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Macroeconomic news surprises and volatility spillover in foreign exchange markets

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Macroeconomic news surprises and volatility spillover in foreign exchange markets

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Abstract

This paper examines the link between exchange rate volatility and economic fundamentals. In the framework of a multivariate volatility model that allows for volatility spillover, we develop a new impulse response analysis to estimate and decompose the simultaneous effect of macroeconomic news surprises on the foreign exchange volatility. We show that news announcement effects include two components; a direct and an indirect effect induced by volatility spillover. We show that more than 50% of the total accumulated news effect on the Pound and the Yen are due to volatility transmission from the two major currencies and mainly from the Euro.

JEL: F31, F4, C32, C5
Keywords: Foreign exchange markets, Volatility spillover, News surprises, Impulse response analysis

1. Introduction

The impact of information on the volatility and market activity of foreign exchange (FX) markets has been theoretically and empirically studied in several papers, e.g. Degennaro and Shrieves (1997), Andersen and Bollerslev (1998), Cai, Cheung, Lee, and Melvin (2001), Bauwens, Ben Omrane, and Giot (2005), Evans and Lyons (2008), and Ben Omrane and Heinen (2010). Each study has focused on the effect of macroeconomic announcements on the volatility of one of the most active currency markets (Euro/US Dollar (EUR/USD), British Pound/US Dollar (GBP/USD) and Japanese Yen/US Dollar (JPY/USD)). They found that foreign exchange volatility increases following macroeconomic news releases.

Andersen, Bollerslev, Diebold, and Vega (2003), however, have studied the response of more than one currency return and volatility to US and German macroeconomic news, but considered independently, without taking into account FX market dependencies. This excludes possible effects due to volatility spillover from other rates, as has been documented e.g. by Hong (2001) for the Deutsche Mark and the Yen. Andersen,

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Bollerslev, Diebold, and Vega (2007) have characterized the response of US, German and British stock, bond and foreign exchange markets to US macroeconomic news only.

Ederington and Lee (1996) show that implied volatilities obtained from option prices decrease following scheduled news releases, but increase following unscheduled announcements. They do not distinguish, however, between announcements that are in line with market expectations and those that are surprises to the market. These two types of announcements may have quite different effects on subsequent volatilities, which is one of the topics we investigate in this paper.

With respect to the previous literature on FX volatility about the impact of news announcements, the aim of this paper is twofold. Firstly, we develop a new methodology that aims to decompose the macroeconomic news effect on volatility within two components: direct and indirect effects induced by volatility spillover. We analyze the simultaneous impact of a more refined and extended set of eight categories of news announcements, involving scheduled and unscheduled news surprises related to US, UK, European and Japanese economic performances, on the three major currency volatilities. Secondly, we investigate volatility adjustment to news surprises throughout the post-announcement period.

So far there has been, to the best of our knowledge, no work on the news effect decomposition and volatility adjustments throughout the post announcement period.

The contribution of our research extends previous results, in at least three important dimensions. First, we develop a multivariate volatility model and implement an impulse response analysis to decompose the news surprise impact on volatility into direct and indirect effects. The latter effect is induced by volatility spillover from one currency to another. Second, we use a new extensive and refined data-set including tradable quotes (as opposed to indicative), macroeconomic expectations, macroeconomic realizations, and unscheduled announcements. Third, we focus on the simultaneous effect of news surprises on volatility, and we address the central open issue in exchange rate economics: the link between FX volatility and fundamentals. We investigate the simultaneous news effects on the major three currencies using a multivariate model that allows for volatility spillover and includes exogenous shocks in a flexible way. In spite of the multivariate setting, our model allows univariate estimation techniques and does not require specification of correlation dynamics, which can be constant or time-varying.

Several studies have linked macroeconomic news surprises to FX volatility increase, and part of our findings confirm and extend this result. Andersen, Bollerslev, Diebold, and Vega (2003), for example, have investigated the effects of scheduled US and German macroeconomic figures on the conditional mean and volatility of five currencies. They find that volatilities adjust to shocks more slowly than the conditional mean. They show that FX volatilities adjust to news only gradually, with complete adjustment occurring only after one hour.

The econometric analysis is performed on a high frequency data-set of 5-minute regularly time-spaced EUR/USD, GBP/USD and USD/JPY quotes. The time period ranges from January 3 to December 31, 2006. Our database also includes real-time macroeconomic expectations, macroeconomic realizations as well as unscheduled headlines that were released on the Reuters news-alert screens. Regarding these news announcements, in comparison to previous literature we consider a much larger set of news events, which can be classified into eight general categories. Furthermore, to highlight the effect of the surprise or the unexpected component of news, we compute the difference between expected and realized macroeconomic figure values.

More generally, the focus of this work is about the economic determinants of the FX return volatility with particular attention to the links between the information flow and the market reactions measured by volatility. We use a multivariate conditional volatility model where we control for intraday seasonality and news arrival. We implement impulse response analysis to decompose the news effect throughout the post-announcement period. Since its introduction by Sims (1980), impulse response analysis has evolved into an important tool for analyzing the dynamics of macroeconomic and financial systems. It has been mainly designed for the conditional mean of linear systems, e.g. VARMA models, but recently interest has focused on generalizations to nonlinear systems and, in particular, to the volatility in conditionally heteroskedastic models. For example, Gallant, Rossi, and Tauchen (1993) define conditional moment profiles in nonlinear models, Koop, Pesaran, and Potter (1996) propose a general simulation-based approach to nonlinear impulse response analysis, Lin (1997) proposes a particular approach to volatility impulse response analysis as a special case of Gallant, Rossi, and Tauchen (1993), and Hafner and Herwartz (2006) use the notion of independence to identify endogenous innovations to the system. These approaches analyze the effect of endogenous innovations, i.e. events that are not explicitly observed but have to be estimated within the econometric system, on volatility. In this paper we use an impulse response methodology to analyze the effect of exogenous news on volatility in a multivariate system. We allow for different types of news to take into account different effects on exchange rate volatility as documented by Cheung and Chinn (2001) and Andersen, Bollerslev, Diebold, and Vega (2003).

Our results show that macroeconomic news surprise effect on volatility include two important components; direct and indirect effects. The latter is induced from volatility spillover. One of the main results consists in discovering that more than 50 percent of the total accumulated effect on the British Pound and the Japanese Yen is induced by volatility spillover from the other two rates and more importantly from the Euro. Moreover, US news surprises, involving scheduled and unscheduled releases, have the most significant effect on the three currency volatilities, and most importantly on the Euro/Dollar.

The rest of this paper is organized as follows. We present our models in Section 2. In Section 3 we describe our high frequency FX executable prices, macroeconomic expectations, macroeconomic realizations and unscheduled announcements. We discuss the estimation results in Section 4, and we conclude in Section 5.

2. The impulse response methodology

We specify and estimate a multivariate model of high-frequency exchange rate volatility dynamics that allows for the possibility of different types and categories of news affecting simultaneously the conditional variances. Our motivation is twofold. First, we hope to improve high-frequency volatility estimation by using a more refined and extended news database (including UK and Japanese macroeconomic figures in addition to US and European ones), and most importantly implementing a multivariate model that considers FX market dependencies ignored by univariate models. Second, we provide a detailed analysis of volatility adjustments to news throughout the post-announcement period using an impulse response analysis. Even though our primary focus is volatility we model the conditional mean accurately by regressing currency returns on cross lagged rates and news announcements. Hence, we allow for cross market dependence and dynamic responses to macroeconomic news surprises.

Consider a system of returns to exchange rates $R_t = (r_{1t}, \ldots, r_{Nt})$. We use the following model

$$R_t = \mu + \sum_{i=1}^{I} \alpha_i R_{t-i} + \sum_{l=1}^{L} \sum_{j=0}^{J} \beta_{lj} S_{l,t-j} + \varepsilon_t, \tag{1}$$

$$\varepsilon_t = H_t^{1/2} z_t, \tag{2}$$

where α_i are $N \times N$ parameter matrices, β_{lj} are $N \times 1$ parameter vectors, and $S_{l,t-j}$ contain news surprises corresponding to the four currency areas, according to the definition in equation (18)[1]. Model (1) is a VAR(I) with exogenous news effects and conditionally heteroskedastic error term.

We fixed the two lag lengths, according to the Schwarz information criterion, at $I = 2$ and $J = 3$. Likewise, the $N \times N$ matrix H_t is a function of past returns and therefore the conditional variance-covariance matrix of returns. The error term z_t is identically and independently distributed (i.i.d.) with mean zero and variance-covariance matrix given by the identity matrix.

We are mainly interested in the elements on the diagonal of H_t, i.e., the conditional variances. The off-diagonal elements of H_t are the conditional covariances, which are left unspecified in this paper. Hence, our framework is consistent with, for example, the constant conditional correlation (CCC) model proposed by Bollerslev (1990), or its multiple extensions, e.g., the dynamic conditional correlation (DCC) model of Engle (2002).

