

News announcements, market activity and volatility in the euro/dollar foreign exchange market

Luc Bauwens^{a,1}, Walid Ben Omrane^{b,2}, Pierre Giot^{c,d,*}

^a *CORE and Department of Economics, Université catholique de Louvain, Voie du Roman Pays 34,
B-1348 Louvain-la-Neuve, Belgium*

^b *Department of Business Administration (IAG), Finance Unit, Université catholique de Louvain,
Place des Doyens 1, B-1348 Louvain-la-Neuve, Belgium*

^c *Department of Business Administration & CEREFIM, University of Namur, Rempart de la Vierge 8,
B-5000 Namur, Belgium*

^d *CORE, Université catholique de Louvain, Voie du Roman Pays 34, B-1348 Louvain-la-Neuve, Belgium*

Abstract

We study the impact of nine categories of scheduled and unscheduled news announcements on the euro/dollar return volatility. We highlight and analyze the pre-announcement, contemporaneous and post-announcement reactions. Using high-frequency intraday data and within the framework of ARCH-type models, we show that volatility increases in the pre-announcement periods, particularly before scheduled events. Market activity also significantly impacts return volatility as expected by the theoretical literature on the order flow.

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* Corresponding author. Department of Business Administration & CEREFIM, University of Namur, Rempart de la Vierge 8, B-5000 Namur, Belgium. Tel.: +3281724887; fax: +3281724840.

E-mail addresses: bauwens@core.ucl.ac.be (L. Bauwens), benomrane@fin.ucl.ac.be (W. Ben Omrane), pierre.giot@fundp.ac.be (P. Giot).

¹ Tel.: +3210474336.

² Tel.: +3210478449.

1. Introduction

The impact of information on the volatility of foreign exchange (FOREX) returns has been theoretically and empirically studied in several papers, e.g. Degennaro and Shrieves (1997), Andersen and Bollerslev (1998), Evans and Lyons (1999), Melvin and Yin (2000) and Cai et al. (2001). As stressed in the literature on market microstructure (see O'Hara, 1995), the 'information' variable includes both a public and a private component. Regarding the market microstructure of the FOREX, both public and private components are strongly related to currency market news announcements. The public component is made up of announcements which take place at fixed times (which we call scheduled public announcements), or at random times (unscheduled public announcements). Regarding private information, the most recent literature on the microstructure of exchange rates allows for two types of private information. Firstly, some market participants could have access to yet unreleased information by central banks or government agencies (i.e. payoff related private information in the terminology used by Lyons, 2001). Secondly, the notion of private information can be extended to include the so-called unrelated payoff information, i.e. private information that a dealer has regarding interim states of the market (for example, a dealer knows that another dealer is keen on selling a large euro/dollar position, which should depress prices in the short run). Because this second possibility is the most probable type of private information event in the FOREX market, private information is strongly related to order flow between traders and their customers.³

With respect to the previous literature on FOREX volatility about the impact of news announcements, the aim of this paper is twofold. Firstly, we analyze the impact of a more refined and extended set of nine categories of news announcements on FOREX volatility in the new euro/dollar market. Secondly, we investigate the volatility dynamics before, during and after scheduled and unscheduled news announcements. The contribution of our research therefore consists in assessing the previous results on the new euro/dollar market and extending these by distinguishing between the impact on volatility of scheduled and unscheduled news in three time periods centered around the release of the news, i.e. the pre-announcement, contemporaneous, and post-announcement periods. We focus more particularly on the reaction of volatility in the pre-announcement periods as this topic has not yet been dealt with extensively in the existing literature. Taking into account the specific features of public and private information, the news impact on volatility can take place both before and after the announcement. In the case of scheduled news announcements, volatility increases in the pre-announcement period could be due to anticipatory trades by dealers who open positions to profit from some personal beliefs, i.e. they hope that the actual news outcome will coincide with their forecast of the outcome. A post-announcement volatility increase can be attributed to heterogeneity of interpretations of the contents of the news, surprised reactions and closing of positions based on prior anticipations. On the other hand, in the case of unscheduled news announcements, an increase in volatility before the announcement is probably linked, as suggested by Degennaro and Shrieves (1997), to the presence of informed traders who exploit their privileged information.

The econometric analysis is performed on a high-frequency data set of 5-min regularly time-spaced FOREX euro/dollar quotes. The time period ranges from May 15 to November 14, 2001. Our database also includes the news headlines that were released on the Reuters news-alert screens. Regarding these news announcements, we consider a much larger set of

³ See Lyons (2001) and references therein for additional information and recent developments.

news events (classified into nine general categories) than those used in the previous literature. Furthermore, to highlight the effect of the possible ‘surprise’ contained in the most important scheduled US macroeconomic figures, we distinguish between so-called positive and negative news (by computing the difference between expected and realized values). As in the previous literature, we also take into account the effect of private information (proxied by the deseasonalized quoting frequency) on the volatility of the euro/dollar returns. More generally, the focus of this work is therefore on the economic determinants of the euro/dollar return volatility with particular attention to the links between the information flow and the market reactions measured by volatility and quoting frequency. We use an EGARCH model where we control for intraday seasonality, news arrival (represented by dummy variables) and quoting frequency.

Our results show that the euro/dollar return volatility increases before the announcement of scheduled news. We surmise that speculative/anticipatory trades, the possible flow of private information or the re-balancing of positions by traders who prefer to avoid announcement ‘surprises’ lead to this increase in volatility. When an announcement is not scheduled, the evidence of volatility increase during the pre-announcement phase is tenuous, except for rumors of central bank interventions. Moreover, for four categories of announcements, volatility increases in total over the pre-announcement and post-announcement periods.

The follow-up of this paper is divided in four sections. In Section 2 we present a brief review of the empirical market microstructure issues related with FOREX news announcements and quote volatility. In Section 3 we describe our data. We present our models and we discuss the estimation results in Section 4. We conclude in Section 5.

2. News announcements and volatility

The impact of news announcements on FOREX return volatility has been studied in several papers (see the reference citations at the beginning of Section 1). These studies have focused on the most active currency markets (dollar/DM, dollar/yen, and sterling/dollar). Analyzing the factors, such as news announcements, which affect FOREX volatility is an important topic in empirical finance as this provides an economic explanation of the volatility in currency markets. Regarding news announcements, it is important to distinguish between scheduled announcements (the announcement is planned, e.g. US macroeconomic figures) and unscheduled ones (e.g. rumors of central bank interventions). Unscheduled announcements can lead to both public and private information, according to their market effects. If the information is public, then an unscheduled event should not be preceded by an abnormal increase in volatility. On the other hand, an unexpected rise in volatility during the pre-announcement period indicates that informed trades (due to private information) take place. For scheduled announcements, an abnormal increase in volatility during the pre-announcement period can be linked to speculative trades initiated on the basis of anticipations, or to traders who close their positions to avoid ‘surprises’ when the news is released.

