-2013), and the post-financial crisis period (2014-2019). Overall, this paper supports the standard view among financial market participants that the ECB has a growing influence on the exchange rate through its monetary policy communication. In support of the conclusion by Altavilla et al. (2019), the paper observes growing sensitivity of the exchange rate response to monetary policy announcements in the post ELB era. The conventional surprise in the form of the "Target" factor as well as the unconventional surprises captured in the "Timing", "Forward Guidance" and "QE" factors have all resulted in exchange rate appreciations across all currency pairs. Importantly, this paper also quantifies the effect of each surprise on the exchange rate within its corresponding period. This is done by each surprise increasing the market's expectations of future monetary policy via driving up inflation expectations. This paper also shows that "Forward Guidance" has had the largest appreciation effects on the exchange rate.

While most of the literature has focused on analyzing the influence of central bank actions on the exchange rate, this paper's analysis of the announcement effect of ECB monetary policy communication extends the literature by showing that the ECB is increasingly influencing the exchange rate through monetary policy announcements themselves. This paper finds that the ECB's communication of monetary policy decisions may be negating the intended effects of its monetary policy action implementation to stimulate inflation and therefore impairing it from achieving its central mandate of maintaining price stability. It presents an interesting trade-off with the preceding announcement effect of monetary policy decisions depressing current inflation levels, contrasting the monetary policy implementation effects of stimulating inflation.

II. Literature Review & Justification

A. Methods of measuring monetary surprises.

In analyzing monetary policy surprises, the main empirical challenge is an endogeneity problem; that is, the problem that the analysis may not isolate the effect of the monetary policy surprise itself and instead include effects caused by other surprises. In what follows, I will explain the two main approaches in the literature that try to measure the monetary policy surprise whilst countering this endogeneity effect. The first is a vector autoregression (VAR). The second method and the applied method of this paper is a high-frequency identification event study (henceforth, H-F approach).

A VAR attempts to overcome the endogeneity problem by placing timing and impact restrictions on the interaction between the policy rate and other financial market or real economy variables (Jardet and Monks, 2014). This approach has been used in studies such as Cardona (2014) and Strakeva and Tang (2015). However, the concern with this approach is the persistence of endogeneity despite attempts to control for it (Nakamura and Steinsson, 2018). Another concern is VAR overidentification, and the literature endorses imposing theory-relevant restrictions in VAR estimation (Strakeva and Tang, 2015).

An H-F approach is a market-based approach focusing on movements in asset prices in a narrow window around scheduled central bank announcements. First established by Cook and Hahn (1989), it has since been widely used to investigate the effect of monetary policy on exchange rates. It involves running an OLS regression, regressing movements on asset prices on key surprise-identifying instruments as variables. The regressions are of the form:

$$\Delta s_t = \alpha + \beta_{surprise} + \epsilon_t \tag{1}$$

where Δs_t is the (log) change in the nominal exchange rate around the policy announcement and ϵ_t captures the changes in s_t not due to monetary policy. The estimated coefficients can be interpreted as follows: a one-percentage-point factor surprise is associated with a $100 * \beta$ percent change in the exchange rate (Ellen et al., 2017).

A focus on changes in exchange rates in a narrow window around scheduled central bank meetings is important because it allows $\beta_{surprise}$ to only respond to surprises relating to monetary policy announcement decisions without reacting to other economic news during that period. Specifically, since this paper considers only a specific subset of all observations (in this case, only days of central bank monetary policy announcements), it will yield an unbiased estimate as the variance of the monetary policy surprise is infinitely large in the limit relative to the variance of other surprises on central bank monetary policy announcement dates. This permits a discontinuity-based identification scheme (Nakamura and Steinsson, 2018). Hence, the narrow window delivers an approximate natural experiment and allow better mapping of the exchange rate response by better controlling for reverse causality and omitted variables (Faust et al., 2007). Other assumptions implicit with the adoption of a narrow window are that financial markets integrate all the information released by the central bank immediately and that risk premia entrenched in asset prices do not change (Cecioni, Martina 2018).

B. Theoretical literature review.

This paper will consider a suitable monetary model of exchange rate determination as a framework for understanding the effect of inflation expectations on nominal exchange rates. This paper will first present the Frankel (1983) Monetary Model of Exchange Rate Determination, and then contrast it to the New Keynesian Engel and West (2006) model used in this paper. While both approaches similarly include home and foreign interest rate differentials, inflation and output gaps in the exchange rate determination, both have different conclusions about the direction of inflation expectations' influence on the exchange rate.

The Frankel (1983) model is derived under perfect information, with the only shock originating from an initial monetary policy surprise. The instrument of monetary policy is money supply, exogenous to the model. The money demand functions are as follows:

$$m = p + \gamma_y y - \gamma_i E(i) \tag{2}$$

$$m^* = p^* + \gamma_y y^* - \gamma_i E(i^*) \tag{3}$$

where m and m^* are the logarithms of the home and foreign money supply, y and y^* are the logarithms of home and foreign real output, i and i^* are the home and foreign interest rates, and E denotes the expectation of a random variable. γ_y is the elasticity of income and γ_i is the elasticity of the interest rate. Assuming prices are flexible in the long run, this means that Purchasing Power Parity (PPP) holds:

$$s = p - p^* \tag{4}$$

where s is the (log) of the nominal spot exchange rate using the price quotation system with units of home currency per unit of foreign currency and p and p^* are (logs) of the home and foreign price levels all at time t. Assuming Uncovered Interest Parity (UIP) holds:

$$\Delta E(s) = i - i^* \tag{5}$$

Here, an expected depreciation of the home currency is equal to the nominal interest rate differential between home and foreign. Since PPP holds:

$$\Delta E(s) = E(\pi - \pi^*) \tag{6}$$

Here, the expected depreciation of the home currency is equal to the expected difference between home and foreign inflation rates at time t. Thus, the representation of the flexible price monetary equation is as follows:

$$s = (m - m^*) - \gamma_y(y - y^*) + \gamma_\pi E(\pi - \pi^*) \tag{7}$$

Now, γ_π replaces γ_i as the elasticity of expected inflation. Hence, the exchange rate is a function of money supply and demand. Increases in the domestic money supply cause exchange rate depreciation and increases in money demand resulting from either an increase in domestic output or a decrease in the expected inflation rate cause an appreciation of the home currency.

