What drives money market rates?*

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Abstract

This paper addresses the question of which fundamentals are the determining factors underlying the price discovery process of money market rates in the euro area (EURIBOR futures). I shed light on how the monetary policy decisions and the external communication of the recently created European Central Bank are actually conveyed to the European money market. The impacts of macroeconomic surprises both in the euro area and in the US are also analysed. I find that both the ECB's monetary policy surprises and macroeconomic releases significantly affect both the level and the volatility of futures returns, and that the adjustment in the conditional variance is more gradual than in the conditional mean. Jumps in the level point to a clear connection between money market rates and fundamentals. The slower adjustment in volatility can be rationalised by the fact that some uncertainty remains in the market after the arrival of new information, and, consequently, traders need some time to find a new consensus. Interestingly, macroeconomic releases in the US have a greater impact than European ones. I also show that the external communication of the ECB mainly impacts on the price variability rather than the level of returns, and that the tone of the ECB's statements is of great importance. This provides clear evidence for the supposition that "central bank talk does matter ". I also extend the analysis to money market rates across the maturity spectrum, and the model employed provides an accurate specification both for the level and the volatility pattern. I show that realised volatility outperforms the GARCH model based measure of the daily price volatility. Finally, a detailed description of the EURIBOR futures market is given, complemented by a statistical analysis of the data.

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1 Introduction

Very little is known about one of the most important issues of financial economics, namely, how new information is incorporated into financial prices. While empirical studies have paid considerable attention to this issue, at least three shortcomings can be identified in the existing literature. First, results coming from papers using low-frequency data are rather ambiguous because, as it was showed in several high-frequency studies[1], price adjustments following data releases or other announcements are very quick and cannot be detected not even at the daily level. Second, most of the empirical studies focus only on three types of financial market, namely, the foreign exchange market, the stock market and the bond market. However, short-term interest rate markets are also of great relevance, particularly from a central bank's point of view. The European Central Bank (ECB) steers its monetary policy via the money market, and it is highly interested in monitoring the price formation process in that market. As monetary policy can only affect the short-end of the yield curve directly, interest rates with short maturities faithfully reflect market expectations about the future path of monetary policy. In this context, the external communication of the ECB also becomes essential, as it may affect short rates. Third, as Andersen et al. (2003b) argued, for an adequate volatility estimation the conditional mean of returns has to be modelled correctly. Still, most papers focus mainly on return volatility rather than on the level of returns. Hence, modelling accurately the conditional mean of returns is also important from a statistical perspective.

The purpose of this paper is to tackle these problems by studying a very important, yet previously unanalysed market, and by using high-frequency data. The paper provides several contributions to the existing literature. First, it studies the EURIBOR futures market, which is the benchmark money market within the European Monetary Union[2]. Today the EURIBOR is one of the most important financial instruments in the world, not only within the interbank market, but also for an increasing number of derivative instruments, both exchange traded and over-the-counter (OTC). The reason why EURIBOR futures are used in this paper is that they display a very high liquidity and price transparency, while the transaction costs and the bid-ask spreads are low.

Second, a tick-by-tick dataset of transaction prices is used. Working with high-frequency data allows for a sophisticated analysis of the price discovery process. As each futures contract has a specific expiration date, long time series cannot be constructed for a certain contract. Hence, most papers look at the nearby contracts since they are generally the most heavily traded ones. Here, however, futures contracts with longer time horizons are also considered. This is done according to their expiration date, which provides five time series, which

[1] See e.g. Ederington and Lee (1993, 1995) and Fleming and Remolona (1999), among others.

[2] To my knowledge, there is only one paper in the literature (Bernoth and von Hagen (2003)) that gives a brief description of the EURIBOR futures market and studies the efficiency of futures prices.

is very useful in studying the term structure of the price determination process. From the tick-by-tick data 5-minute returns are constructed and then used for the empirical analysis.

Third, the propositions are based on the model of Andersen et al. (2003b) employed for both the level and the volatility of returns. However, this model is modified in two important aspects. To capture the conditional heteroscedasticity in returns at the daily or lower frequencies, realised volatility is used in addition to a GARCH model based estimate. Furthermore, instead of assuming a specific volatility response pattern for the different types of announcements, dummy variables are employed to control for the volatility decay effects. The statistical properties of standardised returns are also of great interest.

Fourth, the paper analyses the effects of three different types of public announcements on EURIBOR futures prices. A broad set of 34 macroeconomic data releases is considered with the surprise component calculated for each variable. The dataset includes data from the euro area and the US. In addition, the impacts of the surprises arising from the ECB's monetary policy decisions are also studied. Finally, three communication devices of the ECB are considered: (i) the Introductory Statements after the decisions, (ii) the President's testimonies at the European Parliament, and (iii) selected speeches given by Executive Board members. The three news reveal most of the effects of public information, and allows for a study of how information from different sources is transmitted into prices.

The paper is structured as follows. Section 2 provides a description of the data construction and sources, and a preliminary data analysis. In addition, it supplies data on macroeconomic and monetary policy surprises as well as the construction of communication dummies. The econometric model for the characterisation of both the level and the volatility of EURIBOR futures returns is developed in Section 3. The results are described in Section 4. Finally, Section 5 presents the conclusions.

2 Data description and construction

2.1 EURIBOR futures data

This subsection characterises the statistical properties of the original tick-by-tick dataset, the construction method of 5-minute returns, and the intraday pattern of these series.

2.1.1 Tick data

EURIBOR futures are traded at the London International Financial Futures Exchange (LIFFE). In studying the price formation in this market, derivatives of EURIBOR, particularly futures, are much more useful than spot rates for several reasons. Firstly, short-term interest rate (STIR) futures are the most liquid financial instruments for the interest rate markets: the EURIBOR contracts are the most heavily traded euro-denominated STIR contracts in the world, and they are second to the CME's Eurodollar contracts in terms of overall traded volume[3]. Secondly, interest rate futures markets with expiry periods up to one year are much more liquid than the OTC spot interest rate markets. Thirdly, transaction costs are lower, a typical bid-ask spread is about 10% of the quoted spread of spot interest rates. Fourthly, even tiny moves are tradable in futures markets, which implies a very sensitive measure of interest rate expectations. Finally, LIFFE's EURIBOR contracts are the most liquid of all electronically traded contracts in the world, and are accessible via the most advanced derivatives electronic trading platform. Therefore, it leads to a faster price formation and a higher price transparency.

The primary dataset consists of more than 6 million tick-by-tick EURIBOR futures transaction prices obtained from LIFFE[4]. As the single currency was created as recently as 1999, and European markets were also developed in that year, long time series for the euro area are not yet available. As a result, the sample period covers January, 2000 through September, 2003, i.e. 924 trading days[5]. Interest rate futures markets have regular trading periods on business days, while on holidays and in the weekends no trade takes place. The trading period on a trading day for the EURIBOR futures starts at 7:00 (before December, 2000, at 7:30) and finishes at 18:00, (both London time[6]).

Each futures contract has a specific expiration date and its trade generally starts one year or more in advance. For the 3-month EURIBOR futures, as for most futures contracts, there are four expiration months: March, June, September and December. This implies that for a certain contract it is not possible to construct a long time series. To avoid that, position time series have been created, as proposed by Ballocchi et al. (1999). The first position contains the contracts that expire next in the quarterly sequence, the second position contains the contracts to expire in the following expiration month in the quarterly sequence, and so on. In this way, five positions have been identified, since these are the most heavily traded in the market, and these positions also provide high liquidity and a large number of ticks. As a consequence, five time series with different time horizons have been obtained. Each are uninterrupted by contract expirations, and consist of distinct contracts. One may argue that constructing data series in this manner may be arbitrary and may not reflect the real price discovery process in the futures market. However, as Ballocchi et al. (1999) points out, the construction of time series by position can be justified

[3] The EURIBOR contracts currently account for over 99% of euro-denominated STIR exchange-traded derivative money market activity, with an average daily volume around 1,000,000 contracts.

[4] Tha data was purchased and kindly supplied by the Monetary Policy Stance Division of the ECB.

[5] There is data available for 1999 as well, but, as the market was just developed in that year, there are several data leaks and for many days there are not any observations. However, from the second half of 1999, and mainly from January, 2000, the EURIBOR futures market displays high liquidity and a sufficient number of ticks per business day for an accurate empirical analysis.

[6] Throughout the paper, London time is used rather than GMT as the former is subject to Daylight Saving, hence, it does not have to be adjusted.

by the functioning of the market. To stay in the market, traders generally roll their close-to-expiration contracts into the next expiration contracts. Thus, the time series by position is in effect generated by the traders themselves.

Evidently, on delivery days[7] there may be jumps in the series given that different contracts reflect different information sets. One possible solution to deal with these jumps is rolling to the next contract when the daily tick volume of the contract in question exceeds that of the front month contract. However, jumps are generally not of big magnitude, and they occured mainly in 2000, when the ECB changed its key interest rate six times (also in expiration months). It implies that jumps reflect the change in the markets' expectations about the future path of monetary policy rather than the shift to the next contract. This is also supported by the fact that big jumps characterise mainly the first position, which is the closest substitute of spot rates. Moreover, as the initial return of the trading day is deleted (see next subsection) the major part of the jumps is extinguished. In any case, I control for the delivery days in the econometric specification.

The total number and the average number of ticks per business day are displayed in Table 1.

