Central Bank Information Effects and Exchange Rates

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Abstract

Central banks set interest rates, but they also send signals about the state of the economy and their intentions regarding future monetary policy. This paper investigates the effects of central bank information on the exchange rate. Looking at the euro area, I find the exchange rate to be considerably more sensitive to informational shocks than to conventional monetary policy shocks. Following the methodology of Andrade and Ferroni (2021), I identify two informational monetary policy factors: a Delphic factor, which captures changes to the economic outlook, as revealed by the central bank, and an Odyssean factor, which captures changes in the expected conduct of monetary policy. Both shocks immediately appreciate the euro after a surprise increase in the interest rate. The Odyssean shock has stronger, but less persistent effects, compared to the Delphic shock. These effects are significant and persistent for both financial and macroeconomic variables, and hold at intra-daily, daily, and monthly frequencies.

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1 Introduction

The increasing availability of high-frequency data on financial asset prices has greatly expanded the research frontier on the effects of monetary policy. Observing the response of many financial time series to monetary policy announcements has provided a more detailed view of how central bank decisions and communication affect markets and expectations. These effects are more complex than the implications of conventional monetary policy shocks.

This more refined picture of the immediate effects of monetary policy on financial variables has shed light on puzzles that are difficult to reconcile with conventional monetary theory. For example, it is common for a surprise increase in interest rates to exhibit expansionary effects.[1] While this contradicts our understanding of a conventional monetary policy, it can be explained by central bank information (CBI) effects: if the increase in yields coincides with monetary authorities signaling an improved economic outlook, then an *apparent* monetary tightening may be followed by an expansion.

A recent strand of the literature has identified puzzles regarding the exchange rate effects of monetary policy. Gürkaynak et al. (2021) find that the domestic currency often depreciates after a monetary tightening. This is contrary to standard uncovered interest rate parity (UIP) theory, which suggests that the currency is bound to appreciate in this case. However, Gürkaynak et al. (2021) show that, while inflation or inflation target shocks can theoretically explain the unexpected exchange rate behavior, there remains an identification problem when multiple shocks are used to explain a single covariance in the data. Schmitt-Grohé and Uribe (2022) find that the domestic currency depreciates when the monetary policy shock is permanent, also leading to deviations from UIP. Focusing specifically on CBI shocks, Franz (2020) finds the exchange rate response to be ambiguous and dependent on the currency pair.

This paper aims to examine the effects of monetary policy on the exchange rate, focusing in particular on the informational components of monetary policy. For this, I distinguish between conventional monetary policy shocks and two types of informational monetary policy shocks: The Delphic shock, on the one hand, captures changes in the assessment of future macroeconomic conditions. Similar to a news shock, an unexpected increase in interest rates can serve as a signal of a more optimistic economic outlook, to which the central bank merely reacts. Market participants with imperfect information subsequently revise their expectations. The Odyssean shock, on the other hand, captures changes in the expected future monetary policy stance. Market participants extract signals from central bank communication, in order

[1] see Jarociński and Karadi (2020) or Miranda-Agrippino and Ricco (2021), among many.

to learn whether the stance of monetary policy will change in the future. These signals may be unintentional or intentional. They can include inflation target shocks, permanent monetary policy shocks, forward guidance shocks, or changes in central bank preferences.

My analysis has three stages: First, an analytical exchange rate decomposition illustrates how CBI can affect exchange rates through expectations. Starting from a no-arbitrage condition, I show that the exchange rate depends on the path of future interest rate differentials, risk premia, and the long-run inflation differential. This decomposition sheds light on the dependence of the spot exchange rate on expectations of the future path of these variables. As long as a shock affects the expectation of these components, it should affect the current exchange rate as well. Typically, informational monetary policy shocks have a larger effect on long-run expectations—rather than current macroeconomic variables—and are therefore also predicted to affect the current exchange rate.

Second, I extract three types of shocks (Target, Delphic, and Odyssean) from a factor model using high-frequency financial data and analyze their short-run effects on the exchange rate, as well as on other financial data. The construction of these shocks, using data on interest rate futures and inflation-linked swaps, follows Andrade and Ferroni (2021): the Target factor, which captures conventional monetary policy, is the only factor that loads on the short-term interest rate. The Delphic and the Odyssean factors both raise the 5-year interest rate, but they have opposite effects on inflation expectations. While the Delphic factor is inflationary, the Odyssean factor is deflationary. To get a dynamic view of the short-run effects of these shocks, I employ a proxy structural vector autoregression (SVAR) model using daily asset price data. The domestic currency appreciates after both Delphic and Odyssean shocks. The effects of the Delphic factor are particularly persistent, while the effects of the Odyssean factor fade in a 6-month window of daily data.

Third, to assess the longer-term, macroeconomic, effects of the CBI shocks, I construct a monthly proxy SVAR model that goes beyond financial variables to include macroeconomic aggregates as well. The results show that CBI effects have significant effects on macroeconomic variables such as GDP and inflation. Consistent with the daily analysis, the Odyssean shocks are deflationary and the Delphic shocks are inflationary. In both cases, the exchange rate appreciates. For the Delphic shocks, the appreciation is weaker on impact, but more persistent than for the Odyssean shock.

The primary contribution of this paper is to examine the link between CBI shocks and exchange rates in the euro area. In particular, it demonstrates that the exchange rate effects of CBI shocks are consistent with the theoretical predictions from an analytical decomposition, taking into account a wide array of high-frequency data and distinguishing between Delphic and Odyssean shocks. The study therefore also aims to enhance the understanding of the effects of monetary policy more generally. Because the literature on monetary policy and CBI often focuses on closed-economy effects, they forego potentially valuable information inherent in exchange rates, even though the foreign exchange market is highly liquid and forward-looking (King et al., 2012). Also, Rosa (2011) shows that exchange rates are highly sensitive to monetary news, absorbing monetary surprises almost immediately. Hence, the exchange rate may be a valuable source for a more thorough understanding of the nature of monetary policy shocks and CBI, as this paper aims to demonstrate.

The remainder of this paper is organized as follows: Section 2 reviews the literature to which this paper relates. Section 3 provides an analytical decomposition of the connection between informational monetary policy shocks and exchange rates. Section 4 extracts a Target, a Delphic, and an Odyssean factor from high-frequency asset price surprises. Section 5 presents the effects of the three factors on exchange rates and the economy in high-frequency data, while Section 6 builds a monthly proxy SVAR model to study the long-run effects on exchange rates and the macroeconomy, at a monthly frequency. Section 7 concludes.

2 Related Literature

In simple open-economy models with floating exchange rates, UIP relates exchange rate changes to the interest rate differential (see, among many, Galí and Monacelli, 2005). Thus, monetary policy is understood as a key determinant of the exchange rate. However, many have documented that UIP is not a good empirical approximation of exchange rates—Fama (1984) being the best-known example of this. Faust and Rogers (2003) show that only a small fraction of the exchange rate variance is explained by monetary policy shocks and that instead, there are large deviations from UIP.

Several strands of the literature have emerged to explain the failure of UIP. Some studies have for instance relaxed the assumption of perfect and rational information about current and future interest rate differentials (see Evans and Lyons (2008) and Bacchetta and Van Wincoop, 2006). An important strand of the literature on the failure of UIP is based on the existence of currency risk premia. Seminal papers in this literature are, Lustig and Verdelhan (2007) and Benigno et al. (2011). Engel (2014) provides an informative overview of this line of research. In particular, the study by Leombroni et al. (2021) is closely related to the present paper, as they show that European Central Bank (ECB) communication has long-run effects on risk premia, as measured by the spread between core and periphery interest rates in the euro area.

My study also relates to the literature on information processing in the foreign exchange market. While Evans and Lyons (2005) show that, due to the microstructure of foreign exchange markets, news is incorporated only gradually (in a few days), Rosa (2011) finds that monetary surprises are incorporated into exchange rates within 30-40 minutes.

The present work also contributes to the study of the effects of monetary policy, as identified with high-frequency asset prices. While studying monetary policy through event-study analysis of unexpected asset price changes goes back to Cook and Hahn (1989) and Kuttner (2001), Gürkaynak et al. (2005a) show, using high-frequency asset price changes, that monetary policy has multiple dimensions. Using a principal component approach, they show that central banks affect the path of future interest rates with a factor that is independent of conventional policy shocks, called the Path factor.[2] Altavilla et al. (2019) apply the approach of Gürkaynak et al. (2005a) to the euro area and extend it by using information from the press release, as well as the press conference of the ECB, deriving forward guidance and quantitative easing shocks.[3] Nevertheless, some studies show that high-frequency shocks may not be exogenous to the economy (see, for example, Ramey (2016), Bauer and Swanson (2023), or Miranda-Agrippino and Ricco, 2021).

Several researchers have suggested a further decomposition of the Path factor. Indeed, an increase in the Path factor could result either from (a) changes in the economic outlook, which market participants learn either from the signals emitted by monetary policy decisions or from the accompanying communication by central bankers, or (b) from (perceived) changes in the intended conduct of monetary policy. While the former mechanism underlies Delphic shocks, the latter defines Odyssean shocks (Andrade and Ferroni, 2021).

Some papers focus more on either the Delphic or the Odyssean component. Papers that focus more on Delphic shocks, are for example Melosi (2017), who shows that higher interest rates can serve as a signal that the economic outlook is more positive than previously expected. Miranda-Agrippino and Ricco (2021) show that information effects can have a confounding effect when assessing the transmission of (conventional) monetary policy to the macroeconomy. Papers focusing on Odyssean shocks include, for example, Gürkaynak et al. (2005b), who

[2]A promising extension of how monetary policy affects long-term interest rates is provided by Kaminska et al. (2021), who show that effects of monetary policy can be decomposed into three components: the Target factor, the (expected) Path factor, and a factor capturing the uncertainty of the Path factor.

[3]The work of Altavilla et al. (2019) is also key, as they provide, and regularly update the surprises data, on which this paper and many others depend.

relax the assumption of perfectly known long-run equilibria in GDP, inflation, and interest rates. One way to model this is with (permanent) inflation target shocks, as modeled by Ellingsen and Soderstrom (2001) or Lukmanova and Rabitsch (2023). Schmitt-Grohé and Uribe (2022) do a similar exercise, but focus on the open-economy effects of permanent and transitory monetary policy shocks, and find that permanent shocks are contractionary and lead to a depreciation of the domestic currency.

Focusing on CBI effects, Nakamura and Steinsson (2018) find that information effects have an impact on individual expectations, which they proxy with survey data. Bauer and Swanson (2023), however, challenge this interpretation by showing that there is confounding information between the central bank announcement and the survey date that can also explain the findings. However, this issue does not pertain to the puzzling co-movement between interest rates and other asset prices, as (market-based) expectations are measured at high frequency around monetary policy announcements. Jarociński and Karadi (2020) and Kerssenfischer (2022), among many others, distinguish between conventional monetary policy and CBI shocks via sign restrictions of interest rate and stock price surprises. While both effects move interest rates in the same direction, they have opposite effects on output, and thus on stock prices. Cieslak and Schrimpf (2019) extend this research by additionally identifying growth and risk premia shocks.

Focusing on international effects of CBI shocks, Franz (2020) and Gründler et al. (2023) both employ the interest rate–stock price identification. For the euro area, Franz (2020) finds that the information shock has no significant effect on the exchange rate, but there is heterogeneity between safe and risky currencies due to differential effects of CBI shocks on risk premia. Holtemöller et al. (2020) and Gründler et al. (2023) find that an information shock has a weaker, but more persistent effect on the exchange rate. Pinchetti and Szczepaniak (2021) look at the United States (U.S.) case, and its spillover effects on global economic activity, global risk appetite, and exchange rates, underscoring the global repercussions of U.S. monetary policy. Jarociński (2022) finds that, CBI shocks from ECB policy spill over to the U.S., but pure policy shocks do not.

Focusing on the high-frequency effects of monetary policy on exchange rates, Gürkaynak et al. (2021) model the informational assumptions behind CBI effects. They find that for a significant fraction of central bank announcements, the domestic currency depreciates for both the U.S. and the euro area. They call this unexpected behavior the *exchange rate puzzle*. I revisit the puzzle, focusing on the 5-year maturity, and discuss it in Subsection 5.2.

