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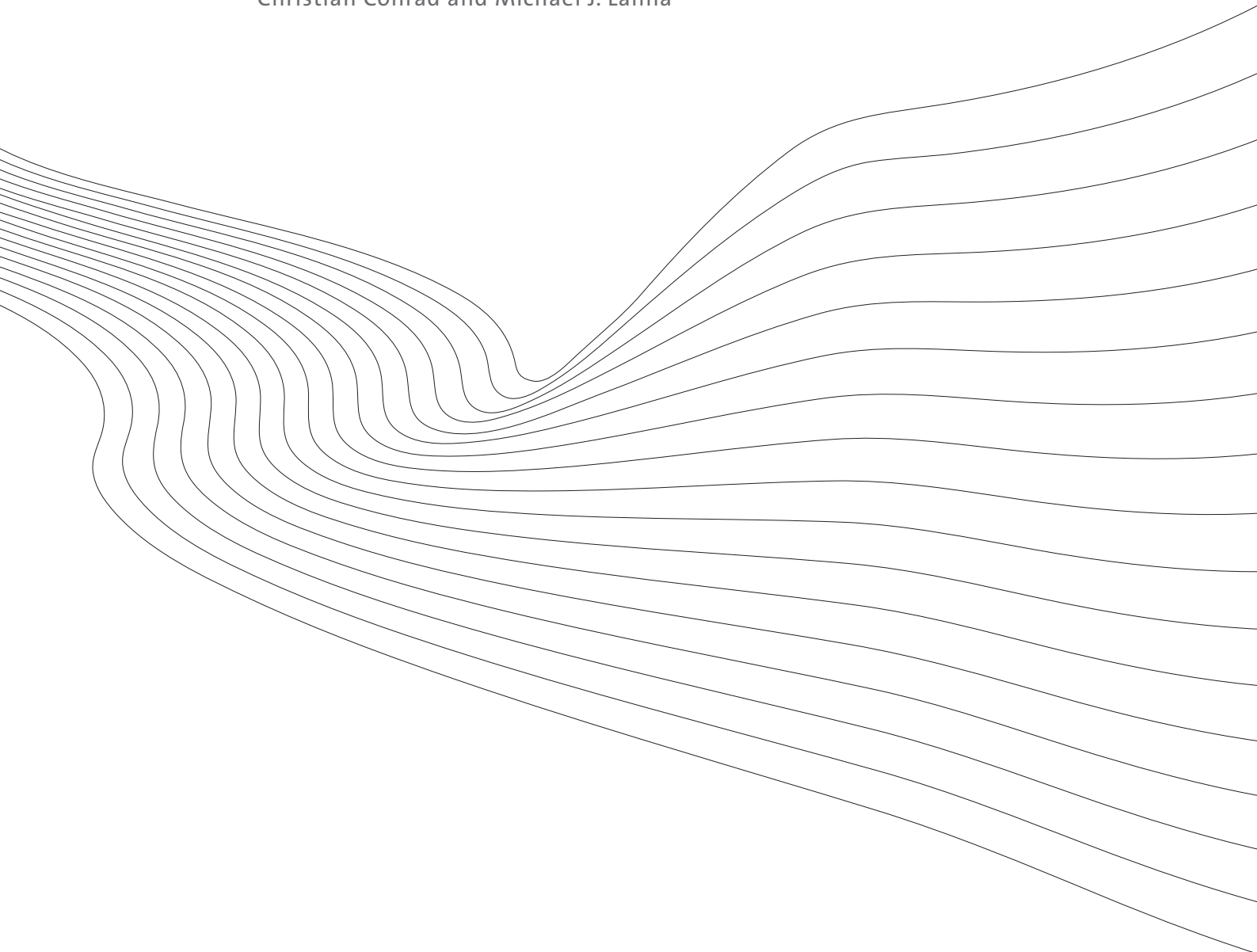
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KOF Working Papers

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THE HIGH-FREQUENCY RESPONSE OF THE EUR-US DOLLAR EXCHANGE RATE TO ECB MONETARY POLICY ANNOUNCEMENTS*

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Abstract

We investigate the impact of the European Central Bank's monetary policy announcements on the level and volatility of the EUR-US Dollar exchange rate employing an AR-FIGARCH specification. Using high-frequency data we estimate the individual and complementary effects of the release of the interest rate decision, the ECB's introductory statement and the question and answer session. Surprise interest rate changes explain the movements in the exchange rate immediately after press release. During the introductory statement, communication with respect to future price developments is most relevant and has two important functions: (i) it explains the previously announced decision and (ii) it serves as a guide for the future path of monetary policy.

Keywords: European Central Bank, monetary policy announcements, communication, exchange rate, expectations, long memory GARCH processes.

JEL Classification: C22, E52, E58, F31.

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1 Introduction

In this article we investigate the high-frequency impact of the European Central Bank's (ECB's) monetary policy announcements on the EUR-US Dollar (EUR-\$) exchange rate throughout the 89 meeting days of the ECB governing council within the period 01/1999–10/2006. A meeting day consists of the announcement of the next key interest rate via a press release at 13.45 CET and the press conference which starts at 14.30 CET with the introductory statement – containing a detailed assessment of the economic situation and future prospects – and ends with a question and answer session (Q&A).¹ All three events are of major importance. First, the reaction of the market participants to the pure interest rate announcement depends on how well the public anticipated the policymakers' decision as well as on how the public interprets this signal, and therefore on how successful the policymaker was in guiding market expectations. Second, the market participants' assessment of the policymakers' communication in the introductory statement is a relevant ingredient to expectation formation and hence matters for the movement in the exchange rate.² Finally, the discussion in the Q&A session allows to clarify certain points mentioned in the statement or being of concern for the market participants who in turn might adjust expectations and thus move the exchange rate. An econometric approach which allows to trace the effects of the pure announcement released at 13.45, the introductory statement beginning at 14.30 and the Q&A following thereafter requires two ingredients: an appropriate modeling of the intraday high-frequency movements of the EUR-\$ exchange rate and a meaningful quantification of the ECB's communication.

The building blocks of our analysis are derived from two strands of existing literature. One strand is concerned with the high-frequency modeling of exchange rate returns with a particular emphasis on the movements in the second conditional moment. In a seminal article, Andersen and Bollerslev (1997) show that high-frequency exchange rate returns are characterized by a strong intraday periodicity in their conditional variance. From their study it is evident, that the “estimation and extraction of the intraday periodic component is both feasible and indispensable for a meaningful intraday dynamic analysis” (Andersen and Bollerslev, 1997, p. 116). Along these lines, Andersen and Bollerslev (1998) analyze high-frequency Deutsche Mark-US Dollar returns and reveal that the volatility

¹Throughout the article all dates are reported as Central European Time (CET).

²E.g., market participants try to judge upon how “hawkish” or “dovish” a central bank acts and to infer how seriously the central bank aims at ensuring price stability.

process can be naturally separated into three components: (i) a deterministic periodic component (including day-of-the-week and calendar effects), (ii) announcement effects and (iii) ARCH effects. Following the articles of Andersen and Bollerslev (1997) and Andersen and Bollerslev (1998) it has become a standard approach to estimate the deterministic periodic component by assuming that the intraday volatility pattern is best described by a flexible Fourier form (FFF). Announcement effects are either estimated directly within the FFF regression or in a two step procedure by investigating the filtered return series, i.e. the original return series divided by the FFF estimated seasonal component. This second approach is employed by e.g. Baillie et al. (2000) and Han (2004). Finally, Andersen et al. (2003) shift the focus of attention to the reaction of the conditional mean of exchange rate returns in response to macroeconomic announcements. While the volatility response is at least partly driven by the pure fact that an announcement is released, the conditional mean reacts only to surprise news, i.e. a deviation of the released figures from what market participants expected. In particular, the impact of monetary policy announcements concerning interest rate decisions on exchange rates has recently received great attention. Among others, the studies of Faust et al. (2007) and Kearns and Manners (2006) point towards a positive relationship between unexpected interest rate changes and exchange rate movements: exchange rates react to an unforeseen monetary tightening (easing) by appreciating (depreciating).

This brings us to the second strand of literature that needs to be considered for a meaningful analysis. At the heart of this literature is the attempt to measure the quantitative implications of central bank communication on exchange rates and interest rates. Jansen and de Haan (2005) discuss the role of the ECB's statements to "speak up" the EUR and discover only a volatility effect using daily exchange rate data. Switching to high-frequency, Jansen and de Haan (2007) find both a mean and a volatility effect. However, the mean effect is comparatively small and rather short-lived. Fratzscher (2004) provides evidence that oral interventions affect the mean as well as the volatility and reports that during actual interventions oral interventions reduce volatility while the actual interventions themselves increase the movement of exchange rates. Similarly, Beine et al. (2004) notice that comments during official exchange rate interventions were partially effective. While these studies use dummy variables to measure communication, recent studies on interest rates create communication indicators. Heinemann and Ullrich (2007) construct an indicator based on specific code words, while Berger et al. (2006) propose a content based indicator. With respect to the EUR-\$ exchange rate Siklos and Bohl

(2006) capture the impact of press releases of the ECB commenting on specific developments in the real sector. Despite this research effort, there is no study which tests for the impact of the ECB's key communication instrument, namely the press conference, on the EUR-\$ exchange rate. This is remarkable because there has been increasing interest in studying the impact of this key communication instrument on interest rates. For example, Ehrmann and Fratzscher (2007b) investigate the effects of the ECB's press conference on the 3-month Euribor futures rates. They report that the press conference can have an even stronger effect than the press release of the interest rate decision.

Our analysis contributes to the existing literature in several ways. We test for the impact of the interest rate announcement, the introductory statement as well as the Q&A session on the mean and the volatility of the EUR-\$ exchange rate by using a long time span (01/1999–10/2006) of five-minute intraday data. The major advantage of employing high-frequency rather than daily data is that we can directly monitor the impact of all three events on the market in real time and bypass problems with regards to causality and identification. In that respect the ECB serves as an excellent example. First, all decisions discussed at the governing council meeting are made public and explained within one day. Second, the content of the introductory statement is not released in one shot but read to the public and the expert group. To the best of our knowledge, we are the first to provide a statistical framework that allows to simultaneously trace the effects of all three events on the EUR-\$ exchange rate and at the same time controls for interdependencies between those events.