Table 1: Tick statistics

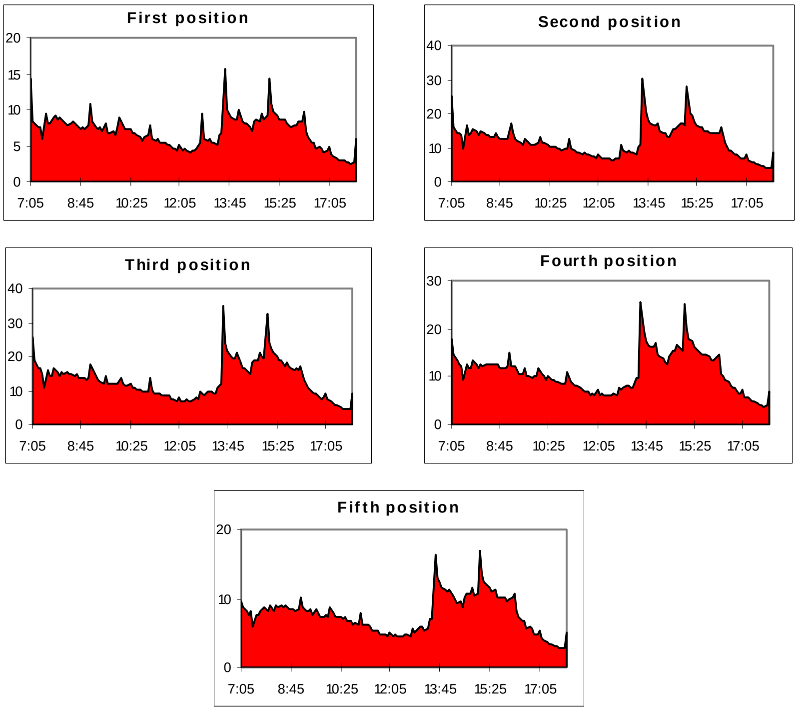
Positions	Total no. of ticks	Average no. of ticks per business day
First	840,918	910
Second	1,421,666	1539
Third	1,582,103	1712
Fourth	1,313,865	1422
Fifth	925,093	1001

As it is clear from the table, the most actively traded position is the third one, and both the total and the average number of ticks per business day decrease as we proceed further ahead in time. In addition, the first position is the less traded, which is, indeed, a counter-example for using nearby futures contracts, a highly popular approach in the empirical literature. Regarding the average number of ticks per business day, a large number of ticks, i.e. around 7 ticks in 5-minute intervals, are available even for the first position. For the third position it is around 13. This suggests a very liquid market with a plenty of observations.

To understand better the price discovery in the EURIBOR futures market, the average number of ticks for each 5-minute interval of the trading day has been calculated. The results are depicted in Figure 1.

[7] The last trading day is two business days prior to the third Wednesday of the delivery months (March, June, September, December). The first business day after this day is the delivery day.

Figure 1: Average number of ticks on a trading day



The intraday tick distribution displays some pronounced features. First, strong activity can be observed in the initial 5-minute interval of the trading day, which probably reflects the adjustment to information accumulated overnight. Second, the lunch break produces a decrease in the number of ticks between 11:00 and 13:00. After lunch a surge of trade begins which lasts until around 16:00. Then, the number of ticks increases again in the final interval. Third, the effect of macroeconomic data releases is highly striking. The average number of ticks attains its maximum at 13:30[8], while the second peak is at 15:00[9]. The former is associated with the announcements of the most important US macroeconomic variables (nonfarm payrolls, GDP, retail sales, PPI, CPI, initial jobless claims) and to the release of the ECB's Introductory Statement, whereas the latter results from other relevant US releases (business confidence, consumer confidence, PMI). In addition, up to one hour after the announcements the tick activity stays significantly higher than normal. The announcement effect is also present with the European macroeconomic data releases, albeit it is not as strong as for US variables. There is a peak at 9:00 (publication of the M3 figures and the PMI), and at 11:00 (GDP, industrial production, economic sentiment, retail sales, PPI, HICP, unemployment rate). However, these impacts seem to be small and short-lived. Another interesting feature is that the longer the time horizon

[8] 8:30 US Eastern Time.
[9] 10:00 US Eastern Time.

of the futures contract the stronger the announcement effects. It reflects the phenomenon that longer-term rates are more sensitive to real economy variables.

For the first two positions, there is also a high peak at 12:45 which is the release time of the ECB's monetary policy decisions. This effect decreases with the position, indicating that monetary policy decisions in the euro area generate less activity in rates with longer maturity. It is not surprising given the fact that monetary policy affects the very short-term interest rates, while longer-term rates are mainly subject to real economy fundamentals.

These findings suggest that news about US macroeconomic variables generate considerably higher activity in the benchmark money market of the euro area than European releases. Moreover, this activity is more persistent after US announcements.

2.1.2 The construction and statistical properties of returns

After filtering and cleaning the tick data for outliers, pricing errors and other anomalies, 5-minute series have been constructed by the previous-tick interpolation method[10], i.e. the futures price for each 5-minute interval is simply defined as the last trade price in the given interval. When no observation is available for that interval, the most recent value has been taken. Another popular approach in the literature is linear interpolation between the preceding and immediately following prices. However, the reason for using the previous-tick interpolation approach is to ensure that, at the time when news hit the market, prices only reflect information already available.

Then, the return at time t, R_t, is simply defined as hundred times the logarithmic difference of consecutive prices, i.e. $R_t = 100\,[\log(P_t) - \log(P_{t-1})]$, where P_t is the futures price at time t. The initial return of the trading day, 7:00-7:05 (before December, 2000, 7:30-7:35), has been deleted as it reflects the adjustment to information accumulated overnight, showing a higher than normal volatility. On the other hand, it also serves to smooth the series on expiration days given that jumps occur in the initial interval of the first trading day of the new expiration period. In this way, a sample of $119,562$ useful observations has been obtained.

Some descriptive statistics of the returns for the five positions are displayed in Table 2.

Table 2: Descriptive statistics of the 5-minute returns

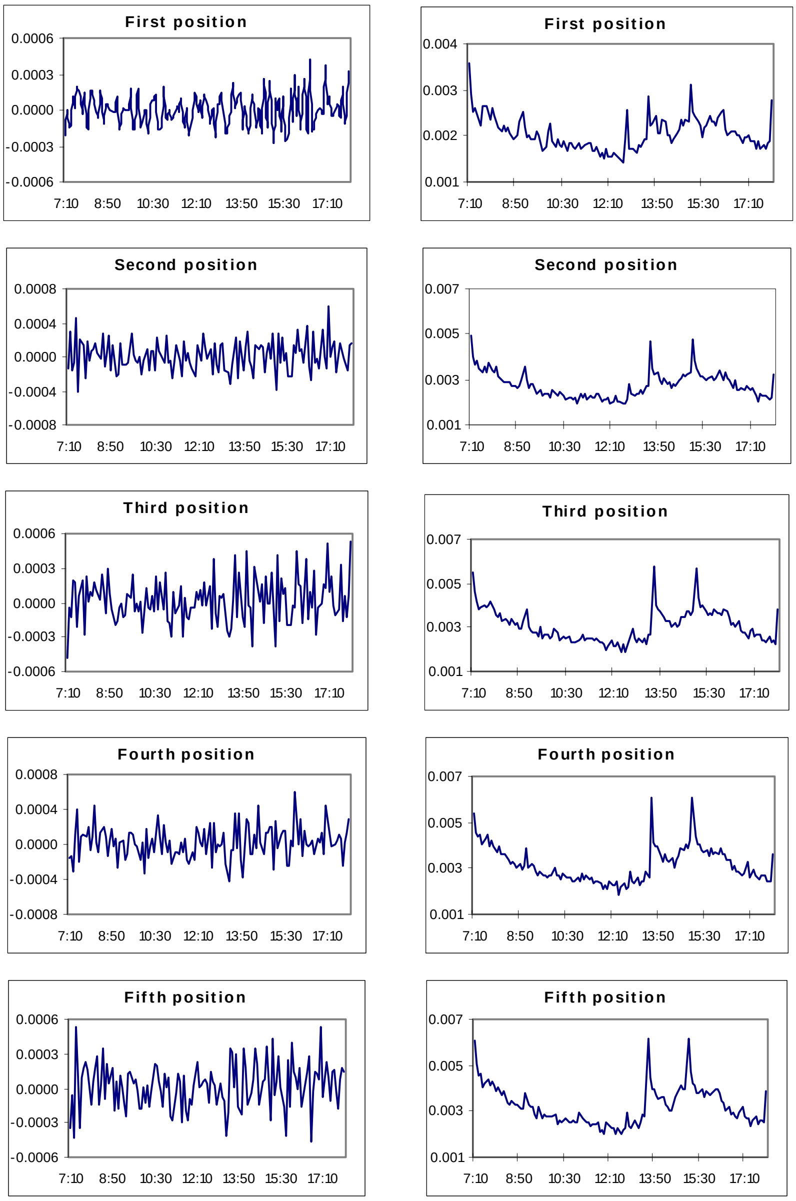
	First	Second	Third	Fourth	Fifth
Mean	1.9×10^{-6}	1.5×10^{-5}	2.1×10^{-5}	2.6×10^{-5}	2.5×10^{-5}
Std. dev.	0.0040	0.0049	0.0053	0.0055	0.0056
Minimum	−0.1152	−0.1050	−0.1033	−0.1618	−0.1148
Maximum	0.1729	0.2038	0.1881	0.1723	0.1724
Skewness	0.4116	1.0322	0.5411	0.0812	0.1155
Kurtosis	48.45	53.65	32.50	34.29	26.60

[10] Originally proposed by Wasserfallen and Zimmermann (1985). See also Dacorogna et al. (2001).

It is clearly seen from the table that the sample mean of each series is statistically indistinguishable from zero. Regarding standard deviation, one can observe a moderately increasing sample volatility with each position. This is in line with the findings of Ballocchi et al. (1999) for Eurofutures. Moreover, the minimum and maximum 5-minute returns indicate that the series are rather smooth and sharp jumps are not present. An interesting feature is the positive skewness for all positions, while the sample kurtosis decreases with each position. Hence, the series are clearly not normally distributed, and the empirical distribution is not symmetric.

In order to study the intraday pattern of the series, average returns and average absolute returns have been calculated for each 5-minute interval. These are depicted in Figure 2.

