The impact of central bank FX interventions on currency components*

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Abstract

This paper assesses the impact of official FOREX interventions of the three major central banks in terms of the dynamics of the currency components of the major exchange rates over the period 1989-2003. We identify currency components of the mean and the volatility processes of exchange rates using the recent Bayesian framework developed by Bos and Shephard (2004). Our results show that in general, the concerted interventions tend to affect the dynamics of both currency components of the exchange rate, while unilateral interventions primarily affect the currency of the central bank present in the market.

Keywords: Central bank interventions, currency components, foreign exchange, Markov chain Monte Carlo, stochastic volatility, structural time series models.

JEL codes: C15, C32, F31, G15

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1 Introduction

The use of direct interventions in the FX market remains a stabilisation instrument in the hand of the central banks. While the Federal Reserve has been increasingly reluctant to rely on such interventions since 1995, the other major central banks have recently been involved in such a policy. In 2000, the ECB conducted a round of sales of foreign currency aimed at supporting the Euro (EUR) against the US Dollar (USD). In recent years, the Bank of Japan has been extremely active in the FX markets, proceeding to massive sales of its currency against both the USD and the Euro. As a piece of evidence, over the year 2003 only, the BoJ was present in the markets during 82 business days and purchased more than 20 billions of USD.

Given the extensive use of these central bank interventions (CBIs hereafter), a large empirical literature has tried to assess their efficiency, both in terms of exchange rate level and volatility. Due to the release of the official data by the three major central banks, most analyses have relied on the financial econometric approaches based on daily and even intra-daily data. Extensive reviews of this literature are provided among others by Sarno and Taylor (2001) and Humpage (2003). On the whole, the literature sheds some doubt about the efficiency of this instrument. While little evidence has been found that direct sales or purchases of foreign currency succeed in driving the exchange rate in the desired direction, most studies using high frequency data (weekly, daily or intra-daily data) conclude that such operations result in increased exchange rate volatility. Another robust finding emphasizes that while concerted operations tend to move the market, unilateral interventions exert some limited impact on the dynamics of exchange rates.

Explanations of the empirical results have been provided mainly by refering to the signalling theory. The signalling channel (Mussa 1981) states that by intervening, the central banks convey some private information about fundamentals to market participants and therefore tend to alter their expectations in terms of future values of the exchange rate. Such a theory stresses the case for potential asymmetric effects of interventions depending on their intrinsic features. In this respect, an important distinction concerns unilateral versus concerted operations. Along the signalling hypothesis, interventions carried out by a single central bank should mainly affect the dynamics of the currency of the central bank present in the market. In contrast, concerted interventions should be seen more as market-wide events that can affect the value of both currencies. Testing for the existence of such asymmetric effects is the primary aim of this paper.

We revisit the analysis of the short-run impact of CBIs conducted by the major central banks (the US Federal Reserve, the ECB and the BoJ) in the foreign exchange market over the recent period (1989-2003). Unlike the rest of the literature, we focus on the impact on the country components of the exchange rates rather than on the exchange rate itself. The level and the volatility of these (unobserved) country components are identified using the recent Bayesian modelling approach proposed by Bos and Shephard (2004). This approach extends the early development of Mahieu and Schotman (1994) and involves the estimation of a state-space model with a stochastic volatility process. Our analysis allows to express each exchange rate as the combination of two unobserved country factors whose moments can be investigated along with the CBIs taking place in the market.

We address three specific issues: (*i*) depending on their nature, do central bank interventions exert asymmetric effects in terms of currency dynamics? (*ii*) is there a dollar bias in the effects of these interventions? (*iii*) is it important to control for interventions on auxiliary markets like the EMS or the Euro/Yen ones even when focusing on the impact on the major foreign exchange markets?

On the whole, our results support the existence of asymmetric effects between unilateral and concerted operations. We find that while coordinated operations affect the volatility of both currencies, unilateral interventions lead to an increase only in the currency component of the central bank present in the market. The traditional analysis in terms of exchange rates turns out to be unable to isolate this last effect. With the alternative identification in terms of currency components of the effect of CBIs we show that while more limited, unilateral operations can still exert detrimental effects in terms of uncertainty. *CSB: Please recheck last sentences.*

The paper is organized as follows. Section 2 reviews the empirical literature on the impact of CBIs and clarifies the nature of our contribution. Section 3 presents both the model and the estimation procedure, comments on the extracted country specific components and gives some insight on the quality of the extracted volatility components. Section 4 details our empirical approach, provides the findings and interprets the results. Section 5 concludes.