Since this paper is investigating the central bank announcement effect on the exchange rate around a narrow window, the paper will thus follow the sticky price assumption in the short run. Frankel presents an exchange rate determination model that incorporates Dornbush's (1976) "overshooting" model where in the short run, the nominal spot exchange rate deviates from its long run equilibrium value. Here, the exchange rate in the short run adjusting toward equilibrium at a rate proportional to the inflation expectation gap:

$$\Delta E(s) = -\theta(s - \bar{s}) + \bar{\pi} - \bar{\pi}^* \tag{8}$$

Here, θ is the speed of adjustment, and a bar over variables show a relationship that holds in the long run. Combine this with the UIP assumption in (5), we have an expression for the gap between the current spot rate and its equilibrium level:

$$s - \bar{s} = -\frac{1}{\theta}[(i - \bar{\pi}) - (i^* - \bar{\pi}^*)] \tag{9}$$

Following (9), a contractionary monetary policy should raise the real interest differential, attracting a capital inflow and subsequently appreciating the currency above its equilibrium value. Frankel 1983 thus combines equations (8) and (9) to obtain the sticky-price monetary equation of exchange rate determination:

$$\begin{aligned} s =& (\bar{m} - \bar{m}^*) - \gamma_y(\bar{y} - \bar{y}^*) \\ &+ (\gamma_\pi + \frac{1}{\theta})(\bar{\pi} - \bar{\pi}^*) - \frac{1}{\theta}(\bar{i} - \bar{i}^*) \end{aligned} \tag{10}$$

The interpretation of the equation remains the same, with the factors affecting the money supply and demand affecting the exchange rate in the same way and direction. Assuming that in a narrow window around central bank announcements, $\bar{m}$ and $\bar{m}^*$, $\bar{y}$ and $\bar{y}^*$, $\bar{i}^*$ and $\bar{\pi}^*$ would remain fixed. Thus, the only change would result from a long-run change in the home expected inflation and the home interest rate. In particular:

$\delta s > 0$ (i.e., a home currency depreciation occurs) if

$$(\gamma_\pi + \frac{1}{\theta})\delta\bar{\pi} > \frac{1}{\theta}\delta\bar{i} \tag{11}$$

$\delta s < 0$, (i.e., a home currency appreciation occurs) if

$$(\gamma_\pi + \frac{1}{\theta})\delta\bar{\pi} < \frac{1}{\theta}\delta\bar{i} \tag{12}$$

However, this paper finds that in the ELB era, this result does not hold empirically. Cesa-Bianchi et al. (2019) argue that this is due to the assumption that interest rate policy is exogenous rather than being determined by a policy rule that responds systematically to economic conditions. Thus, we will require a New Keynesian model with the interest rate as the instrument of monetary policy to aid explanation of exchange rate movements in the ELB era.

The model used in this paper is by Engel and West (2006) who specify a New Keynesian model. Here, the interest rate is endogenously set according to a policy rule, where it typically reacts to a change in the inflation and the output gap. Assuming monetary policy is set using a Taylor rule for both Home and Foreign:

$$i_t = \tilde{r_t} + \gamma_\pi \pi_t + \alpha(i_{t-1} - \tilde{r}_{t-1}) \tag{13}$$

$$i_t^* = \tilde{r_t}^* + \gamma_\pi \pi_t^* + \alpha(i_{t-1}^* - \tilde{r}_{t-1}^*) \tag{14}$$

The time subscript t is added to denote variables corresponding to a specific period. We also specify π_t and π_t^* as the home and foreign inflation, $\tilde{r_t}$ and $\tilde{r_t}^*$ as the home and foreign real interest rate if prices adjusted instantaneously and $0 \leq \alpha < 1$ as the coefficient of interest rate differentials (Engel, 2014). For both home and foreign, an increase in inflation or the output gap would lead to an increase in the policy interest rate. Following that, the new modified Taylor rule with domestic relative to foreign as according to Engel and West (2006) is:

$$i_t - i_t^* = \gamma_q q_t + \gamma_\pi E_t(\pi_{t+1} - \pi_{t+1}^*) + \gamma_y(\tilde{y_t} - \tilde{y_t^*}) \tag{15}$$

Here, q_t is the real exchange rate at time t, γ_q is the elasticity of the real exchange rate and $\tilde{y_t}$ and $\tilde{y_t^*}$ denote the home and foreign output gap. Also, the UIP condition showing the indifference of an investor between deposits in two countries is:

$$i_t - i_t^* = E_t q_{t+1} - q_t + E_t(\pi_{t+1} - \pi_{t+1}^*) \tag{16}$$

Combining (15) and (16) to solve for the real exchange rate in terms of the present values of current and expected

future inflation and output gaps, we arrive at:

$$q_t = -\sum_{j=1}^{\infty}(\frac{1}{1+\gamma_q})^j E_t[\frac{(\gamma_\pi - 1)}{1+\gamma_q}(\pi_{t+j+1} - \pi^*_{t+j+1}) + \frac{\gamma_y}{(1+\gamma_q)}(\tilde{y}_{t+j} - \tilde{y}^*_{t+j})] - \frac{1}{1+\gamma_q}\epsilon_t \quad (17)$$

Based on the Taylor rule and UIP condition, Engel and West (2004) present forward-looking determinants of exchange rates. The assumptions made are that at least one of the countries responds to the exchange rate misalignment and PPP holds in the long-run. Thus, the interest rate responds to changes in the real exchange rate and raises the interest rate when expected inflation or the expected output gap is higher. When the stability condition $\gamma_\pi > 1$ holds, the interest rate rises enough to result in an increase real interest rates, causing a real appreciation.

As prices do not adjust over the short term, the change in q_t originates exclusively from changes in the nominal exchange rate, represented by $s_{t+\Delta} - s_{t-\Delta}$. Thus, (17) becomes:

$$s_{t+\Delta} - s_{t-\Delta} \approx -\sum_{j=1}^{\infty}(\frac{1}{1+\gamma_q})^j (E_{t+\Delta} - E_{t-\Delta}) [(\frac{(\gamma_\pi - 1)}{1+\gamma_q}\pi_{t+j+1} - \pi^*_{t+j+1}) + \frac{\gamma_y}{1+\gamma_q}(\tilde{y_{t+j}} - \tilde{y^*_{t+j}})] \quad (18)$$

The model assumes that the actual inflation and output gap, $\pi_t - \pi_t^*$ and $\tilde{y_t} - \tilde{y_t}^*$,do not change between $t-\Delta$ and $t+\Delta$. Thus, changes in exchange rate over the narrow window are driven only by expectations of future relative inflation rates and output gaps. Given that $\gamma_q > 0$, $\gamma_\pi > 1$ and $\gamma_\gamma > 0$, then the Taylor rule model infers that a higher expected inflation or a higher output gap in the home country will lead to a home real appreciation (Engel, 2014). Given this result, this paper can investigate the extent to which ECB monetary policy announcements are influencing the Euro exchange rate by adjusting market inflation expectations.