As mentioned above, the usage of intraday data requires an econometric methodology which allows to separate the announcements effects from the typical intraday volatility pattern. In our setup, we have to deal with the additional complication that right at the beginning of the introductory statement at 14.30 there are major macroeconomic announcements in the U.S. In a first step, we deseasonalize the high-frequency returns using a control sample from which both the intraday seasonal pattern and the U.S. announcement effects are extracted. For this purpose, we develop a new procedure based on nonparametric kernel smoothing techniques. For the simultaneous analysis of the effects of the press release and the press conference this smoothing step is essential. While at 13.45 market volatility is usually low, it is much higher at 14.30 because of the opening of the U.S. markets at 14.00 and the U.S. announcements at 14.30. Our approach guarantees that this regular increase in volatility is not attributed to the press conference.

Since the filtered absolute returns reveal a clear pattern of long memory and persis-

tence, a model for the conditional variance of the exchange rate should take into account this property. We estimate an AR-FIGARCH specification for the filtered five-minutes returns whereby we control for surprise interest rate announcements, the content of the press conference as well as the Q&A session in both the mean and the variance. Our surprise measure for the interest change is taken from the Reuters business surveys. To assess the impact of the press conference, we rely on a new communication indicator which explicitly takes into account the content of each sentence. We have spawned this new communication indicator based on a coding of the content of the introductory statement provided by a media research institute. The indicator captures information on expected developments in major policy-relevant areas like inflation, the exchange rate, the real economy as well as monetary aggregates.

We show that a surprise in the released interest rate decision leads to significant movements in the level and volatility of the EUR-\$ exchange rate at 13.50 and the following thirty-minutes. More specifically, we find an asymmetry in the response to positive and negative interest rate surprises. While the exchange rate adjusts to positive interest rate surprises immediately after the press release, reactions to negative surprises are partly postponed to the period of the introductory statement. Market participants seem to evaluate negative surprises in connection with the assessment of the ECB. Moreover, there are important interactions between the interest rate surprise and the direction of the interest rate change. For example, our results are very much in line with the ‘practitioners claim’ that prices react more strongly to bad news in good times than to bad news in bad times.

Concerning the introductory statement, our main finding is that financial markets react most strongly to communication about future price developments which effects the mean and the volatility. In line with the predictions of Clarida and Waldman (2007), market participants seem to use the new information about future inflation rates to update their beliefs concerning the ECB’s future interest rate setting. In addition, if the communication was preceded by a (negative) interest rate surprise, the introductory statement serves as a tool for explaining the recent decision. Explicit statements on the expected development of the exchange rate effect the mean but not the volatility of the exchange rate. The other topics (real economy, monetary aggregates) appear to be irrelevant for the reaction of the exchange rate. Finally, by splitting the sample, we find evidence that the introductory statement gained importance in recent times. While the Q&A itself adds no systematically important information to the markets it complements the earlier announced decision of the ECB.

In summary, both the ECB's policy decision on the target interest rate as well as its communication impact the EUR-\$ exchange rate in an order of magnitude which is statistically and economically important.

The remainder of this article is organized as follows. Section 2 briefly elaborates on the linkages between ECB announcements and exchange rate movements. In Section 3 we analyze the time series properties of the five-minute EUR-\$ exchange rate data and suggest a new methodology for extracting the intraday seasonal pattern. Moreover, we introduce the Reuters data on market expectations and the ECB communication indices. Section 4 lays out the properties of the AR-FIGARCH model which is the workhorse for our empirical analysis conducted in Section 5. Finally, Section 6 concludes.

2 ECB Announcement Days and Exchange Rate Movements

In this section we will contend the expected relationship between the different types of announcements and their impact on the exchange rate. Figure 1 displays the timing of the press release, the press conference and the Q&A session during ECB announcement days. At 13.45 the interest rate decision is announced via a press release. This press release contains solely the interest rate decision without any further explanation. From 14.30 onwards the introductory statement is held by the ECB's President and the Vice-President which is then followed by the Q&A session.³ The end of the introductory statement is not a priori fixed in time as it depends on the judgement of the governing council to what extent the relevant topics are addressed. On average it ends around 14.45. The introductory statement is, besides the Monthly Bulletin, the most important communication instrument and comprises a policy-relevant assessment of the governing council on the current standing of the economy, the outlook for future prices and the interest path. As its text is based on a wording agreed upon by all council members it is a valuable source of information. The Q&A session that follows thereafter provides a platform for media representatives around the world for further explanation of the

³The introductory statement has a clear structure. After welcoming the attendants, the ECB's President repeats the interest rate decision and provides a general assessment, which is then followed by a detailed discussion of developments in the real economy, in prices, in the exchange rate, monetary developments and a summary. Before May 2003 the discussion of monetary developments preceded the discussion of the real economy.

monetary policy decision.

Figure 1 about here

The direction in which an interest rate surprise will move the exchange rate is a priori uncertain and depends on the market participants beliefs about the model of exchange rate determination.⁴ Interest rate parity and arbitrage opportunities imply an appreciation of the home currency due to an unexpected monetary tightening. Hence, the surprise announcement of an increasing interest rate should lead to an appreciation of the home currency relative to the foreign currency. However, this need not necessarily to be the case. One aspect, for instance, are differences in the reaction in the short to medium and long-term horizon driven by e.g. Dornbush's overshooting model. Another reason for a movement of the exchange rate that does not match this pattern are expectations about future developments. As Ehrmann and Fratzscher (2005) argue an unexpected easing of monetary policy might signal to the public an economic upturn associated with high economic activity as well as rising asset prices in the future and consequently imply that the home currency appreciates and not depreciates. Similarly, it might happen that an unexpected monetary tightening appears to have no effect on the exchange rate, while it indeed prevented the exchange rate from a further depreciation. Finally, technical trading may serve as an explanation. Agents might bet in front of central bank announcements against or in favor of an exchange rate movement which might swamp the effect of the announced interest rate movement afterwards.

The linkage between the ECB's press conference and the exchange rate has not yet been tackled explicitly in the economic literature. However, attempts were made to discover the impact of ECB announcements targeting the exchange rate. See for instance Jansen and de Haan (2007) or Beine et al. (2004) who test how ECB announcements concerning exchange rate interventions and the assessment of a undervalued/overvalued currency were perceived by the market. As noted earlier the interpretation matters. Following the argumentation in Almeida et al. (1998), communication on rising future inflation could lead to a depreciation of the EUR if the ECB reaction function assigns relatively low weight to the level of inflation. On the other hand, if the central bank reaction function shows a strong preference for low inflation, the same news should induce an appreciation of the EUR. Similarly, Clarida and Waldman (2007) argue that bad news of rising inflation

⁴Of course, also anticipated changes of the interest rate can have an effect on the exchange rate. This effect, however, should be already priced into the exchange rate at the announcement of the decision.

could be good news for the exchange rate markets. If the corresponding central bank follows a Taylor-type monetary policy rule, news about rising inflation should result in a monetary tightening, which in turn implies a higher demand for the national currency and thus an appreciation.

So far, no study provided empirical evidence on the implications of the Q&A session. Its main purpose is not to add new information but to clarify the intentions and the assessments of the decision-makers. Thus, we expect no impact of the Q&A session itself. Nevertheless, the Q&A session could be relevant if we condition on the preceding actions taken.

3 Data

3.1 Exchange Rate Data

Since the ECB's governing council meetings and the respective three events usually take place on Thursdays and it is well known that the intraday volatility pattern varies across the days of the week, we employ for our analysis only high-frequency EUR-\$ exchange rate data stemming from Thursdays.⁵ Our original sample consists of irregularly spaced tick-by-tick quotes of the EUR-\$ exchange rate for all 417 Thursdays in the period January 1999 to October 2006 obtained from Olsen and Associates.⁶ Each quote contains a bid and an ask price along with the time stamp to the nearest second. Taking the immediately preceding and following quotation at the end of each five minute interval we obtain the log price by linearly interpolating the average of the log bid and the log ask at each five-minute mark. Five-minute returns are then constructed as the change in these five-minute log prices. The returns are denoted by $R_{k,n}$, $k = 1, \dots, K$ and $n = 1, \dots, N$, where K is the number of days in our sample and $N = 288$ is the number of five-minute intervals per day. Among all Thursdays there are 89 ECB monetary policy decision days. The remaining "non-announcement" days will serve as control days. The standard summary statistics (not reported) for the ECB announcement days and the control days are virtually identical. The sample mean of the five-minute returns is indistinguishable from zero at any standard significance level. While the skewness is not significantly different from zero,

⁵There are only four exceptions from this rule. On those four days the decision was made on a Wednesday.

⁶We define the exchange rate such that an upward movement implies an appreciation of the EUR relative to the U.S. Dollar.

there is evidence for excess kurtosis significantly larger than three. Hence, the five-minute return distribution is symmetric around zero but non Gaussian which is also confirmed by the Jarque-Bera statistic. As often reported for high-frequency data, there is some evidence of serial correlation for low lags in the five-minute EUR-\$ returns, possibly due to microstructure effects. No significant correlations are found for higher lags. In sharp contrast, the squared and absolute returns are highly correlated even for long lags. In the following we will analyze these intertemporal dependencies in the absolute returns in more detail.

The average absolute returns over the five-minute intervals for the 328 control days (solid) and the 89 announcement days (dashed) are shown in Figure 2. From this figure it is clear that the absolute return series display a pronounced intraday volatility pattern. At 1.00 volatility begins to increase with the opening of the Singapore and Hong Kong markets which are followed by the Tokyo market one hour later and by the Sydney market two hours later. The decline in volatility around 4.00 to 5.30 reflects the lunch hour in the Tokyo and Hong Kong markets. Volatility then sharply increases with the opening of the European markets around 8.00 and tails off again with European lunch time around 12.00. The U.S. markets open at 14.00. Between 14.00 and 17.00 both the European and American markets are open simultaneously and volatility is highest during the day. Finally, after the closing of the European markets around 17.00 volatility starts to decline monotonically back to the level associated with the Pacific segment. The solid line reveals two volatility spikes during the trading day. A first one at 14.35 and a second one at 16.05. Both volatility spikes are induced by major macroeconomic news announcements which take place in the U.S. at 14.30 and 16.00.⁷ The dashed line which is associated with the ECB announcement days reveals an intraday volatility pattern which is almost identical to the one of the control days for most of the trading day. However, exactly at the timing of the ECB press release and during the press conference one can observe distinct differences.