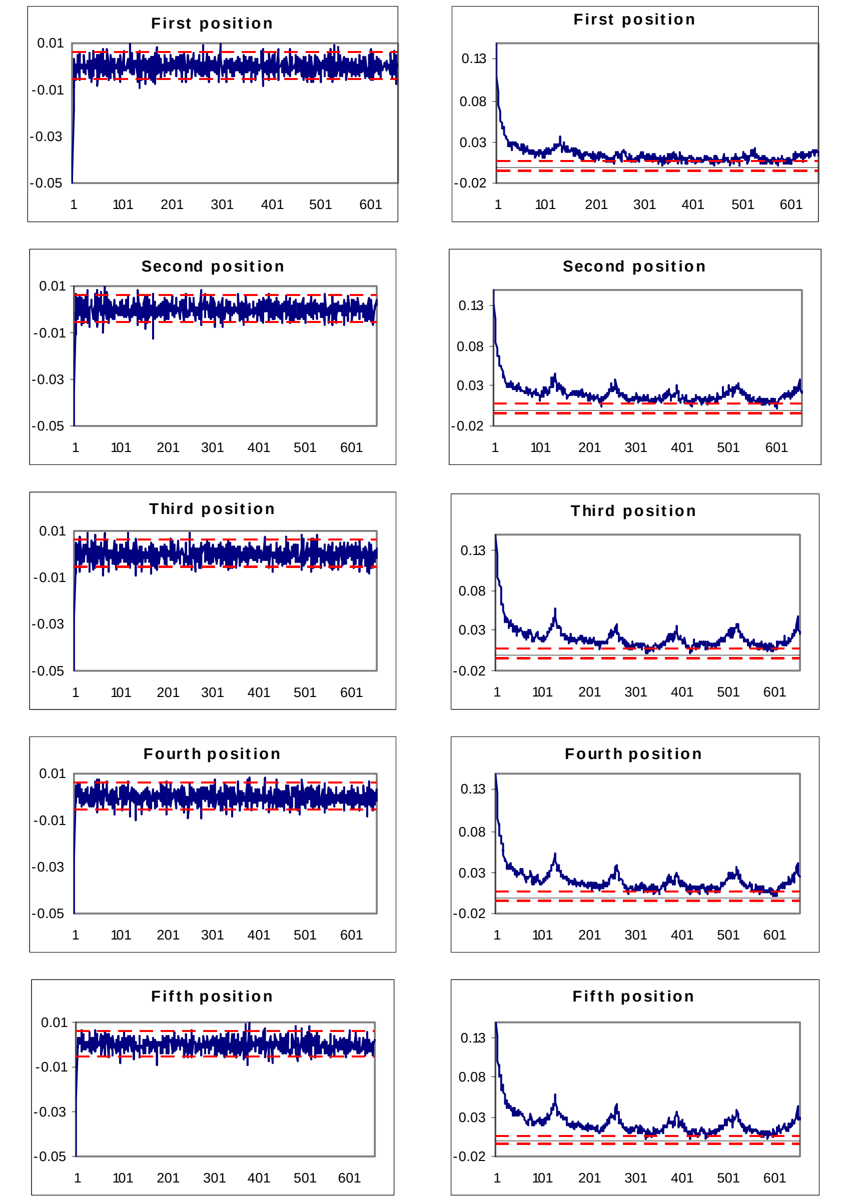
Figure 2: Average returns and average absolute returns



The average returns are centred around zero and have unpredictable sign. However, in the return volatility there is a systematic pattern, which has a very similar shape to the one found for tick activity. This suggests that stronger tick activity induces higher price variablity and that macroeconomic data releases generate excess volatility in the series. This finding implies that, short-term interest rate futures are quite sensitive to macroeconomic data releases.

Concerning the time-series dependencies of the returns, Figure 3 plots the 5-day correlogram for raw and absolute returns.

Figure 3: Five-day correlogram of raw and absolute returns



Note: dashed lines are the Bartlett standard error bands.

What is remarkable at the first sight is that all positions display a strong and highly significant negative first-order serial correlation. This is not unknown in the literature, Goodhart (1989) reported first the existence of a negative first-order autocorrelation of returns at the highest frequencies[11]. He also showed that this is not affected by macroeconomic data releases. It has to be noted that the negative serial correlation is observed not only at the first lag but at further lags too[12], though beyond these few lags the series resemble realizations of white noise. As Dacorogna et al. (2001) argued, this is due to the irregular spacing of ticks, while in tick-time the series only exhibit first-order negative autocorrelation. An explanation for this finding may be the non-synchronous trading, explored by inter alia Lo and MacKinlay (1990). In addition, the first-order serial correlation coefficients decrease with each position[13].

Unlike raw returns, the 5-day correlogram of absolute returns exhibits a regular cyclical pattern. The strong intraday periodicity leads to a distorted U-shape in the sample autocorrelation, each occupying one day. This is not particularly striking for the first position, but with further positions it becomes more notable. Furthermore, the very slow decay in the autocorrelation function points to the presence of long memory in the series. These findings are broadly in line with earlier empirical evidence for FX-rates (Dacorogna et al. (1993), Payne (1996), Andersen and Bollerslev (1997) and Andersen et al. (2003b)), for stock returns (Andersen and Bollerslev (1997) and Andersen et al. (2000)), and also for bonds (Bollerslev et al. (2000)).

2.2 Macroeconomic announcements

The empirical literature shows that it is not the macroeconomic data release itself which has an impact on financial variables, but the existence of a considerable difference between the realised value of the macro variable and the markets' expectation. Hence, greater surprise generates greater changes in asset prices. Clearly, this impact depends on how sensitive a financial asset is to macroeconomic announcements. As it has been seen in the previous subsection, certain data releases induce high price variability in EURIBOR futures prices.

Following Balduzzi et al. (2001) and Andersen et al. (2003b), a surprise component is calculated for each macroeconomic announcements as

$$MA_t^k = \frac{A_t^k - E_t^k}{\sigma_k}$$

i.e. the realised value (A_t^k) less the median expectation value taken from a survey conducted by Bloomberg (E_t^k), normalised by the standard deviation

[11] The negative first-order autocorrelation has also been observed in FX transaction prices (Goodhart et al. (1995)) and in Eurofutures (Ballocchi et al. (1999)). Interestingly, for stock returns, some empirical studies found positive autocorrelation coefficients (see Bouchaud and Potters (2000) or Andersen et al. (2000)).

[12] Up to 3 lags (15 minutes) for the first position and up to 2 lags (10 minutes) for the other positions.

[13] They are −0.2647, −0.2042, −0.1636, −0.1374 and −0.1208, respectively.

of the forecast error (σ_k)[14]. As Balduzzi et al. (2001) argued, the advantage of this normalisation is that it allows for a comparison of the responses of the different macroeconomic releases.

Three types of macroeconomic data are used in this paper: real economic data (on production, investment or employment), survey data and prices. Thirty-four macroeconomic variables are considered, among them 16 are European variables and 18 are US data. The European real economy variables are M3, GDP, industrial production, retail sales, unemployment (both the euro area and Germany), and industrial production in Germany. The survey variables are PMI, business climate, consumer confidence, and finally, IFO and ZEW for Germany. The price data are PPI, HICP, the HICP flash estimate for the euro area, and CPI for Germany.

The US real economy data contains GDP (advance, preliminary and final), industrial production, retail sales, non-farm payrolls, initial jobless claims, factory orders, durable goods orders, and business inventories. The survey variables are manufacturing and non-manufacturing business confidence, consumer confidence, economic sentiment, Philadelphia Fed index and Chicago PMI. Finally, there are two price data variables: PPI and CPI.

It may also be of some interest to study the distribution of macroeconomic releases within a week to detect some day-of-the-week effects. Sebestyén and Sicilia (2005) showed that most of the announcements of European variables are nearly uniformly distributed within a week, with the exception of the ZEW index which is always published on Tuesdays. In contrast, for about half of the US variables, there is a clear intraweek seasonal pattern, for example, the nonfarm payroll numbers and the economic sentiment index are released on Fridays, whereas Thursdays are dominated by the Philadelphia Fed index and the initial jobless claims.

2.3 Monetary policy surprise

The three-month EURIBOR is the benchmark money market rate in the euro area. The market of its futures contracts is the most liquid euro-denominated short-term interest rate market in the world. In this market one can also trade even very small changes, hence, futures prices provide a very good and clean measure of interest rate expectations. Therefore, from the point of view of the ECB it is of particular importance to monitor the EURIBOR futures as they provide a good reflection on market participants' expectations about the future path of monetary policy.

In addition, the ECB is able to affect futures prices by its monetary decisions. Even if a central bank is highly transparent and predictable, there is an adjustment in interest rates to key rate changes, although it may already occur before the decision is published. The nature of monetary policy decisions differs from that of macroeconomic announcements: if the central bank is transparent its decisions are broadly anticipated and do not generate changes after the

[14] I am very grateful to Lars Jul Hansen for providing me the dataset of macroeconomic surprises.

decision is released. Thus, assuming a transparent central bank, interest rates should not react to monetary decisions. In contrast, macroeconomic news provide new information to the market, inducing a price adjustment. These issues imply that central banks are highly interested in studying market reactions subsequent to their decisions so they can examine their predictability. Therefore, mainly in money markets, such as the EURIBOR futures market, the importance of surprises in the central bank's decisions is even more pronounced than for macroeconomic data releases.

The monetary policy surprise in the euro area is defined as the difference between the realised key rate change and the average expectation of market participants as indicated by Reuters polls taken one week before the meeting. It is noteworthy that for the monetary policy surprise the forecast error is not divided by its standard deviation. The reason is that a natural and ordinary measure of monetary surprise is the forecast error in percentage points which is the same unit of measurement as that for the returns on the EURIBOR futures, hence, it can be clearly seen to what extent a monetary policy surprise is transmitted to futures prices with different time horizons.

The use of high-frequency data has its advantages. First, one may detect impacts of monetary policy that are "invisible" at the daily frequency. Second, by using high-frequency data one can adequately characterise the response pattern of EURIBOR futures to monetary decisions, both in the conditional mean and in the conditional volatility. Hence, one can compare the effects of monetary policy to those of macroeconomic data releases, and obtain a better insight into the fundamental determinants of the price discovery process in the EURIBOR futures market.