3 Deconstructing Exchange Rate Surprises

This section develops an analytical decomposition of exchange rate changes based on a no-arbitrage condition. Specifically, this decomposition shows how changes in the exchange rate are related to changes in expectations about future interest rate differentials (between the two respective countries and exchange rates), future risk premia, and future inflation differentials. As explained in the introduction, if a shock persistently affects one or several of these components—as will be the case for these shocks, as shown in Sections 5 and 6—then the analytical decomposition predicts that these shocks should have an impact on contemporaneous changes in the exchange rate.

The derivation builds on Lustig (2021), Stavrakeva and Tang (2015), and Stavrakeva and Tang (2020). The starting point is a representative investor who can freely invest in a domestic or a foreign risk-less bond. The nominal exchange rate serves to equalize the home and foreign bond Euler equation of the investor,

$$E_t\left[M_{t+1}R_t^*\frac{S_{t+1}}{S_t}\right] = E_t[M_{t+1}R_t] = 1, \tag{1}$$

where M_{t+1} is the stochastic discount factor, R_t is the nominal return on a risk-free bond, and S_t is the nominal exchange rate, measured in units of domestic currency per unit of foreign currency.[4] This means that an increase in S_t implies a depreciation of the home currency. The exchange rate adjusts to equalize the investor's expected utility gain. Assuming conditional log-normality of exchange rates and interest rates, and taking logs on both sides, I get the following equation:

$$s_t = E_t(s_{t+1}) + d_t + \sigma_t, \tag{2}$$

where lowercase letters denote variables in logs and $d_t = i_t - i_t^*$ is the nominal interest rate differential. An asterisk denotes a foreign variable. σ_t is the expected excess return, or foreign exchange risk premia.

Here, σ_t serves as the residual term in (2). Thus, the above equation is satisfied by construction.

[4]The notation for the exchange rate is not uniform in this literature. In most theoretical papers, an increase represents a depreciation of the home currency. For empirical papers, an increase depicts an appreciation of the home currency in most of the related articles. For this reason, I will be inconsistent and an increase in S_t in this section denotes a depreciation. In the empirical part of the paper, an increase in the domestic currency implies an appreciation of the euro.

Iterating (2) forward gives

$$s_t = -E_t \sum_{j=0}^{\infty} [d_{t+j} + \sigma_{t+j}] + \lim_{k\to\infty} E_t [s_{t+k}], \tag{3}$$

and, computing the first difference on both sides of the equation gives

$$s_{t+1} - s_t = -d_t - \sigma_t - \sum_{j=1}^{\infty} (E_{t+1} - E_t) [d_{t+j} + \sigma_{t+j}] + (E_{t+1} - E_t) \lim_{k\to\infty} [s_{t+k}]. \tag{4}$$

Now, I use (2) to simplify the equation

$$s_{t+1} - E_t [s_{t+1}] = -\sum_{j=1}^{\infty} (E_{t+1} - E_t) [d_{t+j} + \sigma_{t+j}] + (E_{t+1} - E_t) \lim_{k\to\infty} [s_{t+k}]. \tag{5}$$

From here on, I use $\nu_{t+1}(x_{t+h}) = E_{t+1} [x_{t+h}] - E_t[x_{t+h}]$ to denote the update of conditional expectations for a generic variable x_{t+h}, given the information set at period t and $t+1$. Equation (5) is rewritten:

$$\nu_{t+1}(s_{t+1}) = \sum_{j=0}^{\infty} \nu_{t+1}(d_{t+j+1}) + \sum_{j=0}^{\infty} \nu_{t+1}(\sigma_{t+j+1}) + \nu_{t+1} \left(\lim_{k\to\infty} s_{t+k} \right). \tag{6}$$

The previous expression shows that the exchange rate surprise is a function of surprises in the cumulative interest rate differential, the cumulative risk premia, and the surprise in the expected long-run nominal exchange rate.

To get a better understanding of the last term, I follow Stavrakeva and Tang (2015) and assume that long-run purchasing power parity (PPP) holds, meaning that the real exchange rate $q_t = s_t + p_t^* - p_t$ is stationary. First differencing this definition yields $\Delta q_{t+1} = \Delta s_{t+1} + \pi^*_{t+1} - \pi_{t+1}$, which gives, using (6):

$$\begin{aligned}
\nu_{t+1} \left(\lim_{k\to\infty} s_{t+k} \right) &= E_{t+1} \left[\lim_{k\to\infty} s_{t+k} \right] - E_t \left[\lim_{k\to\infty} s_{t+k} \right] \\
&= E_{t+1} \left[\lim_{k\to\infty} s_{t+k} - s_t \right] - E_t \left[\lim_{k\to\infty} s_{t+k} - s_t \right] \\
&= E_{t+1} \left[\lim_{k\to\infty} \sum_{j=0}^{k} \Delta q_{t+j} + \pi^*_{t+j} - \pi_{t+j} \right] - E_t \left[\lim_{k\to\infty} \sum_{j=0}^{k} \Delta q_{t+j} + \pi^*_{t+j} - \pi_{t+j} \right] \\
&= E_{t+1} \left[\lim_{k\to\infty} \sum_{j=0}^{k} \pi^*_{t+j} - \pi_{t+j} \right] - E_t \left[\lim_{k\to\infty} \sum_{j=0}^{k} \pi^*_{t+j} - \pi_{t+j} \right] \\
&= \sum_{j=0}^{\infty} \nu_{t+1} \left(\pi^*_{t+j} - \pi_{t+j} \right).
\end{aligned}$$

Thus, when the real exchange rate $q_t = s_t + p_t^* - p_t$ is stationary, the change in the long-run value of the exchange rate depends entirely on the surprises regarding the difference in the inflation paths for both countries. This implies that, if long-run PPP holds, equation (6) can be rewritten as

$$\nu_{t+1}(s_{t+1}) = \sum_{j=0}^{\infty} \nu_{t+1}(d_{t+j+1}) + \sum_{j=0}^{\infty} \nu_{t+1}(\sigma_{t+j+1}) + \sum_{j=0}^{\infty} \nu_{t+1} \left(\pi_{t+j}^* - \pi_{t+j} \right). \tag{7}$$

The exchange rate surprise therefore depends on updates in the conditional expectations of the interest rate differential, foreign exchange risk premia, and the inflation differential. Hence, changes in exchange rates depend not only on updates in the expected interest rate differential, but also on risk premia, and importantly, on the inflation differential. In particular, since inflation targeting is the mandated objective of the ECB, actions and communications of the ECB are likely to influence the path of expected inflation rates. The source of this change in expected inflation rates during the monetary policy window could be conventional monetary policy, Delphic, or Odyssean shocks. As informational shocks affect long-run interest rates, which themselves depend on expected average short-term interest rates, one can assume that they have a more meaningful effect on the path of interest rates, when compared to changes in the current short-term interest rate. The following sections show that the Target, the Delphic, and the Odyssean monetary policy shocks do indeed have differentiated dynamic influences on future inflation and interest rates. Accordingly, we can expect these three shocks to also have different effects on exchange rates.

To simplify the analysis and focus on macroeconomic drivers of exchange rates, I will abstract from the risk premium effects. Further, foreign variables could theoretically offset the dynamics in domestic variables, if they are equally affected by the domestic monetary policy shocks. However, to the best of my knowledge, there is no paper in the literature that finds the effects on foreign variables problematic. Therefore, I assume that the dynamics in equation (7) are predominantly driven by domestic variables.

Using the previous decomposition, let us try to predict the signs of the effects of positive Odyssean and Delphic shocks on the exchange rate, defining the shock to be positive if it increases domestic interest rates. Following the definition of Andrade and Ferroni (2021)—which we will use below to construct our shocks—an Odyssean shock has effects of opposite signs on the interest rate (i.e., on the d_{t+j}'s) and inflation (the π_{t+j}'s). Therefore, according to (7), a positive Odyssean shock should lead to an appreciation of the domestic exchange rate. (Note that the signs in front of the d_{t+j} and the π_{t+j} are opposite in (7)) In contrast, a Delphic shock has effects of the same sign on the d_{t+j}'s and the π_{t+j}'s, and the sign of its effect on the exchange rate is therefore ambiguous.[5] The empirical analysis, presented in the following sections, will help to determine this sign.

4 Construction of the Shocks

In this section, I derive three monetary policy shocks using a factor model. Namely, a standard monetary policy shock, as captured by the Target factor, is separated from Delphic and Odyssean shocks. In the following sections, these three shocks are then used to explain the response of exchange rates at high and low frequencies. Before turning to the construction of the shocks (in Subsection 4.2), Subsection 4.1 examines whether the magnitude of the observed effects even warrants a separate investigation of information effects in the first place.

4.1 The Quantitative Importance of Central Bank Information

To investigate whether informational monetary policy shocks are important for the determination of exchange rates, we exploit the specific structure of ECB announcements. On monetary policy days, the ECB's communication starts with the publication of the press release at 13:45 and continues with a one-hour press conference at 14:30.[6] The press release contains only a brief statement about the interest rate decision. The press conference gives a (carefully crafted) statement explaining the decision. Thus, we have two distinct windows in which to observe the market reaction. We assume that the conventional (short-term) monetary policy shock comes from the press release (RE) window, and the informational shocks stem entirely from the press conference (PC) window. This allows us to obtain preliminary insights into the relative importance of pure monetary policy and informational shocks. It can be understood as a model-free, preliminary analysis of the importance of informational shocks.

I run the following regressions:

$$\Delta x_{h,t} = \beta_0 + \beta_1 \Delta x_{w,t} + \varepsilon_t, \tag{8}$$

[5] Note, in particular, that the existence of Delphic shock could rationalize the exchange rate puzzle of Gürkaynak et al. (2021) if the inflation effect were to dominate over the exchange rate effect. However, this is not the case, as shown in Subsection 5.2.

[6] A more detailed description of the monetary policy process of the ECB and the dataset used can be found in Appendix A.

where $w = \{RE, PC\}$ denotes the RE and PC windows, and $h = \{ME, 1d, 7d\}$ denotes the period, over which the asset price change is measured. Each variable is regressed on itself, with different window sizes, in order to determine the persistence of surprises from the RE and PC windows over a period of up to 7 days. The explained variables span the Monetary Event (ME) window (adding the RE and PC effects), daily differences, and 7-day differences. This allows us to compare the relative importance of both windows. Table 1 displays the adjusted R^2 of these regressions.

Table 1: Explained Variance of the Press Release and Press Conference Surprise (in %)

	RE window			PC window		
	ME	$1d$	$7d$	ME	$1d$	$7d$
OIS 3M	51	8	-	53	46	10
OIS 1Y	21	33	42	85	68	16
OIS 5Y	16	10	-	82	46	28
OIS 10Y	13	6	-	80	24	20
USD/EUR	21	10	3	76	44	10
JPY/EUR	14	20	-	72	23	20
GBP/EUR	24	8	5	73	45	-

Notes: This table shows the adjusted R^2 of each regression in equation (8). It shows how intra-daily asset price changes persist over a time period of up to 7 days. The explanatory variable stems from the RE (= press release) window and the PC (= press conference) window, while the explained variable is the same variable for the ME (= monetary event) window (including press release and conference), 1-day difference, and 7-day difference. For regressions that do not reach overall significance (as tested with an F-test at the 1% level), the values are omitted and replaced by "$-$".

The contributions of RE surprises, which make up the left-hand side of the table, come from the press release and thus from the ECB's interest rate decision. The right-hand side of the table shows the effects of PC surprises. The dynamics stemming from the press conference window is assumed to proxy informational effects. The table shows that, apart from the 3-month OIS rate, changes from the PC window have a significantly greater impact than from the RE window. The price changes of the RE window have no lasting effect on the intra-daily, daily, or weekly rate of change of the respective variable. Interpreting the changes in the two windows as pure policy and CBI effects, respectively, the informational effects strongly dominate the effects of conventional monetary policy.

However, the distinction between the press release and the press conference is not perfect. Since March 2016, the ECB has started to include information about the size of large-scale asset purchases in the press release. Even with these additional shocks in the RE window, the PC window still dominates.