2 The state of the literature and contribution of the paper

2.1 Previous empirical findings

The release of high frequency data on their FX interventions by the major central banks has induced the development of an extensive empirical literature aimed at capturing the impact of such operations on the dynamics of exchange rates. Recent works including Sarno and Taylor (2001), Humpage (2003) or Dominguez (2004) have fortunately provided some reviews of this large literature. Different econometric approaches have been proposed to capture the effects of CBIs, including event studies and parametric models. Due to emphasis on the impacts in terms of exchange rate uncertainty, different approaches to measure volatility have been used: GARCH models (Dominguez 1998), implied volatility modeling (Bonser-Neal and Tanner 1996, Beine 2004) or more recently realized volatility (Beine, Laurent and Palm 2004). While the bulk of the empirical analyses has studied the impact using daily data, some recent approaches have investigated the impact in an intra-daily perspective (Dominguez 2003, Payne and Vitale 2003).

As emphasized by several authors, there is no clear consensus in the literature. While Dominguez (2003) and Payne and Vitale (2003) find some robust effects of CBIs in the very short run on the level of exchange rate returns, most studies conducted at the daily frequency find either insignificant or mixed results.[1] The results in terms of exchange rate volatility seem much more clear-cut, pointing out that in general, direct interventions tend to raise exchange rate volatility. This holds for daily data although some recent evidence (Dominguez 2003, Beine et al. 2004) find that these volatility effects might be mean reverting within a couple of hours.

Another feature of this empirical literature is that the results tend to be dependent on the involved currency markets as well as on the sample period under investigation. This is hardly surprising given that exchange rate policies varies over time and across central banks.

[1] A number of papers (see among others (Beine, Bénassy-Quéré and Lecourt 2002)) document even perverse effects on the returns. These perverse effects have been rationalized by some theoretical contributions emphasizing the role of the interaction process between the central bank and the market traders ((Bhattacharya and Weller 1997)).

As an example, while the ECB and the Federal Reserve have been increasingly reluctant to intervene in the FX markets after 1995, the BoJ activity in the FX markets has reached a peak in 2003. As another example, while the BoJ tended to use a transparent policy before 2003, it might have recently favored secret interventions (Beine and Lecourt 2004).

Most of these empirical findings concerning the effects of official interventions have been rationalized using the signalling theory (Mussa 1981). The interventions under investigation have been reported by the central banks to be sterilized, which rules out any monetary channel. The portfolio channel has also received very little support, which is understandable given the relative small amounts used by the central banks in these operations.[2] The signalling theory states that through these interventions, central banks convey some fundamental information about their future policies. Along the signalling channel, the unilateral interventions carried out by a central bank should signal private information mainly useful to assess the future value of its currency. There is much less rationale that such operation aims at conveying any valuable information relative to the other currencies. In this respect, our analysis that disentangles the impact of CBIs into currency components provides a useful way to test further the signalling channel as the main channel at work to explain their effects.

2.2 Contribution of the paper

The general contribution of this paper is to focus on the impact of interventions on the currency dynamics rather that on the exchange rate evolution. There are three main reasons calling for the adoption of an analysis in terms of currency components. In turn, this approach enables to provide answers to three specific questions concerning the impact of CBIs in the FX markets.

First, unlike certain financial events like oil price increases, foreign exchange CBIs are by definition country specific or geographical area specific events. For instance, a sale of Yen by the Bank of Japan is expected to impact the value of the Yen against all the currencies. This is particularly true when such operations are not concerted, i.e. when they involve a single central bank. The investigation in terms of currencies or country components rather than in terms of exchange rates can therefore shed some interesting light on particular effects of these CBIs and on asymmetric effects associated to different types of operations. Basically, the literature finds less impact of unilateral rather than concerted operations, especially in terms of volatility.[3] Given the differentiated content carried out by these operations, one reason for this result could be that an intervention from a given central bank will mostly impact the country component of the exchange rate of the active central bank, without much effect on the component of the counterpart country. Testing for such an effect is only possible after some clear identification of the currency component. In a nutshell, we try to answer to the first following question:

Question 1 *Is there some evidence of asymmetric effects between unilateral and concerted operations in terms of currency dynamics?*

[2]A notable exception is Evans and Lyons (2001). Their analysis nevertheless applies to primarily secret interventions, i.e. unreported official interventions which represent a rather small proportion of the interventions carried out by the three major central banks over this period.

[3]See among others Dominguez (1998) and Beine et al. (2004). It should be emphasized that while the impact of unilateral interventions is generally lower than the one obtained for concerted operations, it has been found to be statistically significant for some of these operations.