Figure 2 about here

Figure 3 about here

Figure 3 renders for a more detailed view on the important time period between 13.00 – 16.00. The solid line represents the difference between the average absolute five-minute

⁷In particular, the announcements at 14.30 consist of releases on GDP, Producer Price Index, personal income, jobless claims, productivity, non-farm payrolls, etc.

EUR-\$ returns on announcement and control days. Clearly, we observe a sharp increase in volatility at 13.50. Since neither in the U.S. nor in Europe any other macroeconomic news is released at 13.45, the dramatic increase in volatility at 13.50 must reflect how market participants process the news associated with the ECB’s monetary policy decision launched by the press release. This increase in volatility has no counterpart on the control days. At 14.35 the difference in the two volatilities is basically zero. This is not surprising, since the ECB’s introductory statement starts with welcoming all the participants and a reiteration of the policy decision, and hence it should not reveal news to the market in the first few minutes. Our interpretation is therefore that at 14.35 both announcement and control days are dominated by the macroeconomic announcements released in the U.S., resulting in the zero difference of the volatilities. However, while on control days the volatility immediately falls back at 14.40, there is a second spike at 14.45 on the announcements days reflecting the new information made public by the communication during the press conference. From 14.45 onwards, the difference in the volatilities of announcement and control days is again declining, indicating that after the finishing of the ECB press conference there is no systematic difference in the two types of days.

Clearly, the systematic movements in the daily volatility pattern of the EUR-\$ exchange rate should have consequences for the dependencies between lagged absolute returns. The autocorrelation functions of the absolute return series over one (left) and five (right) trading days are shown in Figure 4. Similarly, as observed by Andersen and Bollerslev (1997), the sample autocorrelations are characterized by a “distorted U-shape” behavior induced by the strong intraday pattern discussed above. Hence, as argued in Andersen and Bollerslev (1997) it is indispensable for any meaningful analysis employing the intraday returns to first estimate and extract the intraday periodic component of return volatility.

Figure 4 about here

3.2 Modeling the Periodic Intraday Pattern

In this section we propose a new method for filtering out the periodic intraday seasonal component from the high-frequency return series. The procedure is based on a nonparametric kernel estimate of the intraday volatility pattern and – in contrast to previous approaches – does not require the subjective choice of potentially important points in time and the length of their effect on volatility. The typical pattern of a Thursday includ-

ing the U.S. announcement effects will be extracted from the control days, which have – apart from the effects of the ECB announcements – the same intraday seasonal pattern as the announcement days. By doing so, the proposed procedure takes into account intraday seasonality but at the same time ensures that we do not explain away what we are actually interested in.

As in Andersen and Bollerslev (1997), we assume the following structure for the intraday returns

$$R_{k,n} = \mathbf{E}(R_{k,n}) + \frac{\sqrt{h_k s_n} Z_{k,n}}{\sqrt{N}}, \quad (1)$$

where $\mathbf{E}(R_{k,n})$ denotes the unconditional expectation of the five-minute returns, h_k is the conditional variance of day k and s_n a deterministic periodic component for the n -th intraday interval. The innovations $Z_{k,n}$ are assumed to be independently and identically distributed (*i.i.d.*) with mean zero and unit variance. Moreover, we assume that the $Z_{k,n}$ are independent of h_k . Note, that Andersen and Bollerslev (1997) allow the periodic component s_n also to depend on day k . While this is important when one has to deal with day-of-the-week effects, it is unnecessary in our context since we consider Thursdays only.

Next, the aim is to obtain an estimate of the seasonal component s_n . As suggested by Andersen and Bollerslev (1998) we estimate the seasonal component from a regression using a log-transformation of equation (1) which is more robust to extreme outliers in the five-minute return series than a regression in terms of, say $R_{k,n}^2$. Equation (1) can be rewritten as

$$\begin{aligned} r_{k,n} &\equiv 2 \log(|R_{k,n} - \mathbf{E}(R_{k,n})|) - \log(h_k) + \log(N) = \log(s_n^2) + \log(Z_{k,n}^2) \\ &= f(n) + u_{k,n}, \end{aligned} \quad (2)$$

with *i.i.d.* mean zero error term $u_{k,n} \equiv \log(Z_{k,n}^2) - \mathbf{E}(\log(Z_{k,n}^2))$. An estimable version of equation (2) is obtained by replacing $\mathbf{E}(R_{k,n})$ and h_k by suitable estimates. While $\mathbf{E}(R_{k,n})$ can be naturally estimated with the sample mean of the five-minute returns, there are several potential candidates for an estimate \hat{h}_k of h_k . Andersen and Bollerslev (1997) estimate a GARCH model on the daily return series and then substitute h_k by the fitted conditional variance series. However, this approach has the disadvantage that the daily conditional variance is modeled as a slowly varying function of past residuals and past conditional variances. In particular, it captures sharp increases in volatility only with some time lag, since a sudden increase in volatility on a certain day will not

effect the GARCH estimated conditional variance for that day, but for the following day and onwards. Alternatively, we estimate h_k by the realized volatility of the respective day, i.e. by $\hat{h}_k = \sum_{n=1}^N R_{k,n}^2$, which exploits contemporaneous intraday information. In contrast to the fitted conditional variances from a parametric GARCH model which may suffer from misspecification error, the realized volatility results in a consistent estimate of the true h_k .

Replacing $\mathbf{E}(R_{k,n})$ and h_k by their estimates leads to a series $\hat{r}_{k,n}$. The Andersen and Bollerslev (1997) approach assumes that $f(n)$ can be approximated by a parametric function $f(n|\theta)$ which is specified as a flexible Fourier form with trigonometric terms that obey a strict periodicity of one day and additional dummy variables capturing announcement effects. In their framework an estimate of the seasonal component can be obtained by regressing $\hat{r}_{k,n}$ on $f(n|\theta)$ by ordinary least squares. This in particular requires first a subjective election of possibly important announcements and second the knowledge of the exact timing of each particular announcement. Moreover, one has to specify for how long a particular announcement effects the conditional variance.

We suggest an alternative approach based on nonparametric kernel smoothing. To obtain an estimate of the seasonal component we regress $\hat{r}_{k,n}$ non-parametrically on a grid $x = 1, \dots, N$ of five-minute intervals over the trading day. This can be naturally done by using a Naradaya-Watson kernel estimator of $f(x)$ which is given by

$$\hat{f}_b(x) = \frac{\sum_{k=1}^K \sum_{n=1}^N K_b(n-x) \hat{r}_{k,n}}{K \sum_{n=1}^N K_b(n-x)}, \quad (3)$$

where $K_b(\cdot) = b^{-1}K(\cdot/b)$ with K being a kernel function and b the bandwidth parameter. Since the main purpose of our research is to explain the movements in the volatility of the EUR-\$ exchange rate on ECB announcement days by exogenous variables we apply the procedure to the control days only. Thereby, we extract the shape of the *typical* seasonal component of a Thursday including U.S. announcement effects but not the effects due to ECB announcements. In a first step we choose a global bandwidth b_g by cross-validation. This results in an accurate estimate of the overall intraday volatility pattern. In order to accommodate the effects of the U.S. announcements we locally apply a smaller bandwidth $b_l < b_g$ chosen according to the rule suggested in Lepski et al. (1997). This approach allows for an endogenous search for ‘important’ announcements. Moreover, the data determines how long those announcements effect the volatility. The upper part of Figure 5 graphs the fit $\hat{f}(x)$ across the 24-hour trading day in comparison to the average absolute returns

of the ECB announcement days.⁸ Finally, the filtered five-minutes returns are obtained as $\tilde{R}_{k,n} \equiv R_{k,n}/\hat{s}_n$, whereby the \hat{s}_n are standardized such that $1/N \sum_{n=1}^N \hat{s}_n = 1$. The filtered returns are plotted in the lower part of Figure 5. Clearly, both the intraday volatility pattern as well as the effects due to U.S. announcements have been removed, while ECB announcement effects have been preserved.

Figure 5 about here

The autocorrelation function of the absolute filtered return series is plotted in Figure 6. In comparison to Figure 4 (right) which depicts the autocorrelation function of the unfiltered return series, the proposed procedure does its job very well, resulting in a dramatic reduction in the periodic pattern. Interestingly, the autocorrelations of the absolute values of the filtered series initially decay rapidly, but are characterized by an extremely slow rate of decay thereafter. This type of decay is typical for long memory processes associated with autocorrelations decaying as j^{2d-1} , where d denotes the order of fractional integration. To illustrate this point we run the regression $\log(\hat{\rho}_j) = c_0 + c_1 \log(j) + u_j$, $j = 5, 6, \dots, 1440$, where $\hat{\rho}_j$ denotes the sample autocorrelation of the absolute filtered five-minute returns. Figure 6 shows that the rate of hyperbolic decay implied by the estimated persistence parameter of $\hat{d} = (\hat{c}_1 + 1)/2 = 0.41$ fits very well with the autocorrelations of the absolute filtered returns. Hence, an appropriate model for the conditional variance must allow for such long memory behavior. This requirement clearly rules out the class of short memory GARCH models which are characterized by exponentially decaying autocorrelations.

Figure 6 about here

3.3 Reuters Data on Surprises

In order to construct our surprise measure with respect to the monetary policy decision we utilize the Reuters survey of professional forecasters. The surprise measure is constructed as follows: one week ahead of the governing council meeting Reuters asks up to 80 financial

⁸To compare the estimates with the absolute returns we have to convert the intraday seasonality pattern through the transformation

$$|R_{k,n} - \mathbf{E}(R_{k,n})| = \frac{\sqrt{h_k} \exp(f(n)/2) \exp(u_{k,n}/2)}{\sqrt{N}}.$$

analysts about their expectations concerning the key interest rate being decided upon during the central bank meeting. Out of this questionnaire a monetary policy surprise is calculated as the mean respectively the median of the difference between the interest rate announced in the press release on the meeting day and the ex-ante expectations of the analysts. In the following, we will denote the mean surprise measure by $sr_{k,13.45}$. To be able to detect asymmetric responses of the exchange rate to positive and negative surprises, we split $sr_{k,13.45}$ into $sr_{k,13.45}^+$ and $sr_{k,13.45}^-$.