The link between volatility and private information was suggested in the theoretical work of [Admati and Pfleiderer \(1988\)](#). In their model, informed traders prefer to transact during periods of high trading activity in order to maximize the potential profit that comes from their private information. In addition, liquidity motivated traders are also active during this period to profit from the high market activity and the available liquidity. An important empirical implication of this model is that private information leads to increased price volatility during periods of high trading activity. Set in the FOREX framework, this type of analysis suggests that the dynamics

of FOREX quotes will therefore be shaped by the news announcements and by the traders' private information. When no private information is at play, FOREX quotes should adjust to events after the news announcements. When there is information asymmetry, FOREX quotes should adjust to private information before the news announcement and continue their adjustment during the announcement, while volatility should decrease during the post-announcement period. In their empirical study, Degennaro and Shrieves (1997) test the theoretical results of Admati and Pfleiderer (1988). They analyze the pattern of volatility around news announcements and study the impact of the release of macroeconomic, economic policy and interest rate reports on the volatility of the dollar/yen exchange rate. According to their results, a high market activity leads to increases in volatility and spread, which they interpret as private information effects. These results are in agreement with Lyons (1995, 1997) and Evans and Lyons (1999), who show that a significant part of the FOREX order flow is made up of deals between traders and their customers (deals that generate private information). Andersen and Bollerslev (1998) and Cai et al. (2001) analyze the sensitivity of short and long term volatility (for the dollar/DM and dollar/yen FOREX quotes) with respect to US macroeconomic announcements and seasonal factors. Andersen and Bollerslev (1998) show that announcements have a significant positive effect, but for a very short period of time. Seasonal factors, such as the opening of the local markets, lunch breaks, some specific days of the week (Thursday and Friday, i.e. days of US macroeconomic announcements), also lead to volatility increases. Cai et al. (2001) confirm the results of Andersen and Bollerslev (1998) and show the importance of the positive effect on volatility of the order flow, in comparison with the news announcements. Eddelbuttel and McCurdy (1998) do not classify the news in categories but count instead the number of events in a given time interval. Deseasonalized counts lead to increases in both market activity and return volatility for dollar/yen quotes.

Next to return volatility, a second important variable is market activity. FOREX market activity, measured by the number of quotes in a given time interval, is considered in many papers (e.g. Goodhart and Figliuli, 1991; Bollerslev and Domowitz, 1993; Degennaro and Shrieves, 1997; Melvin and Yin, 2000) as a proxy for volatility and should therefore be affected by news announcements. Market activity is also a proxy for private information (Degennaro and Shrieves, 1997; Evans and Lyons, 1999; Rime, 2000). A significant part of the order flow is due to transactions between traders and their customers. Customer–dealer trades are not observable by the other market participants. Therefore, they are a source of information asymmetry among dealers and can be considered as private information. Consequently, when traders execute these orders, they play a role of intermediation or transfer of information between their clients and other traders. For example, Lyons (1997) shows that traders could be motivated to exploit the information contained in their own customer orders to take speculative positions that distort this information intermediation. The empirical study of Degennaro and Shrieves (1997) shows that the unexpected component of market activity (i.e. market activity adjusted for its seasonal component) can be viewed as a proxy for private information: unexpected market activity leads to an increase in volatility and a widening of the spread.⁴

Regarding the methodological framework, the sensitivity of FOREX quotes return volatility to exogenous factors is usually assessed and quantified using GARCH models, as for example in Degennaro and Shrieves (1997) and Melvin and Yin (2000). The use of a conditional

⁴ The relationship between private information and the size of the spread can be traced back to Glosten and Milgrom (1985).

volatility model is justified by the key features of the distribution of FOREX returns (volatility clustering and fat tails). Note, however, that Andersen and Bollerslev (1998) and Cai et al. (2001) set their analysis in the framework of realized volatility, i.e. volatility computed as the sum of high-frequency absolute returns.

Finally, the literature on the volatility of FOREX returns stresses that market openings and closings, week-ends and some days of the week lead to significant cyclical factors in the pattern of volatility (Bollerslev and Domowitz, 1993; Andersen and Bollerslev, 1996, 1998; Degennaro and Shrieves, 1997). For example, Andersen and Bollerslev (1998) show that scheduled news announcements have a seasonal impact on volatility. These announcements induce both a cyclical and a stochastic component, the latter stemming from incorrect anticipation by the market participants and thus a ‘surprise’ effect. To remove the seasonal effects and to highlight the stochastic components, it is first necessary to detect and identify the factors that are likely to generate periodic effects. A number of methods have been put forward in the literature. Degennaro and Shrieves (1997) introduce the ‘cross-sectional’ average of market activity in the volatility equation. In order to model the seasonal impact, Andersen and Bollerslev (1998) introduce a flexible Fourier form (FFF in what follows), i.e. a sum of sinusoids, to detect intraday cycles. Melvin and Yin (2000) divide returns by their cross-sectional average to remove seasonality.

3. Data description

3.1. Euro/dollar exchange rate data

The euro/dollar FOREX market is a market maker based trading system, where three types of market participants interact around the clock (i.e. in successive time zones): the dealers, the brokers and the customers from which the primary order flow originates. The most active trading centers are New York, London, Frankfurt, Sydney, Tokyo and Hong Kong. A complete description of the FOREX market is given by Lyons (2001).

To compute the returns used for the estimation of the models reported in Section 4, we bought from Olsen and Associates a database made up of ‘tick-by-tick’ euro/dollar quotes for the period ranging from May 15 to November 14, 2001 (i.e. 26 weeks and 3 days). This database includes 3,420,315 observations. As in most empirical studies on FOREX data, these euro/dollar quotes are market makers’ quotes and not transaction quotes (which are not widely available).⁵ More specifically, the database contains the date, the time-of-day time stamped to the second in Greenwich mean time (GMT), the dealer bid and ask quotes, the identification codes for the country, city and market maker bank, and a return code indicating the filter status. According to Dacorogna et al. (1993), when trading activity is intense, some quotes are not entered into the electronic system. If traders are too busy or the system is running at full capacity, quotations displayed in the electronic system may lag prices by a few seconds to one or more minutes. We retained only the quotes that have a filter code value greater than 0.85.⁶

⁵ Danielsson and Payne (2002) show that the statistical properties of 5-min dollar/DM quotes are similar to those of transaction quotes.