Another indication of the dominance of informational components in exchange rate changes can be found in the correlation of high-frequency asset price surprises around ECB monetary policy announcements. In the 2004-2022 sample period, exchange rate surprises correlate more strongly with changes in long-term interest rates, rather than short-term interest rates. For example, the USD/EUR exchange rate exhibits a 62% correlation with the 5-year OIS rate, but only a 34% correlation with the 3-month OIS rate.[7] This suggests that the long end of the yield curve, (which depicts an average of short-term interest rates), is more closely related to exchange rate changes.

While the findings in this subsection do not provide a rigorous analysis of the importance of CBI effects, they provide a preliminary analysis that suggests that informational monetary policy shocks are quantitatively important—potentially even more important than conventional monetary policy shocks—and should therefore be taken into account when analyzing the impact of monetary policy (in the broad sense) on exchange rates.

4.2 Factor Model

I build a factor model using data on asset price surprises, in order to derive different monetary policy shocks. Specifically, I use the changes in interest rate, exchange rate, and inflation swaps in a narrow window around ECB announcements. The assumption is that these asset prices are predominantly affected by monetary policy in a narrow window around ECB announcements, and are liquid enough to react immediately to monetary policy. Employing zero and sign restrictions, I derive a Target, a Delphic, and an Odyssean monetary policy factor.[8] The effects of these factors are then analyzed in subsequent sections. For the derivation, I closely follow the methodology of Andrade and Ferroni (2021), as it is well suited to evaluate the effects on exchange rates.

The factor model is of the form

$$Y = F\Omega' + \varepsilon, \tag{9}$$

where Y denotes the data matrix. F contains the principal components in its columns and Ω contains the corresponding factor loadings. $\varepsilon \sim N(0, \Sigma)$ denotes the residuals. Y has

[7] A full correlation table of asset price surprises can be found in the appendix, in Table 6.

[8] The taxonomy of these shocks is taken from Campbell et al. (2012).

dimensions $T \times n$, where T is the number of monetary policy meetings, and n is the number of data series included in the model. F is the $T \times k$ matrix of principal components. Ω is the $k \times n$ matrix of factor loadings, whereas k is the number of factors to be included in the model.

The data matrix Y should contain surprises that are related to current and future monetary conditions, are forward-looking, and are liquid enough such that they quickly incorporate news from monetary policy. That way, they are suitable to capture the potentially multi-dimensional effects of monetary policy. More concretely, I use interest rates across the yield curve, inflation swaps, a stock index, and exchange rates.

For interest rates, I use overnight index swaps (OIS) rates that reflect expected average interest rates, with maturities of 3 and 6 months, as well as 2, 5, and 10 years. For inflation expectations, I use inflation-linked swaps (ILS) with maturities of 2, 5, and 10 years, as well as the 5Y5Y forward inflation rate, which is a common measure of how well inflation expectations are anchored. I combine this data with the euro stoxx50 index, and the USD/EUR, GBP/EUR, and JPY/EUR exchange rates.[9]

The factor model allows us to be agnostic about the number of factors and the asset prices, through which different monetary policy shocks are transmitted. It can also deal well with highly correlated data series, unlike regression-based estimation techniques. However, it would not be advisable to use OIS contracts of all available maturities. In that case, the time period to maturity between different OIS securities would overlap to a large degree, so prices would correlate rather mechanically than for economic reasons. Instead, the model should capture economically meaningful correlations between the data series.[10] The choice of series takes this caveat into account. To avoid this overlap, it would also be possible to calculate forward interest rates (as Andrade and Ferroni, 2021, do), but this does not significantly change the results. Therefore, I opt for the publicly available data from Altavilla et al. (2019).

The OIS, stock index, and exchange rate data is taken from the euro area Monetary Policy Event-Study Database (EA-MPD).[11] The ILS data is taken from Refinitiv and is of daily frequency. See Appendix A for more details.

I use a sample that covers all monetary policy meetings by the ECB from April 2004 to December 2022. The limiting factor for the sample length is the inflation-linked swaps data,

[9]USD/EUR, GBP/EUR, and JPY/EUR denote the euro exchange rate against the U.S. dollar, the British pound, and the Japanese yen, respectively. An increase denotes an appreciation of the euro.

[10]This trade-off is discussed more thoroughly in Swanson (2021).

[11]The EA-MPD is provided by Altavilla et al. (2019) and regularly updated. I use the Monetary Event (ME) window for this analysis, which includes both the press release and the press conference.

which only starts in 2004. However, as Altavilla et al. (2019) point out, the OIS data before 2002 is very noisy, so the loss in explanatory power may be limited.

Before identifying different monetary policy factors, I determine how many statistically significant factors can be found in the data matrix Y. The Cragg and Donald (1997) test is used for this purpose. The test computes a Wald test statistic testing the null hypothesis that there are $k = k_0$ statistically significant factors. Table 2 shows that the hypothesis of two or fewer orthogonal factors is rejected by the test at the 1% level. Therefore, we will aim to identify three orthogonal factors to span the dataset of surprises.

Table 2: Cragg and Donald Test for the number of factors

	F-statistic	p-value
$H_0 : k = 0$	60.48	0.000
$H_0 : k = 1$	48.60	0.000
$H_0 : k = 2$	37.65	0.004
$H_0 : k = 3$	27.58	0.121

Notes: This table presents the Wald test statistics of the Cragg and Donald (1997) test, as well as the corresponding p-values. The test is performed under the null hypothesis that the data in matrix Y is driven by k independent factors. $k = 0$ would imply that the dataset contains only independent white noise series.

This is a meaningful result in itself. Considering the dynamics in interest rates, exchange rates, and inflation swaps surprises, the Cragg and Donald (1997) test states that two factors, for example, a Target and a Path factor, would not be sufficient to explain the effects of monetary policy on the set of asset prices.[12] The test implies that three factors are needed to explain the surprise data. However, the factors need to be rotated to get an economically meaningful identification.[13] This is done in the next subsection.

4.3 Identifying Monetary Policy Factors

For the factors to make economic sense, the principal components F in equation (9) are rotated using an orthogonal matrix Q. This yields

$$Y = (FQ)(\Omega Q)' + \varepsilon = Z\Lambda' + \varepsilon, \tag{10}$$

[12] The findings of Table 2 are independent of any factor rotation. For this reason, this test can be done before identification and factor rotation.

[13] The Cragg and Donald (1997) test is invariant to factor rotations, which is why it is done before the factors are rotated.

where $Z = FQ$ represents the rotated factors, and $\Lambda = \Omega Q$ contains the corresponding factor loadings.[14]

In the following, I aim to identify three different monetary policy factors.[15] The Target factor spans the short end of the yield curve. Since the exchange rate effects of the Target factor are very small (see Subsection 4.1), the focus of this analysis is not on the short end of the yield curve. However, the Target factor is used to orthogonalize the informational factors from the innovations to the short-term interest rate.

I distinguish between shocks to the expected path of future interest rates, captured by the Odyssean factor, and shocks to the macroeconomic outlook, captured by the Delphic factor.

Odyssean shocks are (perceived) exogenous increases in the future path of interest rates, or monetary policy. Since this implies a more aggressive monetary policy stance in the future, long-term inflation expectations are expected to fall, and long-term interest rates and inflation expectations should co-vary negatively.

Delphic shocks, on the other hand, are assumed to capture changes in the economic outlook, as revealed in the monetary policy announcement. The central bank's decision and communication serve as a signal of the expected path of the business cycle. An unexpected increase in long-term interest rates, interpreted as a positive Delphic shock, thus signals to the public that the expected path of interest rates is higher because the economic outlook is more positive. The central bank is merely reacting to the economic outlook. In this case, positive news leads to an increase in interest rate and inflation expectations, and hence to a positive covariance between the two series.

To achieve identification, I use as a first condition a zero restriction on the informational factors, so they do not load on the short-term interest rate. This condition is sensible because central banks have a high degree of control over the short-term interest rate. As a second condition, I exploit the opposite co-variance that Delphic and Odyssean factors have on long-term interest rates and inflation expectations by using sign restrictions to identify the

[14] Each orthogonal matrix Q has the property $QQ' = I_k$, which implies that $F\Omega = (FQ)(\Omega Q)' = Z\Lambda'$ holds for any orthogonal matrix Q.

[15] The identification assumptions are taken from Andrade and Ferroni (2021), as well.

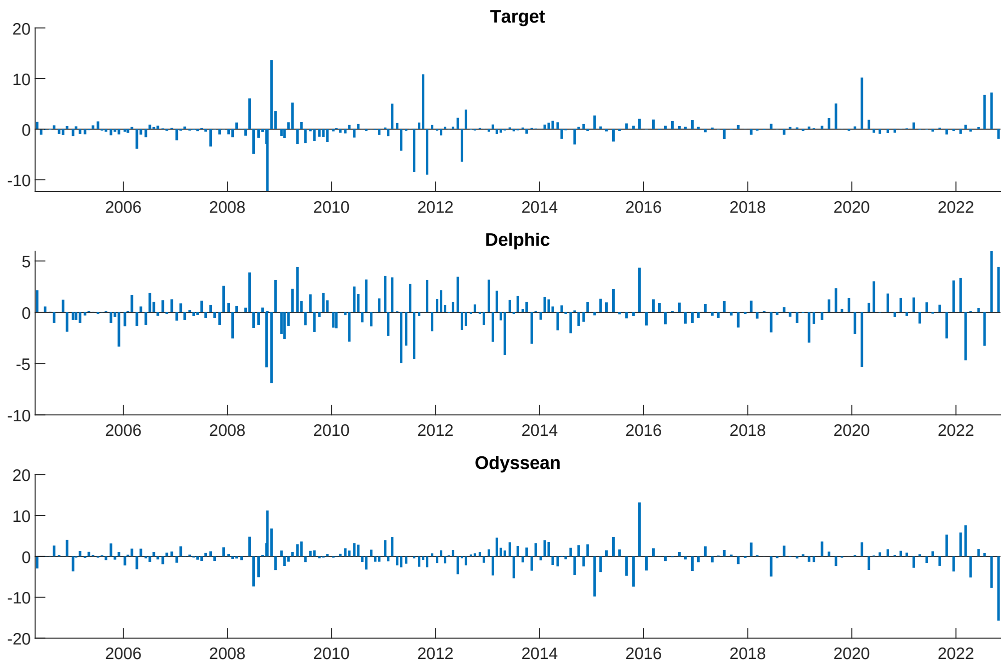
two informational factors. Q is selected such that the following restrictions hold:

$$Y_t = \begin{bmatrix} OIS_{3M,t} \\ OIS_{5Y,t} \\ ILS_{5Y,t} \\ \vdots \end{bmatrix} = \begin{bmatrix} * & 0 & 0 \\ * & + & + \\ * & + & - \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} Target_t \\ Delphic_t \\ Odyssean_t \end{bmatrix} + \varepsilon_t,$$

where the first three columns of Y contain the short and long-term interest rates (OIS_{3M} and OIS_{5Y}), and the inflation-linked swap rate (ILS_{5Y}). The equation is consistent with our identification strategy: The Delphic and Odyssean factors do not load on OIS_{3M}. For an Odyssean shock, the interest rate co-moves negatively with inflation expectations, whereas the co-movement is positive for a Delphic shock. Appendix B lays out the methodology to find the rotation matrix Q.

The factors are only identified up to scale and sign. Therefore, in the final step, the Target factor is normalized such that a unit increase implies a one basis point increase in the 3-month OIS rate. The Delphic and Odyssean factors are normalized such that a unit increase implies a one basis point increase in the 5-year OIS rate.

Figure 1: Monetary Policy Factors



Notes: This figure shows the calculated factors for the baseline factor model, which is calculated as described in this subsection. All factors are normalized, such that a unit increase in the factor denotes a 1 basis point increase in the 3-month OIS rate for the Target factor, and a 1 basis point increase in the 5-year OIS rate for the Delphic and Odyssean factors.

Figure 1 shows the Target, the Delphic, and the Odyssean factor. The Target factor rarely surprises markets. The most significant movement is during crisis periods, such as the Great Financial Crisis or the euro area debt crisis. It is noteworthy that, contrary to a conventional monetary policy shock as captured by Jarociński and Karadi (2020), this Target factor is not constrained to be contractionary. Therefore it partially captures what Jarociński and Karadi (2020) call a CBI shock.