The conditional variances are specified as an extension of the univariate GARCH model to the multivariate case as in Jeantheau (1998) and Ling and McAleer (2003). In order to motivate our model we will start with

[1] Comments on the news definition are provided in Section 3.2, since they are related to news announcements. We have merged the indices (a, ca) into one, l, for better readability.

a restricted version of it, given by

$$h_t = \omega + A\eta_{t-1} + Bh_{t-1} + \sum_{l=1}^{L} \varphi_l |S_{lt}|, \tag{3}$$

where[2] $h_t = dg(H_t)$ is the $N \times 1$ vector containing the diagonal elements of H_t, $\eta_t = (\epsilon_{1t}^2, \ldots, \epsilon_{Nt}^2)'$ and S_{lt} is the scheduled news surprises defined in Equation (18).[3]

We assume that the arrival of news of any type is independent of the past, such that S_{lt} is independent of $S_{l's}$ for all $s \neq t$ and all l'. There are L types of news, for example originating in different markets or indicating scheduled or unscheduled news. Parameters of the model (3) are the $(N \times N)$ matrices A and B and the $(N \times 1)$ vectors ω, $\varphi_1, \ldots, \varphi_L$. This model has the advantage of being sufficiently flexible such that volatility spillover between the exchange rates can be taken into account with non-zero off-diagonal elements in A or B. On the other hand, if B is diagonal then the model is easy to estimate since univariate GARCH estimation tools can be used by adding lagged cross-returns as observed variables in the volatility equation.

Note that, using the lag operator $\mathcal{L}$ and assuming invertibility of the filter $I_N - B\mathcal{L}$ where I_N is the identity matrix of dimension N, model (3) can be written equivalently as

$$h_t = \nu + (I_N - B\mathcal{L})^{-1} A\eta_{t-1} + (I_N - B\mathcal{L})^{-1} \sum_{l=1}^{L} \varphi_l |S_{lt}|,$$

with $\nu = (I_N - B)^{-1}\omega$. Using $(I_N - B\mathcal{L})^{-1} = I_N + B\mathcal{L} + B^2\mathcal{L}^2 + \ldots$, we obtain

$$h_t = \nu + \sum_{j=1}^{\infty} B^{j-1} \left(A\eta_{t-j} + \sum_{l=1}^{L} \varphi_l |S_{l,t-j+1}| \right), \tag{4}$$

such that endogenous (η_t) and exogenous (S_{lt}) news share the same geometric decay rate given by the matrix B. This may not be realistic as one might expect that certain macroeconomic news announcement show less persistence than commonly observed for endogenous effects. Thus, we would like to generalize model (3) to allow for different decay rates of endogenous and exogenous news. A natural extension of model (3) is given by

$$h_t = \omega + A\eta_{t-1} + Bh_{t-1} + (I_N - B\mathcal{L}) \sum_{l=1}^{L} (I_N - C_l\mathcal{L})^{-1} \varphi_l |S_{lt}|, \tag{5}$$

where $C_1, \ldots, C_L$ are $N \times N$ parameter matrices with eigenvalues smaller than one in modulus so that the filters $(I_N - C_l\mathcal{L})$ are invertible. Obviously, if $B = C_1 = \ldots = C_L$ then we obtain model (3) as special case.

[2]The operator dg stacks the diagonal of a matrix into a column vector.

[3]In order to simplify the notation throughout this section, we consider one news type index l instead of two a, ca. Since there are four areas and eight news categories, the number of news types is $L = 32$.

We can write $(I_N - B\mathcal{L})(I_N - C_l\mathcal{L})^{-1} = I_N + (C_l - B)\sum_{j=1}^{\infty} C_l^{j-1}\mathcal{L}^j$. Thus,

$$h_t = \omega + A\eta_{t-1} + Bh_{t-1} + \sum_{l=1}^{L}(C_l - B)\sum_{j=1}^{\infty} C_l^{j-1}\varphi_l|S_{l,t-j}| + \sum_{l=1}^{L}\varphi_l|S_{lt}|, \tag{6}$$

The distributed lag representation of model (5) is given by

$$h_t = \nu + \sum_{j=1}^{\infty}\left(B^{j-1}A\eta_{t-j} + \sum_{l=1}^{L} C_l^{j-1}\varphi_l|S_{l,t-j+1}|\right),$$

when compared to (4) shows the additional flexibility of this model. Note that due to the infinite number of lags in h_t, the model is not Markov. However, the combined process $(h_t', x_{1t}', \ldots, x_{Lt}')'$ is a first order Markov process, where

$$\begin{aligned} h_t &= \omega + A\eta_{t-1} + Bh_{t-1} + \sum_{l=1}^{L}(x_{lt} - Bx_{l,t-1}) \\ x_{lt} &= \varphi_l|S_{lt}| + C_l x_{l,t-1}. \end{aligned}$$

Finally, we want to include unscheduled news announcements in the volatility equation, defining a dummy variable U_l that takes the value 1 if there were unscheduled news announcements of type l at time t, and zero otherwise. Following the same reasoning as for scheduled news, we add the term $(I_N - B\mathcal{L})\sum_{l=1}^{L}(I_N - \tilde{C}_l\mathcal{L})^{-1}\psi_l U_{lt}$ on the right hand side of Equation (5), where ψ_l is the coefficient for unscheduled news of type l and $\tilde{C}_l$ are $N \times N$ parameter matrices with eigenvalues smaller than one in modulus. We obtain the representation

$$\begin{aligned} h_t &= \omega + A\eta_{t-1} + Bh_{t-1} + \sum_{l=1}^{L}\{x_{lt} + \tilde{x}_{lt} - B(x_{l,t-1} + \tilde{x}_{l,t-1})\} \\ x_{lt} &= \varphi_l S_{lt} + C_l x_{l,t-1}, \\ \tilde{x}_{lt} &= \psi_l U_{lt} + \tilde{C}_l \tilde{x}_{l,t-1}. \end{aligned} \tag{7}$$

This representation is the easiest one to use in practical implementations. Starting values are set to zero for $x_{l,0}$ and $\tilde{x}_{l,0}$, $l = 1\ldots, L$, and to $(I_N - A - B)^{-1}\omega$ for h_1.

In practice we may want to reduce the large number of parameters involved in the estimation. Restricting the matrices B, C_l and $\tilde{C}_l$ to be diagonal, we can write for the i-th conditional variance,

$$\begin{aligned} h_{it} &= \omega_i + \sum_{j=1}^{N}\alpha_{ij}\epsilon_{j,t-1}^2 + \beta_i h_{i,t-1} + \sum_{l=1}^{L}\{x_{i,lt} + \tilde{x}_{i,lt} - \beta_i(x_{i,l,t-1} + \tilde{x}_{i,l,t-1})\} \\ x_{i,lt} &= \varphi_{il} S_{lt} + c_{il} x_{i,l,t-1}, \\ \tilde{x}_{i,lt} &= \psi_{il} U_{lt} + \tilde{c}_{il}\tilde{x}_{i,l,t-1}, \end{aligned}$$

where $B = \text{diag}\,(\beta_1, \dots, \beta_N)$, $C_l = \text{diag}\,(c_{1l}, \dots, c_{Nl})$ and $\tilde{C}_l = \text{diag}\,(\tilde{c}_{1l}, \dots, \tilde{c}_{Nl})$. This model allows for spillover of lagged returns $\epsilon_{j,t-1}$ through nonzero elements α_{ij}, $i \neq j$. Moreover, each conditional variance has its own decay rate of scheduled news of type l, given by c_{il}, and of unscheduled news of type l given by $\tilde{c}_{il}$. It is mainly this model that we are going to use in the empirical part of the paper.

We now define the volatility impulse response function of *scheduled* news of type l at time horizon k as

$$V_{kl} = E[h_{t+k}|\mathcal{I}_t, S_{l,t+1} = 1] - E[h_{t+k}|\mathcal{I}_t, S_{l,t+1} = 0], \tag{8}$$

where $\mathcal{I}_t$ is the information set at time t. This definition compares the average effect of a one standard deviation shock of type l on volatility with that of a zero shock. The zero shock case is the baseline scenario and means here that the announcements were perfectly in line with market expectations. Analogously, we define the volatility impulse response function of *unscheduled* news of type l at time horizon k as

$$\tilde{V}_{kl} = E[h_{t+k}|\mathcal{I}_t, U_{l,t+1} = 1] - E[h_{t+k}|\mathcal{I}_t, U_{l,t+1} = 0], \tag{9}$$

comparing the average effect of an unscheduled news event of type l on on volatility with that of a zero shock. Here, the baseline scenario simply means absence of any unscheduled news. In the following, we will focus on V_{kl}, as the corresponding formulae for unscheduled news can be obtained by replacing the coefficients C_l and φ_l by $\tilde{C}_l$ and ψ_l, respectively.

By direct calculation we obtain $V_{1l} = \varphi_l$, $V_{2l} = (A + C_l)\varphi_l$, $V_{3l} = ((A + B)(A + C_l) + (C_l - B)C_l)\varphi_l, \dots$. A general expression for $k \geq 2$ is given by

$$V_{kl} = \left((A + B)^{k-1} + \sum_{j=0}^{k-2} (A + B)^j (C_l - B) C_l^{k-j-2} \right) \varphi_l \tag{10}$$

and a recursive expression by

$$V_{kl} = (A + B)V_{k-1,l} + (C_l - B)C_l^{k-2}\varphi_l. \tag{11}$$

If the process is covariance stationary, then all eigenvalues of $A + B$ and of C are smaller than one in modulus and V_{kl} tends to zero as $k \to \infty$, that is, the impact of shocks on volatility will eventually die out.