⁶ Olsen and Associates recently changed the structure of their HF database. While they provided a 0/1 filter indicator some time ago (for example in the 1993 database), they now provide a continuous indicator that lies between 0 (worst quote quality) and 1 (best quote quality). While a value larger than 0.5 is already deemed acceptable by Olsen and Associates, we choose a 0.85 threshold to have high quality data. We remove, however, almost no data records (Olsen and Associates already supplied us with data which features a filter value larger than 0.5), as most filter values are very close to 1.

From the tick data, we computed mid-quote prices, where the mid-quote is the average of the bid and ask prices. As we use 5-min returns, we have a daily grid of 288 points. At the end of each interval, we used the closest previous and next mid-quotes to compute the relevant price by interpolation. The mid-quotes are weighted by their inverse relative time distance to the interval endpoint. Next, the return at time t is computed as the difference between the logarithms of the interpolated prices at times $t - 1$ and t , multiplied by 10,000 to avoid small values. Because of scarce trading activity during the week-end, we excluded all returns computed between Friday 22h05 and Sunday 24h. In addition, we excluded the first return of each Monday to avoid possible biases due to the lack of activity during the week-end. The total number of returns is 37,653.

The final data transformation consists of adjusting the returns for the intradaily component of volatility. The seasonally adjusted (SA) returns are obtained by dividing the returns by their cross-sectional intradaily average volatility. An average value of volatility is computed and attributed to the endpoint of every 5-min interval. The time series of these values constitutes an intradaily ‘seasonal index’ of volatility. This can be done by considering all days of the week as similar (an overall index), or by computing a specific index for each day of the week. In the [Appendix](#) we explain the details of the procedure we adopted to compute these indices and to adjust the returns. [Fig. 1](#) displays these indices. Comments on their pattern are provided in [Section 3.3](#), since they are related to news announcements.

[Table 1](#) presents summary statistics of the euro/dollar returns, before and after seasonal adjustment. The mean of the SA returns is almost equal to zero and their distribution has fatter tails than the normal, but it is almost perfectly symmetric. The unadjusted returns are much more leptokurtic, and feature a positive skewness coefficient. There is a highly significant negative autocorrelation of order 1 and of order 2 in both series of returns (although the level of autocorrelation is much closer to 0 at order 2). The negative autocorrelation in FOREX returns has been discussed in the academic literature. According to [Goodhart and Figliuli \(1991\)](#), the negative autocorrelation stems from constraints in the control of positions, while according to [Bollerslev and Domowitz \(1993\)](#) and [Lo and MacKinlay \(1990\)](#), this feature comes from the computation of asynchronous price series at the interval endpoints.

3.2. News announcement data

Our news announcements database includes the news headlines that were released on the Reuters news-alert screens over the May 15 to November 14, 2001 period. These events are time stamped to the minute and are a key feature of our news announcements analysis. In addition to the news headlines, Reuters also provides an economic agenda which gives the day and time of some of the announcements that are scheduled in the following week. We work with nine categories of news announcements ([Table 2](#) lists all the news categories). The announcements can be classified into two broad groups: scheduled and unscheduled announcements. The first group contains US macroeconomic figures, more specifically employment reports, producer and consumer price indices, gross domestic product and other important figures. This group also includes European macroeconomic figures, scheduled speeches of senior officials of the government and of public agencies, such as the Chairman of the Federal Reserve, the Chairman of the European Central Bank, and economy and finance ministers. We also classify as scheduled the US and European interest rate reports, although this is debatable. The meeting days of the ECB and the Fed are certainly scheduled, and agents know when the meeting starts and approximately ends. However, the exact time of the announcements is not

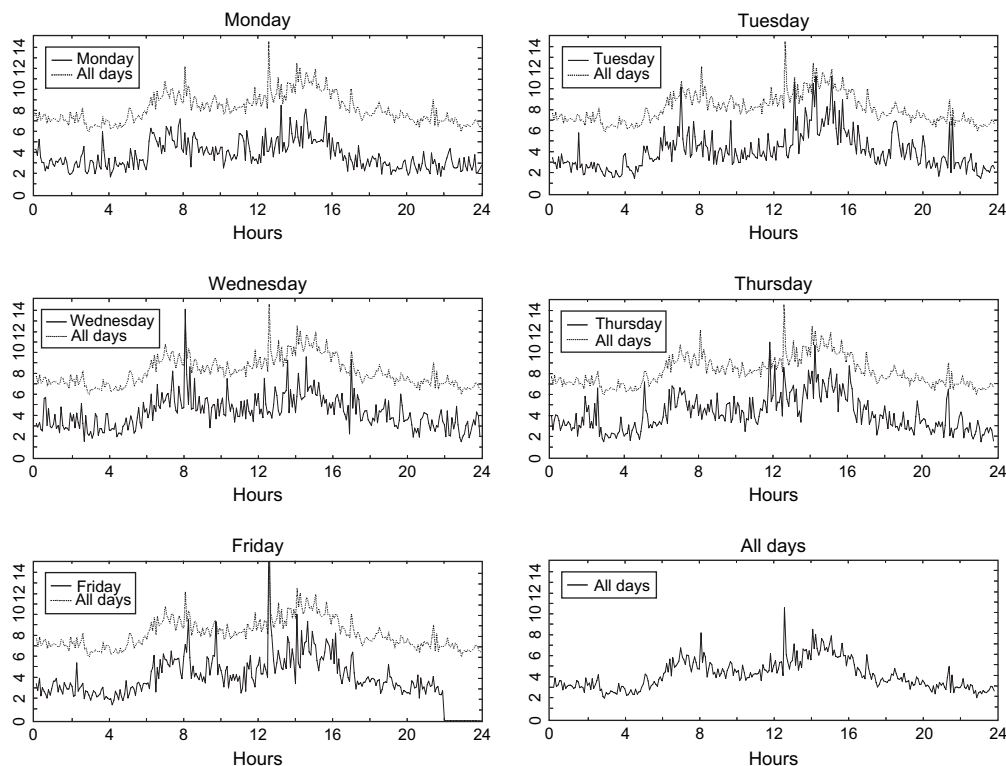


Fig. 1. Intradaily, day-specific and overall, average volatilities (see Eq. (6)). The panel of each day displays the average volatility of that day and the average volatility when all days are treated as having the same pattern. This overall volatility is shifted upwards by 4 units. It is also shown in the bottom right panel (without the shift).

exactly known in advance. The second group is made up of the forecasts of key institutes and specialized organizations, such as the IMF, the World Bank, and the IFO institute (an influential service-based research organization in Germany). This group also contains the declarations of OPEC members, the rumors of central bank interventions and other extraordinary events (natural disasters, wars, terrorist attacks, etc.). To highlight the effect of the possible ‘surprise’ contained in the scheduled US macroeconomic figures, we distinguish positive news from negative news by computing the difference between the expected and realized values: if the realization is larger than the expectation and is a figure which corresponds to economic growth, the news is classified as positive; if the actual figure implies instead higher-than-expected inflation or a slowdown of the economy, it is regarded as negative. The expected values are given on Reuters screens a few days before the news announcements.