This surprise measure is taken at the announcement time (12:45 London Time), and zero otherwise. Clearly, in the week preceding the Governing Council's meeting other new information can be released, which may change the market participants' expectations, but the findings of Sebestyén and Sicilia (2004) are very similar using the Reuters measure to those using other measure of monetary surprise. It has to be noted that the 50 basis point interest rate cut of the ECB on 17 September, 2001 has been dropped out of the sample as it was an intermeeting cut, causing a big surprise, hence, taking into account this effect may lead to misleading results.

It would also be useful to control for the impacts of monetary surprise originating from the Federal Reserve as interest rate decisions in the US generally affect financial markets all over the world. However, decisions about the target federal funds rate are released at 14:15 US Eastern Time which is at 19:15 London Time, i.e. after the close of the EURIBOR futures market. It would be possible to put the surprise variable in the initial interval of the next business day, but the result may be spurious given that this interval contains all information accumulated overnight. That is why the initial interval has been deleted from the series.

2.4 Communication tools

The ECB communicates with the public through various means. In this paper, the focus is on three types of communication tool: (i) Introductory Statements released immediately following the Governing Council's meetings, (ii) testimonies by the President (or by other members of the Executive Board) at the European Parliament (EP) and (iii) speeches of the Executive Board members. For a brief description of these tools, see Sebestyén and Sicilia (2005).

It may be reasonable to suppose that central bank communication should not have significant impacts on asset prices as it generally provides only explanation of the monetary decision and/or a summary of the central bank's assessment of economic developments. However, Introductory Statements and central bank leaders in their public engagements may give additional information to the traders about the state of the economy or deliver hints about the future path of the monetary policy. This possibly generates changes in the level of future interest rates and/or it may lead to bigger price variability.

Sebestyén and Sicilia (2005) found, using daily data, that Introductory Statements affect both the level and the volatility of interest rate differentials up to five years of maturity. They also showed that the impacts on the conditional mean are due to the content of the Introductory Statements, namely, that those with "hawkish" tone increase interest rates, while the volatility effects can be related to key rate changes. The other two communication tools were found insignificant both in the conditional mean and in the conditional variance. Nonetheless, it is possible that these devices also impact on interest rates but the effect is short-lived and it cannot be detected on the daily level. Another advantage of the use of high-frequency data is that one is able to separate the impact of the monetary decision from that of the Introductory Statement as they are released at different times.

It has to be noted that the timing of the Introductory Statement is not unambiguous. It is published on the ECB's website at 13:45 London Time, therefore, it seems to be reasonable to take this time as the release time. However, the Introductory Statement is also read by the President in the press conference, which starts at 13:30, 45 minutes after the monetary policy decision is released. The relevant part (the decision and the brief explanation) is in the second paragraph[15] which is read one or two minutes after the start of the press conference. Hence, it is at 13:35 that market participants normally find out about the news. Therefore, 13:35 is taken as the release time.

The timings of the EP testimonies and that of speeches are not regular, therefore, the dummy was put at the time when they appeared on the Bloomberg screen. This method provides some preselection as the series contain only those speeches which were relevant enough to become a news item in Bloomberg.

[15] The first paragraph contains only a welcome message.

3 Econometric specification

The modelling strategy would need to take into account the following phenomena to construct an adequate model for the EURIBOR futures. It needs to accommodate sharp responses to macroeconomic announcements (*announcement effect*). Data releases may affect both the conditional mean and the conditional volatility of the series. It also needs to account for the pronounced intraday volatility pattern (*calendar effect*), as well as the distorted U-shape in the sample autocorrelation.

In addition, it should consider the conditional heteroscedasticity of returns in lower frequencies, which is commonly known to be present in financial time series[16]. Earlier empirical studies produced a puzzling result, namely, that intraday returns did not exhibit ARCH-effects, while the same data, aggregated to the daily level, was clearly conditionally heteroscedastic. However, Andersen and Bollerslev (1997) demonstrated that the strong intraday volatility pattern is responsible for overshadowing the characteristics of interday volatility.

Hence, taking into account these three important feautures, I build on the model of Andersen et al. (2003b), and employ a model in which news may affect both the conditional mean and the conditional variance. Allowing for jumps in the level owing to announcement surprises, one may obtain an improved high-frequency volatility estimation, because any misspecification in the conditional mean distorts the volatility estimation (Andersen et al. (2003b)).

Thus, the conditional mean of the 5-minute EURIBOR futures returns is modelled in the following way:

$$R_t = \alpha_0 + \sum_{p=1}^{P} \alpha_p R_{t-p} + \sum_{q=0}^{Q} \alpha_q^{MS} MS_{t-q} + \sum_{k=1}^{K} \sum_{r=0}^{R} \alpha_{kr} MA_{t-r}^{k} + \sum_{l=1}^{L} \sum_{s=0}^{S} \alpha_{ls} C_{t-s}^{l} + \varepsilon_t \tag{1}$$

where R_t is the 5-minute returns from time t to time $t+1$[17], MS_t denotes the monetary policy surprise of the ECB, MA_t^k the kth macroeconomic announcement, and C_t^l the lth communication tool. As it has been mentioned above, there are 34 macroeconomic announcements, i.e. $K = 34$, and three communication dummies, i.e. $L = 3$. From (1) it is seen that returns are modelled as a linear function of P lagged values of itself, contemporaneous and Q lagged values of monetary surprises, contemporaneous and R lagged values of macroeconomic news on each of K announcements, and contemporaneous and S lagged values of communication devices. The optimal lags have been determined by the Akaike and the Schwarz criteria. Furthermore, $t = 1, ..., 119562$.

Regarding the conditional variance, one could use an ARCH-type model. However, these models have at least two shortcomings for high-frequency data.

[16] See Bollerslev et al. (1992) for a good survey of ARCH-models.

[17] Note that due to the use the previous-tick interpolation method in the construction of the return series, the return from time t to time $t+1$ is defined as R_t as it captures the effects of news that hit the market at time t.

On the one hand, ARCH-models are not able to capture the seasonality pattern of the intraday volatility[18], which implies that the temporal aggregation properties of these models[19] do not hold for high-frequency data. On the other hand, standard ARCH models imply a geometric decay in the autocorrelation structure, but, as it can be seen in the right panel of Figure 3, the long-run dependencies in the 5-minute EURIBOR futures returns are highly persistent, pointing to the presence of long memory. Clearly, a fractionally integrated GARCH model (FIGARCH) would be able to match long memory, but it also suffers from the problem just mentioned above. Nonetheless, ARCH effects in lower frequencies have to be taken into account for a correct modelling of intraday volatility.

Therefore, instead of an ARCH-type model, following Andersen et al. (2003b), I allow the disturbance term in (1) to be heteroscedastic, and approximate its volatility by the following model:

$$
\begin{aligned}
|\hat{\varepsilon}_t| &= \beta_0 + \beta_1 \frac{\hat{\sigma}_{d(t)}}{\sqrt{N}} + \\
&+ \left\{ \begin{array}{c} \mu_1 \frac{n}{N_1} + \mu_2 \frac{n^2}{N_2} + \sum_{r=1}^{R} \left[\phi_r \sin\left(\frac{2\pi r t}{N}\right) + \varphi_r \cos\left(\frac{2\pi r t}{N}\right) \right] \\ +\gamma D_{exd(t)} + \sum_{i=1}^{D} \delta_i W D_{wd(t)}^{i} \end{array} \right\} + \\
&+ \sum_{j=0,3,6,12} \lambda_j^{MS} |MS_{t-j}| + \sum_{k=1}^{K} \sum_{j=0,3,6,12} \lambda_{kj} D_{t-j}^{k} + \sum_{l=1}^{L} \sum_{j=0,3,6,12} \lambda_{lj} D_{t-j}^{l} + u_t
\end{aligned} \qquad (2)
$$

where N denotes the number of 5-minute intervals on a trading day (in this case $N = 131$, as the initial interval was deleted), n is the nth 5-minute on a trading day, and $N_1 = \sum_{i=1,N} i = N(N+1)/2$ and $N_2 = \sum_{i=1,N} i^2 = N(N+1)(2N+1)/6$ are normalising constants.

In more detail, the second term in (2) is the intraday estimate of the daily volatility factor (capturing the ARCH-effect), which is the estimated conditional standard deviation, $\hat{\sigma}_{d(t)}$, for day $d(t)$ (the day which contains time t). To obtain an estimate for the daily volatility factor, two different avenues have been chosen. First, as a commonly used procedure in the literature, $\hat{\sigma}_{d(t)}$ was estimated by a simple MA(1)-GARCH(1,1) model with Student t-distribution, using daily EURIBOR futures returns from June 2, 1999 through June 7, 2005. Evidently, this approach assumes that volatility is constant over the trading day. A second possibility is the use of realised volatility, that is, $\hat{\sigma}_{d(t)} = \left[\sum_{n=1,N} R_n^2\right]^{1/2}$. For sufficiently large N, the realised volatility provides a good approximation to the quadratic variation of returns, and it is an unbiased and highly efficient estimator of the return volatility (Andersen et al. (2003a)). It is noteworthy that, to be compatible with the construction method of returns, the daily realised volatility is calculated without the initial interval on the trading day[20]. One may argue

[18] See Guillame et al. (1994) for details.
[19] See Nelson (1990, 1992) or Drost and Nijman (1993) for details.
[20] The importance of this fact will be highlighted later.

that this measure of the daily volatility is not reasonable as it also reflects information not available at time t. However, in this case it is desirable to use information throughout the trading day. The idea is similar to that for the smoothed estimate in the Kalman filter (Hamilton (1994)).

Now consider the terms given in brackets. These terms are used for matching the calendar effects. The second-order polynomial captures the U-shape in the intraday volatility. The other part is the flexible Fourier form (FFF), introduced by Gallant (1981, 1982) and popularized by Andersen and Bollerslev (1997) in high-frequency finance, which is ideally suited by the trigonometric functions for modelling the cyclical intraday pattern across trading days[21]. The tuning parameter R determines the order of the expansion. Other calendar effects are also introduced in (2), namely, $D_{exd(t)}$, which is a dummy variable equalling unity on expiration days, while $WD^i_{wd(t)}$ are weekday dummies accounting for day-of-the-week impacts.