For the Delphic and Odyssean factors, the strong decrease in the variance after 2016 is noteworthy. In this period, 5-year interest rates were close to zero. On the one hand, they can't decrease because of the effective lower bound, and on the other hand, quantitative easing programs prevented the 5-year interest rate from increasing. As a result, the movement of the 5-year interest rate was suppressed, and there was little room for informational monetary policy shocks to materialize, contributing to the muted dynamic of both the Delphic and Odyssean factors.

In the subsequent analysis, the identified shocks are considered exogenous to both economic and financial data, as they arise from asset price changes in a very narrow window around monetary policy announcements. The narrow window ensures that the surprises are not influenced by contemporaneous movements in economic or financial variables. Additionally, the assumption is that all information before the monetary policy announcement is already priced in, such that information from before the announcement does not confound the surprises data. In the rest of this paper, I use the monetary policy factors derived here and evaluate their effects on various asset prices and, most importantly, on exchange rates.

5 Exchange Rate Effects at High Frequency

This section focuses on the high-frequency effects of the Target, the Delphic, and the Odyssean shocks. Subsection 5.1 depicts the instantaneous impact of the three shocks on asset prices. Before showing dynamic responses (at the daily frequency) in Subsection 5.3, Subsection 5.2 reexamines the exchange rate puzzle presented by Gürkaynak et al. (2021) in the context of informational monetary policy shocks.

5.1 High-Frequency Regressions

To deduce the immediate impact of the Target, the Delphic, and the Odyssean factor on asset prices, I run the following regression:

$$\Delta x_t = \beta_0 + \beta_1 Target_t + \beta_2 Delphic_t + \beta_3 Odyssean_t + \varepsilon_t. \quad (11)$$

The three factors are orthogonal by construction. Thus, the results of the regression are identical to three separate simple regressions. In Table 3, I have omitted the 3-year and 7-year OIS rates for brevity. The 3-month OIS rate is not displayed, either.[16]

Table 3: Regression of High-Frequency Variables on Monetary Policy Factors

	Target	R^2	Delphic	R^2	Odyssean	R^2
Interest Rates						
OIS 1Y	1.67***	0.55	0.90***	0.44	0.67***	0.16
OIS 2Y	1.61***	0.42	0.98***	0.53	0.90***	0.24
OIS 5Y	1.15***	0.25	1.00***	0.59	1.00***	0.34
OIS 10Y	0.09***	0.09	0.68***	0.56	0.68***	0.33
Inflation-Linked Swaps						
ILS 2Y	−0.56***	0.06	2.18***	0.25	−0.71***	0.19
ILS 5Y	−0.27**	0.03	1.48***	0.34	−0.68***	0.33
ILS 10Y	0.07	0.00	1.05***	0.31	−0.64***	0.46
5Y5Y	0.42**	0.02	0.62***	0.04	−0.60***	0.40
Stock Price						
stoxx50	−0.04*	0.06	0.24	0.09	−0.05***	0.20
Exchange Rates						
USD/EUR	0.04**	0.51	0.16***	0.25	0.19***	0.46
GBP/EUR	0.04***	0.48	0.13***	0.24	0.14***	0.49
JPY/EUR	0.06***	0.59	0.15***	0.22	0.20***	0.51

Notes: This table shows the regression coefficient of simple linear regressions of asset price changes in a 135-minute window around ECB monetary policy announcements, which are regressed on factors from the same time window. The sample period is from April 2004 to December 2022. The units are percentage points for the interest rates and percent for stocks and exchange rates. An increase in the exchange rate denotes an appreciation of the euro. *, **, and *** denote significance of the coefficient at the 10%, 5%, and 1% level, respectively.

The interest rate response is not the focus of this paper. The regressions confirm, however, that all three factors contribute positively and highly significantly to an interest rate increase across the yield curve. It is important to note that the factors are only defined up to sign and scale. The Target and the informational factors are normalized to have a unit effect on the 3-month and 5-year OIS rates, respectively. Therefore, the magnitude of the factors is not meaningful in and of itself. What may be of interest is that the Delphic shock explains a large fraction of OIS rate changes. At the same time, the explanatory power of the Odyssean shock, while significant, is substantially smaller than that of the Delphic shocks.

[16] Regressing the 3-month OIS rate on the Target factor gives a coefficient of one, by normalization. For the Delphic, and the Odyssean factors, the coefficient is zero, according to the factor model restrictions.

The reaction of the stock index is also of secondary importance for this paper. While an Odyssean shock is seen as a contractionary future monetary policy shock, it is expected to decrease stock prices. The Delphic shock, where the central bank merely reacts to a more inflationary economy, does not have a clear effect on stock prices.[17] These properties are confirmed by the stock price response in the above regressions.

The bottom rows of Table 3 are more pertinent to the research question. They show that euro exchange rates consistently appreciate after all monetary shocks. However, the main difference between Delphic and Odyssean shocks can be seen by comparing the R^2 between the shocks: Delphic shocks explain between 22 and 25% of the variation in exchange rates, while the effect of Odyssean shocks is significantly greater, explaining up to 51% of the variation. Hence, exchange rates are more responsive to Odyssean shocks, at least within high-frequency windows.

5.2 The Exchange Rate Puzzle

Before turning to the dynamic responses of asset prices to CBI shocks, I revisit the exchange rate puzzle presented by Gürkaynak et al. (2021) in the context of decomposed monetary policy shocks. This puzzle arises from the observation that the correlation between interest rate surprises and high-frequency exchange rate changes during ECB announcement windows is relatively weak. In particular, a positive interest-rate surprise is accompanied by a depreciation of the euro in many instances. This is unexpected, as the effects in this high-frequency analysis should be less plagued by confounding factors and noise.

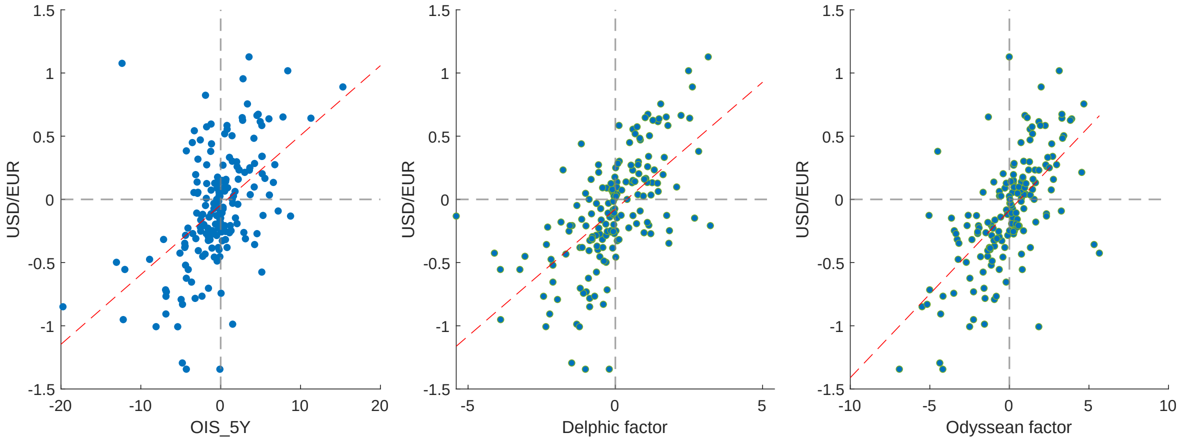
This exchange rate puzzle is not directly comparable to Gürkaynak et al. (2021), as they focus on the puzzle in the Target factor (and even state that it is resolved in the Path factor). Nevertheless, as discussed in the introduction, the response of exchange rates to monetary policy around monetary policy announcements is not clear and therefore warrants further investigation.

The relationship between the 5-year OIS rate and the exchange rate is depicted in the leftmost scatter plot of Figure 2. The regression line shows that on average, an increase in interest rates leads to a stronger currency. Hence, there is no puzzle, on average. However, there are 30% of the ECB announcements in the sample where the covariance between

[17] If the revealed additional inflation comes from an expected demand shock, the Delphic shock is expansionary. If it comes from an expected supply shock, it is contractionary. Andrade and Ferroni (2021) find that the Delphic shock is expansionary in their analysis. Also, Jarociński and Karadi (2020) show in their appendix that expectational supply shocks have no significant effects.

monetary policy and exchange rates is in the “wrong” quadrants, meaning that an unexpected increase in interest rates leads to a depreciation.

Figure 2: Exchange Rate Response to ECB Announcements



Notes: This graph depicts the simultaneous change in the OIS 5-year rate and the USD/EUR exchange rate, on the left, and the Delphic and Odyssean factors derived above. The USD/EUR is measured in percentage points, while the OIS 5Y is measured in basis points. The red dashed line depicts the regression line. The sample period is from April 2004 to December 2022.

Looking at the two plots on the right, the exchange rate appreciates more consistently with less noise in the Delphic and Odyssean factor windows. The link between the two factors, which are both normalized to increase the 5-year OIS rate one-to-one, seems stronger than for the 5-year OIS rate. The fact that both factors are strongly positively correlated with the exchange rate, gives some credence to the interpretation of the shocks in section 4. Further, given the correlation of the factors to the exchange rate is stronger than for the 5-year OIS rate, this lends some support to identifying informational monetary policy shocks with a factor model and many different asset prices, instead of (implicitly) only looking at one time series to gauge the effects of monetary policy.[18]

To get a more accurate picture of the nexus between monetary policy and exchange rates in the announcement window, Table 4 reports the explained exchange rate variance, as explained by the OIS 5Y rate and the two informational factors.

The table shows that the 5-year OIS rate, which has the highest contribution to exchange rates, explains between 42 and 48% of the exchange rate variance. Disentangling monetary policy into a Delphic and an Odyssean shock explains a larger share of the exchange rate variance. Together, they explain between 71 and 73 % of the variance. The Odyssean shock

[18]This argument is about the informational aspect of monetary policy. For conventional monetary policy, the link between the 3-month OIS rate and the Target factor is much stronger, due to the central bank's strong control over the short-term interest rates.

Table 4: Contribution of Monetary Policy to Exchange Rates (in %)

	OIS 5Y	Delphic	Odyssean	**Total**
USD/EUR	42	25	46	**71**
JPY/EUR	48	24	49	**73**
GBP/EUR	43	22	51	**73**

Notes: This table shows the contribution of the 5-year interest rate, as well as the Delphic and Odyssean factors, to the exchange rate variance. Contributions are computed by taking the adjusted R^2 of a simple regression on the exchange rate. All variables are asset price changes in a 135-minute window around ECB announcements. The sample period is from April 2004 to December 2022. USD/EUR, JPY/EUR, and GBP/EUR depict the euro exchange rate vis-à-vis the US dollar, the Japanese Yen, and the British pound, respectively. Since the Delphic and Odyssean factors are orthogonal, the contributions can be added to get the "total contribution" of the 2 factors in the last column

explains the larger share of the variance, which may be due to the fact that the different terms in equation (7) influence exchange rates in the same direction for the Odyssean factor, while they have opposite effects for the Delphic factor.