C. Empirical literature review.

This paper relates to various strands of literature analyzing the market reaction to the announcement of policy decisions. Most of the work has focused on the effect of Federal Reserve Open Market Committee (FOMC) announcement surprises and has only recently expanded to the announcement effects of other central banks. The literature mostly agrees that financial-market reactions to monetary policy announcements are significant (Ehrmann and Fratzscher, 2007).

This paper primarily follows Cook and Hahn (1989), who studied the day change of the Federal Funds key policy rate on bond yields in the 1970s. They concluded that the FOMC has strong influence on market interest rates through its control of the funds rate and that the expectations of the future level of the funds rate strongly influence other money market rates. Kuttner (2001) built upon Cook and Hahn (1989) by instead isolating the surprise component of the change in monetary policy by using the intraday Fed Funds futures rate as a measure of the expected interest rate rather than the intraday change in the key policy interest rate to identify the impact of a monetary policy decision.

Following Kuttner (2001), this paper investigates how exchange rate changes are affected by adjustments of future monetary policy expectations as proxied by market interest rates. One such study is conducted by Zettlemeyer (2004), who applies the event study methods from Cook and Hahn (1989) to study the effect of central bank monetary policy announcement effects in Australia, New Zealand and Canada on USD/AUD, USD/CAD and USD/NZD using daily data from 1990-2000. He finds evidence to support the conventional relationship between exchange rates and monetary policy surprises; that monetary contractions lead to exchange rate appreciations and monetary expansions lead to depreciations. By contrast, Fatum and Scholnick (2006) use a generalized autoregressive conditional heteroskedasticity (GARCH) time-series approach to study the effects of FOMC announcement days and non-FOMC announcement days on the USD/JPY, USD/GBP and USD/Deustchemark from 1989 to 2001 via the change in the Fed Funds rate. They also control for 6 US macroeconomic news announcements, interest rate changes and foreign exchange interventions from other central banks. They find that changes in expectations of future monetary policy affect exchange rates and that an increase in the expectation of the future Fed Funds rate results in a dollar appreciation.

This paper contrasts itself to Zettlemeyer (2004) in 2 ways. Although this paper also uses an event study and defines "surprises" as changes in the market interest rate associated with a given policy announcement, this paper extends analysis of exchange rate responses to ECB monetary policy. This paper will use a narrower window of intraday data as opposed to daily data, improving control for endogeneity and omitted variable bias. Also, in contrast to Zettlemeyer (2004) and in line with Fatum and Scholnick (2006), this paper will examine the effect of how changes in expectations of future monetary policy affect exchange rates. Contrasting both Zettlemeyer (2004) and Fatum and Scholnick (2006), the paper will also examine the exchange rate responses post-2008.

This paper also follows Gürkayanak et al. (2005), who study the effects of monetary policy announcements on bond yields and equities using an intraday sample of announcements from 1990-2004 and use factor identification to extend the single factor of monetary policy to two factors. One factor relates to policy surprises called the "Target" factor, and the other component relates to expected future policy rates orthogonal to the "Target" surprise called the "Path" factor. They confirm that surprises related to the future path of monetary policy are an important driver, particularly for longer-term bond yields. Swanson (2017) extends Gürkayanak et al. (2005) by separately identifying a "target" surprise corresponding to surprise from the change in the fed funds rate, "forward guidance" as a factor affecting medium-term

maturities and "large-scale asset purchases" factor affecting long-term maturities for all FOMC announcements to capture the effects of the new unconventional monetary policy tool employed in new ELB period during 2009-2014.

With the identification of new monetary policy announcement dimensions associated with the new ELB era, Ferrari et al. (2017) conduct a high-frequency event study of monetary policy on the exchange rate for 7 advanced economies using factors identified as in Gürkayanak et al. (2005) and Swanson (2017). They analyze USD/EUR, USD/JPY, USD/GBP, USD/CHF, USD/AUD and USD/CAD responses corresponding to tight windows of various announcements of the respective 7 central banks in a sample period of 2004-2015. They find that exchange rate sensitivity in responding to monetary policy has increased over time and that the drop in interest rates signifying the ELB period contributes to the increase in sensitivity. However, Ferrari et al. (2017) do not include an analysis of market reactions to the ECB press conference and simply considers the press release market reaction. Using the identification pioneered and extended by Gürkayanak et al. (2005) and Swanson (2017), this paper distinguishes itself from Ferrari et al. (2017) by instead focusing on a specific ECB analysis of the market reaction for both the ECB "Press Release" event with the ECB "Press Conference" window, observing the Euro exchange rate response for both.

Distinguishing asset price and money market interest rate movements specific to ECB "Press Release" with the ECB "Press Conference" is made possible with Altavilla et al. (2019)'s paper on ECB monetary policy announcement effects featuring the construction of an event-study dataset of the ECB monetary policy announcements from 2002-2018. Analyzing a sample from 2002-2018, they extend the literature analyzing multi-dimensional central bank monetary policy communication specific to the ECB. They show that one factor, the "Target" surprise with a unit effect on the one-month OIS captures all the variation in the money market rates the "Press Release" window. By contrast, three factors capture nearly all the discrepancy in the market rates for the press conference, with the "Timing" effect on six-month OIS, "Forward Guidance" ("FG") having unit effect on the two-year OIS and "QE" having a unit effect on the ten-year OIS.

Given these results, this paper follows Altavilla et al. (2019) by employing their dataset and identified factors for the "Press Release" window and the "Press Conference" window to analyze exchange rate responses to ECB monetary policy announcements. However, this paper distinguishes itself from Altavilla et al. (2019) in 3 ways. First, the paper extends the baseline EUR/USD response analysis provided in Altavilla et al. (2019) by including an analysis of the monetary policy announcement response of EUR/GBP and EUR/JPY for the pre-crisis, financial crisis, and post-financial crisis periods to determine if there is a heterogeneity of responses across cross-currency pairs. Second, this paper's analysis includes the 2019 period. Finally, this paper replaces the 10-year OIS as the identifying "QE" surprise with the 10-year German bond yield as a more accurate money market instrument to measure the changes in monetary policy expectations. This paper's analysis of the exchange rate responses to ECB monetary policy announcements will be supplemented with the Engel and West (2006) model presented in Section 2.2, concluding as Fatum and Scholnick (2006) do that the announcement of monetary policy actions that alter expectations of future monetary policy influence exchange rates.

III. ECB Monetary Policy

A. The ECB's conventional monetary policy.

Since the ECB's founding in 1999, its main mandate has been to maintain price stability in the Eurozone, defined as inflation close to, but below 2% (ECB, 2011). As the principal issuer of the Euro, it ultimately controls the monetary base and manages liquidity in the money market.