The impact of the scheduled announcements should include both a deterministic (seasonal) component and a stochastic component. The latter reflects the surprise effect due to the discrepancy between the actual contents of the news and the expected contents before the release. US macroeconomic figures are usually released at 12h30 and 14h00 GMT. European macroeconomic figures are mostly released around 7h30 and 10h00 GMT. As far as the announcement days are concerned, Table 3 presents the number of news belonging to each category for each day of the week. The number of news announcements during the 6-month period of our study is

Table 1
Moments of the euro/dollar returns

	Returns	SA returns
Mean	0.007	0.00006
Standard deviation	4.41	1.01
Skewness coefficient	0.34	0.02
Kurtosis coefficient	15.2	4.41
JB normality test	233,879	5922
Autocorrelation of order 1	−0.086	−0.12
Autocorrelation of order 2	−0.025	−0.027
Autocorrelation of order 3	0.000	−0.001

The SA (seasonally adjusted) returns are the returns divided by their intradaily average volatility (see Section 3.1 and Appendix for details). The 5-min returns have been pre-multiplied by 10,000 (to avoid small values). The number of observations is 37,653, corresponding to the period from May 15 to November 14, 2001.

equal to 1040. For example, 61% of US macroeconomic figures are released on Thursday and Friday. Therefore, we expect that regularly scheduled news announcements induce a seasonal effect in volatility.

3.3. The intradaily average volatility

As mentioned above, the euro/dollar currency is almost continuously traded in FOREX markets that belong to different time zones, but the activity (measured by the number of quotes per 5-min interval) varies a lot over the 24 h. It is also well known that the volatility varies. Fig. 1 illustrates the intradaily seasonal pattern of the average volatility of 5-min returns. The bottom right panel of that figure shows the average volatility when all days of the week are assumed to have the same pattern. It shows some components which exist more or less every day, although days differ from each other as can be concluded informally by looking at the other panels.

Volatility increases after midnight, i.e. at the opening of the Singapore and Hong Kong markets, 1 h after the opening of the Tokyo market and 2 h after Sidney. Around 4h GMT, volatility decreases because of the lunch break in the four Asian financial markets. Thereafter, volatility increases again because trading activity resumes in the Asian markets and it reaches a local maximum around 7h–8h GMT, i.e. right after the opening of the key European markets such as London and Frankfurt. This pattern of volatility increases around the opening and closing times of the regional markets are in agreement with [Admati and Pfleiderer \(1988\)](#), who show that these periods are characterized by a sustained level of market activity which attracts different categories of traders. In addition, [Lyons \(1997\)](#) shows that, because traders have to control or close their positions at the end of every day, they increase their activity right before the closing of trading and just after the market opening to get rid of unwanted risky positions. Because of the lunch break in Europe, volatility decreases around 11h30. A rebound in volatility occurs at 12h GMT as New York opens for trading. The big spike between 12h and 13h is due to US news announcements at 12h30 on Friday. Between 12h and 16h GMT volatility is generally at its highest level due to the simultaneous activity of the American and European markets. Just before the New York lunch break (which is clearly visible in the figure around 17h GMT), there is a short volatility increase due to the closing of the European markets. Volatility increases also around 21h GMT, i.e. when the New York trading session ends.

Table 2

News categories

	Positive	Negative
Scheduled news announcements		
1 and 2-US macroeconomic figures	$\eta_{1,\tau}$	$\eta_{2,\tau}$
Employment report	—	+
ISM index (ex NAPM)	+	—
Whole sales	+	—
Gross domestic product (GDP)	+	—
Producer price index (PPI)	—	+
Retail sales	+	—
Housing starts	+	—
Consumer confidence index	+	—
Consumer price index (CPI)	—	+
Construction spending	+	—
Car sales	+	—
Business inventories	—	+
Housing completions	+	—
Import prices	—	+
Current account deficit	—	+
Non-farm productivity	+	—
Personal income	+	—
Real earnings	+	—
House sales	+	—
3-European macroeconomic figures	$\eta_{3,\tau}$	
4-Speeches of senior officials of the government and of public agencies	$\eta_{4,\tau}$	
5-US and European interest rate reports	$\eta_{5,\tau}$	
Unscheduled news announcements		
6-Forecasts made by economic institutes	$\eta_{6,\tau}$	
7-Declarations of OPEC members	$\eta_{7,\tau}$	
8-Rumors of central bank interventions	$\eta_{8,\tau}$	
9-Extraordinary events	$\eta_{9,\tau}$	

The events are the news headlines released on the Reuters money news-alerts.

For US macroeconomic figures, we separate positive and negative news-alerts by comparing the expected and the announced numbers. If the actual numbers are larger than the expectations for economic variables that contribute to economic growth, the announcements are classified as positive (+). If the actual news release means more inflation or a forthcoming economic slowdown, it is classified as a negative news announcement (—). The expected values are given on Reuters screens a few days before the news announcements.

The employment report includes the unemployment figures.

ISM is the abbreviation for the Institute of Supply Management, ex NAPM, National Association of Purchasing Management. It is a monthly composite index and gives the earliest indication of the health of the manufacturing sector. The symbol $\eta_{j,\tau}$ is the coefficient of the dummy variable $d_{j,\tau}$ in the equations reported in Tables 4 and 5. In Table 6, the coefficients are called η_j .

Starting at 21h GMT, a short period of stability is then observed until the opening of the Sidney and Tokyo markets, which leads to an increase in volatility.