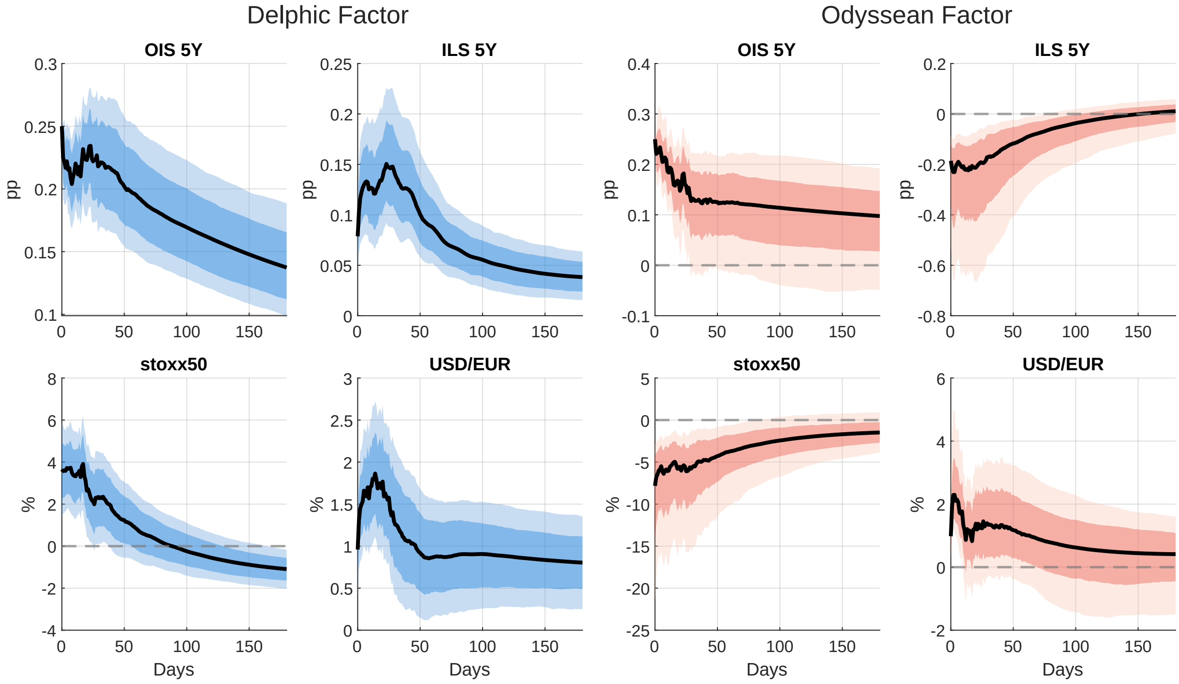
5.3 Persistence of the Effects on Asset Prices

The results displayed in Table 3 (Subsection 5.1) are consistent with the factor interpretation. However, the effects underlying this table may be short-lived. Exchange rates, in particular, are known for strong intra-daily dynamics. Thus, it is not clear whether these effects persist beyond an intra-daily time window. To test this, I build a financial SVAR model with the 5-year OIS rate, the 5-year ILS rate, the stoxx50 index, and the USD/EUR exchange rate. The Delphic and the Odyssean factors are used as instruments in a proxy SVAR methodology.[19]

Figure 3 shows the impact of the two factors for a horizon of 180 working days. Both factors have significant and immediate effects on all variables. A Delphic factor leads to a large increase in inflation expectations (as measured by inflation swaps), and stock prices, as well as to an appreciation of the exchange rate. Interestingly, the stock price effect is the only one that is not persistent. Inflation swaps and the exchange rate remain significantly elevated over the 180-day horizon. The Odyssean factor shows the expected reaction to a monetary policy shock: stock prices and inflation expectations fall, while the currency appreciates. The effects on inflation swaps, stock prices, and the USD/EUR exchange rate are more pronounced for an Odyssean shock when compared to a Delphic shock. The effects are larger, given a normalized 25 basis point increase of the 5-year OIS rate for both shocks. However, the effects

[19]The methodology is described in Section 6.1, as it is identical to the monthly SVAR model. The data and empirical specification are discussed in Appendix C.2.

Figure 3: Financial VAR: Daily Impulse Responses



Notes: This figure shows impulse response functions in a daily proxy SVAR model. The frequency is daily, excluding weekends. An increase in USD/EUR depicts an appreciation of the euro. Both factors are normalized to increase the OIS 5Y rate by 25 basis points. The 68% and 90% confidence intervals are computed by a moving block bootstrap algorithm (Jentsch and Lunsford, 2019). The impulse responses for the Delphic factor, in blue, are on the left-hand side, and the impulse responses for the Odyssean factor, in red, are on the right-hand side of the figure.

of the Odyssean factor are less persistent. The inflation and exchange rate effects go back to zero at the horizon.

6 Exchange Rate Effects at Low Frequency

This section aims to quantify the macroeconomic impact of the two informational monetary policy factors. Since macroeconomic variables are not available at high frequency, this section examines the effects at a lower, monthly frequency. To do this, I construct a monthly proxy SVAR model to combine the high-frequency informational monetary policy factors with monthly data.

The proxy SVAR methodology is well suited for this exercise, as the exogeneity assumption is credibly satisfied when using high-frequency data since confounding variables play a negligible role in short windows. Note, however, that the surprise data is only a partial measure of the underlying shock since central banks can also influence the economy outside of this window.

By construction, the instrumental variable approach is well-suited for leveraging a partial signal of the true exogenous monetary policy shock.

6.1 Setting up a Proxy SVAR Model

The monthly SVAR model mostly follows Stock and Watson (2012) and Mertens and Ravn (2013). It is of the form:

$$Y_t = A_+ X_t + B\varepsilon_t, \tag{12}$$

where $X_t = [Y_{t-1}, ..., Y_{t-p}, 1]$, and B is the structural impact matrix. Y_t has dimensions $T \times n$, and X is $T \times (np+1)$. T, n, and p denote the sample length, the number of variables, and the number of lags, respectively. The reduced-form residuals $u_t = B\varepsilon_t$ are collected in a $n \times 1$ vector, with $u_t \sim N(0, \Sigma)$.

By construction, the structural shocks ε_t are orthogonal to each other and have unit variance. Hence, it must be that

$$\Sigma = BB'. \tag{13}$$

The vector of structural shocks ε_t is partitioned into $(\varepsilon_{1,t}, \varepsilon_{2:n,t})$. The order is irrelevant, as shocks are not identified with a Cholesky decomposition. The structural shock ε_{1t} is instrumented by Z_t where Z_t denotes different exogenous monetary policy shocks (as derived in Section 4). For each monetary policy factor, that is for the Target, the Delphic, and the Odyssean factors, I re-estimate the model separately. For identification, I make the following assumptions, which are typical for an instrumental variable approach:

$$E[\varepsilon_{1,t} Z_t] = \Phi, \tag{14}$$

$$E[\varepsilon_{2:n,t} Z_t] = 0, \tag{15}$$

where $\Phi \neq 0$. These are the relevance and the exogeneity condition, respectively. With these two assumptions, it is possible to derive B_1, the first column vector of B. First, the SVAR model is estimated by ordinary least squares, yielding the residuals u_t. Then, Assumptions (14) and (15) allow us to estimate the impact matrix

$$B_{2,1}/B_{1,1} = E\left[u_{2,t} Z_t\right] / E[u_{1,t} Z_t], \tag{16}$$

where $u_{1,t}$ and $u_{2,t}$ are the residuals for the instrumented variable, and the other four variables, respectively. The structural impact column B_1 is partitioned such that $B_1 = (B_{1,1},\ B'_{2,1}B_{1,1})'$. As a final step, I set $B_{1,1} = 0.25$, normalizing the effect of the monetary policy factors to have a 25 basis point impact on the domestic interest rate, thereby pinning down the matrix B_1.

6.2 Empirical Specification

The sample period runs from January 1999 to December 2022.[20] The model consists of 6 endogenous variables. The main building blocks of UIP are included in the model, namely the European and U.S. 5-year yield, as well as the USD/EUR exchange rate. This allows us to see how the different terms in the UIP equation evolve. To get a clearer picture of the macroeconomic consequences within the euro area, HICP inflation and European industrial production are added to the model. To account for the Great Financial Crisis and the European Debt Crisis, the BBB spread is added to the model as a measure of risk.

The inflation rate and industrial production are linearly detrended, even though this does not significantly change the results. The variables enter the model in log-levels except for the two interest rates and the BBB spread, which are in percentage points. There is a more detailed description of the data in Appendix C

The Delphic and the Odyssean shocks are used as instruments in two separate models, and the European 5-year yield is the instrumented variable.[21] Although the proxy SVAR methodology is valid if Assumptions (14) and (15) hold, it may still produce unreliable results if the instruments are weak. To test whether the instruments are sufficiently strong, the weak instrument test of Olea and Pflueger (2013) is applied to the first-stage regressions.

Table 5 indicates that the Delphic and the Odyssean shocks are sufficiently strong instruments, as the robust F-statistic is above the recommended value of 10. Thus, there is no weak instrument problem in the subsequent analysis.

6.3 Results

This section shows the impulse responses of the endogenous variables in the SVAR model. Figures 4 and 5 display the impulse responses, as well as 68% and 90% confidence bands. As

[20]Note that the sample length of the proxy SVAR model does not have to coincide with the length of the instrument.

[21]The Target factor captures exogenous changes in the short end of the yield curve, but there is no short-term interest rate in the SVAR model. Therefore, applying the proxy SVAR methodology to the Target factor would not be convincing. In addition, the effects of the Target factor are not the focus of this paper, so we omit the analysis of its effects.

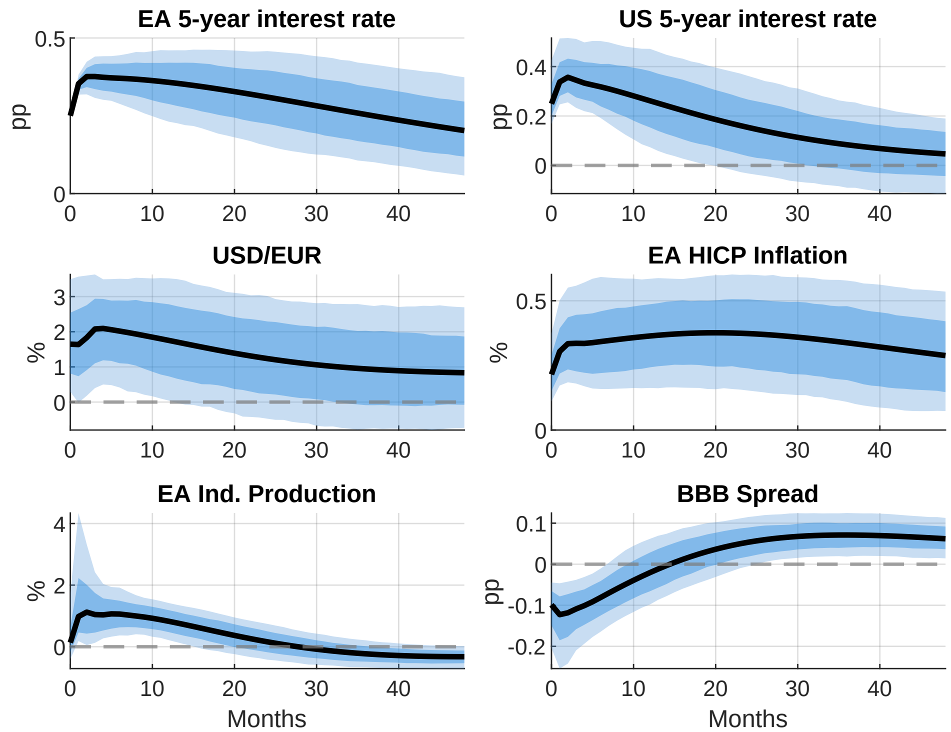
Table 5: Instrument Strength

	Delphic	Odyssean
F-statistic	24.52	29.62
F-statistic (robust)	14.01	24.25
R^2	0.10	0.13
R^2 adj.	0.10	0.12
Observations	225	225

Notes: This table shows different test statistics of the first-stage regressions of the residuals $u_{1,t}$ on the different instruments Z_t The robust F-statistic test is deemed the "weak instrument test". It is robust to heteroskedasticity, serial correlation, and clustering (see Olea and Pflueger, 2013).

the factors are only defined up to scale and sign, the response is normalized to a 25 basis point increase in the domestic interest rate.