We use quasi maximum likelihood (QML) to estimate θ, the vector containing all model parameters. Let $e_t(\theta)$ be the residual of model (1). The log-likelihood for the sample of n observations, up to an additive constant, can be written as

$$L(\theta) = -\frac{1}{2} \sum_{t=1}^{n} \left\{ \ln(|H_t(\theta)|) + e_t(\theta)' H_t(\theta)^{-1} e_t(\theta) \right\}, \tag{12}$$

and the maximum likelihood estimator is defined as $\hat{\theta} = \arg\max_\theta L(\theta)$. The maximization problem has no analytical solution, but numerical methods can be used conveniently. For inference on V_{kl} we first refer to results of Jeantheau (1998) and Ling and McAleer (2003) on the consistency and asymptotic normality, respectively, of QML estimators. Under regularity conditions, they show that $\sqrt{n}(\hat{\theta} - \theta) \xrightarrow{\mathcal{L}} N(0, \Sigma_{\hat{\theta}})$. Analytical expressions for the asymptotic covariance matrix, $\Sigma_{\hat{\theta}}$, are given by Ling and McAleer (2003). For V_{kl} denote an estimator based on QML parameter estimators by $\hat{V}_{kl}$. We can then use standard arguments to show that

$$\sqrt{n}(\hat{V}_{kl} - V_{kl}) \xrightarrow{\mathcal{L}} N\left(0, \frac{\partial V_{kl}}{\partial \theta'} \Sigma_{\hat{\theta}} \frac{\partial V'_{kl}}{\partial \theta}\right), \tag{13}$$

where $\partial V_{kl}/\partial \theta'$ is evaluated at the true parameter values. Analytical expressions for the derivatives are given in Appendix.

One may further be interested in the proportion of the total effect of type l news in one exchange rate that is explained by volatility spillover from some other rates. Let us define the relative type l news spillover effect from the jth to the ith exchange rate at time horizon k as

$$\delta_{ijkl} = \frac{\Gamma_{k,ij}\varphi_{lj}}{\sum_{r=1}^{N} \Gamma_{k,ir}\varphi_{lr}}, \quad i, j = 1 \ldots, N \tag{14}$$

where $\Gamma_k = (A+B)^{k-1} + \sum_{j=0}^{k-2}(A+B)^j(C_l - B)C_l^{k-j-2}$, $\Gamma_{k,ij}$ is the ij-element of Γ_k and φ_{lr} is the r-th element of φ_l. The denominator of (14) is just the i-th component of V_{kl} and thus gives the total effect for the i-th exchange rate after k periods for news of type l. The numerator of (14), $\Gamma_{k,ij}\varphi_{lj}$, is the contribution of the j-th exchange rate to this total effect. If the instantaneous news effect in the j-th exchange rate is not zero ($\varphi_{lj} \neq 0$) and there is volatility spillover (A and/or B are not diagonal), then this contribution will not be zero for $k > 1$. The ratio δ_{ijkl} now gives the relative contribution of individual exchange rates' instantaneous news effects to the total news effects of other exchange rates in subsequent periods due to volatility spillover. Note that δ_{ijkl} converges to the same proportion, δ_{jl} say, for $k \to \infty$ irrespective of i, which means that $\lim_{k\to\infty} \Gamma_{k,ij}/\sum_{r=1}^{N} \Gamma_{k,ir}$ is the same for all i. Thus, for very long horizons the contributions of the jth exchange rate news effect to that of the ith exchange rates is the same irrespective of i and given by δ_{jl}. The reason is that, after the standardization in (14), the process (11) has the structure of a discrete ergodic Markov chain whose invariant distribution is given by δ_{jl}, see e.g. Norris (1997). The Markov chain is given by

$$\begin{pmatrix} V_{kl} \\ Y_{kl} \end{pmatrix} = \begin{pmatrix} A+B & C_l - B \\ 0 & C_l \end{pmatrix} \begin{pmatrix} V_{k-1,l} \\ Y_{k-1,l} \end{pmatrix}, \quad k \geq 2, \quad \begin{pmatrix} V_{1l} \\ Y_{1l} \end{pmatrix} = \begin{pmatrix} \varphi \\ \varphi \end{pmatrix}$$

Denoting $P_l = \begin{pmatrix} A+B & C_l - B \\ 0 & C_l \end{pmatrix}$, we obtain the compact representation

$$V_{kl} = \begin{pmatrix} I_N & 0 \end{pmatrix} P_l^{k-1} \begin{pmatrix} I_N & I_N \end{pmatrix}' \varphi \tag{15}$$

A similar analysis of relative contributions can be performed with the *accumulated* volatility impulse responses, i.e. $\sum_{i=1}^{k} V_{il}$. Note first that, asymptotically, the accumulated impulse responses are given by

$$\lim_{k\to\infty} \sum_{i=1}^{k} V_{il} = \begin{pmatrix} I_N & 0 \end{pmatrix} (I_{2N} - P_l)^{-1} \begin{pmatrix} I_N & I_N \end{pmatrix}' \varphi \tag{16}$$

Based on this total accumulated impact, one can calculate the time lag at which a given proportion of this total impact is attained, for example 50 percent, which could be interpreted as the half-life of a shock in one exchange rate.

In an analogous way, we can define the accumulated relative news spillover effect from the jth to the ith exchange rate after k periods as

$$\Delta_{ijkl} = \frac{\sum_{m=1}^{k} \Gamma_{m,ij}\varphi_{lj}}{\sum_{m=1}^{k}\sum_{r=1}^{N} \Gamma_{m,ir}\varphi_{lr}}, \quad i, j = 1 \ldots, N \tag{17}$$

The coefficient Δ_{ijkl} represents the proportion of the total accumulated type l news effect of exchange rate i that can be attributed to the accumulated news effect of exchange rate j. Unlike the relative contribution at a given horizon k, the relative contribution of the accumulated volatility impulse responses converges as $k \to \infty$ to a proportion that depends on i.

3. Real-Time Exchange Rates, Scheduled Macroeconomic Figures and Unscheduled Announcements

3.1. Real-Time Exchange-Rate Data

The raw tick-by-tick EUR/USD, GBP/USD and USD/JPY quotes were obtained from Hotspot FX Inc. The full sample consists of continuously recorded executable prices from January 3 to December 31, 2006, or 257 days. From the tick data, we compute mid-quote prices, where the mid-quote is the average of the bid and ask prices. As we use five-minute returns, this yields a daily grid of 288 points. At the end of each 5-min interval, we use the closest previous tick to select the relevant price. Next, the return at time t is computed as the difference between the logarithms of the prices at times $t-1$ and t, multiplied by 100.

As is standard in the literature, we explicitly exclude all returns computed between Friday 5.05 pm and Sunday 11.55 pm Eastern Time. We excluded a number of fixed US holidays including Independence day, Labor day and Thanksgiving. We also cut outlier returns (due to miss-displayed prices) as well as the first return of each Monday to avoid possible biases due to the lack of activity during the week-end. We also account for the time change (to winter time) that occurred on October 29, 2006 in United States and Europe including United Kingdom. In the end we are left with 249 days of data (in 2006) with 64,593 high-frequency 5-minute return observations.

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-minute 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 (see Bauwens, Ben Omrane, and Giot (2005) for the details of the procedure). Figure 1 displays these indices. Further comments on their pattern are provided in Section 3.2, since they are related to news releases.

Table 1 presents summary statistics of the three considered currency returns, before and after standardization. The mean of the SA returns is higher than that of the unadjusted ones and their distribution has fatter tails than the normal, but they are almost perfectly symmetric in the case of the Euro and the Pound. The Yen distribution is however skewed to the left. The unadjusted returns are much more leptokurtic, and feature a higher skewness coefficient. There is a highly significant negative autocorrelation of order one and of order two in both series of returns. The negative autocorrelation in FX returns has been discussed in the literature and is often attributed to the bid-ask bounce or the computation of asynchronous price series at the interval endpoints (Lo and MacKinlay (1990) and Bollerslev and Domowitz (1993)).

To highlight the comovements among the three currency markets, Table 1 also reports unconditional return correlations. All correlations are positive and higher than 50%. Unconditionally, the correlation between the Euro and the pound is higher than the correlations including the Japanese Yen. Intuitively, it would not be surprising if volatility spillover between the Euro and Pound markets is higher than that between the Euro and Yen or the Pound and Yen, since the unconditional linear dependence between the former is stronger than for the latter rates. However, to formally treat the question of volatility spillover, we analyze it using the multivariate volatility model discussed in Section 2.