The ECB has three key interest rates; the marginal lending rate, the short-term repo rate, and the overnight deposit rate (ECB, 2011). Key interest rate changes, which comprise the ECB conventional monetary policy toolkit affect the shortest maturities and peak around the one-month maturity of the yield curve . Their evolution over time can be seen in Figure 1 in Appendix A. Beginning March 2009 with the onset of the global financial crisis, key interest rates substantially dropped to 0.5% and even reached negative territory, signifying the ELB era. Ever since, monetary policy has been unsuccessful in its attempts to stimulate inflation and aggregate demand exclusively via conventional monetary policy. As a result, the ECB has since increasingly supplemented its expansionary conventional measures with unconventional measures in order to stimulate inflation (ECB, 2011).

B. The ECB's unconventional monetary policy.

To date, the ECB has introduced a few unconventional monetary policy measures, and this paper will focus on two of these measures. In hopes of encouraging more open and transparent communication of future policy to affect medium-term market rates in the deflationary Euro-area economies, the ECB began to implement forward guidance in July 2013 to clarify the ECB's intentions not only about the expected future path of the ECB's key interest rates, but also the horizon of its asset purchase program (ECB, 2017).

The ECB's asset purchase program was introduced in January 2015, a liquidity improving action affecting longer-term rates known as QE (ECB, 2011). It is executed through the purchase of long-term government bonds and financed by an increase in the reserve accounts held by commercial banks within the central bank. The hope is for the measure to aid in providing a monetary stimulus by increasing long-term bond prices and therefore lowering long-term yields in the ELB era.

Swanson (2017) found that both forward guidance and QE have a hump-shaped effect on the yield curve. Specifically, he found that forward guidance manifests this hump-shape with its largest effect on shaping market expectations at two to five years maturity, whilst leaving both current short and expected

short rates far into the future unaffected. In contrast, QE announcements have their largest effect on shaping market expectations further into the future, peaking at around the ten-year maturity.

C. The institutional characteristics of ECB monetary policy announcements.

ECB monetary policy announcements have a clear segregation of news regarding the key policy rates and the communication of details regarding their decision. This enables clear analysis by specifically identifying different types of monetary policy news and their respective impacts on the exchange rates, making it ideal for an H-F approach (Brand et al., 2010).

During the ECB's inception in 1999, the ECB Governing Council announced policy decisions twice a month, while a press conference took place only once a month at the first meeting of the month (Altavilla et al., 2011). After November 2001, policy meetings were rescheduled to once a month, specifically, the first Thursday of every month. These monthly meetings were accompanied by press conferences, with minimal exceptions (Ehrmann and Fratzscher, 2009). Since January 2015, monetary policy announcements have evolved to a six-week cycle.

Monetary policy is communicated in two separate events on Governing Council announcement days. The first event is a brief online press release describing what action was taken (or not taken) on the key policy interest rate at 13:45, Central European Time. Since the decision contains nothing about the ECB's future policy or outlook, it is reasonable to assume that market movements are reacting instantly after the press release, with the reaction relating only to immediate policy changes. However, the ELB period after March 2009 may alter the market movement responses to this event window since the interest rate remains effectively unchanged. On top of that, March 2016 marked a change in the communication of the Press Release with the introduction of description of changes in both the target rate as well as a description of unconventional measures the ECB is making. Thus, the decision after this period should reflect both immediate policy changes and the future path of policy, which is not accounted for in this paper in the analysis of the "Press Release" event.

The second event, a "Press Conference" is held at 14:30 and lasts 15 minutes. Here, the ECB President explains the monetary policy decision in detail. It begins with a statement summarizes and explains both monetary policy developments and the monetary policy decision of the Governing Council (Ehrmann and Fratzscher, 2009). Then, at 14:45, the President answers journalists' questions relating mainly to considerations contributing to the policy decision (Brand et al., 2010). Similar to Altavilla et al. (2019), this paper will assume that market reactions to the "Press Conference" event are reactions that relate to the future path of policy, since investors have already accounted for target rate changes following the press release.

IV. Data

A. Euro Overnight Index Swaps (OIS) as a measure of monetary policy expectation.

Given this paper's definition of monetary policy, it is important to explain OIS, the primary interest rate used in this paper and associated benefits of using this market interest rate as a measure of a market participant's interest rate expectations.

OIS is the average Euro Overnight Index Average (EONIA) expected at a given maturity. These instruments are a combination of expectations of future short-term interest rates and a term premium. While expectations of monetary policy actions are not directly observable, OIS rates are a good market-based proxy for those expectations.

The exchange of an OIS involves one institution swapping a floating interest rate and the other swapping a fixed short-term interest rate at a given maturity. In the absence of arbitrage opportunities, OIS should reflect the minimal risk-adjusted market participants' expectation of the average policy rate over the swap maturity, since the principal remains unexchanged between the parties (Hubert and Labondance, 2018). Additionally, despite market-based interest rates incorporating a risk premium, the change in the market interest rate remains a good proxy for the policy surprise since the risk premium is unlikely to move in the narrow window of the event study specified in this paper. Thus, a measure of the change in the OIS rate as used in this paper would exclude this risk premium.

Notably, Lloyd (2018) shows that OIS Euro Area-wide interest rates at 1- to 2-year maturities provide accurate measures of investors' interest rate expectations. Compared to fixed-rate bonds, OIS rates are less volatile. However, Lloyd (2018) also warns that OIS rates beyond 2 years show positive and statistically significant ex-post excess returns, indicating the presence of term premia characteristic of longer-maturity contracts. This marginally diminishes their usefulness as a market-based measure of monetary policy expectations and may make them a biased proxy of the QE effect. Thus, contrary to Altavilla et al. (2019) and in line with Ferrari et al. (2017), I will be replacing the OIS-10 year with the German 10-year Bund as a factor representing the 10-year maturity instrument. As the largest economy in the Eurozone, the German 10-Year Bund quotes should be representative of Euro-area bond yields. Whilst the OIS ceases to be traded beyond 2-year maturities, the high market liquidity of German 10-year Bund will decrease the term premia and volatility stemming from reduced liquidity risk, making them a better proxy for the QE surprise in comparison to the 10-year OIS (Bundesbank, 2018).