Figure 4: Impulse Response after a Delphic shock

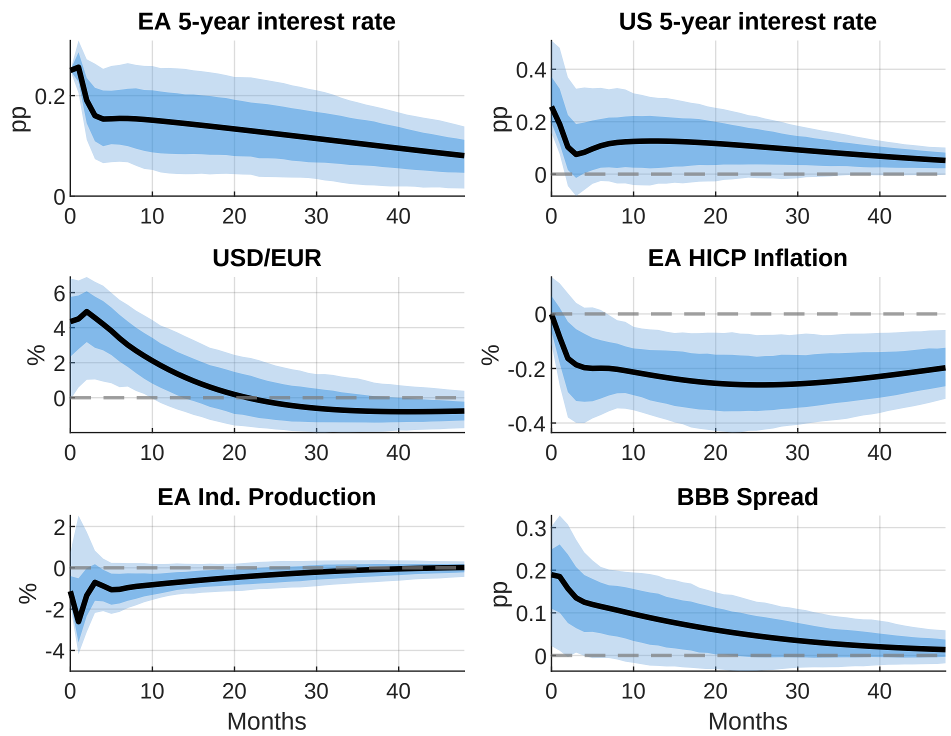


Notes: This figure shows impulse response functions, as well as 68% and 90% confidence intervals computed by a moving block bootstraps algorithm (Jentsch and Lunsford, 2019). EA stands for the euro area and USD/EUR for the bilateral euro-dollar exchange rate. An increase denotes an appreciation of the euro. The shock is normalized to increase the 5-year European yield by 25 basis points.

Consistent with its characterization as an expectational shock on macroeconomic fundamentals (see Subsection 4.3), Figure 4 shows that a positive Delphic shock is expansionary. Interest rates remain persistently high after an increase in the Delphic factor. The USD/EUR exchange rate, inflation, and industrial production all increase significantly on impact, which is suggestive of an expansionary movement. Besides, the BBB spread decreases, which is also typical for expansions.

These effects are highly persistent. This is in line with Gründler et al. (2023), who note the strong persistence of CBI shocks. Real output, as measured by industrial production, and the BBB spread, are the least persistent, returning to the steady state after 1-2 years. Nominal variables show more persistence, consistent with the classical dichotomy assumption, which states that monetary policy does not affect real variables in the long run.

Figure 5: Impulse Response after an Odyssean shock



Notes: This figure shows impulse response functions, as well as 68% and 90% confidence intervals computed by a moving block bootstraps algorithm(Jentsch and Lunsford, 2019). EA stands for the euro area and USD/EUR for the bilateral euro-dollar exchange rate. An increase denotes an appreciation of the euro. The shock is normalized to increase the 5-year European yield by 25 basis points.

Consistent with its characterization as an exogenous change in future monetary policy (see Subsection 4.3), Figure 5 shows that a positive Odyssean shock is contractionary. Moreover, in contrast to the Delphic shock, inflation falls after an Odyssean shock. Given the identifying assumptions of the factors, the inflation decrease may not be surprising. However, the high significance, as well as the strong and persistent disinflationary effects suggest a high explanatory power of the Odyssean factor. The fall in industrial production and the increase in the BBB spread point to the contractionary effects of the shock. The appreciation on impact is almost twice as strong for the same interest rate increase as is the case for the Delphic factor.[22]

The results are also in line with the analytical derivation in Section 3, which indicates that Odyssean shocks appreciate the domestic currency not only through interest rates, but also through the inflation differential. However, despite the larger magnitude of the effect on both the USD/EUR exchange rate and industrial production, these effects exhibit less persistence and tend to dissipate more rapidly compared to the effects of the Delphic shock. This is in line with what Gründler et al. (2023) find for the U.S. case.

7 Conclusion

This paper examines the effects of central bank information (CBI) shocks on exchange rates in the euro area. I evaluate the exchange rate response to different types of informational shocks, namely a Delphic and an Odyssean shock: Delphic shocks capture changes to the economic outlook as revealed by the central bank, and Odyssean shocks capture changes in the expected conduct of monetary policy.

I find that the effect of the Target factor—an exogenous change in the short-term interest rate—on the exchange rate is small when compared to the two informational factors. This is consistent with the analytical derivation, which shows that changes in the exchange rate depend on the infinite expected path of interest rate differentials. The analytical derivation also shows that there is a direct link between the targeted (long-run) inflation and the current exchange rate.

Using high-frequency regressions and a daily proxy SVAR model, I show that while the effects of the Delphic factor are expansionary, the effects of the Odyssean shock are contractionary. I also find that both factors lead to a significant and immediate appreciation of the currency. While the analytical derivation predicts this in the case of the Odyssean shock, the sign was a priori ambiguous for a Delphic shock. The results also suggest that while the responses to a Delphic shock are long-lived (at the daily frequency), the effects after an Odyssean factor slowly revert back to the mean.

A monthly proxy SVAR model is further used to examine the long-run, macroeconomic effects of the informational monetary policy shocks. The Delphic and Odyssean shocks are shown to have lasting effects over the long term. The Delphic shock is expansionary, leads to

[22] Note that both factors are normalized to increase the 5-year OIS rate by 25 basis points.

an appreciation, and is highly persistent. By contrast, the Odyssean shock is contractionary. It also leads to an appreciation that is stronger in the short run but dissipates more quickly.

These findings underscore the importance of informational monetary policy shocks in shaping exchange rate dynamics and highlight the quantitative importance of new information relative to conventional monetary policy decisions. By examining the nature and transmission of different informational shocks affecting exchange rates, this paper contributes to a deeper understanding of the interplay between monetary policy and exchange rate dynamics.

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A High-Frequency Asset Price Data

This section provides more information on the high-frequency asset price data, known as surprises. This data is used to construct the factor model and also serves as the explained variable in high-frequency regressions. For this reason, it is presented in a separate appendix. I use surprises on interest rates, a stock price index, inflation-linked swaps, and the USD/EUR, JPY/EUR, and GBP/EUR exchange rates. The available sample covers every ECB monetary policy announcement from April 2004 until December 2022.

Interest Rate, Stock, and Exchange Rate Surprises

For the OIS interest rate swaps, the stoxx50 index, and the exchange rates data, I graciously rely on the work of Altavilla et al. (2019), who provide this data and update it regularly.[23] They use underlying tick data from the Thomson Reuters Tick History database.[24] Not all OIS surprises are available from the beginning of the sample. In that case, the series are prepended by the German interest rate swaps series of the same maturity.[25]

This data includes asset price changes in the press release (PR) window, in which the monetary policy decision is being announced, which takes place at 13:45 CET (Central European Time). It also covers the press conference (PC) window that follows the release and starts at 14:30 CET, and that usually takes an hour. The surprise data for the RE window is the difference of each asset price 15 minutes before (median of values from 13:25-13:35), to 20 minutes after the release (median of values from 14:00-14:10). The PC window captures the difference from 10 minutes before the press conference (median of 14:15-14:25) to 15 minutes after the press conference (median of 15:40-15:50). The monetary event window (ME) combines the effects from the RE and the PC windows by capturing the changes from the 13:25-13:35 window (before the press release) and the 15:40-15:50 window (after the press conference).[26]

For the baseline factor model, all data series are from the ME window. Using only the PC window does not significantly change the results, implying that the RE window is of minor importance for information shocks. This is demonstrated in Subsection B.2.

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[23]The dataset which is continually updated can be downloaded under `https://www.ecb.europa.eu/pub/pdf/annex/Dataset_EA-MPD.xlsx`.

[24]see Altavilla et al. (2019), as well as their appendix for details on the EA-MPD surprises dataset.

[25]The German OIS series are available for the whole sample period, and its surprises are also provided by Altavilla et al. (2019).

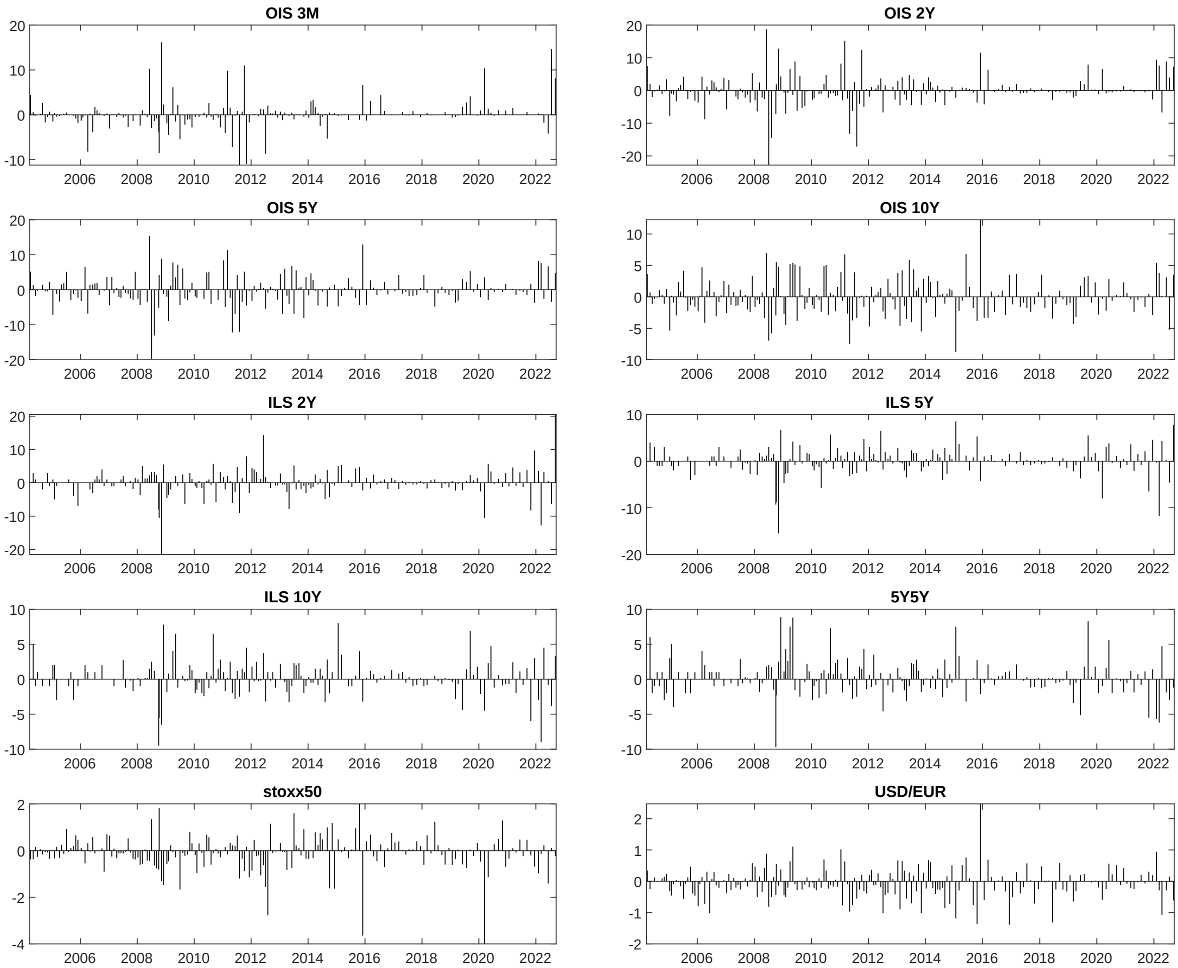
[26]The timing of the press release and press conference was changed in July 2022, but the window sizes remained the same.

Inflation-Linked Swaps

For the inflation-linked swaps (ILS) data, I use data from Refinitiv, namely the data under the ticker "ICAP EU INFL-LKD SWAP HICP xY" where x is replaced by the maturity of the swap (that is, by the numbers 1 through 10 for the respective maturities). The underlying inflation rate is the official HICP inflation rate excluding tobacco. The series is daily and contains the swap price at 19:00 CET. This is well after the ECB announcements have ended. Thus, I take the difference between the day t (day of the announcement) and day $(t-1)$ to get daily ILS surprise data.

A selection of the surprise data is displayed in Figure 6. Table 6 shows the correlation coefficients between the surprise data series.

Figure 6: Factor Model Data



Notes: This graph displays all the data points that enter the factor model derived in Section 5. An increase in OIS and ILS rates depicts an expected average increase up to the maturity of the swap. An increase in the stoxx50 stock index depicts an increase in its price. An increase in the USD/EUR exchange rate depicts an appreciation of the euro vis-à-vis the dollar.