Finally, consider the announcement effects. According to the empirical findings of Ederington and Lee (1993, 1995) and of Fleming and Remolona (1999), the largest price changes occur within the first few minutes following an announcement, but the volatility remains higher than normal for up to an hour. Furthermore, as Rich and Tracy (2003) showed, dummy variables provide a better measure of uncertainty than surprises. This was supported empirically by Andersen et al. (2003b, 2005), who established that the fit was generally better for models including dummies in the conditional volatility equation. These findings suggest that an announcement itself tends to increase volatility, and at least 12 lags for each of the announcements are needed to capture the whole volatility response pattern. The only exception is the monetary policy surprise for which initial experimentations showed that dummies are not able to capture the volatility pike at the time of the announcement. It indicates that the mere presence of a monetary decision does not generate higher volatility; instead, the price variability increases when the actual decision of the ECB differs from the market expectations.

However, including many lags for each variable would lead to a cumbersome estimation, however. To circumvent this problem, Andersen and Bollerslev (1998) proposed the imposition of a polynomial decay structure on the volatility response pattern and the estimation of the degree to which an announcement loads onto this pattern. This approach has become popular in the high-frequency literature[22], since it saves degrees of freedom. However, such a specification is rather arbitrary, and relies on the assumption that all announcements have a uniform volatility response pattern. Instead, I use dummy variables to allow for slow decaying effects in the volatility[23]. For each announcement, four dummies are defined: one at the time of the announcement and the other three 15, 30 and 60 minutes after the announcement, respectively. This is reflected in the last row of (2) by j which indicates the jth lag of the

[21] In the literature a number of other deseasonalization methods have been used, for a survey, see Dacorogna et al. (2001).

[22] See, e.g., Ahn et al. (2002), Andersen et al. (2000, 2003b) and Bollerslev et al. (2000).

[23] I am grateful to Clara Vega for suggesting this approach.

announcement dummies.

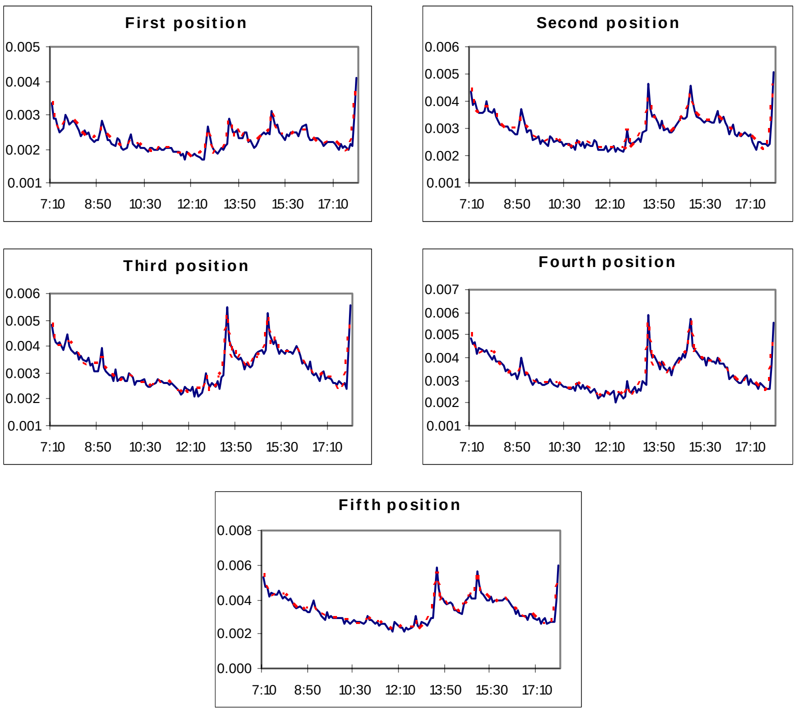
The model has been estimated by two-step weighted least squares (WLS). In the first step (1) has been estimated by ordinary least squares (OLS), and then the regression residuals, ε_t, have been evaluated. Thereafter, (2) has been estimated, and the fitted values of the regressand, $|\hat{\varepsilon}_t|$, have been used for a WLS estimate of (1).

4 Results

4.1 General results

The model described in (1) and (2) seems to be an accurate specification for the returns on EURIBOR futures, using both the GARCH-model based and the realised volatility measure of the daily volatility factor. In Figure 4, the average absolute and the average fitted residuals, coming from the model based on the realised volatility, are depicted. It is obvious that the fitted average intraday volatility suits very well to the actual one.

Figure 4: Average absolute and fitted residuals



Note: solid lines are the average absolute residuals ($|\varepsilon_t|$), dotted lines are the average fitted residuals ($\hat{\varepsilon}_t$).

One important finding is that realised volatility outperforms the GARCH estimate of the daily conditional variance from several aspects. First, estimating (2) using the realised volatility yields much higher estimate for β_1 and considerably higher R^2 for the regression. In addition, other goodness of fit measures, as the Akaike and Schwarz criteria also point to a better fit. This suggests that realised volatility captures better the daily variability of returns. As Andersen et al. (2001) argued, this is not surprising given that realised volatility reflects the return variability on a day conditional on the almost continuous sample path of returns up to and including that day, while the GARCH-based estimate is conditional on the discrete sample path of returns up to but not including that day. Accordingly, the estimated coefficients of calendar dummies, e.g., those controlling for day-of-the-week effects and for expiration days, are much smaller, not significant any longer or only barely in (2) using realised volatility. Hence, by approximating the daily price variation with realised volatility it is possible to control for one part of the intraday and interday volatility pattern of returns.

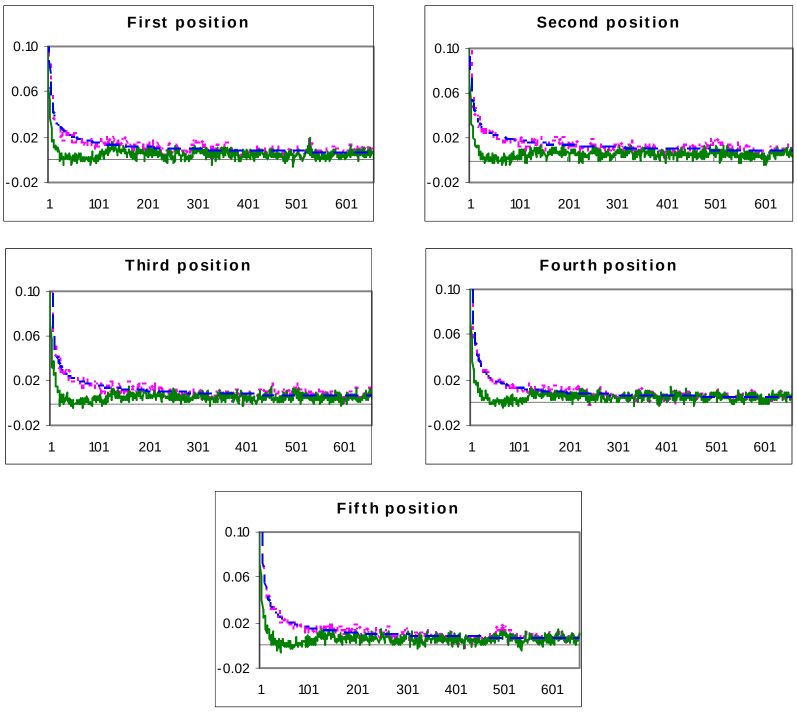
Second, by calculating standardised returns, $R_t / |\hat{\varepsilon}_t|$, evaluated $\hat{\varepsilon}_t$ by both daily volatility measures, the best performance of realised volatility is even more striking. Using the GARCH-based estimate, both the skewness and the kurtosis of the series decrease only slightly compared to those of raw returns given in Table 2. However, the standardisation by the realised volatility based estimate provides skewness coefficients close to zero and much smaller kurtosis than for the original raw returns[24], rendering the standardised returns nearly Gaussian. It has to be noted that standardising the daily returns by both daily volatility estimates, as in Andersen et al. (2001), those standardised by the GARCH-based standard deviation estimates do not provide any improvement compared to raw returns, while the results with the realised volatility depend considerably on its definition. If it is calculated using also the initial interval of the trading day the standardised EURIBOR futures returns are Gaussian according to the Jarque-Bera statistics. However, by using the definition described in Section 3, standardised returns will exhibit outliers, and their statistical properties will be similar to those based on the GARCH measure. This is because the latter volatility measure is not able to eliminate the outliers on expiration days, distorting the daily volatility estimates, whereas the former definition takes into account the jumps in the initial 5-minute interval on delivery days. This distortion is not present in the standardised intraday series as it does not contain the initial return of the trading day. This finding highlights the relevance of the definition of realised volatility. Deleting the first interval of the trading day yields better fit for the intraday volatility pattern of returns, whereas for a study with daily data it is recommended that one take into account all the intraday price movements. This is particularly relevant for futures prices for two reasons. Futures markets do not have a 24-hour trading cycle; thus, the first interval of the trading day may generate an unwanted noise in the intraday pattern of returns. In addition, owing to the contract expiry dates jumps may

[24] Kurtosis coefficients reduce to the range $[5.76; 8.95]$ after the standardisation. Complete descriptive statistics are available upon request.

occur, leading to outliers in the returns series.

Turning to the intraday properties of the standardised returns, the very pronounced intraday volatility pattern, displayed in the right panel of Figure 2, vanishes completely, as a result, the average absolute standardised returns centre around one, without any visible announcement effects. Regarding the temporal dependencies of the standardised series, the highly significant negative first-order autocorrelation is still present, indicating that it may originate from some microstructure effects, which affect the level of returns, regardless of the adequate volatility model. In contrast, the regular cyclical pattern of absolute returns almost completely evaporates. What is more striking is that the standardised series seem to lose their long-memory property by using the realised volatility based measure. In Figure 5 shows clearly that there is a very fast decay in the sample autocorrelations (see solid lines), then the serial correlation coefficients fall roughly within the band of Bartlett standard errors.