B. Euro Area Monetary Policy Event-Study Database (EA-MPD).

The underlying data for this paper originates from the EA-MPD database compiled by Altavilla et al. (2019). The database features policy news reaching the financial markets corresponding to the institutional features of ECB monetary

policy communication via the "Press Release" and "Press Conference" windows as specified in Section 3.3. This paper will specifically make use of their OIS 1-month, 6-month and 2-year quotes, their German 10-year bund quotes, replacing 10-year OIS as better market interest rate instrument than in Altavilla et al. (2019), as well as their EUR/USD, EUR/GBP and EUR/JPY exchange rate crosses. All data is quoted in basis points. As an example, the OIS quotes in the EA-MPD are calculated as follows:

$$\begin{aligned}\Delta MPSurprise_t =& OIS_{median[t+20min;\ t+10min]} \\ &- OIS_{median[t-10min;\ t-20min]}\end{aligned} \quad (19)$$

The equation shows a change in the median OIS interest rate in 20 minutes to 10 minutes pre-press-release, to the change in the median OIS interest rate 10 minutes to 20 minutes post-press-release quote. In other words, the rate setting surprise can be expressed as the change in two OIS observations defined as above, denoted as $MPSurprise_t$. Similarly, the EA-MPD takes the change in the median OIS interest rate in 20 minutes to 10 minutes pre-press conference quote, to the change in the median OIS interest rate 10 minutes to 20 minutes as the post-press-conference quote. Other bond yields and currency cross quotes used in this paper are calculated in corresponding fashion.

V. Method

A. Decomposing policy surprises.

Following the identified factors as in Altavilla et al. (2019), the regressions can be formed specific to the "Press Release" and "Press Conference" event windows using the general OLS regression form specified in Section 2, equation (1). The regressions that follow will be implemented for said event windows across 3 sub-samples. These sub-samples are the pre-financial crisis period (January 2002 until December 2007), the financial crisis period (January 2008 until December 2013), and the post-financial crisis period (January 2014 until June 2019) to observe if there is a difference in the response before and after the ELB.

For the "Press Release" event window, the paper regresses the (log) exchange rate changes on the "Target" surprise:

$$\Delta s_t = \alpha + \beta_{target} \cdot \underbrace{(MPSurprise_t^{OIS1M})}_{\text{Target Surprise}} + \epsilon_t \quad (20)$$

where, for event t, $MPSurprise_t^{OIS1M}$ is the change in the 1-month OIS interest rate. Here, ΔS_t is the change in the (log) exchange rate defined as units of foreign currency per unit of home currency, following the volume quotation system. Therefore, a positive value of the (log) exchange rate change shows an appreciation of the home currency.

The "Press Conference" event window regression is as follows:

$$\begin{aligned}\Delta s_t = \alpha &+ \beta_{Timing} \cdot \underbrace{(MPSurprise_t^{OIS6M})}_{\text{Timing Surprise}} \\ &+ \beta_{FG} \cdot \underbrace{(MPSurprise_t^{OIS2Y\perp})}_{\text{Forward Guidance Surprise}} \\ &+ \beta_{QE} \cdot \underbrace{(MPSurprise_t^{DE10Y\perp})}_{\text{QE Surprise}} + \epsilon_t\end{aligned} \quad (21)$$

The specification here is that $MPSurprise_t^{OIS6M}$ is the change in the 6-month OIS interest rate, identifying it as the "Timing" surprise. The interpretation of the "Timing" surprise, peaking at about six months maturity, is a market revision of policy expectations that shifts the expectation of the policy action from something that was highly expected to happen on the day to now more likely to happen during the next upcoming announcements. Importantly, it leaves longer-term policy expectations unaffected.

$MPSurprise_t^{OIS2Y\perp}$ is the orthogonal change in the 2-year OIS. The change should be driven by expectations of the medium run future short rates, peaking at about 2-year maturity. The $MPSurprise_t^{DE10Y\perp}$ is the orthogonal change in the 10-year German Bund (identifying the "QE" surprise). The "QE" surprise will be largely traced to changes in long-term interest rate, peaking at about 10-year maturity. The "Forward Guidance" surprise is omitted for the pre-financial crisis sample, and the "QE" surprise is omitted in the pre-financial crisis and the financial crisis samples.

VI. Results and Discussion

While running both regressions, this paper observes that movement in market rates takes place instantly after news on monetary policy decisions becomes available. This is consistent with literature that finds that the Euro area money market is efficient in incorporating new information rapidly (Brand et al., 2010). All figures and tables referenced in this section can be found in Appendix A.

A. Results of "Press Release" regression.

Referring to Table 1, Panel (A) and Figure 2, there is a clear heterogeneity of responses for the pre-financial crisis and financial crisis responses for the cross-currency pairs, with more statistically significant homogeneous responses post-financial crisis. The effect of a 1-unit increase in β_{target} during the pre-financial crisis period of interest rate hikes did not have a statistically significant effect on EUR/USD but caused a statistically significant 0.01% appreciation in EUR/GBP and a 0.01% depreciation in EUR/JPY. Prior to the ELB, increasing interest rate hikes has resulted in lower future inflation expectations resulting in a lower expected long run value of euro returns stemming from the Taylor rule, with lower inflation expectations resulting in lower interest rates. This causes the Euro to depreciate against foreign currencies, leading to a small and economically insignificant

coefficient prior to the ECB beginning their ELB policy as exemplified in the depreciation of EUR/JPY.

By contrast, the financial crisis period showed a statistically insignificant effect for both EUR/USD and EUR/GBP, with a statistically significant 0.02% depreciation in EUR/JPY. While this era was marked by drastic interest rate cuts to stimulate the economy during the crisis, the EUR/JPY depreciation is probably more reflective of market participants moving towards purchasing more Yen currency to diversify their assets from the impact of the US-born financial crisis, with the Yen currency having the most negative correlation to 10-year U.S. Treasury yields.

Post-financial crisis, the effect of a 1 unit increase in β_{target} is a statistically significant 0.14% appreciation on average across all currency pairs. Post ELB, higher inflationary expectations in the future also increases the expectations of an interest rate hike in the future. Therefore, monetary surprises originating from the ECB announcements are now associated with a statistically significant appreciation of the Euro. It is also worth noting the increased sensitivity of the exchange rate to a "Target" surprise in the post-crisis period, also observed in Figure 2. This may be due to the strength of the Forward Guidance and QE effects in shaping market expectations, particularly in influencing longer term inflation expectations.

B. Results of "Press Conference" regression.

Referring to Table 1, Panel (B) and Figure 3, the regressions show that the "Timing" surprise is only relevant in the pre-financial crisis period, with a 1-unit increase in the coefficient of the "Timing" surprise (β_{timing}) having an average 0.05% appreciation for all currency pairs. However, during and after the financial crisis, β_{timing} has lost its place as a key driver of the exchange rate response, contrary to the results in Altavilla et al. (2019), that show β_{timing} as significant across all three subsamples. This suggests that monetary policy announcements no longer leave longer-term policy expectations unchanged.