Table 6: Factor Data Correlation Table

	OIS 3M	OIS 1Y	OIS 2Y	OIS 5Y	OIS 10Y	ILS 2Y	ILS 5Y	ILS 10Y	Y5Y5	stoxx50	USD/EUR
OIS 3M	1										
OIS 1Y	0.82	1									
OIS 2Y	0.69	0.96	1								
OIS 5Y	0.53	0.83	0.93	1							
OIS 10Y	0.32	0.59	0.71	0.88	1						
ILS 2Y	-0.06	0.05	0.01	-0.03	-0.01	1					
ILS 5Y	-0.1	-0.03	-0.06	-0.07	-0.04	0.88	1				
ILS 10Y	-0.03	-0.01	-0.04	-0.05	-0.02	0.71	0.9	1			
Y5Y5	0.05	0.02	-0.01	-0.02	0	0.32	0.54	0.86	1		
stoxx50	-0.23	-0.21	-0.22	-0.2	-0.13	0.16	0.21	0.2	0.13	1	
USD/EUR	0.34	0.48	0.53	0.62	0.59	0	-0.04	-0.05	-0.04	-0.3	1

Notes: This table displays Pearson correlation coefficients of high-frequency asset price surprises that comprise the factor model in Section 5. They span the Monetary Event window (see Appendix A) for the period April 2004 through December 2022

B Deriving a Factor Model

This section gives more information on the factor model, the applied matrix rotation, and the robustness of the results.

B.1 Rotating the Factor Matrix

For the factors to be economically meaningful, they have to be rotated. For this, I replicate the methodology of Andrade and Ferroni (2021), employing zero and sign restrictions to rotate the factors. For convenience, I reproduce equations (9) and (10) from the main text:

$$Y = F\Omega' + \varepsilon, \tag{17}$$

where Y is the data matrix with the surprises data. F contains the principal components and Ω corresponds to the factor loadings matrix. $\varepsilon \sim N(0, \Sigma)$ denotes the residuals. The matrices F and Ω are rotated by an orthogonal matrix Q such that

$$Y = (FQ)(\Omega Q)' + \varepsilon = Z\Lambda' + \varepsilon, \tag{18}$$

where $Z = FQ$ and $\Lambda = \Omega Q$ contain the rotated factors, and the corresponding factor loadings, respectively.[27] The objective is to find an orthogonal rotation matrix Q such that the following restrictions are satisfied:

[27]Any orthogonal matrix Q has the property $QQ' = I_k$, which implies that $F\Omega' = (FQ)(\Omega Q)'$ holds for any orthogonal matrix Q.

$$Y_t = \begin{bmatrix} OIS_{3M,t} \\ OIS_{5Y,t} \\ ILS_{5Y,t} \\ \vdots \end{bmatrix} = \begin{bmatrix} * & 0 & 0 \\ * & + & + \\ * & + & - \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} Target_t \\ Delphic_t \\ Odyssean_t \end{bmatrix} + \varepsilon_t. \tag{19}$$

As equation (19) shows, $\Omega_{3:3}Q$ is subject to both zero and sign restrictions (where $\Omega_{3:3}$ denotes the top 3×3 matrix of Ω). To achieve these restrictions, I let the rotation matrix Q be the product of two orthogonal rotation matrices, i.e. $Q = RS$.[28] To achieve the zero restrictions, I choose R such that $\Omega_{3:3}R$ is lower triangular. For this, I set

$$R = \Omega_{3:3}^{-1} \operatorname{chol}\left(\Omega_{3:3}\Omega_{3:3}'\right).$$

R is orthogonal (since $R'R = I$), and $\Omega_{3:3}R = \operatorname{chol}(\Omega_{3:3}\Omega_{3:3}')$ is lower triangular and therefore assures the zero restrictions in the rotated loadings matrix $\Omega_{3:3}R$.

Then, I rotate the second and third factors. The function $S(\theta_j)$ takes the form

$$S(\theta_j) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_j & -\sin\theta_j \\ 0 & \sin\theta_j & \cos\theta_j \end{pmatrix},$$

where $\theta_j = \{0, 0.02, 0.04, ..., \pi\}$. This structure ensures that the three factors remain orthogonal, while at the same time spanning all possible rotations of the second and third factors. Let $\Lambda(\theta_j) = \Omega RS(\theta_j)$. Since $S(\theta_j)$ does not rotate the first row of ΩR, the zero restrictions in the first row of ΩR persist. Discard all $S(\theta_j)$ for which $\Lambda(\theta_j)$ does not fulfill the sign restrictions in equation (19). With the remaining J matrices, I compute

$$S = \frac{1}{J}\sum_{j=1}^{J} S(\theta_j),$$

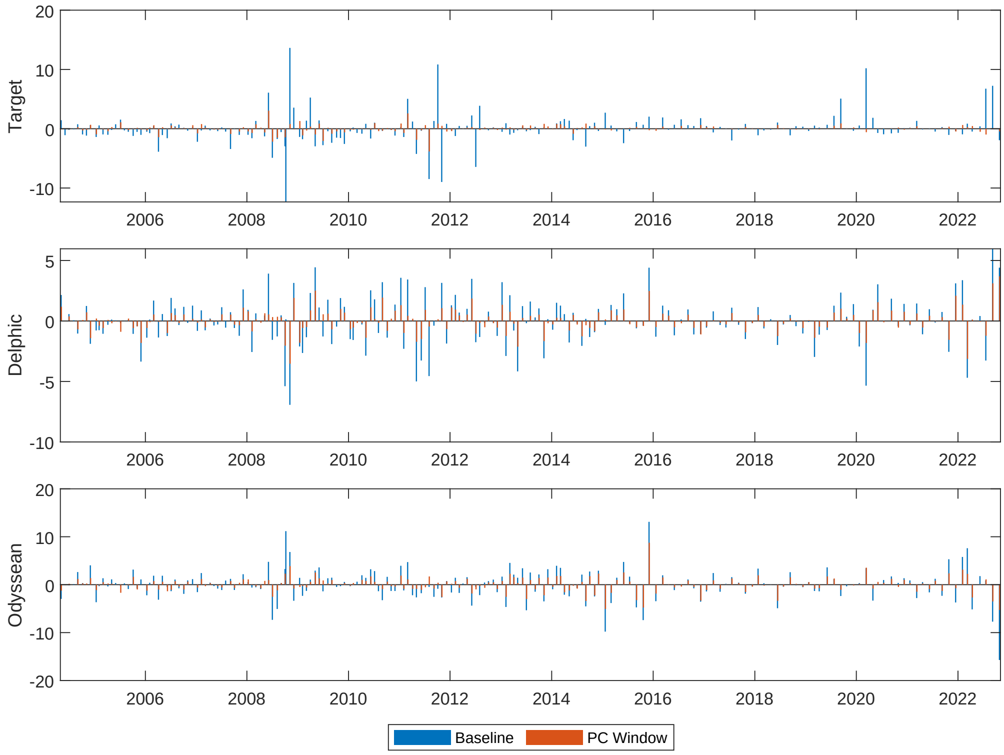
which is the element-by-element average of the candidate matrices $S(\theta_j)$. Then, $\Lambda' = (\Omega Q)' = (\Omega RS)'$ fulfills the restrictions in equation (19) and $Z = FQ = FRS$ contains the Target, Delphic, and Odyssean monetary policy factors.

[28]This decomposition of the rotation matrix Q is possible because R assures the zero restrictions in the first factor, while S leaves the first factor unchanged and only rotates the other factors.

B.2 Robustness Checks and Factor Model Diagnostics

This subsection provides a robustness check of the factor model. I rerun the factor model, using only data from the press conference window data, and thus ignoring the effects of the press release. This is compared to the baseline model, which combines the asset price changes from the press release and the press conference window.

Figure 7: Factor Data Baseline and PC model



Notes: This figure shows the data for the Target, the Delphic, and the Odyssean factors. It makes the comparison between the baseline model (Section 4) and the PC model from this appendix. The correlation between the sets of factors is reported in Table 7.

To get an overview of how the different factors are related, Table 7 shows the correlation coefficients between the baseline factors (in the rows) with the PC model factors and with the original factors from Andrade and Ferroni (2021), which cover the sample period 2004 to 2016. Note that the correlation of each factor triplet is given by the identity matrix and is not displayed here.

Table 9 reports the variance explained by each principal component in the baseline and the PC model. All three factors contribute significantly to the variance of the high-frequency data. The effect of the removal of the press release is negligible. Next, I present the factor loadings of the rotated factors.

Table 7: Correlation of Factors (in %)

Baseline	PC Factor Model Target	Delphic	Odyssean	AF Factor Model Target	Delphic	Odyssean
Target	48	-9	10	84	24	6
Delphic	35	92	3	8	74	4
Odyssean	24	-17	93	39	4	66

Notes: This table shows the Pearson correlation coefficients between the Baseline Factors (spanning the rows), the factors from the PC window (spanning columns one to three), and the factors as calculated by Andrade and Ferroni (2021) (spanning columns four to six).

Table 8: Regression of High-Frequency Variables on Baseline and PC Factors

	Baseline Model Delphic	R^2	Odyssean	R^2	PC Model Delphic	R^2	Odyssean	R^2
Interest Rates								
OIS 1Y	0.90***	0.44	0.67***	0.16	0.85***	0.05	0.41**	0.03
OIS 2Y	0.98***	0.53	0.90***	0.24	0.95***	0.04	0.73***	0.07
OIS 5Y	1.00***	0.59	1.00***	0.34	1.00***	0.05	1.00***	0.14
OIS 10Y	0.68***	0.56	0.68***	0.33	0.79***	0.07	0.75***	0.16
Inflation-Linked Swaps								
ILS 2Y	2.18***	0.25	−0.71***	0.19	3.31***	0.58	−1.52***	0.30
ILS 5Y	1.48***	0.34	−0.68***	0.33	2.32***	0.56	−1.14***	0.34
ILS 10Y	1.05***	0.31	−0.64***	0.46	1.70***	0.47	−0.86***	0.30
5Y5Y	0.62***	0.04	−0.60***	0.40	1.08***	0.17	−0.59***	0.13
Stock Price								
stoxx50	0.24	0.09	−0.05***	0.20	−0.10**	0.02	−0.19***	0.23
Exchange Rates								
USD/EUR	0.16***	0.25	0.19***	0.46	0.20***	0.20	0.18***	0.38
GBP/EUR	0.13***	0.24	0.14***	0.49	0.15***	0.19	0.13***	0.37
JPY/EUR	0.15***	0.22	0.20***	0.51	0.15***	0.10	0.17***	0.34

Notes: This table reports the regression coefficient of simple linear regressions of asset price changes in a 135-minute window around ECB monetary policy announcements, which are regressed on factors from the same time window. The sample period runs from April 2004 to December 2022. The units are percentage points for the interest rates and percent for stocks and exchange rates. An increase in the exchange rate indicates an appreciation of the euro. *, **, and *** indicate the significance of the coefficient at the 10%, 5%, and 1% level, respectively.

The PC model's Target factor loads significantly more on the short-term interest rates. This is due to the fact that the press release has the greatest impact on the short end of the yield curve. Generally, the factor loadings are very similar for the Delphic and Odyssean factors.

Table 9: Variance Explained by each Factor (in %)

	Baseline	PC model
Target	41	40
Delphic	22	22
Odyssean	16	11
Total	**79**	**73**

Notes: This table displays the variance explained by the first three principal components of the model. These values are independent of any factor rotation.