The five day-specific panels of Fig. 1 indicate that the seasonality of volatility is also dependent on the day of the week: shocks are mainly observed on Tuesday and Wednesday around 8h, 10h and 16h30 (interest rate reports and European macroeconomic figures), Thursday and Friday around 12h, 12h30 and 16h30 (US macroeconomic figures and speeches of senior officials of the government). Therefore, the seasonality of volatility stems partly from the cyclical component of scheduled news announcements. In addition, Fig. 1 shows that volatility

Table 3
Daily news announcement frequencies

Category	Monday		Tuesday		Wednesday		Thursday		Friday		Total
	Total	%	Total	%	Total	%	Total	%	Total	%	
d1	11	<i>13</i>	13	<i>15</i>	12	<i>14</i>	23	<i>26</i>	29	<i>33</i>	88
d2	5	<i>7</i>	12	<i>17</i>	8	<i>12</i>	25	<i>36</i>	19	<i>28</i>	69
d3	42	<i>14</i>	68	<i>23</i>	76	<i>25</i>	59	<i>20</i>	54	<i>18</i>	299
d4	45	<i>22</i>	39	<i>19</i>	46	<i>22</i>	41	<i>20</i>	36	<i>17</i>	207
d5	21	<i>26</i>	27	<i>33</i>	13	<i>16</i>	15	<i>19</i>	5	<i>6</i>	81
d6	24	<i>27</i>	16	<i>18</i>	25	<i>28</i>	14	<i>16</i>	11	<i>12</i>	90
d7	21	<i>21</i>	17	<i>17</i>	24	<i>24</i>	19	<i>19</i>	18	<i>18</i>	99
d8	5	<i>42</i>	1	<i>8</i>	2	<i>17</i>	2	<i>17</i>	2	<i>17</i>	12
d9	22	<i>23</i>	14	<i>15</i>	20	<i>21</i>	24	<i>25</i>	15	<i>16</i>	95
Total	196	<i>19</i>	207	<i>20</i>	226	<i>22</i>	222	<i>21</i>	189	<i>18</i>	1040

Entries are the numbers of announcements, and in italics, the percentages per day. d1: Positive US macroeconomic figures. d2: Negative US macroeconomic figures. d3: European macroeconomic figures. d4: Speeches of senior officials of the government and of public agencies. d5: US and European interest rate reports. d6: Economic institute forecasts. d7: OPEC member declarations. d8: Central bank intervention rumors. d9: Extraordinary events.

increases for a short period of time in all markets at the beginning of the trading sessions of each Monday. Volatility increases every Monday around 0h, 8h, 13h, and 22h, which are, respectively, the opening hours of the Asian, European, American, and Australian markets. These increases during the first minutes of trading of every week are linked to the control of positions: FOREX traders who accumulate customers' orders at the end of the Friday session and who could not settle their positions have to keep them during the week-end. To minimize the risk of these positions, dealers are keen on executing their remaining orders in the first minutes of the Monday session. They do so by quoting attractive prices to attract counterparts and quickly close their positions.

4. Models and empirical results

4.1. Impact of announcements and activity on volatility

We want to study the sensitivity of volatility with respect to the news announcements and market activity. Following the discussion in Sections 1 and 2, we want to answer four broad questions:

1. Is there an increase of volatility, considering the reaction of the market before announcements?
2. Is there an increase of volatility, considering the total reaction of the market (before, during, and after announcements)?
3. Is there a difference between scheduled and unscheduled announcements in the answers to the previous questions?
4. Is there an impact of 'market activity' on volatility, in particular of the unexpected component of market activity, considered as a proxy of traders' private information?

We use the EGARCH model of Nelson (1990) to model SA returns (denoted q_t) and their conditional variance, denoted h_t (our measure of volatility).⁷ The level of returns is modelled by a moving average process of order 2 to account for the detected autocorrelation (see Table 1):

$$q_t = \theta_0 + u_t + \theta_1 u_{t-1} + \theta_2 u_{t-2}, \quad (1)$$

and the error term u_t by an EGARCH(2,2) process⁸:

$$u_t = \sqrt{h_t} \epsilon_t, \quad (2)$$

$$\begin{aligned} \ln h_t = & \omega + \sum_{i=1}^2 \left(\beta_i \ln h_{t-i} + \alpha_i \left[|\epsilon_{t-i}| - \sqrt{2/\pi} \right] + \gamma_i \epsilon_{t-i} \right) \\ & + \sum_{j=1}^9 \sum_{\tau=1}^3 \eta_{j,\tau} d_{j,\tau,t} + \phi a_{t-1} + \delta a_{t-1}. \end{aligned} \quad (3)$$

The innovations ϵ_t are assumed identically and independently distributed. We proceed as if their distribution was normal, i.e. we estimate the model by the quasi maximum likelihood (QML) method, thus accounting for lack of normality in computing asymptotic standard errors. Table 4 reports the estimation results. The standardized residuals and squared residuals are not autocorrelated (according to Q -statistics). The EGARCH coefficients are significant (except for the asymmetry effects) and compatible with a stationary process. Next, we define the variables appearing in the second line of Eq. (3). In conjunction with hypothesis tests (discussed below), the coefficients of these variables allow us to tackle the questions raised above.

The variable denoted $d_{j,\tau,t}$ is a dummy variable for the existence of an announcement of category j during the period τ , relative to the 5-min return at time t . It is equal to 1 if there is a news announcement during the time interval τ and is equal to 0 otherwise. The index τ indicates an observation window: a pre-announcement period ($\tau = 1$), a period just after the announcement ($\tau = 2$), and a post-announcement period ($\tau = 3$). The observation windows are equal to 15 min before the announcement ($\tau = 1$), 5 min just after the announcement ($\tau = 2$), and 20 min after the announcement ($\tau = 3$). Said differently, we allow one lead and two lags in the effect of the dummy variable for the event j . Since there are nine categories of events (see Table 2), there are 27 $\eta_{j,\tau}$ coefficients. The impact of the announcement dummy variables is significant, since the Wald test for the null hypothesis that the 27 coefficients are equal to 0 delivers a P -value smaller than 1% (the Wald statistic is equal to 114).

Now we can answer questions 1, 2, and 3 regarding the news announcements (see Table 2). To answer question 1 for category j , we simply test the hypothesis that $\eta_{j,1} = 0$ against $\eta_{j,1} > 0$ (since we presume a positive impact). Rejection implies that volatility increases before the announcement. To answer the second question, we test if $\sum_{\tau=1}^3 \eta_{j,\tau} = 0$ against the hypothesis that it is greater than 0. Rejection implies that after an announcement volatility increases (if the sum is positive) before reverting slowly to its initial level. Reversion to the initial level is implied by

⁷ Since we model SA returns, h_t is the deseasonalized conditional variance.

⁸ An EGARCH(1,1) structure was not sufficient to clean the autocorrelation of the squared standardized residuals.