Instead, in the financial crisis and post-financial crisis periods, the coefficients on the "Forward Guidance" surprise (β_{FG}) and the "QE" surprise (β_{QE}) indicate that these have emerged as key drivers. The effect of a 1 unit increase in β_{FG} is a 0.04% increase in the exchange rate across all currency pairs, and the effect has strengthened to 0.16% post-crisis. This suggests that expectations of future short-term rates related to monetary policy are a key driver of the exchange rate response, and the significance of central bank forward guidance affecting the shorter-end of the yield curve (Swanson, 2014). The strengthened response to forward guidance surprises post-financial crisis may reflect the effectiveness of the enhanced forward guidance adopted by the ECB in June 2018 for reducing uncertainty regarding the expected future path of short-term interest rates (Cœuré, 2018).

The QE effect in the post financial crisis period is significant for EUR/USD and EUR/JPY, with a unit increase in β_{QE} having a 0.04% increase for EUR/USD and a 0.057% increase for EUR/JPY. However, the effect is not significant for EUR/GBP, suggesting that β_{QE} surprises only transmit to the EUR/USD and EUR/JPY exchange rates. "QE" surprises are effectively reducing uncertainty around the expected future path of long-term interest rates for EUR/USD and EUR/JPY, with a smaller magnitude of effect compared to forward guidance.

C. Further discussion.

Overall, the results confirm the prediction in the Engel and West (2006) model that a currency tends to appreciate when there are higher inflation expectations affecting expected future policy rates via the Taylor rule. Specifically, the conventional monetary policy announcement surprise captured in the "Target" factor, coupled with the unconventional monetary policy announcement surprises captured in the "Forward Guidance" and "QE" factors have resulted in a measured quantifiable appreciation in all the exchange rate pairs. This is achieved through their successful transmission of their monetary policy tools in increasing inflation expectations in short, medium and long-term rates.

Contrasting Strakeva and Tang (2015), who, upon analyzing FOMC announcement effects on the exchange rate, concluded that the importance of conventional monetary policy in impacting the exchange rate is decreasing relative to unconventional monetary policy during the ELB, this paper finds the both the ECB conventional and unconventional monetary policy surprises have an increased role in explaining exchange rate changes since the ELB. The strongest appreciation effects stem from the "Forward Guidance" surprise, followed by the "Target" surprise. The "QE" surprise has the lowest magnitude effect on currency appreciation across all currency pairs.

Some reasons for the increasing exchange rate sensitivity may also be the reduced liquidity and intermediation ability of brokers resulting from changes in regulation post-financial crisis. This in turn leads to the declining willingness of market actors to bear inventory risk during high-risk periods of the financial crisis and post-financial crisis years during central bank announcement days (Ferrari et al., 2017). Another possible driver could be recent technological innovations, such as algorithmic trading tools and faster news transmission through fibre-optic cables, resulting in faster processing of monetary policy announcement information.

Other observations include the EUR/GBP exchange rate having the lowest magnitude of monetary policy announcement surprise effect of all the currency pairs. This is observed in the reduced magnitude of the coefficient in the following surprises across Panel (A) and Panel (B). Specifically, the transmission of monetary policy announcement surprises to EUR/GBP is the weakest in the "Target" surprise in the post financial crisis period, the "Timing" surprise in the pre-financial crisis period, the "Forward Guidance" surprise in the financial crisis period and the "QE" surprise in the post financial crisis period. Future work could explore the reasons behind this difference in the response for EUR/GBP and analyze if the effects are similar for other widely traded Euro cross currency pairs.

VII. Robustness Checks

All regressions have been checked and cleared of multicollinearity and heteroskedasticity. A robustness check replacing OIS rates with German bunds is included in Appendix B for "Press Release" and "Press Conference" and shows that the same observations hold.

VIII. Potential Shortfalls of Research

A. US initial jobless claims report.

The US weekly Initial Jobless Claims (IJC) is the only repeatedly occurring economic release that coincides with the ECB monetary policy announcements. Specifically, it is released during the beginning of the "Press Conference" window. As explained in Section 2, other news releases that occur during the same period may result in omitted variable bias in the regression despite the narrow windows. However, both Brand et al. (2010) and Altavilla et al. (2019) evaluated the impact of the US report on the identified factors of monetary policy announcements and found very small, statistically insignificant coefficients and made no difference to the coefficients of interest with its inclusion or omission in the regressions. As such, excluding a control for the IJC in the "Press Conference" regression should not bias the results of this paper.

B. Drawbacks of the H-F approach.

The H-F approach used in this paper is useful to estimate immediate effects of monetary policy on financial variables. However, estimating longer term persistence of monetary policy announcement effects on the exchange rate becomes much more difficult with this approach and is beyond the scope of this paper. Future research on analyzing the persistence of the monetary policy announcement effects on these currency pairs will require the VAR approach.

C. Possible broader definition of monetary policy.

Given this paper's strict definition of monetary policy, actions that do not affect market rates are not treated as monetary policy surprises. This is a useful definition during an ELB era compared to defining monetary policy as measured by key policy short rates alone, but a broader concept of monetary policy is still possible (Wright, 2019). It may also have different and interesting implications for the impact of monetary policy on the exchange rate (Wright, 2019).

IX. Conclusion and Future Policy Implications

Overall, the paper observes the growing sensitivity of exchange rate response to monetary policy announcements, supporting the conclusion by Altavilla et al. (2019) that the ECB has growing influence on the exchange rate in the post-ELB era. The conventional surprise in the form of the "Target" factor as well as the unconventional surprises captured in the "Timing", "Forward Guidance" and "Quantitative Easing" factors have all resulted in exchange rate appreciations across all currency pairs. This happens through a communication channel resulting in increases in the market's expectations of future monetary policy by driving up inflation expectations. Notably, the relative strength of the "Forward Guidance" effect on the exchange rate in comparison to the "Target" effect demonstrates the growing prominence of the ECB's unconventional monetary policy toolkit on aiding the transmission of monetary policy.

In terms of policy implications, the ECB Governing Council should increasingly consider that while their monetary policy announcements result in higher future inflation expectations, the corresponding effect of Euro nominal exchange rate appreciations will cause a present-day decrease in the level of current inflation. Since Altavilla et al. (2019) finds that the surprise effects of monetary policy announcements are persistent, this can lead one to infer that a nominal exchange rate appreciation would cause imports to become cheaper, making them more attractive and causing demand for local products to fall. To stay competitive, Euro-area firms lower their prices, resulting in overall lower inflation.