In comparison to our measure, previous studies employed a less explicit instrument to control for a surprise in the interest rate announcement. Zettelmeyer (2004) as well as Kearns and Manners (2006) propose to use the change in the 1-month respectively 3-month treasury bill interest rates. Clearly, this is a much more indirect measure of a surprise to the markets. Moreover, it may be distorted by market movements not related to the ECB decision.⁹

3.4 ECB Communication Indicator

To capture the impact of communication, the introductory statements have to be transformed into quantitative measures. Reviewing the earlier indices generated to portray the content of the wording we decided to spawn a new index. An appealing feature of this index is that it measures the content of the press conference, but is not generated by simply counting and valuing signal words as done in earlier studies. The new indicator is based on a coding of each introductory statement provided by the media research institute Mediatenor, which was commissioned by the KOF Swiss Economic Institute. Mediatenor has a long track record in handling press releases and no self interest in a specific outcome. We aggregate the coding into an index in a sensible way explained later in the text.

Most of the empirical studies that focus on the impact of communication events such as central bankers speeches or central bank statements use binary proxies (i.e. if there was a statement or not). This, however, only allows to analyze the effect of a statement, no matter what the content is. In reality financial markets closely watch central bankers lips and analyze their speeches thoroughly. Therefore, a measure that allows us to quantify the *content* of these statements is of major importance.

Some recent studies like Heinemann and Ullrich (2007) identify “code words” from ECB statements or publications to construct indicators for “hawkishness” in ECB state-

⁹There may have been, for instance, a trend in the interest rate movement.

ments. The advantage of such approaches is that they are relatively mechanical in quantifying ECB communication and are therefore in principle reproducible.¹⁰ However, financial market agents, especially the so called “ECB Watchers”, exactly analyze the statements and pay attention to the specific content of these statements. Moreover, there is no distinction of whether a “code word” such as “upside risk” is related to developments in the real economy, in prices or in money growth. Allowing for such distinctions might be of major importance since the ECB’s interpretation on developments in a certain sector may be completely ignored by financial markets, while they react strongly to interpretations on other sectors. The mechanical quantification by only counting certain expressions therefore disregards too much information relevant for our purpose. Incorporating the entire content and allowing for different dimensions – as is done in our indicator – seems to be a more appropriate solution. In a recent study Berger et al. (2006) construct an ECB communication indicator which is based on an interpretation of the introductory statement and thereby tries to capture not only the obvious content but also allows for a “reading between the lines”. The main drawback of their index is that it lacks objectivity and reproducibility, since the quantification mechanism is based on the opinion of a few selected economists.

To capture the content and to guarantee a high degree of objectivity and reproducibility we let Mediatenor, a media research institute, code the introductory statements.¹¹ Mediatenor surveys the content of the introductory statements from 01/1999 until 10/2006. Overall 89 statements have been coded. Each sentence has been analyzed in a variety of ways.¹² For our purpose we extract information about future prices, the real economy, the exchange rate and money growth. Obviously, these sectors correspond to the topics which are individually addressed in the introductory statement. For each of those sectors we calculate the share of statements addressing expectations by the central bank concern-

¹⁰Constructing indicators which solely on code words is questionable, because there are tendencies within the ECB to abandon the usage of specific code words (see e.g. an interview with Dr. Axel Weber, president of the Bundesbank and member of the ECB governing council, published in the Financial Times Europe, 28. May 2007).

¹¹Mediatenor has a strong experience in coding articles of media releases and capturing their content. Their analysts achieve a high rate of correlation which means that doing this exercise twice should lead to almost the same outcome. Furthermore, the employees are well trained in semantic coding but are not professional economists.

¹²For instance we capture the main theme, the judgement assessed to it, the directional change, the time horizon, etc.

ing rising values relative to falling values. For prices we use statements dealing with the consumer price index, prices in general, wages, and oil price developments. For the real economy we employ statements on GDP development, for exchange rates and monetary growth we just included statements on these specific topics. Furthermore, as a statement in time t has to be seen in relation to previous statements – that is $t - i$ – we aggregate over the past shares. Figure 7 depicts the index on future price developments together with the main refinancing rate of the ECB. The graph clearly shows that our index leads the interest rate cycle. Calculating the cross-correlations reveals that the highest correlation is reached at a 3-months lagged difference. This finding is perfectly in line with the observed ECB monetary policy. The ECB prepares markets for possible actions well in advance.

Figure 7 about here

3.5 A Closer Look at the Data

Table 1 visualizes the movement in the absolute five-minute returns during the time span of interest (13.40–15.30) for all control days, all announcement days, announcement days with no (median) surprise and announcement days with (median) surprise.¹³ The three largest volatilities in each column are marked by three, two and one stars respectively where three stars signify the largest volatility. The largest volatility in each row is marked as a bold number. Due to the U.S. announcements at 14.30, the control days reveal a single peak in volatility at 14.35. At 14.40 volatility immediately falls back to its previous level. The announcement days are characterized by three volatility peaks. The first and largest one due to the ECB press release at 13.45, the second one (as with the control days) at 14.35 and the third one due to the introductory statement at 14.45. Since the introductory statements start with a general assessment followed by comments on prices, the real economy and monetary aggregates, it is reasonable that the volatility becomes more pronounced somewhere in the mid-end of the statement. The announcement days with no surprise have two major volatility peaks. A first one again induced by the U.S. announcements, and a second one clearly due to the ECB introductory statement, i.e. on announcement days with no surprise the attention of the market participants shifts from the press release to the press conference. Finally, announcement days with surprise are

¹³Here we use median surprises because they occur less frequent than mean surprises and hence allow for a ‘strong’ separation of our sample in surprise and no surprise days.

dominated by the huge increase in volatility right after the press release. If we concentrate on the highest volatility across samples, at each point in time the surprise sample dominates all other samples' movements with only two exceptions over the whole time span. Especially at the announcement time of the interest rate decision the absolute return is nearly six times larger than in our control sample. Even compared to the non-surprise announcement days it is five times larger.

Table 1 about here

Overall, this eyeballing exercise suggests that both the press release and the press conference have a strong impact on the volatility of the EUR-\$ exchange rate on ECB announcement days. Moreover, there is clear evidence for the outstanding role of interest surprises in comparison to usual announcement days.

4 The FIGARCH Model

The decay behavior of the autocorrelation function of the absolute filtered return series investigated in Section 3.2 suggests that the conditional variance of the filtered return series should be modeled as a fractionally integrated process. Among the GARCH-type models which allow for such a behavior in the conditional variance, the Fractionally Integrated GARCH (FIGARCH) model proposed by Baillie et al. (1996) is definitely the most prominent one. The FIGARCH model has been successfully applied e.g. by Baillie et al. (2000) to analyze the high-frequency Deutschmark-\$ exchange rate and by Beine et al. (2002) to investigate the effects of central bank interventions on the volatility of the Deutschmark-\$ and Japanese Yen-\$ exchange rate.

The econometric model we apply to the filtered return series is autoregressive in the mean and obeys residuals which follow a FIGARCH process. In both equations – the conditional mean and variance – we allow for explanatory variables, namely the surprise measures, the communication indicators, controls for the Q&A session and interaction terms. For the mean equation we assume the following autoregressive structure for the filtered returns $\tilde{R}_{k,n}$ including I_1 exogenous regressors $X_{k,n,i}$.

$$\tilde{R}_{k,n} = \mu + \sum_{j=1}^P \varphi_j \tilde{R}_{k,n-j} + \sum_{i=1}^{I_1} \delta_i X_{k,n,i} + \varepsilon_{k,n} \quad (4)$$

The innovations $\{\varepsilon_{k,n}\}$ follow a FIGARCH(p, d, q) process defined via the equations

$$\varepsilon_{k,n} = Z_{k,n} \sqrt{h_{k,n}}$$

where $\{Z_{k,n}\}$ is a sequence of *i.i.d.* random variables with $\mathbf{E}(Z_{k,n}) = \mathbf{E}(Z_{k,n}^2 - 1) = 0$, and

$$(1 - L)^d \Phi(L) \varepsilon_{k,n}^2 = \omega + B(L) v_{k,n}, \quad (5)$$

for some $\omega \in \mathbb{R}^+$, with $v_{k,n} = \varepsilon_{k,n}^2 - h_{k,n}$, lag polynomials $\Phi(L) = 1 - \sum_{i=1}^q \phi_i L^i$, $B(L) = 1 - \sum_{i=1}^p \beta_i L^i$, and $0 \leq d \leq 1$ being the fractional differencing parameter. The FIGARCH model reduces to the GARCH model for $d = 0$ and to the IGARCH model for $d = 1$. For any $0 < d < 1$ the FIGARCH process is not covariance stationary, since its unconditional variance does not exist. The question whether the model is strictly stationary or not is still open at present. For an in depth discussion of the properties of the FIGARCH model see Conrad and Haag (2006). An important issue in specifying a valid FIGARCH model is to restrict the parameters of the process such that the conditional variance $h_{k,n}$ is non-negative almost surely for all k and n . Necessary and sufficient conditions have been derived in Conrad and Haag (2006). These conditions ensure that all the ψ_i coefficients in the so-called ARCH(∞) representation of the FIGARCH process are non-negative. The FIGARCH implies the ARCH(∞) representation

$$h_t = \frac{\omega}{B(1)} + \left(1 - \frac{(1 - L)^d \Phi(L)}{B(L)}\right) \varepsilon_t^2 = \frac{\omega}{B(1)} + \sum_{j=1}^{\infty} \psi_j \varepsilon_{t-j}^2, \quad (6)$$

where, for simplicity, we changed the notation for the subindex from k, n to $t = 1, \dots, KN$. Since the FIGARCH(1, d , 1) will be used in the next section, we restate the necessary and sufficient condition for this model explicitly. First, note that for the (1, d , 1) model the ARCH(∞) coefficients can be derived recursively as $\psi_1 = d + \phi_1 - \beta_1$ and $\psi_j = \beta \psi_{j-1} + (f_j - \phi_1)(-g_{j-1})$ for $j \geq 2$, where $f_j = (j - 1 - d)/j$ and $g_j = f_j \cdot g_{j-1}$ with $g_0 = 1$. The necessary and sufficient conditions are then given by (see Conrad and Haag, 2006, Corollary 1): case (i) $0 < \beta_1 < 1$, either $\psi_1 \geq 0$ and $\phi_1 \leq f_2$ or $\psi_{j-1} \geq 0$ and $f_{j-1} < \phi_1 \leq f_j$ with $j > 2$; case (ii) $-1 < \beta_1 < 0$, either $\psi_1 \geq 0$, $\psi_2 \geq 0$ and $\phi_1 \leq f_2(\beta_1 + f_3)/(\beta_1 + f_2)$ or $\psi_{j-1} \geq 0$, $\psi_{j-2} \geq 0$ and $f_{j-2}(\beta_1 + f_{j-1})/(\beta_1 + f_{j-2}) < \phi_1 \leq f_{j-1}(\beta_1 + f_j)/(\beta_1 + f_{j-1})$ with $j > 3$.