Figure 5 Correlogram of absolute standardised returns



Notes: dotted lines represent the correlogram using the GARCH measure, dashed lines represent the corresponding hyperbolic rates of decay, solid lines represent the correlogram using the realised volatility measure.

Using the GARCH-based daily volatility factor, the degree of volatility persistence has been obtained by the time-domain estimator proposed by Robinson (1994). In particular, the autocorrelations of a long-memory process (ρ_j) are all positive, and for a large value of j, can be approximated by $\rho_j \approx cj^{2d-1}$, where c is a factor of proportionality, and d is the degree of fractional integration. Taking logarithm gives

$$\log\left(\rho_j\right) = \log(c) + (2d-1)\log(j)$$

and a simple OLS estimate for d can be obtained by replacing ρ_j by the sample autocorrelations. Applying this estimator to the absolute standardised returns results in estimates for d which are between 0.19 and 0.29 for the five positions. As all these values fall clearly between 0 and 0.5, which implies that standardised returns can be treated as covariance stationary and fractionally integrated, when they are standardised by the GARCH-based volatility estimate. The implied hyperbolic rates of decay are also displayed in Figure 5 (see dashed lines). Evidently, this estimator cannot be applied to the autocorrelations of the realised volatility based standardised returns as they exhibit several negative coefficients.

This result is very striking as it suggests that, by using a proper estimate for the daily volatility, long memory can be annihilated from the return series. For example, Bollerslev et al. (2000) estimated a similar model for the volatility, approximating the daily volatility factor by a MA(1)-FIGARCH(1,d,1) model, and they found that while that model was able to extinguish the intraday patterns, it could not eliminate the long-run dependencies. However, it seems that realised volatility is capable of filtering out long memory.

4.2 Conditional mean

Before estimating, the values of P, Q, R and S in (1) have been determined using the Akaike and Schwarz information criteria. The implied optimal lags are roughly similar across positions and are displayed in Table 3.

Table 3: Implied lags by the AIC and SC criteria

	First	Second	Third	Fourth	Fifth
P	7	5	3	2	2
Q	4	6	6	6	6
R	2	2	2	2	2
S	6	4	4	4	4

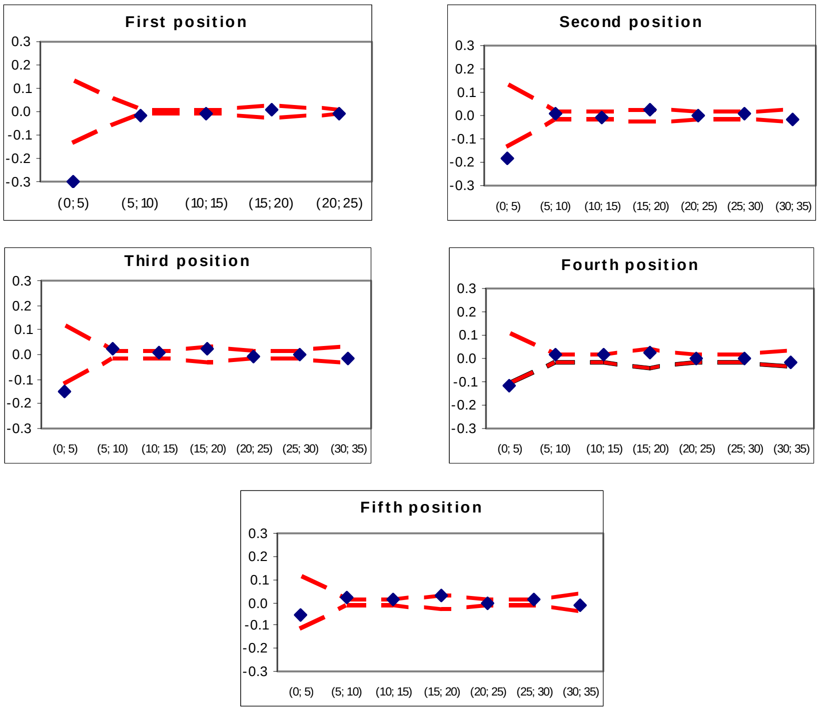
The tables shows that for macroeconomic releases it is sufficient to use 2 lags (i.e. up to 10 minutes after the announcement), which may suggest a fast adjustment in EURIBOR futures returns. However, for both the monetary policy surprise and the communication tools, the implied lags are 4 to 6 lags (20 to 30 minutes after the announcement). This may indicate longer-lived impacts and bigger heterogeneity between the beliefs of the traders. In what follows, I explain the estimated coefficients in details.

Here only the results are presented which are based on the volatility estimation using the realised volatility. The results using the GARCH volatility estimates are similar, although a number of coefficients are no longer significant.

4.2.1 Monetary policy surprise

As the model contains a large number of parameters, it is perhaps more useful to display the results graphically. In Figure 6 the estimated responses and the two standard error bands are depicted. The estimated coefficients for the monetary policy surprise show some noteworthy features. First, there is a very quick adjustment in the futures interest rate returns. It is remarkable that the largest coefficients are associated with the immediate response, that is, with the interval 12:45-12:50. Then, for some positions some correction can be observed, i.e. a move in the opposite direction, but these changes are dwarfed by the immediate impact. Second, the coefficients for the contemporaneous response decrease with position. This is not surprising, and it is in line with the expectation hypothesis, as monetary policy is able to affect directly the very short-term interest rates, whereas effects on longer maturities are rather indirect.

Figure 6 Impacts of the monetary policy surprise on the conditional mean of returns



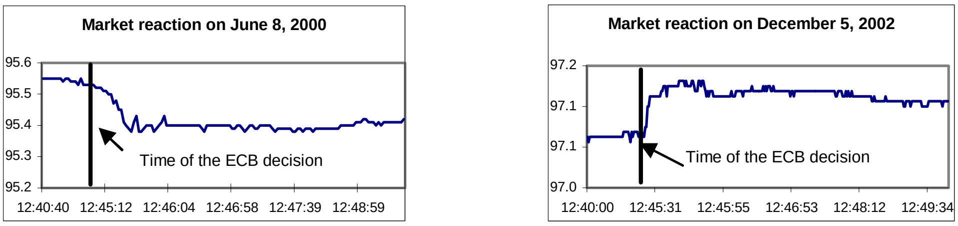
Notes: dots represent the responses of returns to monetary policy surprises.
Dashed lines are two standard error bands, under the null hypothesis of zero response.

Third, the impacts of further lags are considerably lower, although 15 minutes following a monetary policy decision significant effects for some positions can still be detected. One possible explanation for this may be that, on the preceding days of a monetary decision, market expectations are rather homogeneous, there is a general consensus the central bank's decision concerning its key interest rate. After a surprise occurs, this homogeneity evaporates, and market participants need a certain amount of time to assess the new information and to form new expectations. Hence, the coefficients for the immediate response only indicate a "first reaction" to the news, while those for further lags probably reflect the way towards a new consensus among traders about future EURIBOR rates.

The negative sign of the estimated coefficients is what has been expected, that is, a positive surprise (a larger- rise or lower-than-expected cut) implies a higher interest rate in the future, or equivalently, a decrease in the futures price.

To give an example how the EURIBOR futures market reacted to monetary policy surprises in the sample period, Figure 7 depicts the behaviour of futures prices surrounding the June 8, 2000 and December 5, 2002 meetings, respectively. Tick-by-tick observations are displayed in a 10-minute window, from 5 minutes before to 5 minutes after the decision. The reason for selecting these two meetings was that the ECB caused the largest positive and negative surprises on these meetings, respectively. In June 8, 2000, it rose its key rate by 50 basis points while market participants expected a weaker tightening. In the other meeting, the ECB cut the minimum bid rate by 50 basis points, which was more than expected by analysts. The reaction of prices is only shown for the first position as this can be considered as the most sensitive to monetary policy decisions.

Figure 7 Tick-by-tick prices around two important monetary meetings



Notes: the figure shows tick-by-tick price data for the first position around two important ECB meetings. See text for details.

With respect to the figures, there are some intriguing findings. First, the price jumps almost immediately after the decision, in both cases the jump occurs around 12:45:30, that is, at the time when markets are informed about the monetary decision. Second, in the 5-minute interval preceding the release of the decision the tick activity is very weak, while in the next 5-minute interval market activity jumps and a surge of trading takes place. The former may be due to the "calm before the storm" effect, i.e. traders go blank and wait for the decision. After the surprise is released, traders try to realize some extra profit, then the market calms again and the market participants' beliefs become homogeneous. Third, it can be clearly seen in the left panel that there are much less ticks in the monitored ten-minute interval than in the right panel, indicating the fact that the liquidity of the EURIBOR futures market increased considerably in two years.