Table 4

EGARCH model for impact of announcements and activity on volatility

$$q_t = \theta_0 + u_t + \theta_1 u_{t-1} + \theta_2 u_{t-2}, \quad (1)$$

$$u_t = \sqrt{h_t} \epsilon_t, \quad (2)$$

$$\ln h_t = \omega + \sum_{i=1}^2 \left(\beta_i \ln h_{t-i} + \alpha_i \left[|\epsilon_{t-i}| - \sqrt{2/\pi} \right] + \gamma_i \epsilon_{t-i} \right) + \sum_{j=1}^9 \sum_{\tau=1}^3 \eta_{j,\tau} d_{j,\tau,t} + \phi a_{t-1} + \delta a_{m,t-1}. \quad (3)$$

Coefficient	Estimation	P-value (%)	Coefficient	Estimation	P-value (%)
θ_0	0.003	49	θ_1	−0.134**	0.0
θ_2	−0.028**	0.0	ω	−0.072**	0.0
α_1	0.305**	0.0	$\eta_{5,1}$	0.167**	0.0
α_2	−0.221**	0.0	$\eta_{5,2}$	0.024	73
γ_1	−0.003	55	$\eta_{5,3}$	−0.024	70
γ_2	0.006	31	$\eta_{6,1}$	−0.074	21
β_1	1.264**	0.0	$\eta_{6,2}$	0.003	97
β_2	−0.295**	0.0	$\eta_{6,3}$	0.032	63
$\eta_{1,1}$	0.100*	2.0	$\eta_{7,1}$	0.081*	1.2
$\eta_{1,2}$	0.049	49	$\eta_{7,2}$	−0.106	8.9
$\eta_{1,3}$	−0.083	15	$\eta_{7,3}$	0.096	9.0
$\eta_{2,1}$	0.212**	0.0	$\eta_{8,1}$	0.484**	0.0
$\eta_{2,2}$	−0.039	64	$\eta_{8,2}$	−0.565*	2.4
$\eta_{2,3}$	−0.007	91	$\eta_{8,3}$	0.101	61
$\eta_{3,1}$	0.105**	0.0	$\eta_{9,1}$	0.095	7.4
$\eta_{3,2}$	−0.091*	1.3	$\eta_{9,2}$	0.091	22
$\eta_{3,3}$	0.000	99	$\eta_{9,3}$	−0.013	84
$\eta_{4,1}$	0.111**	0.1	ϕ	0.005**	0.0
$\eta_{4,2}$	−0.171**	0.1	δ	0.000	11
$\eta_{4,3}$	0.133**	0.0			
Obs.	37,650			$W(\eta_{j,\tau} = 0)$	114**
j	1	2	12	24	
$Q(j)$	1.17	1.76	10.29	19.64	
$Q^2(j)$	2.88	5.49	11.76	30.22	

The symbols ** and * indicate, respectively, significance at 1% and 5%.

$W(\eta_{j,\tau} = 0)$ is the Wald statistic for the hypothesis of nullity of the 27 coefficients $\eta_{j,\tau}$.

$Q(j)$ and $Q^2(j)$ are the Ljung–Box statistics of order j , respectively, for standardized residuals and for their square. Twelve lags correspond to 1 h.

Variables in Eqs. (1)–(3): q_t is the SA return (multiplied by 10,000); $d_{j,\tau,t}$ is a dummy variable for the event j announced during period τ relative to time t ; a_t is the SA market activity, and $a_{m,t}$ the market activity seasonal index.

Estimation was done by the quasi maximum likelihood method.

the stationarity of the EGARCH model: the persistence degree is determined by the sum of the coefficients β_1 and β_2 estimated at 0.97. Table 5 presents the results of the tests.

Clearly, the answer to question 1 is positive for *scheduled* announcements: these increase volatility during the pre-announcement period. Volatility increases by 10% prior to the release of US

Table 5

Pre-announcement and total impact of announcements

Announcement category (j)	$\hat{\eta}_{j,1}$	$\sum_{\tau=1}^3 \hat{\eta}_{j,\tau}$
Scheduled		
1-Positive US macro figures	0.10*	0.07
2-Negative US macro figures	0.21*	0.17**
3-European macro figures	0.11**	0.01
4-Speeches of senior officials	0.11**	0.07**
5-Interest rate reports	0.17**	0.17**
Unscheduled		
6-Economic institutes forecasts	-0.07	-0.04
7-OPEC member declarations	0.08*	0.07
8-Central bank intervention rumors	0.48**	0.02
9-Extraordinary events	0.10	0.17**

The second column gives the pre-announcement impact and the last column the total impact. Estimates are taken in Table 4. The symbols ** and * indicate, respectively, significance at 1% and 5%, for one-tail tests.

positive and European macroeconomic figures, and official speeches. It increases by around 20% prior to negative US macroeconomic figures and interest rate reports. A possible explanation of such volatility increases is that they are caused by anticipatory trades, i.e. by traders who open positions hoping that their anticipations will coincide with the contents of the news. However, another category of traders may also take part in the trading. These traders, who are characterized by a high level of risk aversion, prefer to execute their clients' orders right before the news release to avoid possible reversals of trends in the currency rate (Lyons, 1991).

The answer to question 1 is also positive for two types of *unscheduled* announcements: declarations of OPEC members (+8%), and especially rumors of central bank interventions (+48 percent!). These increases are probably not due to anticipatory trades. For example, before being broadcasted by a specialized news agency, rumors of an intervention circulate for a certain period of time from one dealer to another until they become widely disseminated. Then, specialized agencies treat them seriously and announce them. It is during this circulation phase that the market reacts to the news, through price adjustments.

The answer to question 2 depends on the category of the announcements. A significant total impact on volatility, of the order of 17%, is found for interest rate reports and US negative announcements. For speeches of senior officials, an impact of 7% is found on average. Unscheduled announcements have a zero total impact, with the exception of extraordinary events. Thus, for example, concerning rumors of central bank interventions, once the rumor is refuted or confirmed, volatility drops immediately ($\eta_{8,2}$, estimated at -0.57, significant at 5%, annihilates the pre-announcement positive effect estimated at 0.48).

Thus, with respect to question 3, there is no fully systematic difference between scheduled and unscheduled announcement effects on volatility (whether before the announcement, or globally). Rather, we can conclude that regarding the pre-announcement period, almost all types of news increase volatility, whereas regarding the total reaction (pre + during + post), only three categories of scheduled news increase volatility.

A question of related interest, regarding the news announcements, is whether there is a difference in the revealed volatility reaction between *positive* and *negative* US macroeconomic announcements. There is no strong evidence in favour of a difference: for the pre-announcement period, the P -value of the test of the hypothesis $\eta_{1,1} = \eta_{2,1}$ is equal to 7%, and for the total effect, the P -value for $\sum_{\tau=1}^3 \eta_{1,\tau} = \sum_{\tau=1}^3 \eta_{2,\tau}$ is at 5.8%.