Second, most analyses of CBIs conducted in the context of flexible exchange rate regimes involve the USD currency. When it comes to CBIs, this choice is a natural one because the dollar is often the currency against which foreign central banks try to stabilize their currency. Furthermore, the investigation of the USD allows to make a clear distinction between coordinated and unilateral operations.[4] Once more, such a distinction stems from the different signalling content conveyed by these two types of interventions. While the choice of the USD is rational, general conclusions on the impact of these interventions might nevertheless be dangerous to draw given the special situation of the USD as the world leading currency. The USD is by far the most liquid currency, especially on spot transactions.[5] Detken and Hartman (2000) discuss the various features involving the international role of currencies (financing and investment roles), with a special emphasis on the changes associated with the inception of the Euro. They document the leading position of the USD in all segments, especially during the period before 1999 in which the Fed and the Bundesbank were active on the markets. Disentangling the impact in terms of currencies rather than in terms of exchange rates might therefore be useful to assess the part of the results related to the special situation of the USD. In other words, we address the second following question:

Question 2 *Is there a dollar effect driving the empirical results regarding the effects of CBIs?*

A third and important contribution is the way one can control for what is called auxiliary interventions in the FX markets. Auxiliary interventions are interventions involving a particular currency but occurring on another market. Infra-marginal interventions in the context of the European Monetary System (EMS) provide a good example of these auxiliary interventions.[6] The massive sales of DEM by the Bundesbank against some European currencies (like the Italian Lira, the Spanish Peseta or the French Frank) during the 1992/3 EMS crisis might have impacted the DEM against the USD. However, while it is tedious to find a clear rationale for introducing these interventions in a classical exchange rate equation of the DEM/USD, it is more straightforward to allow for some impact on the DEM currency component. In turn, this ensures a better control for other type of news in the model and hence a better estimation of these CBI effects. Our analysis therefore aims at answering a third question:

Question 3 *Should one account for interventions on auxiliary markets when analysing the impact of FX operations in the major markets?*

3 Modelling exchange rates in factors

3.1 Exchange rate data

Our dataset contains hourly data for three major exchange rates (four currencies), the Japanese Yen (YEN), the Euro (EUR, with corresponding Deutsche Mark value before the

[4]Basically, the YEN/USD and the EUR/USD markets are the only liquid markets on which concerted interventions have taken place over the recent period. A given intervention is considered as concerted if it is carried out by the two involved central banks the same day and in the same direction. Such a situation is partly due to the strategy of the Fed favoring these two important markets.

[5]The last triennial survey on FX markets conducted by the Bank for International Settlements (BIS, 2001) shows that over the 1989-2001, the USD entered on average on one side of 86.6% of all foreign exchange transactions, against 38 and 23.48% for the Euro and the YEN, respectively.

[6]The other case considered in this paper concerns unilateral YEN sales of the BoJ against the Euro.

introduction of the Euro in 1999) and the British Pound (GBP) against the US Dollar (USD). For these three exchange rates, we have about 14.5 years of intraday (hourly) data, from January 1989 to June 2003. The raw data consists of all interbank EUR/USD, YEN/USD and GBP/USD bid-ask quotes displayed on the Reuters FX screen during this period. The series are presented in Figure 1.

As standard in the literature, we compute hourly exchange rate prices $S_{tij}(\theta)$ at time t, quoted at hour $\theta = 0, \ldots, 23$ (GMT+1) between currencies i and j from the linearly interpolated average of the logarithms of bid and ask quotes for the two ticks immediately before and after the hourly time stamps throughout the global 24-hour trading day. Next we obtain daily and intradaily returns as the first difference of the logarithmic daily or intradaily prices, multiplied by 100 for ease of presentation whenever convenient.