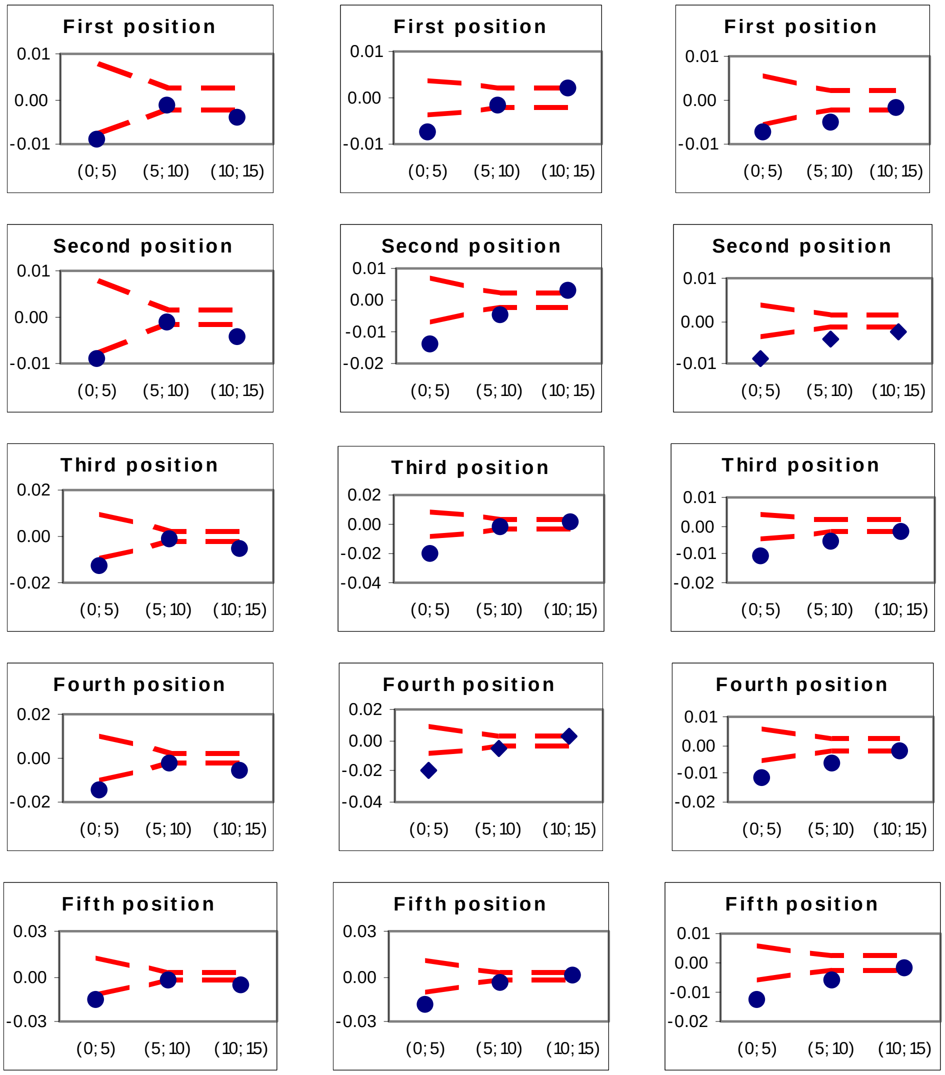
4.2.2 Macroeconomic announcements

As an overall result, EURIBOR futures prices adjust very quickly to macroeconomic surprises. A jump can be observed immediately after the announcement and little movement thereafter. Generally, almost none of the significant price changes has been found within 10 minutes following the releases. Beyond this overall pattern, there are some noteworthy features. First, as Andersen et al. (2003b) and Sebestyén and Sicilia (2005) showed, US news matter. Both the number of significant variables and the magnitude of their impact are larger than those of European ones. In Figure 8, the mean responses of the three most important US macroeconomic news are depicted, also showing the two standard error bands. Besides these variables, several other US releases exert significant influence on the EURIBOR futures returns, including Chicago PMI, consumer confidence, Philadelphia Fed index, initial jobless claims, the non-manufacturing business confidence index, durable goods order, factory orders and business inventories. There are two plausible explanations for this. One is that US data are released one month prior to European ones. For example, the industrial production figures, which correspond to January, are published one month earlier in the US than in the euro area. The reason is simply that in the euro area the national numbers come out first, then one has to wait for the aggregated data. The second reason might be that European data releases are leaked many times, while in the US very strict rules are employed for the publication of macroeconomic data. For more details on data leaks, see Andersson et al. (2005).

The set of significant macro variables is similar to that found by Andersen et al. (2003b, 2005), suggesting that US releases are relevant factors in the price determination of different types of asset prices. Only three European announcements affect significantly the level of returns for all positions: the ZEW index, the IFO index, and the German industrial production. This result is also in line with the findings of Sebestyén and Sicilia (2005), and reflect the key role of the German economy in the euro area, and it may also indicate the relevance of national releases.

Figure 8 Mean responses to US macroeconomic news

Nonfarm payrolls US | GDP advance US | Man. bus. conf. US



Notes: dots represent the responses of returns to US macroeconomic announcements. Dashed lines are two standard error bands, under the null hypothesis of zero response.

Second, survey data are of great importance. Most of the releases that affect significantly the level of EURIBOR futures returns are survey variables, which suggests that expectations about the real economy play an important role in the price discovery process. Moreover, survey variables seem to have longer-lived impacts on returns than real economy data. While the latter generally cause an immediate jump and tiny moves thereafter, forward-looking variables also affect returns 5 minutes following the announcements. Third, the magnitude of the impacts (in absolute value) increases with position, i.e. the longer the time horizon of the EURIBOR futures contracts, the more sharply they react to macroeconomic surprises. This result supports the hypothesis that longer-term interest rates reflect real economy fundamentals rather than monetary policy actions, and it also explains why previous empirical findings have shown that bond prices react so sharply to macroeconomic surprises.

The sign of the estimated coefficients is what has been expected, i.e. positive surprises ("good news") cause a drop in the futures price, that is, an increase in the futures interest rate.

4.2.3 Communication tools

Regarding the Introductory Statement, it turns out to be insignificant for all positions, only its first lag is highly significant for the nearby futures contracts. This result is in contrast with that of Sebestyén and Sicilia (2005), who found, using daily data, that Introductory Statements affect significantly the interest rate differentials with maturities from three months up to ten years. They also showed that the tone of the statements mattered in the sample period, i.e. the hawkish Introductory Statements were responsible for the overall significance of the estimated coefficients. Therefore, using the same classification of Introductory Statements, made by Béranger and Gies (2005)[25], the model was estimated by including two dummy variables, one for the hawkish Introductory Statements, and the other for the dovish ones. The results do not show any improvement, indicating that the tone of the statements does not affect significantly the level of intraday EURIBOR futures returns.

Turning to the President's testimony at the European Parliament, at the fourth lag, there is a highly significant negative coefficent, which increases (in absolute value) with position. The interpretation of this result may be that, in his testimonies, the President may give some hints of the ECB's view about the economy of the euro area which are considered relevant by market participants. The significance of the variable only at the fourth lag may indicate that analysts need some time to interpret the new information and to attain a new consensus. This result also suggests that the President's testimonies are widely monitored by traders.

Regarding the speeches of the Executive Board members, there are some barely significant coefficients for some positions but one cannot observe any systematic pattern. It may be due to the fact that it is difficult to match the exact timing of the speeches and/or Executive Board members try not to give the markets any additional information in their public engagements.

4.3 Conditional volatility

The model described in (2) provides an adequate approximation to the conditional variance dynamics of the series, as it can be seen in Figure 4. The

[25] For a detailed description of the classification, see Sebestyén and Sicilia (2005).

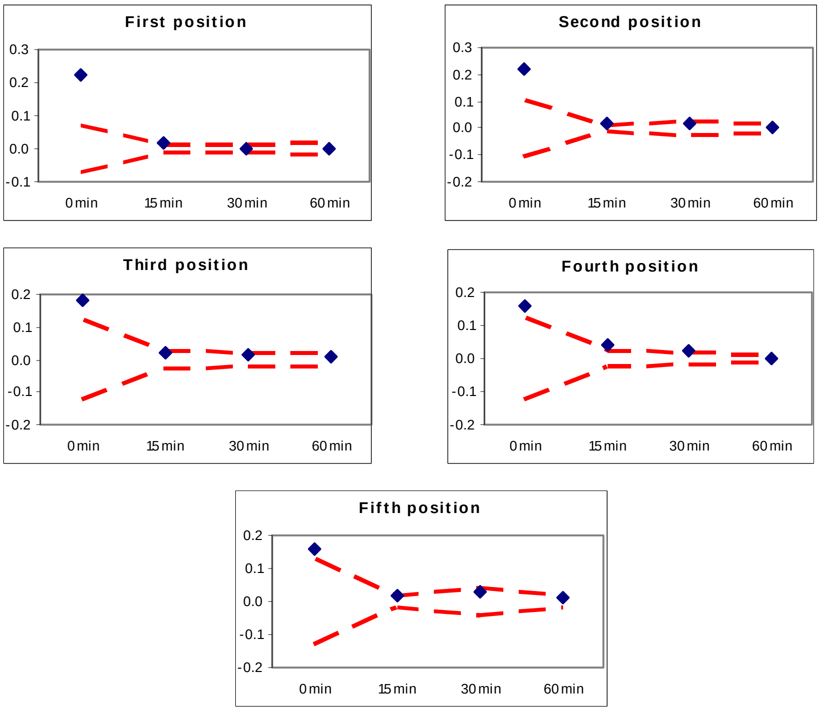
Akaike and Schwarz criteria propose $R = 9$ as the number of trigonometric terms. Both these terms and the second-order polynomial terms proved to be highly significant, but as this part of the equation provides a non-parametric fit to the intraday volatility pattern, the estimated coefficients have no economic interpretation[26].

The following is a discussion of the estimated individual coefficients for the different types of announcements.

4.3.1 Monetary policy surprise

The volatility responses of EURIBOR futures returns to monetary policy surprises resemble mean responses in the sense that an immediate boost occurs following the monetary decision (see Figure 9), then the price variability reduces considerably, although it remains significantly above zero up to 15 minutes following the announcement (for the fourth position up to half an hour).

Figure 9 Volatility responses of the monetary policy surprise



Notes: dots represent the volatility responses of returns to monetary policy surprises. Dashed lines are two standard error bands, under the null hypothesis of zero response.

This result is in contrast with previous empirical findings, namely, that the volatility response is a great deal more gradual, with the complete adjustment

[26] Details are available upon request.

occurring only one hour following the announcement. This is due to the different specification of volatility responses. Assuming the polynomial response pattern, proposed by Andersen and Bollerslev (1998), one can detect significant impacts one hour after the monetary decision, whereas, with the use of lagged values and without any assumption on the shape of the response pattern, the reaction of the futures prices is fairly different, pointing to faster volatility adjustment.