Within the ECB's own definition of price stability, this monetary policy announcement channel driven by changes in inflation expectations may be detrimental to that goal. Additionally, it may adversely affect the credibility of the ECB, since the communication of monetary policy decisions counter the intended effects of the monetary policy actions to stimulate inflation. With this paper specifically outlining the effect of monetary policy announcements on each currency pair, the ECB could alter their communication during monetary policy announcements to influence exchange rates in a way that stimulates foreign demand-driven domestic growth.

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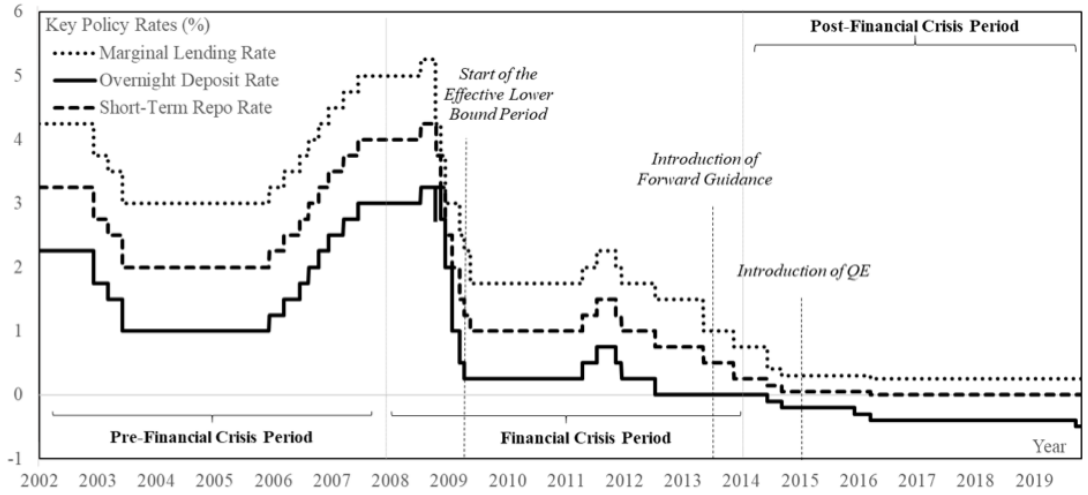
X. Appendix A: Tables and Figures

Figure 1. Evolution of ECB monetary policy over time.



Source: Datastream

Table 1. Regression results of "Press Release" and "Press Conference"

Panel (A): Press Release Window

Time Period	Pre- Financial Crisis Jan-2002 ~ Dec-2007			Financial Crisis Jan-2008 ~ Dec-2013			Post-Financial Crisis Jan-2014 ~ Jun-2019		
VARIABLES	**EUR/USD**	**EUR/GBP**	**EUR/JPY**	**EUR/USD**	**EUR/GBP**	**EUR/JPY**	**EUR/USD**	**EUR/GBP**	**EUR/JPY**
Target	-0.01	0.01***	-0.01*	-0.01	0.01	-0.02***	0.15***	0.12***	0.14***
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.05)	(0.04)
p-value of Target	0.37	0.02	0.09	0.22	0.29	0.02	0.00	0.00	0.00
R^2	0.01	0.08	0.04	0.02	0.02	0.08	0.18	0.19	0.24
Adjusted R^2	0.00	0.07	0.03	0.01	0.00	0.07	0.17	0.17	0.23
Observations	72			73			48		

Panel (B): Press Conference Window

Time Period	Pre- Financial Crisis Jan-2002 ~ Dec-2007			Financial Crisis Jan-2008 ~ Dec-2013			Post-Financial Crisis Jan-2014 ~ Jun-2019		
VARIABLES	**EUR/USD**	**EUR/GBP**	**EUR/JPY**	**EUR/USD**	**EUR/GBP**	**EUR/JPY**	**EUR/USD**	**EUR/GBP**	**EUR/JPY**
Timing	0.06***	0.03***	0.05***	0.01	0.02	0.01	-0.03	0.01	0.04
	(0.03)	(0.01)	(0.01)	(0.02)	(0.02)	(0.03)	(0.10)	(0.07)	(0.09)
Forward Guidance				0.04***	0.03***	0.05***	0.20***	0.16***	0.13**
				(0.02)	(0.01)	(0.02)	(0.07)	(0.06)	(0.07)
Quantitative Easing							0.04*	0.02	0.06***
							(0.02)	(0.02)	(0.02)
p-value of Timing	0.00	0.01	0.00	0.81	0.33	0.67	0.73	0.89	0.65
p-value of FG				0.00	0.04	0.01	0.01	0.01	0.05
p-value of QE							0.07	0.31	0.01
R^2	0.16	0.11	0.18	0.43	0.41	0.41	0.62	0.61	0.66
Adjusted R^2	0.15	0.09	0.16	0.42	0.39	0.40	0.59	0.59	0.63
Observations	67			72			48		

Note: ***=1%,**=5%, *=10%, significance level for both panels. Robust standard errors in parenthesis. Target = 1-month OIS, Timing= 6-month OIS, Forward Guidance = 2-year OIS, QE= 10-year German Bund

Figure 2. “Press Release” Analysis - Correlation of the Target Surprise with currency pairs.