Bollerslev and Mikkelsen (1996) provided a sufficient condition for the non-negativity of the conditional variance, which is overly restrictive in comparison to the necessary and sufficient set. In particular, their condition implies the upper bound $\phi_1 < f_3$, which is often violated for high-frequency data (see Baillie et al., 2004).

Alternatively, we allow for I_2 exogenous regressors in the conditional variance equation.

$$B(L)h_{k,n} = \omega + \sum_{i=1}^{I_2} \omega_i X_{k,n,i} + (B(L) - (1 - L)^d \Phi(L)) \varepsilon_{k,n}^2 \quad (7)$$

In equation (7) all exogenous variables $X_{k,n,i}$ are chosen such that they are known at time $k, n - 1$ with certainty. In this way, we ensure that $\mathbf{E}(\varepsilon_{k,n}^2 | \mathcal{F}_{k,n-1}) = h_{k,n}$ is a constant and can be interpreted as a conditional variance. E.g. the conditional variance at 13.50 will be explained by the surprise realized at 13.45, i.e. we explain $h_{k,13.50}$ by choosing $X_{k,n,i}$ as $sr_{k,13.45}^+$ and $|sr_{k,13.45}^-|$.

5 Empirical Results

5.1 Pure AR-FIGARCH Models

Before we analyze the effects of the monetary policy decisions on the level and volatility of the EUR-\$ exchange rate in detail, we present in Table 2 estimation results from pure AR-FIGARCH models for the control sample and the announcement days without including any exogenous regressors.¹⁴ The serial correlation in the filtered five-minute return series is well captured by the inclusion of three autoregressive lags in the mean equation, while in the conditional variance a FIGARCH(1, d , 1) was the preferred specification based on the Akaike and Schwartz information criteria compared to models of higher order. To capture the apparent leptokurtosis in the filtered return series, the innovation term is assumed to be t -distributed with ν degrees of freedom. As can be seen from Table 2, the constant and the estimated AR parameters in the mean equation are highly significant. The estimated persistence parameter, \hat{d} , in the conditional variance equation is around 0.3 and significantly different from zero or one. The $\hat{\phi}_1$ and $\hat{\beta}_1$ parameters are again highly significant and lie inside the necessary and sufficient parameter set provided by Conrad and Haag (2006).¹⁵ Moreover, the Ljung-Box Q -statistics for the squared standardized residuals (not reported) indicate that the FIGARCH specification does very well in capturing the hyperbolic memory in the squared filtered returns. Most importantly, the parameters estimated for the control days and the announcement days are very similar and, with the exception of $\hat{\phi}_1$, not statistically different from each other.¹⁶

¹⁴For reasons of comparability, we use a control sample which consists of 89 days, the same number of days that we have for ECB announcement days. The control days were chosen randomly as the Thursday either one week before or one week after the announcement day.

¹⁵Note, that they lie outside the sufficient parameter set given by the Bollerslev and Mikkelsen (1996). In particular, $\hat{\phi}_1 > \hat{f}_3$, the case typically observed for high-frequency data.

¹⁶The lower first order autoregressive coefficient estimated for the announcement days sample is presumably due to the news which effect the market on those days and drive the exchange rate into a

Thus, we conclude that the same underlying process is apparent in both samples.

Table 2 about here

Next, we reestimate the AR(3)-FIGARCH(1, d , 1) models with dummy variables in the conditional mean and variance equation at 13.50, 14.35 and 14.45.¹⁷ As expected, for the control days none of the dummies is significant, indicating that the filtered control day returns are free of any effects due to macroeconomic announcements. The picture for the announcement days is very different. While we find no significant effects in the mean, the dummies in the variance are highly significant at 13.50 and 14.45, but not at 14.35. This outcome is convincing. First, only surprise news (which are not adequately captured by a simple dummy variable) should have an effect on the exchange rate return, while as reported in Andersen et al. (2003) the volatility obeys a pure announcement effect. Second, the effects due to the U.S. announcements which were clearly visible in Table 1 are no longer evident in the filtered series. Finally, we controlled for the possibility that news may leak into the markets before the official release date. However, any additional dummy variable before the press release at 13.45 turned out to be insignificant.¹⁸

5.2 The Explanatory Power of Surprises and Communication

In the following section we use the Reuters surprise data and the communication indicators to investigate whether the movements in the mean and variance can be explained by the size and sign of those variables. Tables 3 and 4 present our main estimation results. For utmost transparency the results are structured in the following way. First, in the spirit of Almeida et al. (1998) and Kearns and Manners (2006), we aggregate the response to the press release over different time intervals. Thus we can compare the magnitude and the direction of the response at a 5, 20 and 30 minute interval. This allows us to judge whether there is an immediate response, whether the response is building up or whether there is a backlash. Second, we aggregate the returns surrounding the introductory statement over direction unforecastable by the autoregressive specification.

¹⁷We omit the parameter estimates for reasons of brevity.

¹⁸Ehrmann and Fratzscher (2005) argue that news may leak into the markets before the official release date. This argument has low applicability for central banks. For instance central bank officials are not allowed to speak one week ahead of the official press release about the upcoming decision meeting. Hence, there is low probability that this information comes into the market short before the official meeting.

the period 14.35-14.50.¹⁹ This is necessary since statements e.g. about future inflation are made at different points in time during the various introductory statements. By doing so, we capture the overall impact of the introductory statement. For the sake of brevity we do not report the structural AR-FIGARCH parameters which were found to be very similar to the ones presented in Table 2.

After a preliminary analysis, we decided to separate the surprise measure into positive and negative surprises in order to control for asymmetries. There are good reasons to believe that for instance good news lead to different responses relative to bad news. E.g. Andersen et al. (2003) as well as Ehrmann and Fratzscher (2005) provide evidence for asymmetric responses. With respect to the communication instrument we include forward-looking communication on exchange rates, inflation, the real economy and monetary aggregates. Notably only news on exchange rates and inflation significantly drive exchange rates. All other communication did neither impact the mean nor the variance equation.²⁰ For space considerations we omitted the parameter estimates of those variables from the tables presented below. The result makes intuitively sense since (i) exchange rates should directly be affected by an assessment of the central bank and (ii) news on future price movements should be naturally the most important message as it is the ECB's primary objective to achieve price stability. In addition, we also controlled for a possible impact of the Q&A session by employing dummy variables for the period 14.50-15.15 in the estimation setup. Those were, however, not significant.

Table 3 about here

Turning now to the estimation results, a very stable and compelling picture emerges. Table 3 presents the coefficient estimates for the three different aggregation schemes denoted by (1)–(3). E.g. in aggregation scheme (2) the five-minute returns for the periods 13.45-14.05 and 14.35-14.50 are replaced by the aggregate returns $\tilde{R}_{k,13.45-14.05}$ and $\tilde{R}_{k,14.35-14.50}$. As can be seen from Table 3, an unexpected increase of the interest rate has an immediate positive and significant impact on the exchange rate. The positive effect is increasing within the first twenty-minutes and then comes back to the size of the initial

¹⁹The return from 14.30 to 14.35 is excluded from the aggregation scheme, because it may be contaminated by reactions to the U.S. announcements which take place at 14.30.

²⁰In line with Lamla and Rupperecht (2006), Ehrmann and Fratzscher (2007b) report that during the press conference especially statements on inflation had the “largest and most systematic” impact on the 3-month Euribor futures rates.

reaction after thirty-minutes. Hence, a positive surprise leads to a prolonged appreciation of the EUR-\$ exchange rate. This can be explained by market participants who expect further rising interest rate returns and a booming economy. Another line of argumentation would be that market participants try to predict the interest step assuming that the ECB follows some type of Taylor-rule. If they observe that the countermeasures taken by the ECB to fight inflationary pressure are more hawkish than expected, that is if the interest step taken implies that the inflation aversion parameter of the Taylor-rule function has to be adjusted upward, the logical consequence is to demand more currency. Looking at the effect of a positive surprise on the volatility, we find evidence for a cumulative volatility response which is gradual and seems to build up during the thirty-minute interval, an observation also made by Andersen et al. (2003).²¹ The negative surprise is significant at the twenty-minute interval only, i.e. it seems to require some time to evoke a significant market reaction which then vanishes again at the horizon of half an hour. At the twenty-minute interval a negative surprise implies a depreciation of the home currency which is in line with the impact of the positive surprise. As we will see in the upcoming section, it seems sensible to control for the type of the surprise which raises the relevance of a negative interest rate surprise. The effect of negative interest rate surprises on the level of volatility is similar to the one of positive surprises. However, the cumulative volatility response reaches its maximum at twenty-minutes already. To sum up, the asymmetry in the reported results justifies our estimation setup.

Concerning our communication indicators, the ECB's statements assessing the future exchange rate development ($CE_{k,14.35-14.50}$) are of great importance. Interestingly, the estimated coefficient is very stable independent of the time aggregation surrounding the press release. Because the coefficient has a positive sign, it indicates that the ECB has the credibility to talk up the exchange rate. Notably, there is no significant effect on the variance. This result is quite remarkable since it suggests that the ECB is able to steer the exchange rate without disturbing the markets or causing inefficient variation in the exchange rate. A similar result is found in Siklos and Bohl (2006) who report that ECB statements that focus on the outlook for the EUR-\$ exchange rate lead to a diminution of exchange rate volatility and hence they argue that "statements can be constructed as being informative in the sense that these reduce the risks surrounding exchange rate

²¹This does not mean that the level of volatility is constantly increasing during the thirty-minutes after the press release. The main increase in volatility occurs directly after the press release and is then followed by a period of "more than usual" volatility.

developments”.