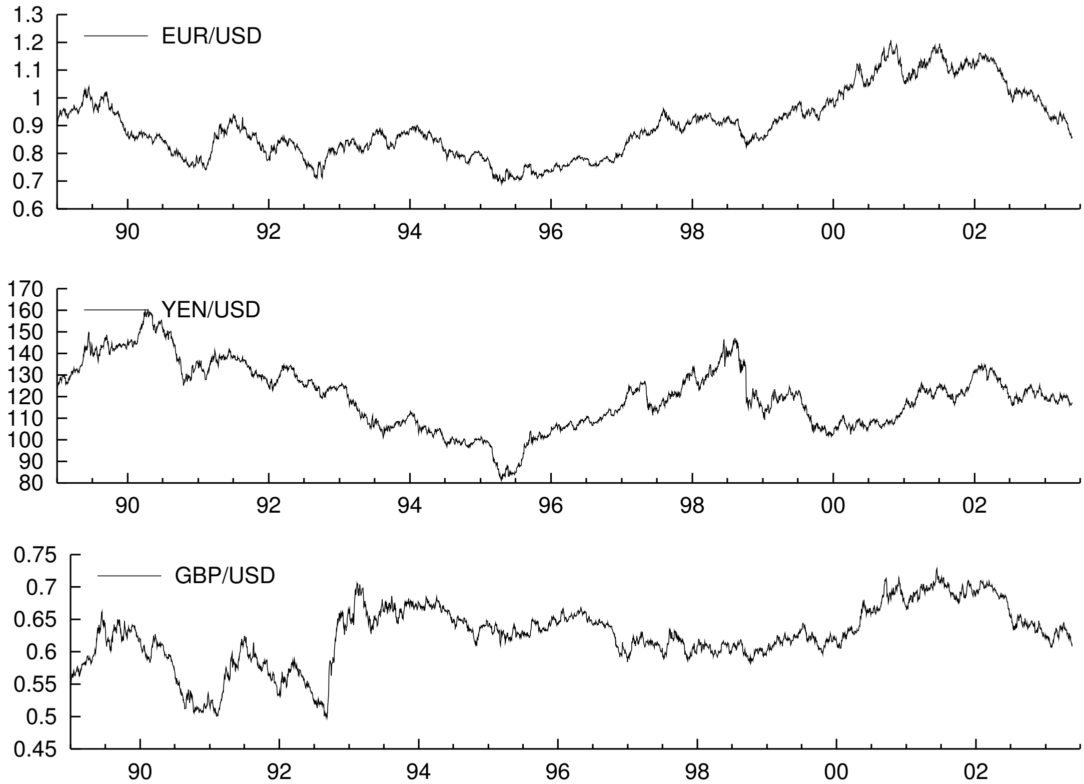

Figure 1: Daily exchange rates EUR/USD, YEN/USD and GBP/USD over the 1989-2003 period, quoted at 16h00 GMT+1.

3.2 The model

Exchange rates

Current models in the exchange rate literature tend to model the exchange rates between currencies i and j at time t S_{tij} directly (or the first difference of its logarithms).[7] For

[7]For ease of presentation, we do not specify the quotation time of the exchange rates in this section.

multivariate models, using S_{tij} and S_{tik} jointly, this induces a strong source of correlation, as both exchange rates involve the common currency i.

Mahieu and Schotman (1994) propose to model each underlying, unobserved, currency factor separately, thus explicitly taking the correlation in exchange rates along. Each exchange rate S_{tij} (e.g. the EUR/USD) at time t between currencies i and j comprises information on the two currencies E_{ti} (e.g. the EUR) and E_{tj} (e.g. the USD), as

$$S_{tij} = \frac{E_{ti}}{E_{tj}}, \tag{1}$$

or, in logarithms,

$$s_{tij} = e_{ti} - e_{tj}$$

with $s_{tij} = \log S_{tij}, e_{ti} = \log E_{ti}$. If such a decomposition into country factors is made, it becomes possible to distinguish the effect of CBIs on each of the currencies separately.

Multivariate system of exchange rates

It is inherently impossible, given only one exchange rate, to extract both underlying factors. Each increase or drop in s_{tij} can be caused by either a change in e_{ti}, in e_{tj}, or by a combination of changes in both. Nevertheless, from the correlation structure between s_{tij} and s_{tki} it is possible to unravel the factors, though some degree of uncertainty about the exact value of the factors always persists after the estimation. Using more than two exchange rates can improve the estimability of the system.

In what follows, we use a series of n exchange rates vis-à-vis a common currency, in practice the USD. This common denominator will take index 0, leading us to model $n+1$ country factors. Including cross-rates of currencies $i, j \neq 0$ in the system does not add any further information, as the relation holds that

$$s_{tij} = s_{ti0} - s_{tj0}.$$

Therefore, knowledge of the values of the exchange rates s_{ti0} and s_{tj0} includes all information on the exchange rate s_{tij}.