The variable as_t in the EGARCH equation is the proxy for unexpected market activity. Market activity would be ideally measured by the flow of orders between traders and their customers. This is not usually available on FOREX markets. However, market activity is usually proxied by the number of issued quotes. Danielsson and Payne (2002) show that quote data tend to reflect the actual pace of market activity. From the series of the number of quotes per 5-min interval of our database, we construct a series of average market activity for each day of the week (like we did to build the average volatility of each day, see the Appendix). This yields the variable am_t (average market activity at point t of the week). The variable as_t is obtained by dividing the number of quotes by the corresponding average.

With these two variables in the model, we can answer question 4 stated at the start of this section, i.e. we can assess the impact of private information as proxied by unexpected market activity. If ϕ is positive and δ is equal to zero, an increase in SA volatility can only be due to unexpected trading activity, which basically corresponds to the flow of orders (private information) between dealers and their customers. The results in Table 4 show that ϕ is positive and highly significant (with a P -value smaller than 1%) but that δ can be considered not to differ from 0 ($P = 11\%$). Thus, volatility rises in periods of unusually high activity. This increase is fed by information asymmetry between traders. Each trader benefits from his privileged information that originates from the order flow with his own customers (Lyons, 1997).

4.2. Impact of announcements on intradaily average volatility

In this section, we want to test whether news announcements have any impact (altogether and individually) on the average volatility of the days of the week. Therefore, we create a series (called mv_t) by stacking the intradaily volatility series of each day of the week, from Monday to Friday, making up a total of 1415 observations as explained in the Appendix. We regress mv_t on 9 variables $z_{t,j}$ (j ranges from 1 to 9) corresponding to the nine categories of news announcements we have defined. The variable $z_{t,j}$ is the number of news announcements belonging to category j , which occurred during the 5-min time interval indexed by t . For example, $z_{1,1}$ is the number of news announcements corresponding to positive US macroeconomic figures released on Monday between 00h05 and 00h10 over the 6-month sample of our database.

We control for autocorrelation in the regression by use of an ARMA(1,1) model. Seasonal effects that originate from the structural characteristics of the FOREX market (opening times, lunch breaks, closing times,...) are controlled for by an FFF of order 4 (this number was chosen according to the Akaike criterion). The model used for estimation is:

$$mv_t = c_0 + \beta mv_{t-1} + \sum_{p=1}^4 (\delta_{c,p} \cos x_{t,p} + \delta_{s,p} \sin x_{t,p}) + \sum_{j=1}^9 \eta_j z_{t,j} + \alpha \epsilon_{t-1} + \epsilon_t, \quad t = 1, \dots, 1415. \quad (4)$$

The variable $x_{t,p}$ in the FFF is defined by:

$$x_{t,p} = \frac{2\pi p n_k}{N_k} \quad \text{for } n_k = 1, 2, \dots, N_k, \text{ and } k = 1, 2, \dots, 5, \quad (5)$$

where N_k is the number of time intervals per day (287 on Monday, 264 on Friday, and 288 the other days). Therefore, there is a one-to-one correspondence between each value of the index t

Table 6

Impact of announcements on intradaily average volatility

$$mv_t = c_0 + \beta mv_{t-1} + \sum_{p=1}^4 (\delta_{c,p} \cos x_{t,p} + \delta_{s,p} \sin x_{t,p}) + \sum_{j=1}^9 \eta_j z_{t,j} + \alpha \epsilon_{t-1} + \epsilon_t. \quad (4)$$

Coefficient	Estimate	P-value (%)	Coefficient	Estimate	P-value (%)
c_0	18.39**	0.0			
β	0.85**	0.0			
α	−0.69**	0.0	η_1	7.59**	0.0
$\delta_{c,1}$	−10.97**	0.0	η_2	4.41**	0.1
$\delta_{c,2}$	−1.17	30	η_3	1.30**	0.9
$\delta_{c,3}$	4.89**	0.0	η_4	−2.68*	1.3
$\delta_{c,4}$	−2.67**	0.9	η_5	3.36**	0.0
$\delta_{s,1}$	−3.75**	0.0	η_6	−1.66	30
$\delta_{s,2}$	2.97**	0.7	η_7	−0.54	73
$\delta_{s,3}$	−2.71*	1.2	η_8	−1.07	80
$\delta_{s,4}$	2.08*	4.4	η_9	3.11*	4.0
Obs.	1415	R^2	0.39	$W(\eta_j = 0)$	321**
j	1	2	12	24	
$Q(j)$	0.88	1.04	22.75	42.85	

The symbols ** and * indicate, respectively, significance at 1% and 5%.

$W(\eta_j = 0)$ is the Wald statistic for the null hypothesis of nullity of the 9 coefficients η_j .

$Q(j)$ is the Ljung–Box statistic of order j of the residuals.

Variables in Eq. (4): mv_t is the intradaily average volatility for each time interval t (see Section 4.2); $z_{t,j}$ is the number of announcements for the news category j during 5 min before t ; $x_{t,p} = 2\pi p n_k / N_k$ where $k = 1, \dots, 5$, N_k is the daily time interval number (287 for Monday, 264 for Friday, 288 for the other days), and $n_k = 1, \dots, N_k$. Estimation was done by the quasi maximum likelihood method.

of $x_{t,p}$ (and of mv_t) and a given 5-min interval endpoint in a specific day of the week. The link is made via the relationship $t = f(1, k, n_k)$, see Eq. (7) in the Appendix.

Table 6 gives the estimation results of Eq. (4). By a Wald test, we strongly reject the null hypothesis of joint nullity of the 9 coefficients of the announcement counts (the P -value is much lower than 1%, the statistic being equal to 321). Clearly, announcements have an impact on the average volatility. More precisely, the variables for the scheduled news announcements, in particular US macroeconomic figures, European figures, speeches of senior officials of the government, and interest rate reports have significant coefficients quasi at the 1% level. Thus these events have a seasonal impact on volatility. These results confirm those of Andersen and Bollerslev (1998) with respect to the seasonal impact of scheduled events on volatility. FFF coefficients are, with one exception, significant at 5%. These coefficients take into account the seasonal effects not due to the cyclical news releases.