With respect to news about the future inflation rate ($CI_{k,14.35-14.50}$) we find evidence for a positive relationship. As argued in Section 2, this result suggests that market participants use the new information about future inflation rates to update their beliefs about the ECB’s future interest rate setting. This result is also in line with the predictions of Clarida and Waldman (2007). They argue that a positive inflation surprise together with a Taylor-type monetary policy rule leads to an appreciation of the exchange rate.

In order to obtain a deeper understanding for the communication indicator we are most interested in, namely the one on future inflation developments, we reestimate our models after dividing the sample into two sub-periods using May 2003 as the breakpoint. At this date the ECB changed the structure of the introductory statement, highlighting the importance of non-monetary issues.²² The results presented in Table 4 provide strong support for the hypothesis that communication on future price developments gained importance over time.²³ While in the period 01/99–04/03 the coefficient estimate for the communication on the future inflation rate is negative, tiny and insignificant, it turns out to be positive and significant in the period 05/03–10/06. Also the variance of the EUR-\$ exchange rate is significantly effected by communication on the future inflation rate in the second subperiod. According to Ehrmann and Fratzscher (2007a) central banks can influence asset prices by their communication only if they possess credibility and a strong track record to do so. In the light of the above results, the ECB considerably gained credibility during the last years, making its communication a more and more powerful tool with which it can influence the exchange rate.²⁴ The introductory statement reveals important information about how the central bankers assess the future outlook, in particular with regards to inflation. Thus, the introductory statement serves as an important channel through which valuable information about the future policy path is provided to the market participants.

Table 4 about here

Figure 8 supplements the above findings concerning the rising importance of ECB

²²For a discussion on this potential breakpoint see also Berger et al. (2006).

²³The results presented in Table 4 are robust to the different aggregation schemes surrounding the time of the press release.

²⁴Notably this is not an exclusive explanation. One could also argue that the public learned to better understand the ECB over time or that the ECB is now able to communicate in greater clarity than it did at the beginning.

communication by a simple graphical illustration. For all announcement days, the figure shows a striking difference in the intraday volatility pattern of the EUR-\$ exchange rate between the subperiods 01/99–04/03 and 05/03–10/06. While in 01/99–04/03 the press release dominates the whole day, it loses much of its importance in 05/03–10/06. In sharp contrast, in this second period the press conference has become most important.²⁵ Hence, we observe two developments: first, interest rate surprises become smaller and, second, communication becomes more important. Whether the first development is due to the fact that the ECB recently better prepared its interest rate decisions or whether market participants learned better to forecast the decision can not be decided on the basis of our analysis. However, it should be undoubted that market participants increased the weight they attach to the introductory statement.

Figure 8 about here

In summary, our results are very much in line with Almeida et al. (1998, p. 396) who argue that “. . . the exchange rate behaves according to a model where international capital flows dominate trade flows, i.e. the key variable for exchange rate determination is the interest rate differential and where the monetary authorities set interest rates according to their expectations of future inflation.”

5.3 Further Evidence

This section will we elaborate on the stability of our results and gain some additional insights while conditioning on several circumstances. In Table 5 we interact our surprise measure controlling for positive and negative interest rate changes. To put it differently, we analyze the possibility that the effect of interest rate surprises depends on the direction of the interest rate change. For example, a positive surprise might on the one hand result from a stronger monetary policy tightening than expected but on the other hand might represent a situation in which the forecasters expected a significant loosening while the outcome was just a marginal lower interest rate. Controlling for these possibilities we indeed find significant differences. While a positive surprise driven by an increase in the interest rate triggers an appreciation of the exchange rate, a positive surprise in

²⁵A similar pattern emerges when we focus on announcement days with no surprise only. For those days the press conference and the press release are of equal importance in the first subsample, while the press conference is clearly more important in the second subsample.

combination with a falling interest rate has no significant effect. While the first result is in line with the outcome reported in Table 3, the second result is a bit surprising. However, the second result is mainly driven by the interest rate change on October 11th, 2001. After the terror attacks of 09/11 the ECB reduced the interest rate by 50 basis points, whereas market participants expected an even stronger monetary loosening. Thus, our negative and insignificant coefficient can be explained by the fact that the market participants did not consider the action taken by the ECB to stabilize the economy as being sufficiently strong.

With regards to the two types of negative surprises, both are associated with a depreciation of the home currency. They are, however, significantly different from each other. A negative surprise associated with a rising interest rate has a much stronger impact than a negative surprise of the same size associated with a declining interest rate. That is, if market participants overestimate a monetary tightening they adjust much stronger than if they would have underestimated a loosening. A likely explanation for this phenomenon might be that individuals fear inflationary pressure more than deflationary tendencies. In line with Andersen et al. (2003) this finding can also be interpreted as evidence for the claim that bad news in good times cause stronger reactions than bad news in bad times. This is, because negative interest rate surprises in combination with positive interest rate changes are likely to appear in a booming economy which might have reached its turning point. Negative interest rate surprises in combination with negative interest rate changes usually occur during recessions. Overall, it becomes clear that focussing on the characteristics of positive and negative surprises has more to tell than assumed so far.²⁶

Table 5 about here

Obviously, this detailed view might have implications for the way the communication is conducted and how it is perceived by the public. Those implications are captured by Table 6 where we interact our communication indicator, $CI_{k,14.35-14.50}$, with several dummy variables controlling for the sign of the previous interest rate change and surprise. First, we observe that the variables which measure communication with respect to inflation and the EUR-\$ exchange rate remain reasonably stable independent of the control variables we added. This is certainly an outcome that underlines the coherence of our results with respect to the role that communication plays.

²⁶However, it should be noted, that the coefficient estimates for the cases $sr_{k,13.45}^+ \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$ and $|sr_{k,13.45}^-| \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$ are based on a few observations only.

Table 6 about here

With Model (1) we check whether communication is perceived differently when inflation is high (above 2.2) or low (below 1.5) percent. The results reveal that the impact of communication does not vary with inflation lying outside the upper target of the ECB. However, if inflation is below 1.5, then the net effect of news about raising future inflation is no longer significantly different from zero. The reason behind this might be that in such a situation market participants do not expect the ECB to increase the interest rate since inflation is moving towards its target level.

Turning to Models (2), (3) and (4) it becomes obvious that communication is most relevant in connection with negative interest rate changes as well as negative surprises. Not surprisingly, the negative surprise variable has a stronger impact than the negative interest rate change, since the latter contains also an expected component. If there is a monetary loosening and the ECB notes that the inflation is going down ($CI_{k,14.35-14.50} \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$) this implies a further appreciation of the exchange rate, because market participants would expect that the engagement of the ECB to fight inflation paid off. Moreover, if the public views that the positive interest change is lower than expected (negative surprise) and the communication indicates a rise in future inflation ($CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^-} \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$) this is very bad news for the public and leads to a strong depreciation. In this case people fear that the action taken by the ECB may not be sufficient to fight inflation. If in such a scenario the ECB raises concerns about rising future inflation this amplifies the message and leads to a further depreciation of the home currency. If there is a positive surprise going along with a falling interest rate and the ECB communicates an expected rise in the future inflation ($CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^+} \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$), this might indicate a turnaround and may be interpreted as rising future interest rates which in turn lead to an appreciation of the exchange rate. Note, that only interacting a positive surprise with a positive change had no significant effect. However, in such a constellation the EUR-\$ exchange rate appreciated already immediately after the press release and so ECB communication seems to add no additional news.

The results concerning the Q&A session which are reported as Model (5) are striking. The Q&A session itself does not have a significant effect. However, when we condition on the preceding interest rate decision as well as on the communication the Q&A session turns out to gain importance.²⁷ This result does not come by surprise as the Q&A is meant

²⁷Here, we could only condition on two situations. This reason for this is that throughout our sample,

to complement the interest rate decision as well as the introductory statement. The following result emerges: if a negative surprise is complemented with an outlook of falling inflation ($\text{Q\&A}_{k,14.50-15.15} \times \mathbf{1}_{sr_{k,13.45}^-} \times \mathbf{1}_{\Delta CI_{k,14.35-14.50}^-}$) the Q&A serves as an instrument to compensate the shock of the press release and is followed by an appreciation.

To summarize, the overall effect of the press conference crucially depends on whether it was preceded by an interest rate surprise or not. If there was no surprise then the effect is mainly driven by the new information which shapes the markets expectations about future monetary policy. If there was a preceding surprise the effect is driven by the ECB's ability to explain its decision and hence can either strengthen or weaken the immediate response of the press release.

Finally, we would like to point out that our results deliver further support for a conjecture made in Andersen et al. (2003), namely that "news effects are in general a function of state uncertainty". E.g. we show that the effect of communication on the future inflation rate is very much dependent on whether this communication was preceded by an interest rate surprise or not. If market participants correctly anticipated the interest rate decision, their reaction mirrors that they feel certain about the state of the economy and the ECB's future monetary policy. On the other hand, if the decision lead to a surprise, this creates state uncertainty and the market participants reaction is driven by an adjustment process.

6 Conclusions

We analyze the effect of the ECB's monetary policy announcements on the level and volatility of the EUR-\$ exchange rate. In particular, we disentangle the effects of an announcement day by focussing on the impact of the interest rate decision at 13.45, the introductory statement starting at 14.30 and the Q&A session following thereafter. The key result is that each of the three events significantly drives EUR-\$ exchange rate movements at all three events. In detail, we find strong asymmetries in the response to the interest rate announcement, highlight the relevance of the ECB's assessment of the expected inflation path and exchange rate movements and provide evidence that all three instruments are interrelated and complement one another.

First, the impact of the interest rate announcement is significant if the decision was not

positive (negative) interest rate surprises almost always occurred in connection with changes in our communication indicator of the same sign.

anticipated by the market participants. Being more specific, an unexpected tightening of the monetary policy leads to an immediate appreciation of the EUR-\$ exchange rate. The immediate reaction to an unexpected easing is weaker and the full response is partially delayed towards the press conference. Positive interest rate surprises induce prolonged increases in the volatility of the exchange rate, in contrast negative surprises have only weak effects.

Second, the introductory statement plays an important role for market participants. In particular, the forward-looking content is closely followed by market participants who try to predict the future policy path. In a fine grained analysis we provide evidence that the ECB's assessment of inflationary and exchange rate developments are outstanding for the response of the EUR-\$ exchange rate. There is compelling evidence that a rise in the expected inflation rate mentioned in the introductory statement increases the value of the EUR. As our price indicator leads the interest rate cycle market participants might react to the expected rise of future market rates. This is in line with arguments put forward by Clarida and Waldman (2007). Thus, we provide evidence that information on price developments reveal more news to market participants than the ECB's assessment of developments in the monetary or real sector. Moreover, the index capturing news about expected movements of the exchange rate is relevant for market participants. Remarkably, while comments on the expected path of the exchange rate significantly impact exchange rate returns, they do not increase the volatility. We conclude that the ECB gained enough reputation to guide the public.