Country factors and volatility

Before the factors can be extracted, a further assumption about the evolution of the underlying factors needs to be made. The basic assumption is to allow the factors to evolve according to a random walk (which implies the assumption of unpredictable returns on the exchange rates), with independent normal disturbances. Stochastic volatility (SV) components (Harvey, Ruiz and Shephard 1994, Jacquier, Polson and Rossi 1994) govern the variance of the series. The country factors evolve along the lines of

$$\begin{aligned} e_{t+1\,i} &= \beta_{ti} + e_{ti} + \epsilon_{ti}, && (2)\\ \epsilon_{ti} &\sim \mathcal{N}(0, \exp(h_{ti})), && i = 0, \ldots, n\\ h_{t+1\,i} - \gamma_{t+1\,i} &= \phi_i(h_{ti} - \gamma_{ti}) + \xi_{ti}, && (3)\\ \xi_{ti} &\sim \mathcal{N}(0, \sigma^2_{\xi\,i}). \end{aligned}$$

The stochastic volatility specification for the variances of the random walk disturbances allows for more flexibility than the standard deterministic GARCH specification (Bos, Mahieu and Van Dijk 2000, Carnero, Peña and Ruiz 2001), as there is an extra element of random variation in the model. This point will be further commented on in Section 3.4. The drawback of allowing for stochastic volatility however is that the estimation tends to be much more computationally demanding. This seems to be the main reason that relatively few applications have appeared in the literature.

The assumptions for the country factors imply a random walk structure for the logarithm of the exchange rates as well, with an intricate correlation of first and second moments due to the combination of the country factors for level and volatility. The implied structure for the exchange rates is consistent with the findings of the literature on the impossibility of predicting the level of exchange rates (certainly on longer horizons), but with clear persistence in the variance.

Interventions

Both the random walk equation (2) and the stochastic volatility equation (3) allow for a time varying mean to model the baseline variance and the interventions of the central banks. We model

$$\beta_{ti} = W_{ti}\beta_i \tag{4}$$

$$\gamma_{ti} = \gamma_{0i} + |W_{ti}|\gamma_i \tag{5}$$

with W_{ti} a vector of indicators for the different interventions affecting the currency at time t (see Section 4.1), and β, γ the corresponding vectors of parameters. The indicators take the value 0 when nothing happens, and -1 or 1 in case of a buy or sell of USD on a specific currency market.[8] The equation for γ_{ti} includes an overall constant γ_{0i} to govern the baseline variance, and only takes the timing, not the direction, of interventions into account.

Disturbances

The disturbances ϵ_{ti} are taken independent across time t and countries i. As exchange rate returns themselves show little or no autocorrelation, the underlying factor increments can be reasonably assumed independent across time.

The independence across countries is a different issue. It can be assumed that a global crisis has a negative effect on all or some currencies jointly. Tims and Mahieu (2003) introduce a 'world factor' influencing all exchange rates, such as to allow for some correlation between currencies. An alternative approach would be to allow ϵ_{ti} and ϵ_{tj} be correlated directly; this is left for further research as it strongly complicates the computational process, and is obviously not necessary to address the issues raised in this article.

3.3 Unobserved components and estimation

The system of exchange rates is build up from unobserved components describing the level of the currency factors e_{ti} and their volatility h_{ti}. Such a setup allows for estimation in state-

[8]For the auxiliary interventions, i.e. those not involving the USD, -1 and 1 correspond to the buy or sell of the counterpart currency. More precisely, the counterpart currency is the (unknown) European currency in the case of the EMS interventions involving the DEM, and the Euro in the case of the BoJ interventions on the Euro-Yen market.

space form (Harvey 1989, Durbin and Koopman 2001). As the dependence on the volatility factors is non-linear, the standard filtering equations are not valid. Estimation of models with combined level and volatility components is involved. We follow the Bayesian setup explained in Bos and Shephard (2004), which improves on earlier Bayesian Gibbs samplers for stochastic volatility models as in Jacquier et al. (1994) and Harvey et al. (1994).[9] An overview over the estimation procedure is given in Appendix A.

In the Bayesian estimation procedure, prior densities need to be specified for the parameters in the model. Based on earlier experience we fixed an inverted Gamma prior-density for the parameters $\sigma_{\xi,i}$ with expectation and standard deviation of 0.2; for ϕ_i the prior is a Beta, with expectation 0.86 and standard deviation 0.1, and all intervention and mean parameters get normal priors centered at zero with standard deviation 2. Such priors are informative in the sense that no problems with non-existing posteriors can occur, but vague enough to allow the data to choose the location and spread of the posterior density.