3.2. Scheduled and Unscheduled News Announcements

We use Reuters real-time data on expected and realized macroeconomic fundamentals as well as unscheduled news announcements from January 3 through December 31, 2006. Expected macroeconomic figures are provided through Reuters economic calendars some days before their release. These data correspond to the economic performance of United states, Europe, United Kingdom and Japan and they are time stamped to the minute. Table 2 provides descriptive statistics for the first news type: Unscheduled news announcements. It shows the news categories and the number of each news per category. The eight category of news are: real-activity, consumption, investment, prices, forward looking, employment, monetary policy and interviews of senior officials of the government and of public agencies. Unscheduled news content often involves discussions about already released figures, revisions for some expected macroeconomic figures, and some other economic related articles. The announcement time of unscheduled news is not known in advance as opposed to scheduled announcements. Unscheduled news announcements are mainly related to the economic performance of USA (42.34%) followed by Europe (36.75%). Most of the US events occur around 10.00am and

4.00pm, at 4.00am and 8.00am for European news, 5.00am for UK, and 2.00am and 10:00pm for Japanese scheduled news. The total number of unscheduled news is 22,805, where more than half correspond to the monetary policy related to each currency area.

The second type of news involve scheduled macroeconomic announcements. In our sample, the total number of scheduled news is 1,317. They are associated with the same categories as unscheduled events except the eighth category which is related to the current account figure instead of interviews. The total number of US scheduled news is 624 where 58% involves only three news categories: real-activity, investment and forward looking figures. Most of US scheduled figures are released at 8.30am and 10.00am, except for some of them, in particular monetary policy figures, which occur around 2.00pm. Details about scheduled news announcements related to Europe, United Kingdom and Japan are not reported explicitly but available upon request. They involve the same categories as US news but occur at different times. Most of European releases occur at 5.00am, at 4.30am for UK and at 7.50pm for Japan. In total, we have 409 European scheduled announcements, 239 UK announcements, and 315 Japanese announcements.

Figure 1 illustrates the intradaily seasonal pattern of the average volatility of five-minute returns corresponding to the three major currencies. It shows the average volatility when all days of the week are assumed to have the same pattern.

They exhibit almost the same diurnal volatility pattern with some few differences. The highest common spike in volatility occurs at 8.30am, the time of US scheduled news release. Three other common volatility peaks are reached around 10.00am, 2.00pm and 5.00pm. The first two peaks also correspond to US scheduled news releases, but the last one could be related to US foreign exchange market closing time. Admati and Pfleiderer (1988) show that financial market closing period is characterized by a sustained level of market activity which attracts different categories of traders. Moreover, 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. This is called the "hot-potato trading".

The impact of the scheduled announcements should include both a deterministic (seasonal) component and a stochastic component. The latter reflects the unexpected news component or the surprise effect due to the discrepancy between the actual contents of the news and the expected contents before the release.

We define "news surprise" as the unexpected news component measured by the difference between expected and realized macroeconomic figures. Because units of measurement differ across macroeconomic figures, we follow Balduzzi, Elton, and Green (2001) and Andersen, Bollerslev, Diebold, and Vega (2003) in implementing standardized news, we divide the news surprise by its standard deviation to facilitate interpretation. The standardized news surprise associated with the currency area a corresponding to the news category ca at time t is defined by

$$S_{a,ca,t} = \begin{cases} \frac{R_{a,ca,t} - E_{a,ca,t}}{\sigma_{a,ca}}, & \text{if there are scheduled news at time t} \\ 0, & \text{else,} \end{cases} \tag{18}$$

where $R_{a,ca,t}$ is the realized figure value of type (a, ca), $E_{a,ca,t}$ is its expected value as displayed in Reuters economic calendar, and $\sigma_{a,ca}$ is the standard deviation of $|R_{a,ca,t} - E_{a,ca,t}|$ conditional on the presence of a scheduled news event. Using standardized news gives more sense to the comparisons of volatility responses toward different category of news. Because $\sigma_{a,ca}$ is constant for any news type (a, ca), the standardization will have no statistical effects on the estimated responses.

4. Empirical Results

4.1. Simultaneous news effects on FX volatilities

Estimation results of the conditional mean equation (1) show that cross currency returns have significant effect as well as some news surprises. These results are consistent with those found by Andersen, Bollerslev, Diebold, and Vega (2007). Because equation (1) contains many estimated parameters, and our main focus is on volatility, we do not report estimation results of the conditional mean, but these are available from the authors upon request. Regarding the conditional volatility, estimation results of equation (7) are given in Table 3 for EUR/USD, Table 4 for GBP/USD, and Table 5 for JPY/USD.

To test for model adequacy, we use the multivariate portmanteau statistic, see e.g. Lütkepohl (1993), applied to the residuals of the return equation (1) and to the squares of standardized residuals $H_t^{-1/2} e_t$. We test the hypothesis whether autocovariances of these vectors are zero up to order K, where we choose $K = 12$, i.e. one hour. The p-values of the corresponding test statistics are given by 0.1724 for the residuals and by 0.0237 for the squared standardized residuals. We cannot reject the null hypothesis of zero autocorrelation up to order 12 at level 1% and take this as evidence in favor of a correct specification of the model.

The diagonal elements of A tend to be higher than those off the diagonal, showing that the own lagged squared returns of an exchange rate have a higher impact on its volatility than those of other rates. However, there is significant spillover in volatilities, as all off-diagonal elements of A are significantly different from zero. Note that the estimator of B is substantially smaller than in typical GARCH estimates without exogenous news dummies, i.e. the estimated persistence is smaller. The maximum eigenvalue of the matrix $A + B$ is given by 0.955 as opposed to values typically much closer to one for GARCH (1,1) models applied to high-frequency FX rates. The reason is that some of the persistence is absorbed by the exogenous news.

US macroeconomic news surprises trigger high volatility in major FX markets. The estimated $\varphi_{1,l}$ coefficients, corresponding to US scheduled news announcements, are almost all significant for the three major currencies. The highest volatility spike is exhibited by the Euro followed by the Pound and the Yen, stemming from US monetary policy figures including FOMC announcements. FOMC news are seriously followed by market participants, such that they trigger the strong boost in the three currency volatilities and mainly the Euro. This is not surprising since the Euro/Dollar market is the largest in terms of volume, liquidity and number of participants.

In general, scheduled news exhibit higher positive and significant effects on volatility than unscheduled news releases. European and UK scheduled and unscheduled news releases also display significant effects on the three foreign exchange volatilities but to a lesser extent than US news announcements. European news releases have more significant impacts on the Euro than the Pound and the Yen volatilities. UK real activity and current account figures have a strong impact on EUR/USD volatility with some persistence, while UK investment, prices and forward looking announcements have a significant immediate impact on Pound volatility but without persistence. Except for monetary policy announcements, Japanese news announcements have negligible effects on EUR/USD and GBP/USD volatility, which could be attributed to the relatively low market activity of these exchange rates during the trading period of the asian market. The effect of Japanese announcements on JPY/USD volatility are somewhat higher but still less important than US or European announcements.

To sum up the estimation results, the three major currency volatilities are sensitive with different degrees to the various news types. The Pound volatility responds not only to news announcements related to US and UK economic performances (which has been documented in the literature) but also to European and Japanese news releases. This result provides a sense for the comovements in currency markets during times of news announcements.

In the preceding discussion of the estimation results, we have simplified the interpretation of the impact of a particular news announcement on the volatility of an exchange rate by interpreting the coefficient $\varphi_{a,l}$ as the immediate impact, and the coefficient $C_{a,l}$ as the persistence of this impact over time. For the persistence, this is a simplification because we ignored the contribution of volatility spillover from other rates induced by the news announcement, which is explained by the endogenous part of the volatility model, i.e. the significant off-diagonal elements of the parameter matrix A. In order to accurately interpret the results in terms of immediacy and persistence, we have to look at volatility impulse response functions as defined in Section 2, which we do in the following section.

4.2. The estimated volatility impulse response functions

In order to analyze the volatility adjustments throughout the post-announcement period, Figures 2 and 3 illustrate the impulse response functions for the major currencies toward US scheduled news releases. While consumption, forward looking and monetary policy announcements have similar impacts across FX rates, they are quite different for real actvity, prices and current account news, where the Yen volatility does not show any persistence. In all FX rates, the impact of investment and employment figures is quite small and almost negligeable, which might be surprising since e.g. Andersen, Bollerslev, Diebold, and Vega (2003) and Evans and Lyons (2005) find substantial impact of US employment figures. Both studies, however, are mainly concerned with price discovery rather than volatility.

For all three FX rates, the highest volatility impact is induced by monetary policy announcements, both in terms of immediacy and persistence, and it is closely followed by forward looking announcements. In most cases, the news announcements have been mostly absorbed in volatility after one hour, which corresponds to previous findings in the literature. The effect of consumption, monetary policy and forward looking announcements, however, are still significant after two hours, albeit close to zero. To show statistical significance, we plot in Figure 4 the impulse response function for US consumption including 95% pointwise confidence bands, where the asymptotic distribution in (13) has been used to calculate the standard errors of impulse responses. We see that, indeed, the response is still significant after two hours.