5. Conclusion

Using 5-min high-frequency data for the May 15–November 14, 2001 time period combined with a Reuters news database, we shed light on the impact of news announcements and private information on the volatility of euro/dollar FOREX returns. Regarding the news releases, we highlight the impact of both scheduled and unscheduled news announcements and focus on

the reaction of volatility in the pre-announcement periods. We also take into account FOREX private information, proxied by the level of deseasonalized market activity. Our results show that the release of scheduled news leads to a pre-announcement rise in volatility. This increase in volatility does not occur in the case of announcements of unscheduled news, except for rumors of central bank intervention. Our interpretation of volatility increases right before the announcement of scheduled news is that these categories of news attract traders who wish to make anticipatory trades based on their personal beliefs. Another result drawn from estimation is that the reaction of volatility in the post-announcement period is in most cases muted. Indeed, most of the news announcements considered in our study have not been followed by significant volatility increases or decreases in the post-announcement period. In addition, the volatility of euro/dollar returns is positively and significantly affected by market activity (adjusted from its seasonal component). This stresses the importance of private information in FOREX markets as a key determinant of volatility, the private information stemming primarily from the flow of orders between traders and their clients.

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Appendix

To compute the intradaily average volatility at time n_k of day k (called mv_{n_k}), we divide each day into 288 5-min intervals. We assume for simplicity that we have exactly S weeks of data. For each interval endpoint per day of the week over the S -week period, we have one euro/dollar return. We thus compute in principle 288 values mv_{n_k} for each day of the week. Actually, as explained in Section 3.1, we delete the first interval of Monday and the intervals from 22h05 to 24h of Friday. Hence, we have 287 points on Monday and 264 on Friday. That makes a total of 1415 values over a week.

Each value mv_{n_k} is the square root of the average of the S squared returns at time n_k of day k ($k = 1$ for Monday, $k = 5$ for Friday). For example, the value of mv_{n_k} on Thursday at 12h ($k = 4$ and $n_4 = 144$) is the square root of the average of the squared returns observed every Thursday at 12h during the S -week period. Formally,

$$mv_{n_k} = \left(\frac{1}{S} \sum_{s=1}^S r_{f(s,k,n_k)}^2 \right)^{0.5}, \quad (6)$$

where

$$f(s, k, n_k) = 1415(s - 1) + \sum_{j=1}^{k-1} N_j + n_k, \quad (7)$$

for $s = 1, \dots, S$, $k = 1, \dots, 5$, $N_1 = 287$, $N_2 = N_3 = N_4 = 288$, $n_1 = 2, \dots, 288$, $n_2 = 1, \dots, 288$, n_3 and n_4 likewise, and $n_5 = 1, \dots, 264$ as stated above. Notice that when s varies from 1 to $S = 26$ for example, the function $f(s, k, n_k)$ takes the values from 1 to 36,790. Actually, in our database, we have 37,654 price observations (hence one return less), corresponding to 26 full weeks starting a Tuesday and 3 more days of the 27th week. In Fig. 1, each day-specific panel displays the temporal profile of mv_{n_k} for that day (the lower line). The last panel displays the temporal profile of average volatility when the days are considered as identical, e.g. the average volatility at 12h is the same for all days. For this, the average of squared returns is taken over all returns corresponding to 12h in the sample (e.g. for 26 weeks, there are 5×26 squared returns). That overall profile is also displayed in the day-specific panels, after shifting it upwards to make it visible.

To adjust the returns for seasonality, we just divide the return at the endpoint of each 5-min interval by the corresponding value of the intradaily average volatility (using the day-specific volatility). That means, for example, that all returns at 12h on Thursday in the sample are divided by the same value (the average volatility at 12h on Thursday).

Remark. We took care in making the seasonal adjustment to account for the time change (to winter time) that occurred on October 29, 2001. This concerns GMT hours from 6h until 21h (corresponding to market times in Europe and the USA). After the change, a return at some GMT time has to be divided by the average volatility value adjusted for the time switch (i.e. 1 h later).

References

- Admati, A., Pfleiderer, P., 1988. A theory of intraday patterns: volume and price variability. *The Review of Financial Studies* 1, 3–40.
- Andersen, T., Bollerslev, T., 1996. Heterogeneous information arrivals and returns volatility dynamics: uncovering the long-run in high frequency rendements. NBER Working Paper 5752.
- Andersen, T., Bollerslev, T., 1998. Deutsche mark–dollar volatility: intraday volatility patterns, macroeconomic announcements and longer run dependencies. *The Journal of Finance* 1, 219–265.
- Bollerslev, T., Domowitz, I., 1993. Trading patterns and prices in the inter-bank foreign exchange market. *The Journal of Finance* 4, 1421–1443.
- Cai, J., Cheung, Y.L., Lee, R.S.K., Melvin, M., 2001. Once in a generation yen volatility in 1998: fundamentals, intervention and order flow. *Journal of International Money and Finance* 20, 327–347.
- Dacorogna, M., Muller, U., Nagler, R., Olsen, R., Pictet, R., 1993. A geographical model for the daily and weekly seasonal volatility in the foreign exchange market. *Journal of International Money and Finance* 12, 413–438.
- Danielsson, J., Payne, R., 2002. Real trading patterns and prices in the spot foreign exchange markets. *Journal of International Money and Finance* 21, 203–222.
- Degennaro, R., Shrieves, R., 1997. Public information releases, private information arrival and volatility in the foreign exchange market. *Journal of Empirical Finance* 4, 295–315.
- Eddelbuttel, D., McCurdy, T., 1998. The impact of news on foreign exchange rates evidence from high frequency data. Working paper, University of Toronto.
- Evans, M., Lyons, R., 1999. Order flow and exchange rate dynamics. Berkeley Working paper.

- Glosten, L., Milgrom, P., 1985. Bid ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics* 13, 71–100.
- Goodhart, C., Figliuli, L., 1991. Every minute counts in financial markets. *Journal of International Money and Finance* 10, 23–52.
- Lo, A., MacKinlay, A., 1990. An econometric analysis of nonsynchronous trading. *Journal of Econometrics* 45, 181–211.
- Lyons, R., 1991. Private beliefs and information externalities in the foreign exchange market. NBER Working Paper 3889.
- Lyons, R., 1995. Tests of microstructural hypotheses in the foreign exchange market. *Journal of Financial Economics* 39, 321–351.
- Lyons, R., 1997. A simultaneous trade model of the foreign exchange hot potato. *Journal of International Economics* 45, 181–211.
- Lyons, R., 2001. *The Microstructure Approach to Exchange Rates*. MIT Press.
- Melvin, M., Yin, X., 2000. Public information arrival, exchange rate volatility and quote frequency. *The Economic Journal* 110, 644–661.
- Nelson, D., 1990. Conditional heteroskedasticity in asset returns: a new approach. *Econometrica* 59, 347–370.
- O'Hara, M., 1995. *Market Microstructure*. Blackwell.
- Rime, D., 2000. *Private or Public Information in Foreign Exchange Market? An Empirical Analysis*. University of Oslo, (Memorandum 14).