3.4 A look at the extracted components

While a detailed examination of the posterior densities of the model parameters is postponed until Appendix C, it is at this stage informative to present estimates of the currency factors and related volatilities. Figures 2 and 3 plot the extracted factors obtained after the estimation of equations (2)-(3) without interventions. Each of the plots displays the evolution of the posterior mean of the level e_{ti} or volatility factor $\sigma_{ti} = \exp(h_{ti}/2)$, and a 1-standard deviation error bound. The index numbers between parentheses identify the time of occurrence of the financial events listed in Table 1.

In order to illustrate the relevance of these extracted factors, it is interesting to proceed to some preliminary analysis. We conduct three types of illustrations:

- isolation of important financial events identified through the inspection of the factors;
- regression analysis of the different volatility measures;
- assessment of the sensitivity to the addition of the fourth currency in the estimation procedure.

Financial events

Figure 2, that plots the level of the currency factors, suggests that the USD has globally appreciated between 1995 and 2001. It also captures the steady depreciation trend of the Euro after its inception in 1999 until halfway 2001, and reproduces the sharp depreciation of the GBP following its exit from the EMS. Figure 3 uncovers interesting patterns of currency volatility. In particular, it shows that the long-term volatility of the USD has decreased since 1991 and is on average lower than the one of the Euro and the YEN. The graphs in the second and fourth panels depict the effects of the EMS crisis in September 1992. Interestingly, this impact is not visible in the factors peculiar to the USD and the YEN, which makes sense since the EMS crisis primarily affected the European currencies. Also, the figure shows that the pound was more affected that the Euro, which is meaningful since the British currency was at the heart of the EMS troubles at that time. To sum up, the factors allow to uncover

[9] The improvement is found in a method to lower correlation in the Gibbs chain. With higher frequency data over long sample periods, the correlation in original methods becomes prohibitively high.

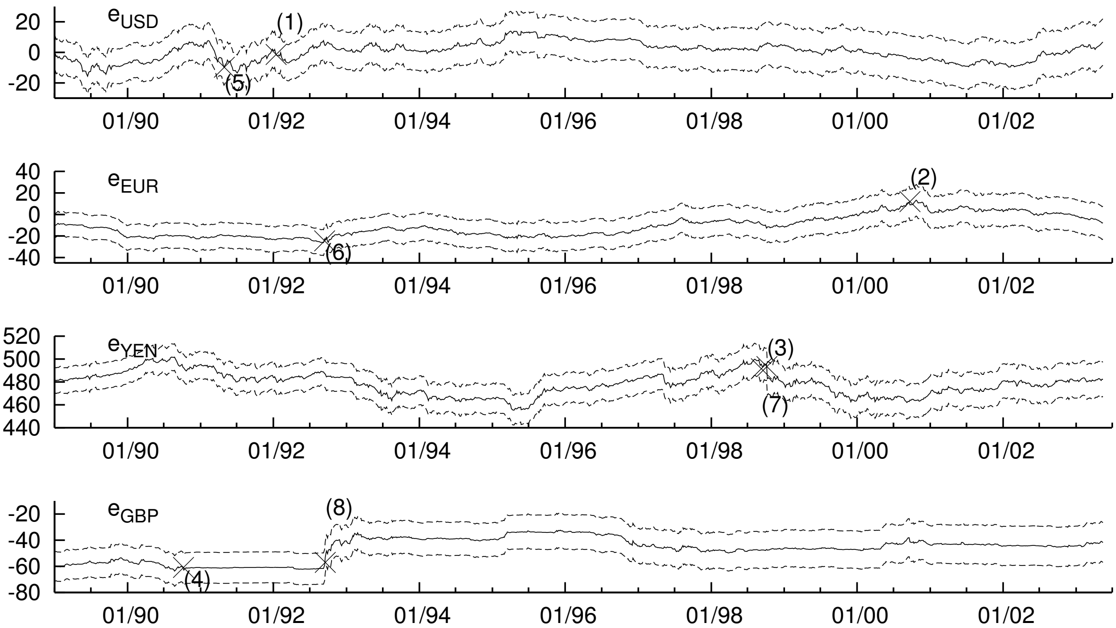

Figure 2: Posterior mean of level factors e_{it} extracted for the currencies, with a one-standard deviation error bound; the numbers between parentheses refer to events in Table 1