To be more precise about the persistence of shocks in a given exchange rate, we give in Table 6 the half-life, i.e. 50 percent, and the 95 percent proportion of the total accumulated impact given by equation (16). Again we concentrate on US scheduled news as these are the most significant ones. We see that, for example, fifty percent of the total accumulated impact of US consumption announcements on EUR/USD volatitlity is attained after 45 minutes, and 95 percent after 270 minutes. These numbers are, of course, less meaningful for those announcements that have a negligeable total accumulated effect, as is the case for investment and employment. The higher lags obtained for the Yen correspond to the higher persistence of the endogenous part of the estimated volatility equations, where e.g. the estimated parameter of the autoregressive component is higher for the Yen than for the other rates.

One could state that, in most cases, the majority of the total news effect is absorbed after one hour (the case where the half-life is less than 60 minutes), which is in line with previous results, in particular Andersen, Bollerslev, Diebold, and Vega (2003). However, a non-negligeable fraction of this effect is explained only after several hours. This rather confirms the results of Evans and Lyons (2005), who find that effects may remain significant for days. This is evidence against the efficiency of even the most liquid FX rates, whose price adjustments after news announcements are not instantaneous.

Finally, we evaluate the total impact of US scheduled news on the three exchange rates as a proportion of the corresponding unconditional sample variances. In the literature, this proportion has been of some interest to understand whether exchange rates are mainly driven by exogenous news announcements or by endogenous trading-induced uncertainty and adjustments. For example, Andersen, Bollerslev, Diebold, and Vega (2003) find that only roughly two percent of exchange rate variation are explained by news announcements, see also Evans and Lyons (2008). Table 7 reports first the total accumulated news effect $\lim_{k\to\infty}\sum_{i=1}^{k} V_{il}$ for US scheduled news. Second, these effects are multiplied by the relative frequency of the corresponding events in the sample. Since the unconditional variances of each FX rate are standardized to be 1, the obtained numbers are the percentages of unconditional variance explained by the total effect of one news type. For example, the total effect of real activity on EUR/USD volatility, 4.173, is multiplied by 80/64,593, where 80 is the number of scheduled US real activity announcements. This gives 0.516 percent of EUR/USD volatility explained by scheduled US real activity announcements. The sum of all percentages is, for all three FX rates, around three percent, which is slightly more than the results of Andersen, Bollerslev, Diebold, and Vega (2003). Taking into account the other announcements (scheduled non-US, and unscheduled news), one arrives at slightly more than five percent explained by our news types. This is more than what Andersen, Bollerslev, Diebold, and Vega (2003) obtained, but still the big majority of exchange rate variation is left unexplained.

4.3. Decomposition of volatility impulse responses

Tables 8 and 9 (Appendix) show the proportions of the total news effect of type "l" on the exchange rate "i" volatility induced by volatility spillover from exchange rate "j" after "k" periods given by δ_{ijkl}, defined in equation (14). First of all, we see that the ergodic distribution is almost attained after six hours. For example, for US real activity news, roughly 46% of its long-run impact on EUR/USD volatility is attributed to the direct effect from EUR/USD, 54% to the indirect effect, of which 31% to spillover from GBP/USD and 23% to spillover from JPY/USD. Moreover, this distribution is the same for GBP/USD and JPY/USD volatilities, meaning that long-run spillover effects from the Euro tend to be more important than direct effects. This holds for most of the news types, with the exception of investment and forward looking figures, where spillover from the Yen is more important than effects from the Euro. It should be remembered, however, that these are the proportions for the long-run impact of news, whose magnitude in most cases becomes negligible after a few hours. The relative contributions after a short period, 15 minutes say, are very different from the long-run distribution, and are clearly dominated by the direct effects. For example, depending on the news type, the direct effects account for 64% to 99 percent for EUR/USD. The direct effects in GBP/USD and JPY/USD after 15 minutes are somewhat smaller, in particular for employment announcements (1 and 24 percent, respectively), but recall that the overall effect of employment is rather small in magnitude. It is remarkable however that the direct effect in GBP/USD volatility decays rapidly not only after employment, but also after investment and current account announcements. Both the Pound and the Yen volatilities after US employment announcements are dominated quickly, even in the short period following the announcement, by volatility spillover from the Euro.

Tables 10 and 11 show the proportions of the *accumulated* total news effect of type "l" on the exchange rate "i" volatility induced by volatility spillover from exchange rate "j" after "k" periods given by Δ_{ijkl}, defined in equation (17). Six hours after the announcements of US scheduled news, more than 60 percent of the accumulated effect on EUR/USD volatility is for all news types genuinely driven by the direct effect of EUR/USD. The smallest direct effect is accounted for by forward looking announcements (62,98%), and the largest by employment news (97,74 %). This shows that EUR/USD volatility is predominantly determined by its own dynamics rather than by spillover from the other rates.

On the other hand, considering GBP/USD volatility and US consumption, employment, monetary policy and current account announcements, more than 50% of the accumulated impulse responses are induced by spillover from the Euro and the Yen. As already indicated, the total effect of employment is rather negligible, so that we only focus on monetary policy and current account news here. For the former, the accumulated effect on GBP/USD after 6 hours is 33 percent for the Euro and almost 18 for the Yen, together accounting for 51 percent of the total effect of US monetary policy on GBP/USD volatility, and hence from pure spillover from other rates. For the latter, i.e. US current account announcements, 37 % of the accumulated effect on GBP/USD is induced by the Euro and almost 15 % by the Yen, which sums to 52 %, again more than half of the total effect. This shows again the importance of volatility spillover in analyzing the effects of news announcements on subsequent FX rate volatilities.

Finally, six hours after US real activity and prices announcements, spillover from the Pound and the Euro accounts for more than 50 percent of the accumulated effect on JPY/USD volatility. In particular, for real activity, this is 34 % (EUR/USD) and 23 % (GBP/USD), while for prices it is 30 % (EUR/USD) and 24 % (GBP/USD), respectively, confirming the importance of volatility spillover. Note that the significance of spillover depends both on the analyzed FX rate and the news type. We cannot find a particular news type having a similarly strong indirect effect across all FX rates. The overall conclusion of this analysis is that, news announcements have direct effects on FX rate volatility, but due to causality links between different rates, there may be indirect effects depending on the news types that are non-negligible and, in fact, in some cases more important than the direct effects.

5. Conclusion

We have analyzed the simultaneous impact of a refined and extended set of eight categories of news announcements, involving scheduled and unscheduled news surprises related to US, UK, Europe and Japan economic performances, on FX volatility of the three major currencies, using 5-minute high frequency executable prices from January 1 through December 31, 2006. We have introduced a new concept of assessing the importance of the post-announcement news effects on volatility of exchange rates through a detailed impulse response analysis.

For some news types and origins, we find significant effects on volatility of currencies whose country is different from the origin of the news. For example, some European news surprises trigger significant effect in the British Pound and the Japanese Yen in addition to the Euro. We show however that the most important and significant effects are generated by US announcements, and we provide an analysis of these effects by decomposing it into *direct* effects, i.e. effects that are genuinely driven by the exchange rate itself, and *spillover* effects from other rates.

Six hours after the news releases, more than 95% of the total accumulated impulse responses are attained for all news types. Up to this time lag, less than 40 percent of the accumulated effects of all news types on EUR/USD volatility are due to spillover from the Pound or Yen. For many news types, on the other hand, more than half of the accumulated effects on GBP/USD and JPY/USD volatility are due to spillover from the Euro.

These results show the importance of the Euro/Dollar market, generating volatility spillover to other markets after news announcements, while itself being less affected by spillover from these rates.

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Appendix

For the volatility impulse response function in (10), straightforward matrix calculus yields the following results: $\partial V_{kl}/\partial\omega' = 0$, $\partial V_{kl}/\partial\varphi_l' = (A+B)^{k-1} + \sum_{j=0}^{k-2}(A+B)^j(C_l - B)C_l^{k-j-2}$, $\partial V_{kl}/\partial\varphi_r' = 0$, $r \neq l$,

$$\begin{aligned}
\frac{\partial V_{kl}}{\partial \text{vec}(A)'} &= (\varphi_l' \otimes I_N)\sum_{i=0}^{k-2}(A'+B')^{k-2-i} \otimes (A+B)^i \\
&+ \sum_{j=1}^{k-2}(d_{lj}' \otimes I_N)\sum_{i=0}^{j-1}(A'+B')^{j-1-i} \otimes (A+B)^i \\
\frac{\partial V_{kl}}{\partial \text{vec}(B)'} &= \frac{\partial V_{kl}}{\partial \text{vec}(A)'} + \sum_{j=0}^{k-2}(\varphi_l' C_l'^{k-j-2} \otimes (A+B)^j) \\
\frac{\partial V_{kl}}{\partial \text{vec}(C)'} &= \sum_{j=0}^{k-2}(\varphi_l' \otimes (A+B)^j(C_l - B)) \sum_{i=0}^{k-j-3}(C'^{k-j-3-i} \otimes C^i) \\
&+ (\varphi_l' C'^{k-j-2} \otimes (A+B)^j)
\end{aligned}$$

where $\otimes$ is the Kronecker product operator and $d_{lj} = (C_l - B)C_l^{k-j-2}$. These results can be used to construct pointwise confidence bands for the estimated volatility impulse response functions.