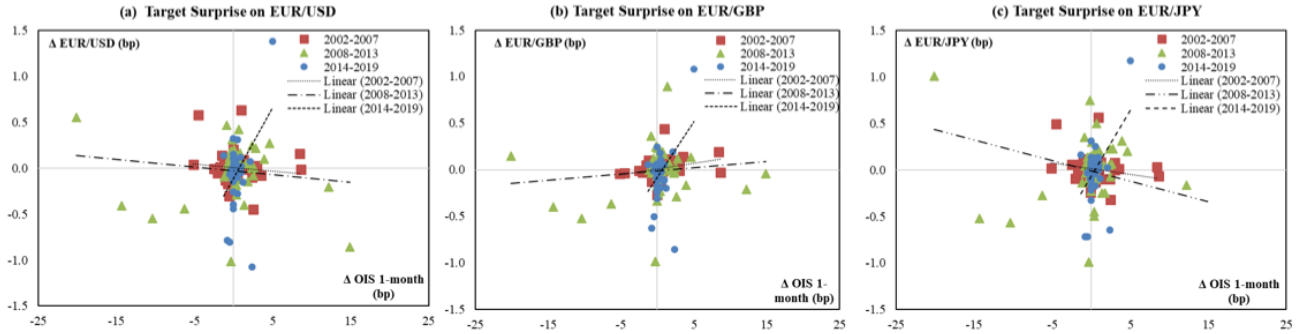
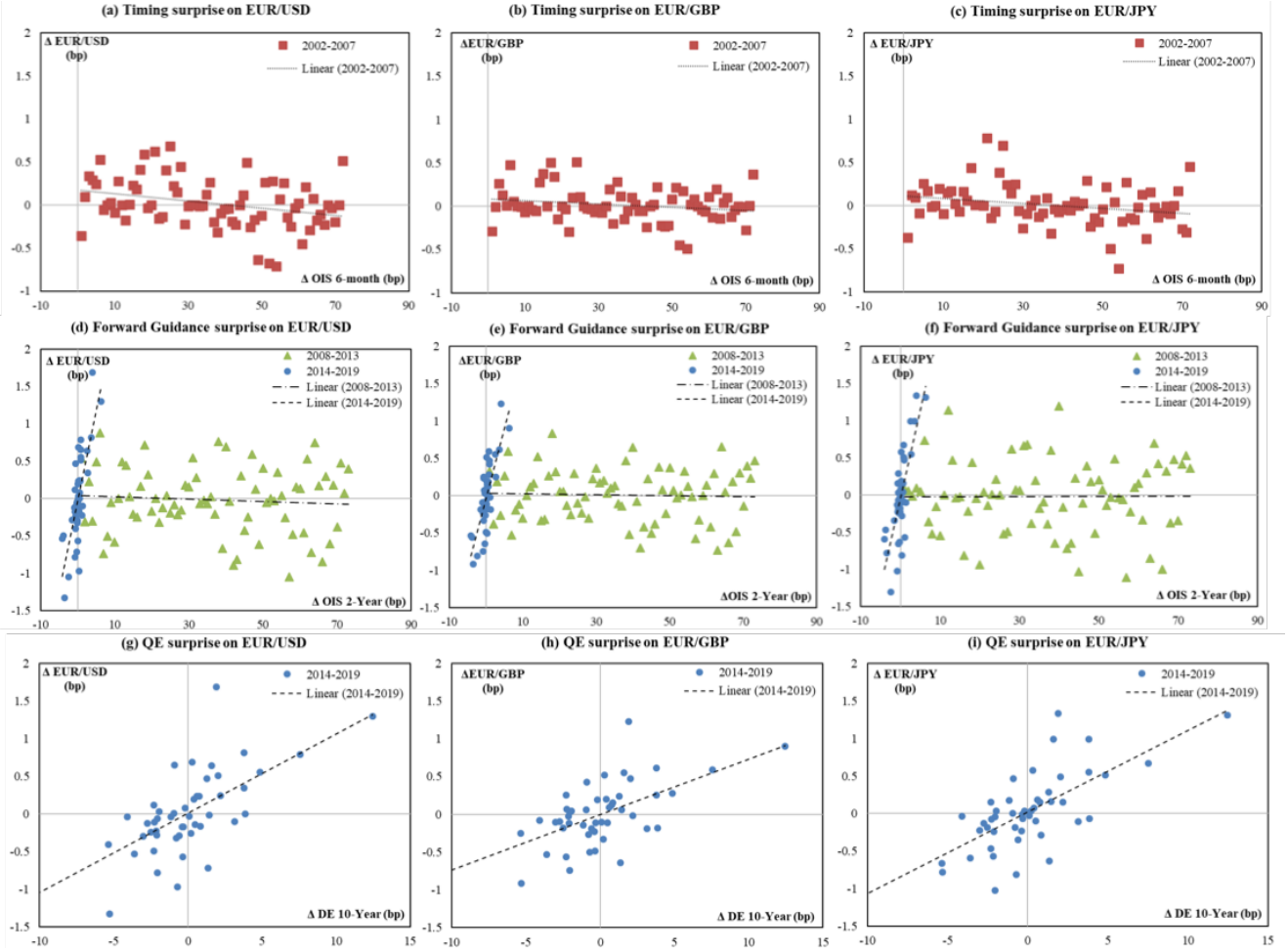


Figure 3. “Press Conference” Analysis - Correlation of Timing, Forward Guidance and QE Surprises with currency pairs.



XI. Appendix B: Robustness Check for Regressions, with German Bund Yields

Panel (A): Press Release Window

Time Period	Pre- Financial Crisis			Financial Crisis			Post-Financial Crisis		
	Jan-2002 ~ Dec-2007			Jan- 2008 ~ Dec- 2013			Jan- 2014 ~ Jun- 2019		
VARIABLES	EUR/USD	EUR/GBP	EUR/JPY	EUR/USD	EUR/GBP	EUR/JPY	EUR/USD	EUR/GBP	EUR/JPY
Target	-0.02	0.00	-0.01	-0.01	0.00	-0.03***	0.03	0.03	0.04
st. error	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.04)	(0.03)	(0.03)
p-value of Target	0.27	0.73	0.47	0.27	0.59	0.02	0.38	0.35	0.18
R^2	0.06	0.01	0.02	0.02	0.00	0.07	0.02	0.02	0.04
Adjusted R^2	0.01	-0.04	-0.02	0.00	-0.01	0.06	0.00	0.00	0.02
Observations	72			73			48		

Panel (B): Press Conference Window

Time Period	Pre- Financial Crisis			Financial Crisis			Post-Financial Crisis		
	Jan-2002 ~ Dec-2007			Jan- 2008 ~ Dec- 2013			Jan- 2014 ~ Jun- 2019		
VARIABLES	EUR/USD	EUR/GBP	EUR/JPY	EUR/USD	EUR/GBP	EUR/JPY	EUR/USD	EUR/GBP	EUR/JPY
Timing	0.11***	0.08***	0.08***	0.00	0.01	0.02	0.07	0.07*	0.10*
st. error	(0.02)	(0.01)	(0.01)	(0.02)	(0.44)	(0.02)	(0.06)	(0.06)	(0.05)
FG				0.05***	0.03***	0.04***	0.15***	0.15***	0.10***
st. error				(0.01)	(0.00)	(0.01)	(0.04)	(0.04)	(0.04)
QE							0.03***	0.03***	0.06***
st. error							(0.02)	(0.02)	(0.02)
p-value of Timing	0.00	0.00	0.00	0.97	0.44	0.39	0.24	0.06	0.06
p-value of FG				0.00	0.00	0.00	0.00	0.00	0.01
p-value of QE							0.08	0.28	0.00
R^2	0.57	0.59	0.59	0.43	0.43	0.40	0.68	0.66	0.71
Adjusted R^2	0.56	0.57	0.57	0.42	0.41	0.38	0.65	0.64	0.69
Observations	67			72			48		

Note: *=1%,**=5%, *=10%, significance level for both panels. Robust standard errors in parenthesis. Since German 1-month bund quotes were not available, the Target surprise is replaced with 3-month German Bunds, and hence may not be an accurate comparison. Timing= 6-month German Bund, Forward Guidance = 2-year German Bund, QE= 10-year German Bund.**