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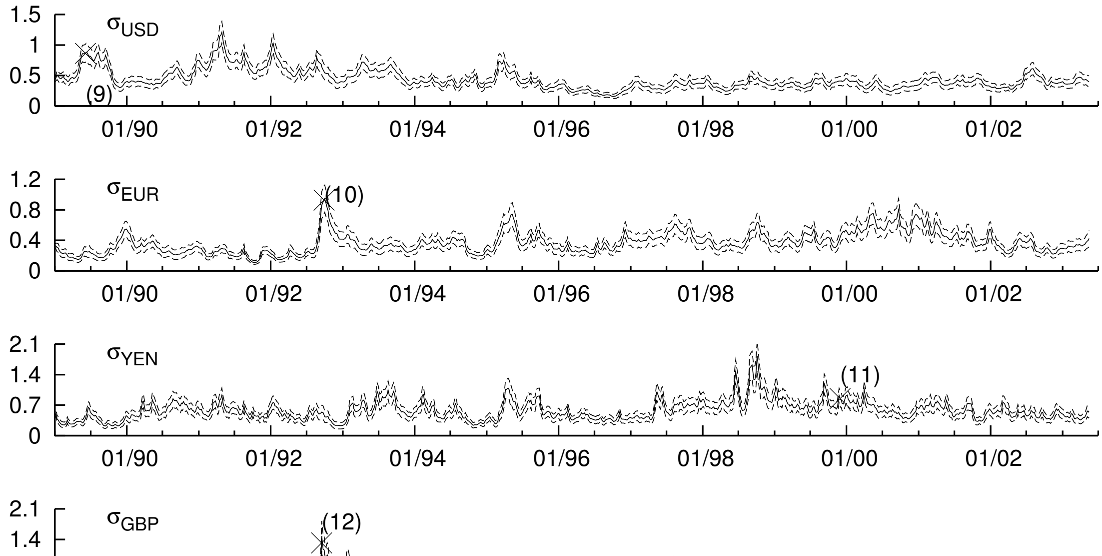

Figure 3: Posterior mean of volatility factors $\sigma_{it} = \exp(h_{it}/2)$ extracted for the currencies, with a one-standard deviation error bound; the numbers between parentheses refer to events in Table 1

patterns specific to the dynamics of the currencies which are not directly observable from the evolution of exchange rates.

Table 1: Extracted currency components and event study

Currency	Date	Index	Event
Largest appreciation			
USD	01-15-92	(1)	61 points surge in the Dow Jones
EUR	09-22-00	(2)	Concerted ECB intervention
YEN	10-07-98	(3)	Reported Japanese repatriation of funds
GBP	10-08-90	(4)	Entry in the EMS
Largest depreciation			
USD	05-01-91	(5)	Interest rate cut by the Fed
EUR	09-14-92	(6)	Interest rate cut by the BB
YEN	09-09-98	(7)	First interest rate cut in 3 years
GBP	09-17-92	(8)	Leaves the EMS; interest rate cut of 2%
Largest volatility increase			
USD	06-06-89	(9)	Unilateral Fed intervention
EUR	09-28-92	(10)	EMS crisis
YEN	11-30-99	(11)	BoJ Unilateral BOJ intervention
GBP	09-16-92	(12)	EMS crisis

The table reports the dates of the largest variations in the currency factors, along with the reported events according to the Factiva data base. The index numbers refer to the indices in Figures 2–3.

In a more systematic way, the ability of the factors to capture sharp variations of currencies can be illustrated by the identification of important events. To illustrate that, using the Factiva online events database (see `www.factiva.com`), we isolate the most important events associated to extreme variations in these currency factors. In particular, we pick up the days of the largest appreciation, largest depreciation and highest surge in volatility of each currency implied by the extracted factors and isolate the most reported event on that particular day. Table 1 reports the days and the associated event, while these are also reported in Figures 2 and 3. The table suggests that the sharp variation of these factors correspond to major financial events known to exert important impacts on the exchange rate. Interestingly, the majority of these particular events are country-specific or currency-specific events, i.e. shocks peculiar to a specific country or currency like unilateral interventions or key interest rates variations. This illustrates that the evolution of factors captures idiosyncratic dynamics of currencies.

Volatility regressions

The main purpose of the paper it to quantify the impact of CBIs on the country specific factors described by the SV model with unobserved components, i.e. equations (2) and (3). As surveyed by Humpage (2003), GARCH-type models have been extensively used in the empirical literature and might be considered as a useful benchmark to assess the contribution of our analysis. We propose to rely on the Exponential GARCH model of Nelson (1991) (EGARCH hereafter) since it ensures a positive variance, which might be useful when news variables (such as CBIs) are supposed to impact the volatility dynamics.