Table 1: Moments of Currency Returns

	EUR/USD		GBP/USD		JPY/USD	
	Returns	SA Returns	Returns	SA Returns	Returns	SA Returns
Mean	0.0002	0.0068	0.0002	0.0078	-7.03e-06	-0.0031
Standard deviation	0.031	1.00	0.031	1.00	0.034	1.00
Skewness coefficient	0.350	0.044	0.973	0.067	0.994	0.038
Kurtosis coefficient	62.39	6.046	86.01	6.045	41.90	5.839
Autocorrelation of order 1	-0.009	-0.022	-0.022	-0.010	-0.015	-0.023
Autocorrelation of order 2	-0.009	-0.020	-0.009	-0.020	0.004	-0.013
Correlation matrix						
EUR/USD	1		0.636		0.557	
GBP/USD	0.636		1		0.536	
JPY/USD	0.557		0.536		1	

The SA (seasonally adjusted) returns are the returns divided by their intradaily average volatility (see Section 3.1). The 5-minute returns have been pre-multiplied by 100 (to avoid small values). The number of observations is 64,593 corresponding to the period from January 3 to December 31, 2006.

Table 2: **Unscheduled News Announcements**

Announcement	Reg. Coeff.	USA ($a = 1$)	Europe ($a = 2$)	UK ($a = 3$)	Japan ($a = 4$)	Total
1-Real activity	$\psi_{c,1}$	1,884 (36.20%)	2,358 (45.30%)	513 (9.86%)	450 (8.64%)	5,205
		19.51%	28.14%	33.71%	13.85%	22.44%
Consumer credit expenditure		431	21	16	0	
Economic growth		992	1,423	325	323	
Industrial production		170	400	53	84	
Retail and wholesale sales		291	514	119	43	
2-Consumption	$\psi_{c,2}$	522 (37.72%)	615 (44.44%)	79 (5.70%)	168 (12.14%)	1,384
		5.41%	7.33%	5.19%	5.17%	5.97%
Vehicle sales		438	517	0	168	
Home sales		84	98	79	0	
3-Investment	$\psi_{c,3}$	141 (60.78%)	89 (38.36%)	0 (0%)	2 (0.86%)	232
		1.46%	1.06%	0%	0.06%	1.00%
Factory orders		89	89	0	0	
Wholesale inventories		52	0	0	2	
4-Prices	$\psi_{c,4}$	315 (22.07%)	984 (68.96%)	89 (6.24%)	39 (2.73%)	1,427
		3.26%	11.74%	5.85%	1.20%	6.15%
Inflation		315	984	89	39	
5-Forward looking	$\psi_{c,5}$	548 (34.90%)	766 (48.79%)	158 (10.06%)	98 (6.25%)	1,570
		5.68%	9.14%	10.38%	3.02%	6.77%
Consumer sentiment		415	698	150	62	
Housing starts		133	68	8	36	
6-Employment	$\psi_{c,6}$	249 (33.79%)	430 (58.34%)	27 (3.66%)	31 (4.21%)	737
		2.58%	5.13%	1.77%	0.95%	3.17%
Unemployment		249	430	27	31	
7-Monetary policy	$\psi_{c,7}$	5,772 (49.72%)	2,843 (24.49%)	596 (5.13%)	2,398 (20.66%)	11,609
		59.79%	33.92%	38.96%	73.81%	50.04%
Interest rate statement		5,428	2,779	585	2347	
Money supply		344	64	11	51	
8-Interviews	$\psi_{c,8}$	222 (34.63%)	296 (46.18%)	60 (9.36%)	63 (9.83%)	641
		2.30%	3.53%	3.94%	1.94%	2.76%
Interviews		222	296	60	63	
Total		9,653 (42.34%)	8,381 (36.75%)	1,522 (6.66%)	3,249 (14.25%)	22,805

The events are the news headlines released on the Reuters money news-alerts. Integers are the number of events according to nine categories. Percentages are the proportions of each news category related to the same currency area. Percentages between parentheses are the proportions of news category related to one currency area all currency areas.

The symbol $\psi_{a,ca}$ is the coefficient of the news variable $U_{a,ca,t}$ in the equation (3). The announcements are time stamped to the minute in US Eastern Standard Time (EST).

Table 3: Estimated effects of scheduled and unscheduled news on volatility

Constant	ω_i	0.050**		
EUR/USD	A_{i1}	0.056**		
GBP/USD	A_{i2}	0.016**		
JPY/USD	A_{i3}	0.024**		
Autoregression	B_{ii}	0.851**		
	Scheduled News		Unscheduled News	
	$\varphi_{a,j}$	$C_{a,j}$	$\psi_{a,j}$	$\tilde{C}_{a,j}$
US Figures ($a = 1$)				
Real activity	1.097**	0.331**	0.060**	
Consumption	0.685**	0.733**		
Investment	0.373**			
Prices	0.561**	0.634**		
Forward looking	1.348**	0.346**		
Employment	0.091**	0.650**		
Monetary policy	4.966**	0.219**		
Current account	1.351**	0.614**		
European Figures ($a = 2$)				
Real activity			0.059*	
Consumption	1.040**			
Investment	0.284**			
Prices	0.104**			
Forward looking	1.475**	0.354**	0.068**	
Employment				
Monetary policy			0.030*	
Current account			0.040*	
UK Figures ($a = 3$)				
Real activity	0.517**	0.492**		
Consumption	n.a.	n.a		
Investment				
Prices	0.159**			
Forward looking				
Employment			0.047*	
Monetary policy	0.056**			
Current account	1.645**	0.218**	0.481**	
Japanese Figures ($a = 4$)				
Real activity				
Consumption				
Investment				
Prices				
Forward looking				
Employment			0.093**	
Monetary policy			0.079*	0.561**
Current account	0.013*	0.030*		

Estimation results for model (3.7) applied to EUR/USD. ** and * indicate respectively significance at 1% and 5%. Only significant estimates are reported. The sample involves 64,593 observations from January 3 to December 31, 2006.

Table 4: Estimated effects of scheduled and unscheduled news on volatility

Constant	ω_i	0.084**		
EUR/USD	A_{i1}	0.030**		
GBP/USD	A_{i2}	0.062**		
JPY/USD	A_{i3}	0.026**		
Autoregression	B_{ii}	0.800**		
	Scheduled News		Unscheduled News	
	$\varphi_{a,j}$	$C_{a,j}$	$\psi_{a,j}$	$\tilde{C}_{a,j}$
US Figures ($a = 1$)				
Real activity	0.830**	0.552**	0.065**	
Consumption	0.614**	0.480**		
Investment	0.231**			
Prices	0.837**	0.592**	0.022**	
Forward looking	1.133**	0.501**	0.034**	
Employment		0.009	0.096**	
Monetary policy	2.477**	0.187**		
Current account	1.463**		0.058**	
European Figures ($a = 2$)				
Real activity				
Consumption	0.078**		0.044*	
Investment	0.249**		0.217**	0.014*
Prices				
Forward looking	0.538**	0.765**	0.088**	0.015*
Employment			0.021*	0.014*
Monetary policy				
Current account			0.043*	
UK Figures ($a = 3$)				
Real activity				
Consumption	n.a.	n.a.		
Investment	0.489**			
Prices	0.202**			
Forward looking	0.128**			
Employment			0.375**	
Monetary policy				
Current account			0.462**	
Japanese Figures ($a = 4$)				
Real activity				
Consumption				
Investment				
Prices				
Forward looking			0.106**	
Employment			0.241**	
Monetary policy	1.240**		0.063**	0.584**
Current account			0.022**	

Estimation results for model (3.7) applied to GBP/USD. ** and * indicate respectively significance at 1% and 5%. Only significant estimates are reported. The sample involves 64,593 observations from January 3 to December 31, 2006.

Table 5: Estimated effects of scheduled and unscheduled news on volatility

Constant	ω_i	0.034**		
EUR/USD	A_{i1}	0.020**		
GBP/USD	A_{i2}	0.011**		
JPY/USD	A_{i3}	0.064**		
Autoregression	B_{ii}	0.872**		
	Scheduled News		Unscheduled News	
	$\varphi_{a,j}$	$C_{a,j}$	$\psi_{a,j}$	$\tilde{C}_{a,j}$
US Figures ($a = 1$)				
Real activity	0.585**		0.028*	
Consumption	0.824**	0.551**		
Investment	0.274**	0.060**		
Prices	0.649**			
Forward looking	1.126**	0.466**	0.090**	
Employment	0.016*		0.076**	
Monetary policy	1.608**	0.479**		
Current account	1.235**	0.026*	0.061**	
European Figures ($a = 2$)				
Real activity				
Consumption	0.217**	0.028*		
Investment	0.027*	0.046**		
Prices				
Forward looking	0.362**	0.090**		
Employment				
Monetary policy				
Current account	0.099**			
UK Figures ($a = 3$)				
Real activity				
Consumption	n.a.	n.a.		
Investment				
Prices			0.029*	
Forward looking				
Employment				
Monetary policy	0.070**			
Current account				
Japanese Figures ($a = 4$)				
Real activity				
Consumption			0.068**	
Investment	0.030*			
Prices				
Forward looking				
Employment	0.032*			
Monetary policy	0.027*			
Current account	0.027*	0.028*		

Estimation results for model (3.7) applied to JPY/USD. ** and * indicate respectively significance at 1% and 5%. Only significant estimates are reported. The sample involves 64,593 observations from January 3 to December 31, 2006.