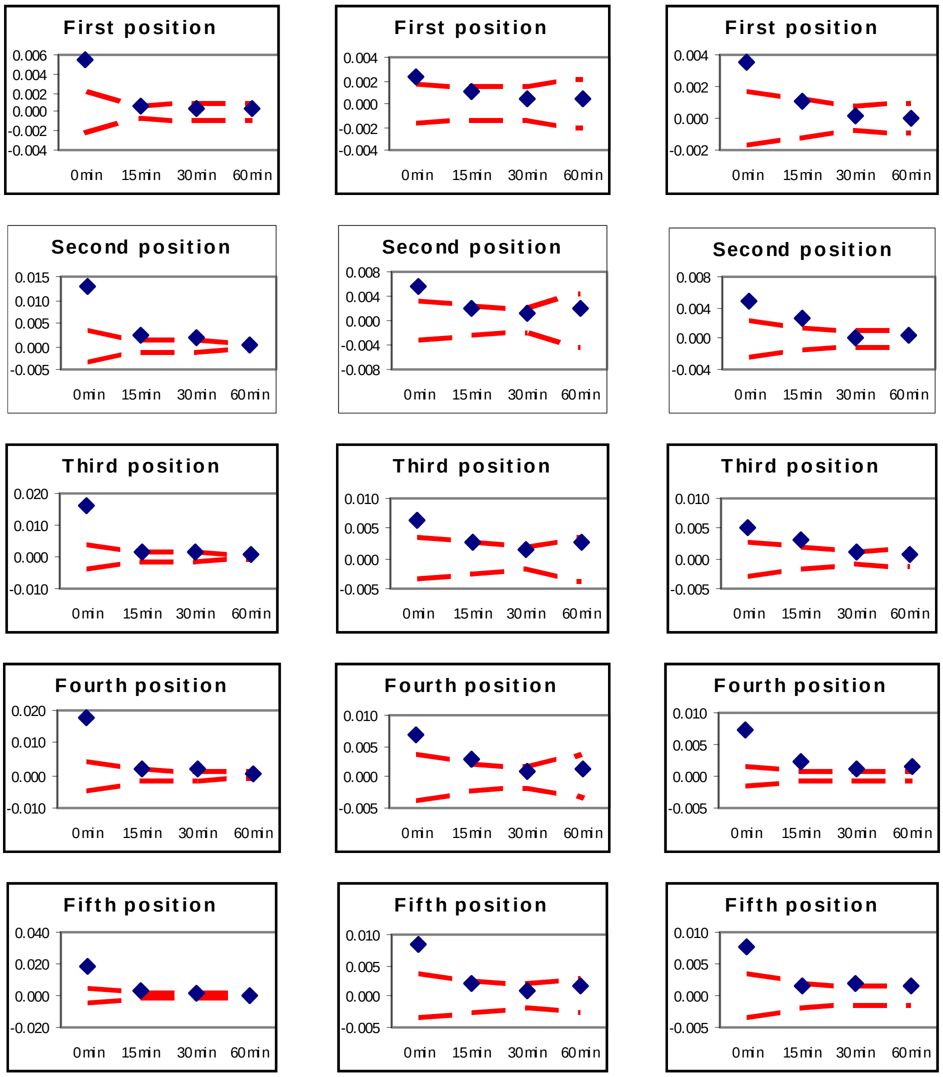
In line with monetary theory, surprises from the decisions of the ECB affect more sharply the price variability of shorter-term rates, i.e. the estimated immediate response coefficients decrease with position. That is 0.22 for the first position, which implies that a monetary policy surprise of 100 basis points, regardless of its sign, leads to a 22-basis-point increase in the return volatility of the nearby EURIBOR futures. This does not seem to be very large, but given the sample standard deviation of 0.4 basis points (see Table 2), it induces a 55 times higher volatility than normal. Clearly, a monetary surprise of 100 basis points is not realistic, since the largest surprise in the sample period (in absolute value) is around 25 basis points. This implies a contamporaneous jump in the volatility of 5.5 (25×0.22) basis points, which is almost 14 times higher than normal. As a conclusion, surprises caused by the ECB's monetary decisions boost volatility of short-term interest rate futures prices immediately after the decision is released, and the adjustment lasts up to around 15 minutes.

4.3.2 Macroeconomic announcements

Similarly to the volatility responses of the monetary policy surprise, those of the macroeconomic announcements are more gradual than mean reactions, but less gradual than those implied by polynomial responses. Only a limited number of macroeconomic variables affect significantly the return volatility beyond 30 minutes, while the increased price variability generally returns to its normal level after 15 minutes. In Figure 10, the volatility responses of the three macroeconomic announcements which have the biggest impacts on the price variability of EURIBOR futures are plotted.

Figure 10 Volatility responses to US macroeconomic news

Nonfarm payrolls US | GDP advance US | Man. bus. conf. US



Notes: dots represent the volatility responses of returns to US macroeconomic announcements. Dashed lines are two standard error bands, under the null hypothesis of zero response.

In addition to these releases, several other announcements exert significant influence on return volatility, the set is roughly the same as for the conditional mean. In addition, the same conclusions can be drawn as for the mean results, namely, that US news and survey variables matter, and the size of immediate impacts increases with position.

4.3.3 Communication tools

Introductory Statement releases generate significantly higher variability in EURIBOR futures prices for all positions at the time of the announcement and remain higher than normal 15-30 minutes following the release. The estimated immediate coefficients increase with position, from 0.0021 for the first position to 0.0066 for the fifth one[27]. They are smaller than those for the monetary policy surprise but larger than those for most of the macroeconomic dummies. In general, only the nonfarm payroll and the GDP advance releases induce a higher immediate jump in the volatility than Introductory Statements.

Regarding the estimation results using dummies indicating the tone of the Introductory Statements, it is striking that hawkish Introductory Statements are the main driver of the volatility increase described in the previous paragraph. Their estimated coefficients are considerably higher than those for most macroeconomic releases, except for the nonfarm payroll. Moreover, the hawkish tone seems to have also longer-lived effects, for example, the impacts of hawkish statements last until one hour after the release for the first position. Concerning the Introductory Statements with a dovish tone, they also boost return volatility at the time of the release, but the estimated coefficients are around half of the hawkish ones, and they exert generally short-term influence on the price variability of EURIBOR futures prices.

These findings suggest that the Introductory Statements are considered as very important news by market participants and, as a consequence, they are widely monitored. Traders pay considerable attention to the President's press conferences, and any hint at the future stance of monetary policy may generate excess variability in returns. Moreover, if the Introductory Statement has a hawkish tone it may induce larger and longer-lived impacts on volatility. This may be explained by the fact that a hawkish Introductory Statement is likely to be associated with the ECB's response to inflationary pressures, which are the most important risk factors from the point of view of monetary policy in the euro area.

Turning to the President's testimonies at the European Parliament, although the immediate response coefficients are not significant, they affect the price variability of EURIBOR futures 15 minutes after the news appears on the traders' displays for all positions but the first one (for the second and the third, the impacts 30 minutes following the release are also significant). The estimated coefficients increase with position, as with Introductory Statements, but they are not of a great magnitude. The conclusions may be similar to those for the Introductory Statements, i.e. new information on the future path of the ECB's monetary policy and on the euro area economy may generate higher than normal volatility in the EURIBOR futures market.

Speeches by Executive Board members did not cause excess price variability in the sample period. The causes may be the same as with the conditional mean, namely, that it is difficult to determine the exact timing of speeches, and

[27] Detailed results are available upon request.

that the Executive Board members do not supply additional information to the markets in their public engagements.

5 Conclusions

The EURIBOR market is the benchmark money market of the euro area, and EURIBOR futures contracts are the most heavily traded euro-denominated short-term interest rate contracts in the world. Moreover, the ECB steers its monetary policy via this market and it is highly interested in monitoring the price formation process. However, very little is known about how new information about fundamentals is incorporated into prices in this market. This paper has investigated the price discovery process in the EURIBOR futures market, using high-frequency data, and has examined the effects of the arrival of various types of public information such as monetary policy and macroeconomic surprises, as well as the external communication of the ECB. I have focused on both the level and the volatility impacts.

A general description of the original tick-by-tick data and the construction of 5-minute returns have been presented. I have constructed time series by position in order to study the price behaviour of futures with different time horizons. I have shown that EURIBOR futures display a pronounced intraday volatility pattern, with considerable announcement effects which increase as we proceed further ahead in time. Then I have proposed a model to characterise both the conditional mean and the conditional variance of futures returns. It has been found that this model is capable of capturing the intraday and interday patterns of 5-minute returns, and also matches adequately the effects of different announcements.

The most important findings of the paper are the following. First, I have shown that realised volatility is a more accurate measure of the daily price variation than a GARCH model based estimate. Returns standardised by the realised volatility based volatility estimate exhibit no announcement effects, no cyclical pattern in the sample autocorrelations, and lose their long memory properties.

Second, monetary policy surprises exert a significant influence on both the level and the volatility of intraday returns. The mere presence of a monetary policy meeting does not induce a jump in the volatility at the time of the announcement, but a surprise in the ECB's decision boosts considerably the price variability. In contrast, macroeconomic data releases themselves generate higher volatility, announcement dummies seem to be a better measure of uncertainty than announcement surprises.

Third, the adjustment in the level of returns is very fast, there is an immediate jump at the time of the releases and little move thereafter. However, the volatility responses are more gradual, although not as slow as a polynomial decay structure, broadly used in the literature, would imply. Employing dummies to capture the volatility decay effects, the general finding is that higher price variability fades out around 15 minutes after the announcements.

Fourth, the external communication of the ECB exerts significant influence on EURIBOR futures, mainly on volatility. Introductory Statements do not affect the level of intraday returns, still they boost price variability, and their effect is rather long-lived. Statements with a hawkish tone are liable for this finding, which can be explained by the anti-inflationary monetary policy pursued by the ECB. However, the President's testimonies at the European Parliament seem to be widely monitored by market participants as they may include some hints about the future path of monetary policy.

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