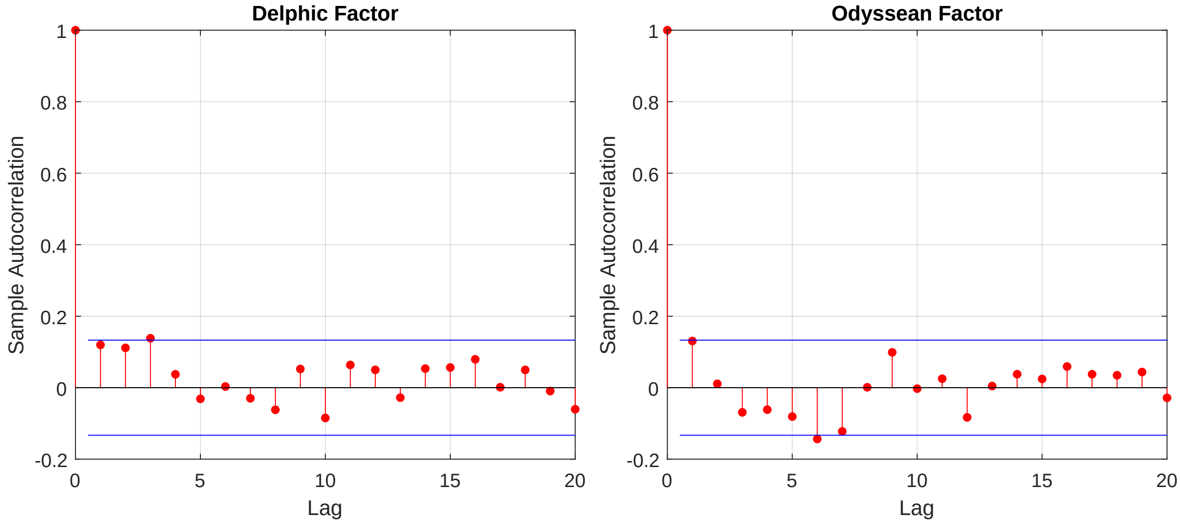
Table 10: Factor Loadings

	Baseline Model			PC Model		
	Target	Delphic	Odyssean	Target	Delphic	Odyssean
OIS 3M	0.34	0	0	0.99	0	0
OIS 5Y	0.16	0.20	0.20	1.19	0.20	0.2
ILS 5Y	−0.02	0.36	−0.17	0.08	0.60	−0.32
OIS 3M	0.35	0.06	0.06	1.31	0.10	0.06
OIS 1Y	0.28	0.16	0.13	1.38	0.19	0.09
OIS 2Y	0.24	0.17	0.16	1.33	0.18	0.14
OIS 10Y	0.07	0.21	0.20	0.93	0.23	0.22
ILS 1Y	−0.01	0.35	−0.14	0.09	0.58	−0.27
ILS 2Y	−0.01	0.37	−0.16	0.16	0.62	−0.30
5Y5Y	0.06	0.20	−0.11	0.07	0.34	−0.20
stoxx50	−0.11	0.040	−0.09	0.22	−0.07	−0.31
USD/EUR	0.02	0.26	0.19	0.33	0.44	0.40
JPY/EUR	0.04	0.25	0.21	0.56	0.35	0.38
GBP/EUR	0.05	0.25	0.19	0.37	0.40	0.40

Notes: This table shows the factor loadings of the baseline and the PC model on the data. The same factor rotations are applied to the loadings matrix as to the factor matrix.

Lastly, the factors should not be autocorrelated for them to be valid exogenous innovations in the SVAR models. In Figure 8 the sample autocorrelation function of the factors from the baseline model is displayed.

Figure 8: Autocorrelation of Factors



Notes: This figure shows the sample autocorrelation function of the factors at a monthly frequency. The monthly factors are aggregated by summing over each month.

C Estimating a Proxy SVAR model

This appendix provides more information on the implementation of the proxy SVAR model. There will be no further information on the methodology, as I exactly follow Gertler and Karadi (2015). The methodology is laid out very clearly in Stock and Watson (2012) and Mertens and Ravn (2013). In the following, I present the data used for the monthly and the daily SVAR model.

C.1 Monthly SVAR Model

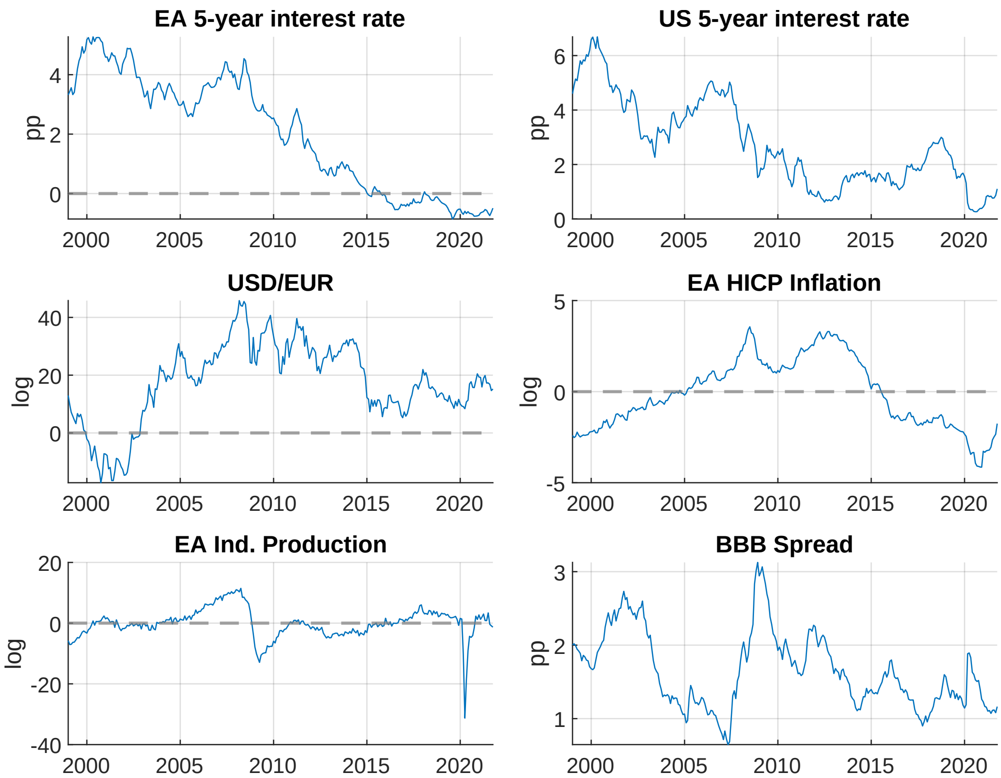
The sample period runs from January 1999 to December 2022. The lag length is set to 12. The model consists of 6 endogenous variables. The main building blocks of UIP, namely the European and U.S. 5-year yield, as well as the USD/EUR exchange rate, are included. Further, HICP Inflation and European industrial production are added. To account for the Great Financial Crisis and the European debt crisis, I add the BBB spread to the model as a measure of risk.

For the domestic interest rate, I use the euro area 5-year government bond rate,[29] which includes all countries that have a AAA rating (with changing composition). For the U.S., I choose the 5-year constant maturity treasury yield. Both are daily time series. I transform them to monthly by using the end-of-period value for both. For the USD/EUR exchange

[29]This series only goes back to September 2004. It is prepended by the series for 5-year German government bond yields for the period before that (source: data.snb.ch/en/topics/ziredev/chart/rendeidgdtch)

rate, I use the end-of-period series of the spot exchange rate. For inflation, I use the HICP overall inflation index which is working-day and seasonally adjusted, as well as the euro area industrial production (excluding construction, fixed composition of 19 countries). For the BBB spread, I use the Option-Adjusted Spread of the ICE BofA Euro High Yield Index which gives the difference between company bonds that are below investment grade (average of Moody's, S&P, and Fitch ratings), and government bonds. The sources for the data series are reported in Table 11.

Figure 9: Endogenous Data Series in the Monthly SVAR Model



Notes: This figure displays all endogenous variables in the baseline proxy SVAR model in Section 6. The EA and US yields, as well as the BBB spread, are in percentage points. The exchange rate, Inflation, and Industrial Production are transformed by $100 * log(x)$ where x stands for the respective time series. The inflation rate and Industrial Production are linearly detrended, even though this changes the results only marginally. The frequency of the data is monthly.

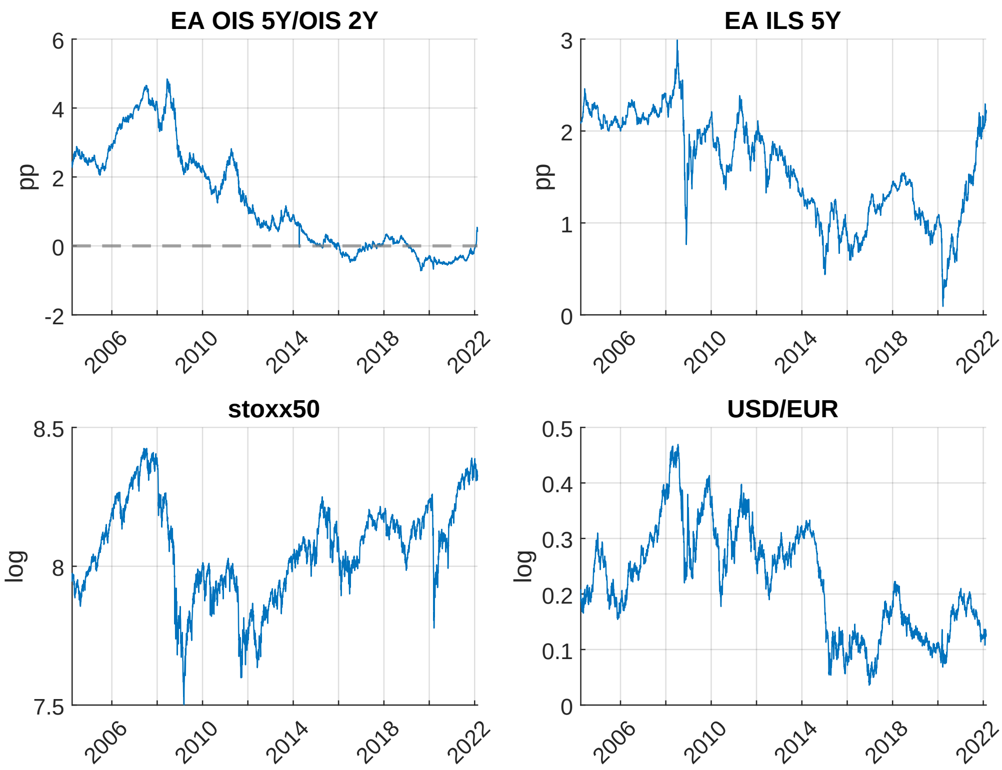
Table 11: Data Sources of the Monthly SVAR Model

Variable	Transformation	Source	Identifier
5-year EA interest rate	none	sdw.ecb.europa.eu	YC.B.U2.EUR.4F.G_N_A.SV_C_YM.SR_5Y
5-year US interest rate	none	fred.stlouisfed.org	DGS5
USD/EUR	log-levels	fred.stlouisfed.org	CCUSSP01EZM650N
HICP Inflation Index	lin. detrended	sdw.ecb.europa.eu	ICP.M.U2.Y.000000.3.INX
Industrial Production	lin. detrended	sdw.ecb.europa.eu	STS.M.I8.Y.PROD.NS0020.4.000
BBB spread	log-levels	fred.stlouisfed.org	BAMLHE00EHYIOAS

C.2 Daily SVAR Model

This subsection provides more details on the daily proxy SVAR model. The data is at workday frequency. The lag length is chosen to be 30. The sample period runs from April 2004 to December 2022. This gives a sample length of 4054 observations. The model consists of 4 endogenous variables, namely the 5-year OIS interest rate, the 5-year ILS rate, the euroStoxx 50 index, and the USD/EUR exchange rate. The 5-year OIS rate is only available since June 2008, which is why it is prepended by the 2Y OIS rate (the two rates exhibit a correlation of 94%). The data is presented in Figure 10 and the data sources are reported in Table 12.

Figure 10: Endogenous Data Series in the Daily SVAR Model



Notes: This figure displays all endogenous variables in the daily proxy SVAR model in Section 5. The stock index and the USD/EUR are used in logs, whereas the OIS and the ILS rates are given in percentage points. The sample period is from April 2004 to December 2022. The 5-year OIS rate starts in June 2008. Before, the series is prepended by the 2-year OIS rate. The frequency of the data is daily (working days).

Table 12: Data Sources of the Daily SVAR Model

Variable	Transformation	Source	Identifier
5-year OIS rate	none	Refinitiv	ICAP EURO 5Y OIS
2-year OIS rate	none	Refinitiv	ICAP EURO 2Y OIS
5-year ILS rate	none	Refinitiv	ICAP EU INFL-LKD SWAP HICP 5Y
stoxx50 index	log-levels	Google finance	SX5E
USD/EUR	log-levels	BIS data portal	D.XM.EUR.A