Table 6: Number of minutes after which either 50 or 95 % of the total accumulated impulse response effect of an announcement is attained.

	EUR/USD		GBP/USD		JPY/USD	
Proportion	0.5	0.95	0.5	0.95	0.5	0.95
Real activity	30	260	25	225	75	330
Consumption	45	270	50	285	60	315
Investment	30	265	35	265	50	315
Prices	40	265	25	225	75	330
Forward looking	40	280	30	250	55	305
Employment	25	225	80	320	100	355
Monetary policy	25	255	35	265	60	315
Current account	30	250	40	270	70	325

Only scheduled US news are considered here.

Table 7: Total accumulated impulse response effect and percentage explained of total variance.

	EUR/USD		GBP/USD		JPY/USD	
US news	total	% of variance	total	% of variance	total	% of variance
Real activity	4.173	0.516%	4.194	0.519%	3.196	0.395%
Consumption	6.524	0.606%	4.345	0.403%	6.456	0.599%
Investment	0.988	0.168%	0.741	0.126%	1.019	0.173%
Prices	4.094	0.221%	4.494	0.243%	3.352	0.181%
Forward looking	6.185	1.091%	5.987	1.056%	7.179	1.267%
Employment	0.497	0.052%	0.149	0.015%	0.213	0.022%
Monetary policy	15.19	0.540%	10.10	0.359%	12.65	0.450%
Current account	7.980	0.432%	4.965	0.269%	5.883	0.318%
Total		3.626%		2.99%		3.403%

Only scheduled US news are considered here.

Table 8: US scheduled news relative contributions to the volatility impulse responses at lag k

			EUR/USD ($j = 1$)				*GBP/USD* ($j = 2$)				*JPY/USD* ($j = 3$)			
	k	Δt	REAL	CONS	INVE	PRIC	REAL	CONS	INVE	PRIC	REAL	CONS	INVE	PRIC
EUR/USD	1	5 min	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
($i = 1$)	3	15 min	0.8518	0.9058	0.6469	0.8824	0.0881	0.0302	0.1220	0.0679	0.0599	0.0638	0.2310	0.0495
	6	30 min	0.6521	0.8066	0.6066	0.7345	0.2318	0.0581	0.1334	0.1755	0.1159	0.1351	0.2598	0.0898
	12	1 hour	0.5738	0.6692	0.5461	0.5712	0.2839	0.0923	0.1458	0.2860	0.1422	0.2383	0.3080	0.1427
	72	6 hours	0.4614	0.4606	0.4056	0.4333	0.3108	0.1104	0.1443	0.3282	0.2276	0.4288	0.4500	0.2384
GBP/USD	1	5 min	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
($i = 2$)	3	15 min	0.1089	0.1320	0.3464	0.0641	0.8530	0.7437	0.4145	0.8967	0.0379	0.1242	0.2390	0.0391
	6	30 min	0.2315	0.3341	0.3677	0.1804	0.6932	0.4095	0.3624	0.7458	0.0752	0.2562	0.2697	0.0737
	12	1 hour	0.3497	0.4515	0.3973	0.3182	0.5244	0.2355	0.2788	0.5551	0.1258	0.3128	0.3237	0.1265
	72	6 hours	0.4598	0.4579	0.4035	0.4315	0.3109	0.1104	0.1441	0.3283	0.2292	0.4315	0.4522	0.2400
USD/JPY	1	5 min	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000
($i = 3$)	3	15 min	0.3704	0.0656	0.2612	0.2531	0.1817	0.0280	0.09069	0.2047	0.4478	0.9062	0.6480	0.5420
	6	30 min	0.3933	0.2131	0.2954	0.3323	0.2429	0.0696	0.1059	0.2631	0.3636	0.7172	0.5986	0.4045
	12	1 hour	0.4133	0.3462	0.3312	0.3761	0.2788	0.0947	0.1212	0.2962	0.3077	0.5589	0.5475	0.3276
	72	6 hours	0.4576	0.4531	0.4000	0.4290	0.3098	0.1098	0.1431	0.3272	0.2325	0.4369	0.4567	0.2436

Relative contributions δ_{ijkl}, defined by (14) as the contribution of exchange rate j (in the columns) to the volatility impulse response V_{kl} of the ith exchange rate, divided by the corresponding total value of V_{kl}.

Table 9: US scheduled news relative contributions to the volatility impulse responses at lag k

			EUR/USD ($j = 1$)				*GBP/USD* ($j = 2$)				*JPY/USD* ($j = 3$)			
	k	Δt	FORW	EMPL	MONE	CURR	FORW	EMPL	MONE	CURR	FORW	EMPL	MONE	CURR
EUR/USD	1	5 min	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
($i = 1$)	3	15 min	0.7952	0.9915	0.8435	0.9216	0.0832	0.0003	0.0704	0.0340	0.1214	0.0081	0.0859	0.0442
	6	30 min	0.5416	0.9824	0.7037	0.8397	0.1883	0.0006	0.1168	0.0686	0.2699	0.0168	0.1793	0.0916
	12	1 hour	0.4537	0.9645	0.6425	0.7295	0.2164	0.0012	0.1313	0.1104	0.3297	0.0341	0.2261	0.1599
	72	6 hours	0.3205	0.9247	0.5042	0.5896	0.2077	0.0018	0.1385	0.1308	0.4716	0.0733	0.3572	0.2794
GBP/USD	1	5 min	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
($i = 2$)	3	15 min	0.1092	0.9054	0.3571	0.3616	0.8031	0.0114	0.5184	0.4572	0.0876	0.0830	0.1244	0.1811
	6	30 min	0.2207	0.9376	0.4488	0.4947	0.5711	0.0060	0.3485	0.3346	0.2081	0.0563	0.2026	0.1705
	12	1 hour	0.2889	0.9421	0.4841	0.5642	0.4016	0.0037	0.2655	0.2427	0.3093	0.0541	0.2503	0.1930
	72	6 hours	0.3187	0.9239	0.5021	0.5875	0.2073	0.0018	0.1384	0.1309	0.4738	0.0741	0.3593	0.2814
USD/JPY	1	5 min	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000
($i = 3$)	3	15 min	0.0908	0.7543	0.1817	0.3172	0.0473	0.0028	0.0493	0.1197	0.8617	0.2428	0.7689	0.5630
	6	30 min	0.2032	0.8460	0.3484	0.4370	0.1252	0.0021	0.0964	0.1155	0.6714	0.1518	0.5551	0.4473
	12	1 hour	0.2567	0.8859	0.4247	0.5036	0.1683	0.0019	0.1201	0.1212	0.5748	0.1120	0.4551	0.3750
	72	6 hours	0.3157	0.9225	0.4985	0.5838	0.2057	0.0018	0.1377	0.1306	0.4785	0.0755	0.3637	0.2854

Relative contributions δ_{ijkl}, defined by (14) as the contribution of exchange rate j (in the columns) to the volatility impulse response $V_{k,l}$ of the ith exchange rate, divided by the corresponding total value of V_{kl}.

Table 10: US scheduled news relative contributions to the accumulated volatility impulse responses up to lag k

			EUR/USD ($j=1$)				*GBP/USD* ($j=2$)				*JPY/USD* ($j=3$)			
	k	Δt	REAL	CONS	INVE	PRIC	REAL	CONS	INVE	PRIC	REAL	CONS	INVE	PRIC
EUR/USD	1	5 min	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
($i=1$)	3	15 min	0.9653	0.9570	0.9520	0.9491	0.0189	0.0139	0.0169	0.0267	0.0156	0.0290	0.0310	0.0240
	6	30 min	0.9181	0.9134	0.9002	0.8983	0.0504	0.0270	0.0345	0.0615	0.0313	0.0595	0.0652	0.0401
	12	1 hour	0.8541	0.8575	0.8357	0.8291	0.0942	0.0424	0.0554	0.1095	0.0515	0.0999	0.1088	0.0613
	72	6 hours	0.7393	0.7407	0.7114	0.7050	0.1650	0.0674	0.0871	0.1864	0.0956	0.1917	0.2014	0.1084
GBP/USD	1	5 min	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
($i=2$)	3	15 min	0.0421	0.0439	0.0736	0.0236	0.9410	0.9130	0.8774	0.9583	0.0167	0.0429	0.0488	0.0180
	6	30 min	0.0813	0.1113	0.1329	0.0557	0.8900	0.7932	0.7747	0.9141	0.0286	0.0954	0.0922	0.0301
	12	1 hour	0.1268	0.1994	0.1899	0.1003	0.8289	0.6476	0.6707	0.8538	0.0441	0.1529	0.1392	0.0458
	72	6 hours	0.2049	0.3114	0.2655	0.1783	0.7148	0.4442	0.5074	0.7385	0.0801	0.2443	0.2270	0.0830
USD/JPY	1	5 min	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000
($i=3$)	3	15 min	0.0699	0.0219	0.0432	0.0377	0.0321	0.0098	0.0148	0.0307	0.8979	0.9682	0.9419	0.9315
	6	30 min	0.1511	0.0610	0.0882	0.1032	0.0818	0.0229	0.0309	0.0826	0.7669	0.9160	0.8808	0.8140
	12	1 hour	0.2326	0.1276	0.1431	0.1854	0.1413	0.0406	0.0511	0.1470	0.6259	0.8316	0.8057	0.6675
	72	6 hours	0.3422	0.2622	0.2425	0.3041	0.2252	0.0708	0.0876	0.2377	0.4324	0.6669	0.6697	0.4580

Relative contributions Δ_{ijkl}, defined by (17) as the contribution of exchange rate j (in the columns) to the accumulated volatility impulse response V_{kl} of the ith exchange rate.