Third, while the previous paragraph highlighted the importance of the introductory statement because of its forward-looking character, we also find that the introductory statement has an important role in explaining unexpected interest rate decisions, in particular negative surprises. We provide remarkable evidence for interactions between communication and interest rate decisions. While, on average, communication has a positive coefficient estimate, this effect might be overruled if a surprise interest rate decision was announced beforehand. This is sensible because all three instruments are intended to complement each other and, consequently, must not be seen and estimated individually as it is the case in all the studies published so far. For instance, if there was a monetary tightening which was less strict than expected and if, in addition, the ECB states that inflationary pressure increases, this consequently leads to a depreciation.

Fourth, if there was a negative surprise and the ECB reported falling future inflation rates, we find a substantial movement during the Q&A session. The Q&A reinforces the

statement. It seems that the Q&A session contains little news in itself but must be seen as a complement to the earlier assessment of the ECB.

Finally, we explore the stability of our findings by splitting the sample period. We chose a breakpoint suggested by Berger et al. (2006) which is motivated by a change in the structure of the introductory statement. The results indicate that there is growing relevance of the introductory statement. The communication indicator concerning price developments gains in significance and magnitude suggesting that communication has become a more and more powerful tool to guide expectations. We conclude that some learning process took place. The interrelationship between ECB decisions and the expectations of the market participants evolves and seems to stabilize over the recent years.

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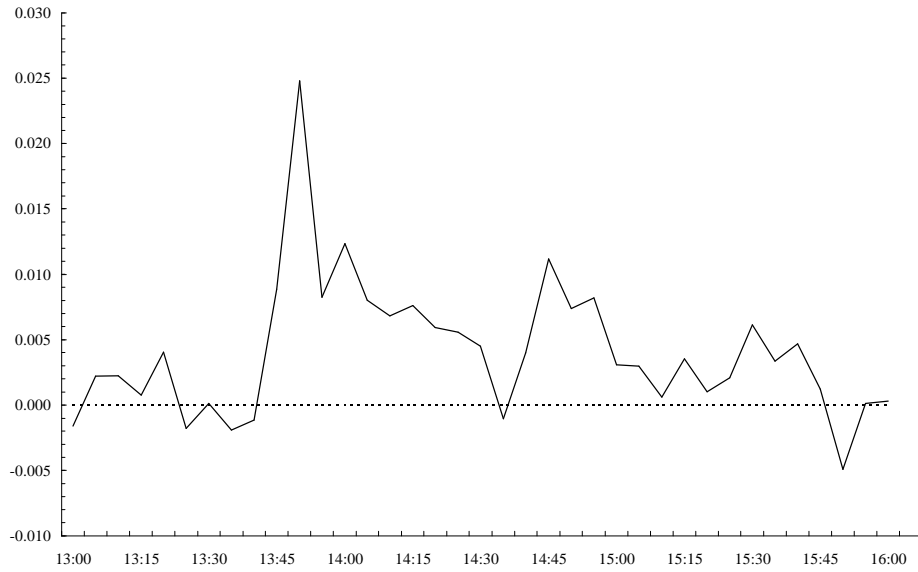


Figure 3: Difference between the average absolute five-minute EUR-\$ returns on announcement and control days in the time period 13.00 – 16.00.

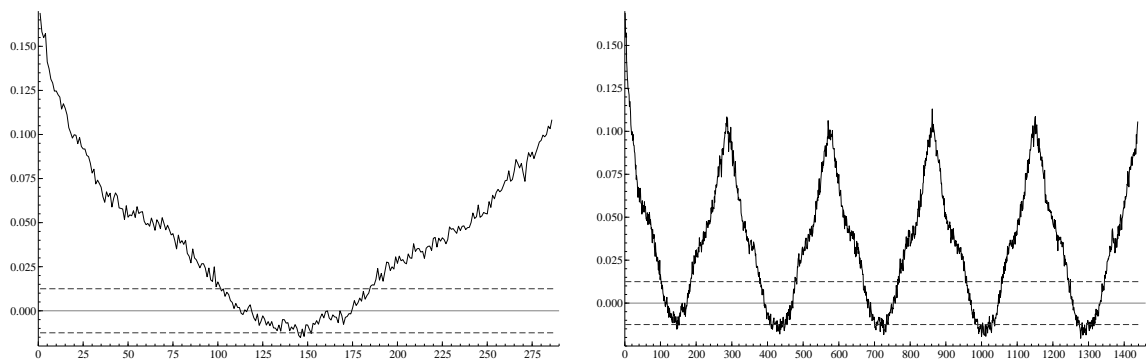


Figure 4: Sample autocorrelation functions of five-minute absolute EUR-\$ returns for one day (left) and five days (right). Dashed lines are 95% confidence bands.

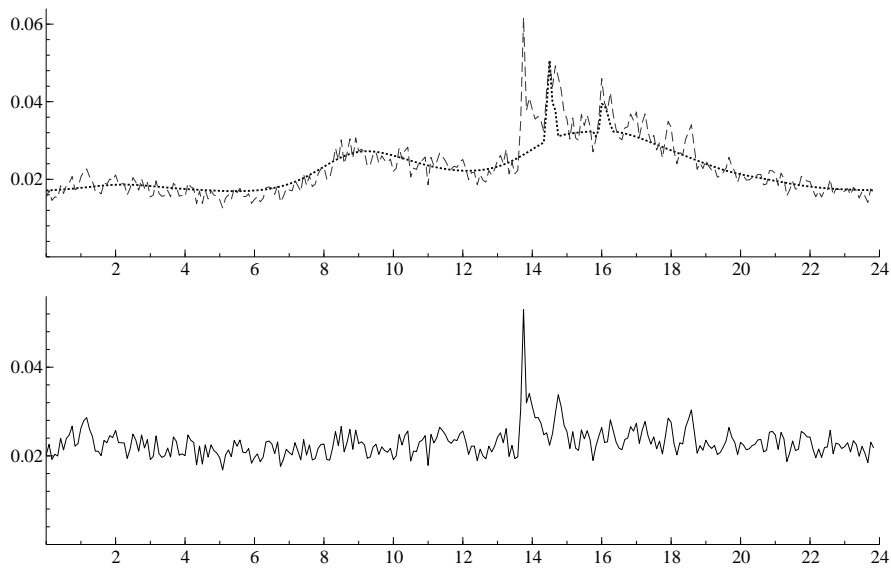


Figure 5: The upper figure graphs the nonparametric fit to the intraday seasonality of all control days (dotted line) together with the average absolute returns for all ECB announcement days (dashed line). The lower figure graphs the filtered average absolute returns for all ECB announcement days.

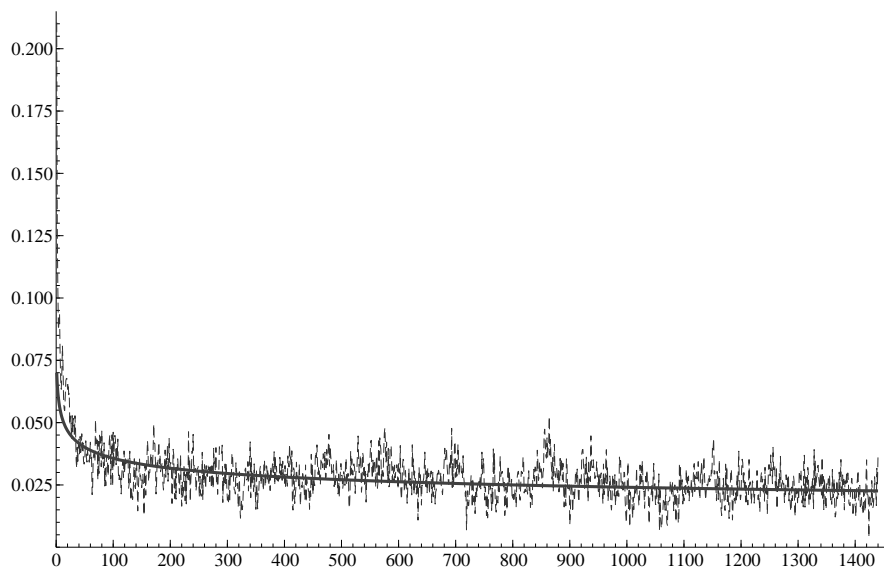


Figure 6: Sample autocorrelation function of the filtered absolute return series (dashed) and fitted hyperbolic decay (bold).

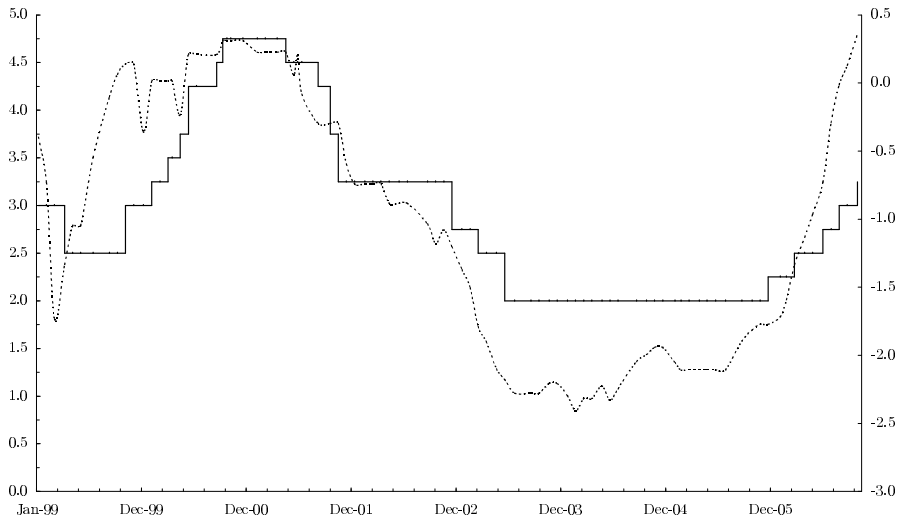


Figure 7: ECB Communication and Interest Rates. Solid line, left scale: ECB key refinancing rate; dashed line, right scale: communication indicator on future price developments.

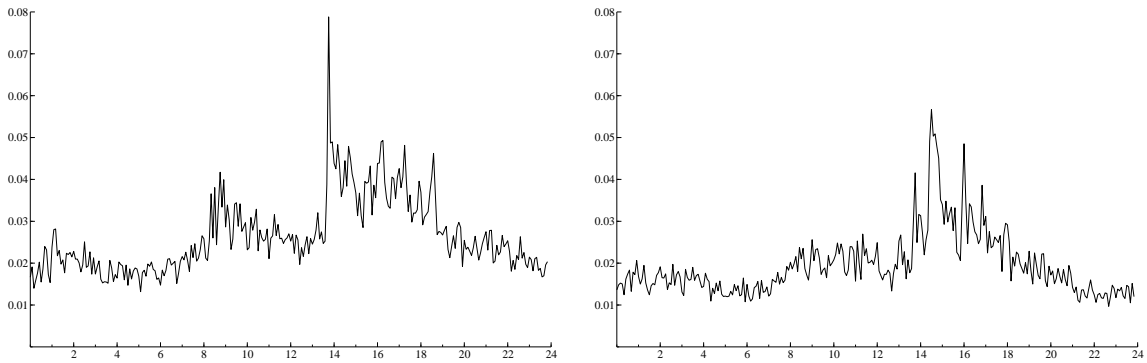


Figure 8: Average absolute five-minute EUR-\$ returns for each five minute interval. The left panel shows announcement days before May 2003. The right panel shows announcement days from May 2003 onwards.

Table 1: Mean absolute value of five-minute EUR-\$ returns.

	CD	AD	NS	SD
13.40	0.024	0.022	0.022	0.025
13.45	0.023	0.035	0.032	0.056
13.50	0.028	0.062 ^{***}	0.043	0.213^{***}
13.55	0.027	0.038	0.035	0.063
14.00	0.025	0.041	0.035	0.085[*]
14.05	0.028	0.038	0.036	0.059
14.10	0.027	0.036	0.033	0.054
14.15	0.026	0.036	0.030	0.086^{**}
14.20	0.028	0.035	0.032	0.061
14.25	0.026	0.032	0.029	0.055
14.30	0.037 [*]	0.043	0.043	0.046
14.35	0.051 ^{***}	0.050 ^{**}	0.049 ^{***}	0.056
14.40	0.039 ^{**}	0.044	0.044	0.045
14.45	0.035	0.049 [*]	0.048 ^{**}	0.056
14.50	0.036	0.046	0.046 [*]	0.053
14.55	0.033	0.043	0.040	0.066
15.00	0.034	0.037	0.034	0.061
15.05	0.032	0.035	0.035	0.032
15.10	0.030	0.030	0.028	0.047
15.15	0.031	0.036	0.035	0.041
15.20	0.030	0.031	0.030	0.039
15.25	0.028	0.030	0.030	0.028
15.30	0.029	0.036	0.036	0.039

Notes: CD: control days, AD: announcement days, NS: no median surprise days, SD: median surprise days. The three largest volatilities in each column are marked by three, two and one stars respectively. The largest volatility in each row is marked as a bold number.

Table 2: AR(3)-FIGARCH(1, d, 1) models for filtered EUR- $\$$ returns.

	μ	φ_1	φ_2	φ_3	$\omega \cdot 10^{-4}$	ϕ_1	β_1	d	ν
CD	0.0009** (0.0004)	0.1234*** (0.0072)	-0.0653*** (0.0065)	-0.0239*** (0.0063)	1.3899*** (0.2019)	0.7271*** (0.0300)	0.8241*** (0.0221)	0.2976*** (0.0176)	5.5060*** (0.1865)
AD	0.0008** (0.0003)	0.0941*** (0.0070)	-0.0557*** (0.0062)	-0.0288*** (0.0059)	1.3413*** (0.1986)	0.7083*** (0.0315)	0.8032*** (0.0236)	0.3103*** (0.0201)	5.4455*** (0.1824)

Notes: Robust standard errors are given in parenthesis. CD: control days. AD: announcement days.

Table 3: The impact of surprises and communication on the filtered EUR-\$ returns (01/99 - 10/06).

	(1)	(2)	(3)
	$\tilde{R}_{k,13.45-13.50}$	$\tilde{R}_{k,13.45-14.05}$	$\tilde{R}_{k,13.45-14.15}$
	$\tilde{R}_{k,14.35-14.50}$	$\tilde{R}_{k,14.35-14.50}$	$\tilde{R}_{k,14.35-14.50}$
	Mean Equation		
$sr_{k,13.45}^+$	0.7294*	1.8330***	0.7346**
	(0.4351)	(0.4466)	(0.394)
$ sr_{k,13.45}^- $	-0.0992	-0.9340***	-0.4439
	(0.6460)	(0.3257)	(0.4918)
$CE_{k,14.35-14.50}$	0.1490***	0.1411***	0.1463***
	(0.0368)	(0.0386)	(0.0381)
$CI_{k,14.35-14.50}$	0.0108***	0.0103**	0.0102***
	(0.0042)	(0.0040)	(0.0037)
	Variance Equation		
$sr_{k,13.45}^+$	0.1685*	0.5488*	0.7401**
	(0.0867)	(0.2983)	(0.3270)
$ sr_{k,13.45}^- $	0.2034	0.4980***	0.2185
	(0.1267)	(0.2329)	(0.3400)
$ CE_{k,14.35-14.50} $	0.0036	0.0034	0.0038
	(0.0031)	(0.0028)	(0.0027)
$ CI_{k,14.35-14.50} $	0.0063***	0.0062***	0.0062***
	(0.0024)	(0.0023)	(0.0023)

Notes: *, ** and *** denote significance at the 10%, 5% and 1% level. Robust standard errors are given in parenthesis. $sr_{k,13.45}^+$ measures positive surprises, while $|sr_{k,13.45}^-|$ is the absolute value of negative surprises. $CE_{k,14.35-14.50}$ and $CI_{k,14.35-14.50}$ are the communication indicators with respect to the future development of the exchange rate and prices.

Table 4: The impact of communication: structural stability.

	Mean Equation		Variance Equation	
	01/99 - 04/03	05/03 - 10/06	01/99 - 04/03	05/03 - 10/06
$CI_{k,14.35-14.50}$	-0.0079 (0.0088)	0.0150*** (0.0045)	0.0061 (0.0055)	0.0057** (0.0022)

Notes: *, ** and *** denote significance at the 10%, 5% and 1% level. Robust standard errors are given in parenthesis. Returns surrounding the press release were aggregated for the period 13.45-14.05, returns surrounding the introductory statement for the period 14.35-14.50.

Table 5: Interactions surprises.

$sr_{k,13.45}^+ \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$	$sr_{k,13.45}^+ \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$	$ sr_{k,13.45}^- \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$	$ sr_{k,13.45}^- \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$
0.6914**	-0.0309	-24.6121***	-0.8524***
(0.2951)	(3.8514)	(1.6322)	(0.3157)

Notes: *, ** and *** denote significance at the 10%, 5% and 1% level. Robust standard errors are given in parenthesis. $\mathbf{1}_{\Delta r_{k,13.45} > 0}$ defines an indicator which is one if there was positive interest rate change.

$\mathbf{1}_{\Delta r_{k,13.45} < 0}$ is defined analogously. Returns surrounding the press release were aggregated for the period 13.45-14.05, returns surrounding the introductory statement for the period 14.35-14.50.

Table 6: Interactions communication.

	(1)	(2)	(3)	(4)	(5)
	Mean Equation				
$CE_{k,14.35-14.50}$	0.1753*** (0.0383)	0.1425*** (0.0386)	0.1420*** (0.0385)	0.1406*** (0.0386)	0.1743*** (0.0427)
$CI_{k,14.35-14.50}$	0.0353*** (0.0110)	0.0118*** (0.0038)	0.0115*** (0.0040)	0.0110*** (0.0039)	0.0327*** (0.0094)
$Q\&A_{k,14.50-15.15}$					0.0008 (0.0082)
$CI_{k,14.35-14.50} \times \mathbf{1}_{\pi_{k,13.45} > 2.2}$	-0.0011 (0.0131)				
$CI_{k,14.35-14.50} \times \mathbf{1}_{\pi_{k,13.45} < 1.5}$	-0.0422* (0.0238)				
$CI_{k,14.35-14.50} \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$		0.0099 (0.0292)			
$CI_{k,14.35-14.50} \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$		-0.0421** (0.0203)			
$CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^+}$			-0.2257 (0.3064)		-0.1262 (0.3514)
$CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^-}$			-0.0923*** (0.0193)		-0.0985*** (0.0082)
$CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^+} \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$				-0.4639 (0.3353)	
$CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^+} \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$				0.1780*** (0.0219)	
$CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^-} \times \mathbf{1}_{\Delta r_{k,13.45} > 0}$				-7.6822*** (0.1340)	
$CI_{k,14.35-14.50} \times \mathbf{1}_{sr_{k,13.45}^-} \times \mathbf{1}_{\Delta r_{k,13.45} < 0}$				-0.0873*** (0.0181)	
$Q\&A_{k,14.50-15.15} \times \mathbf{1}_{sr_{k,13.45}^+} \times \mathbf{1}_{\Delta CI_{k,14.35-14.50}^+}$					0.0292 (0.0398)
$Q\&A_{k,14.50-15.15} \times \mathbf{1}_{sr_{k,13.45}^-} \times \mathbf{1}_{\Delta CI_{k,14.35-14.50}^-}$					0.0866** (0.0367)

Notes: *, ** and *** denote significance at the 10%, 5% and 1% level. Robust standard errors are given in parenthesis. $\mathbf{1}_{\pi_{k,13.45} > 2.2}$ is a dummy variable taking the value of one if inflation is above 2.2. The variable $\mathbf{1}_{\pi_{k,13.45} < 1.5}$ is defined analogously. Similarly, $\mathbf{1}_{\Delta CI_{k,14.35-14.50}^+}$ and $\mathbf{1}_{\Delta CI_{k,14.35-14.50}^-}$ indicate whether there are positive/negative changes in the communication indicator with respect to inflation. Returns surrounding the press release were aggregated for the period 13.45-14.05, returns surrounding the introductory statement for the period 14.35-14.50.