Table 11: US scheduled news relative contributions to the accumulated volatility impulse responses up to lag k

			EUR/USD ($j=1$)				*GBP/USD* ($j=2$)				*JPY/USD* ($j=3$)			
	k	Δt	FORW	EMPL	MONE	CURR	FORW	EMPL	MONE	CURR	FORW	EMPL	MONE	CURR
EUR/USD	1	5 min	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
($i=1$)	3	15 min	0.9506	0.9960	0.9743	0.9644	0.0199	0.0001	0.0121	0.0155	0.0293	0.0037	0.0134	0.0199
	6	30 min	0.8787	0.9931	0.9375	0.9380	0.0495	0.0002	0.0268	0.0268	0.0717	0.0065	0.0355	0.0351
	12	1 hour	0.7870	0.9889	0.8878	0.9015	0.0864	0.0004	0.0450	0.0418	0.1265	0.0106	0.0671	0.0565
	72	6 hours	0.6298	0.9774	0.7871	0.8235	0.1371	0.0007	0.0746	0.0682	0.2330	0.0218	0.1381	0.1081
GBP/USD	1	5 min	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
($i=2$)	3	15 min	0.0398	0.7844	0.0852	0.0573	0.9295	0.1251	0.8877	0.9073	0.0306	0.0903	0.0270	0.0352
	6	30 min	0.0781	0.8823	0.1640	0.1456	0.8551	0.0467	0.7733	0.7894	0.0666	0.0709	0.0625	0.0649
	12	1 hour	0.1197	0.9151	0.2375	0.2452	0.7683	0.0234	0.6593	0.6604	0.1119	0.0614	0.1031	0.0943
	72	6 hours	0.1811	0.9262	0.3322	0.3714	0.6161	0.0111	0.4914	0.4808	0.2026	0.0626	0.1762	0.1476
USD/JPY	1	5 min	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000
($i=3$)	3	15 min	0.0293	0.2115	0.0674	0.0463	0.0145	0.0009	0.0184	0.0213	0.9561	0.7874	0.9141	0.9322
	6	30 min	0.0642	0.4591	0.1324	0.1271	0.0359	0.0014	0.0362	0.0424	0.8997	0.5393	0.8312	0.8304
	12	1 hour	0.1091	0.6527	0.2091	0.2320	0.0663	0.0017	0.0581	0.0650	0.8245	0.3455	0.7326	0.7028
	72	6 hours	0.1901	0.8189	0.3339	0.3951	0.1221	0.0018	0.0934	0.0969	0.6877	0.1791	0.5726	0.5079

Relative contributions Δ_{ijkl}, defined by (17) as the contribution of exchange rate j (in the columns) to the accumulated volatility impulse response V_{kl} of the ith exchange rate. The symbol $\varphi_{a,ca}$ is the coefficient of the news variable $S_{l,t}$ in the equation (3). $a = 1$ for US news, $a = 2$ for European news, $a = 3$ for UK news, and $a = 4$ for Japanese news.

Figure 1: Diurnal Volatility

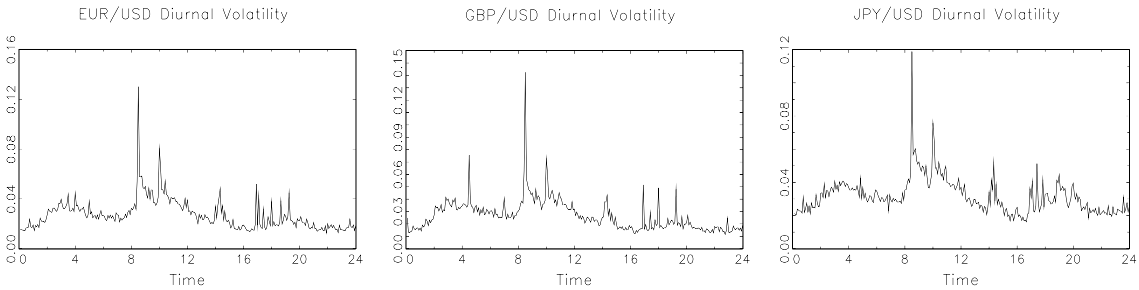


Figure 2: Volatility impulse responses for scheduled US real activity, consumption, investment and prices announcements

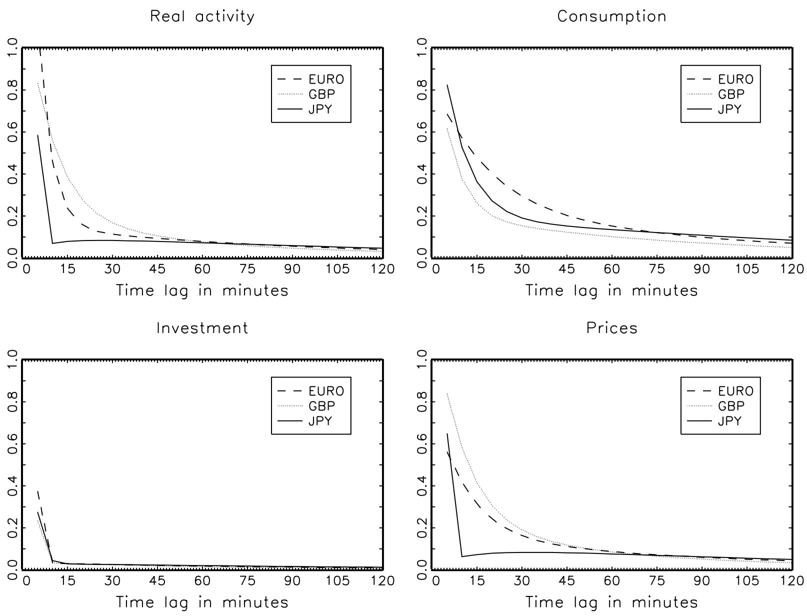


Figure 3: Volatility impulse responses for scheduled US forward looking, employment, monetary policy and current account announcements

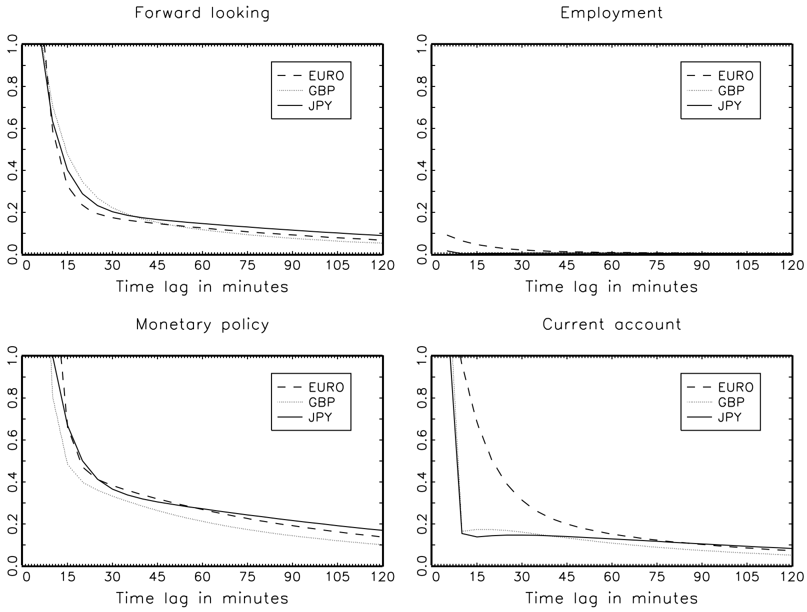
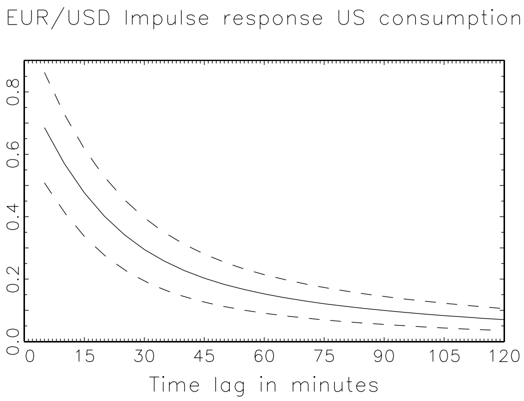


Figure 4: EUR/USD impulse response function for scheduled US consumption announcements with 95% pointwise confidence bands



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