Defining the exchange return r_{tij} as $r_{tij} = s_{tij} - s_{t-1\,ij}$, the EGARCH$(1,1)$ model is specified as follows

$$r_{tij} = \beta^{\dagger}_{t\,ij} + \epsilon_{tij}, \tag{6}$$

$$\epsilon_{tij} \equiv \exp(h_{tij}/2) z_{tij}, \qquad z_{tij} \sim \mathcal{N}(0,1)$$

$$h_{tij} = \gamma^{\dagger}_{t\,ij} + \vartheta^{\dagger}_{1,ij} z_{t-1\,ij} + \vartheta^{\dagger}_{2,ij}[|z_{t-1\,ij}| - E(|z_{tij}|)] + \delta_{1,ij} h_{t-1\,ij}, \tag{7}$$

where $\vartheta^{\dagger}_{1,ij}, \vartheta^{\dagger}_{2,ij}$ and $\delta^{\dagger}_{1,ij}$ are parameters governing the evolution of the GARCH process. The CBIs are introduced both in the conditional mean and variance equations, as they were in the SV model (see equations (4) and (5)). The interventions influence equations (6)–(7) through

$$\beta^{\dagger}_{tij} = \beta^{\dagger}_{0,ij} + W_{tij}\beta^{\dagger}_{1,ij} \tag{8}$$

$$\gamma^{\dagger}_{tij} = \gamma^{\dagger}_{0,ij} + |W_{tij}|\gamma^{\dagger}_{1,ij}, \tag{9}$$

where W_{tij} is a vector of indicators for the different interventions effecting the exchange rate S_{ij} at time t. When there is no intervention, W_{tij} takes the value 0, otherwise it has a value of -1 or 1 in case of a buy or sell on a specific currency market. $\beta^{\dagger}_{ij} = (\beta^{\dagger}_{0,ij}, \beta^{\dagger}_{1,ij})$ and $\gamma^{\dagger}_{ij} = (\gamma^{\dagger}_{0,ij}, \gamma^{\dagger}_{1,ij})$ are the corresponding vectors of parameters. Unlike the SV model, these two vectors of parameters capture the effect of CBIs on the dynamics of the exchange rate returns and not in terms of the country specific components.[10]

No universally acceptable loss function exists for the ex-post comparison of highly non-linear forecasts. Following Andersen and Bollerslev (1998), we assess the relative forecasting performances through the the analysis of the value of the coefficient of multiple correlation, or R^2, in a Mincer-Zarnowitz regression approach (see Mincer and Zarnowitz 1969). We nevertheless need a benchmark measure of volatility to assess the quality of these regressions. A traditional measure for the observed volatility in the literature is the square of the returns or the absolute returns (Pagan and Schwert, 1990). However, in a recent paper dealing with daily volatility, Andersen and Bollerslev (1998) have shown that this measure is not fully relevant and have proposed an alternative measure. This new measure uses cumulated squared intradaily returns, also called "realized volatility", which is a more precise measure of the daily volatility. Following these authors, we compute the daily realized volatility as:

$$\mathrm{RV}_{tij}(\theta) = \sum_{k=0}^{23} r^2_{tij,\theta-k}, \tag{10}$$

where $r_{tij,h}$ denotes the intraday hourly return of the corresponding exchange rate peculiar to day t between time $h-1$ and h (by convention $r_{tij,-h} = r_{t-1\,ij,24-h}$ for $h = 1, 2, \ldots, 23$).

For a given quotation time θ (we drop the θ index for the sake of simplicity in the notations), we project RV_{tij} on a constant and the in-sample one-step-ahead forecast of r_{tij}, denoted $F_{tij|t-1}$, based on the EGARCH(1,1) model of Nelson (1991) or on the SV model with unobserved components.[11] More specifically the Mincer-Zarnowitz regression takes the

[10] Estimation of this model has been done by quasi-maximum likelihood using the G@RCH 4.0 package (see Laurent and Peters 2002) on the three main exchange rate returns vis-à-vis the US dollar, i.e. EUR/USD, YEN/USD and GBP/USD.

[11] We do not investigate the out-of-sample performance of these models since the models are only used to quantify the impact of interventions.

form

$$\mathrm{RV}_{tij} = a + bF_{tij|t-1} + u_t, t = 1, \dots, T. \tag{11}$$

Note that for the SV model, since the country components are assumed independent, $F_{tij|t-1} \equiv \widehat{\exp(h_{ti})} + \widehat{\exp(h_{tj})}$. The forecasts of the factor standard deviations $\widehat{\exp(h_{ti})}$ are extracted from a run of the particle filter (Pitt and Shephard 1999) at the posterior mode of the parameters of the model.

Recently, Andersen, Bollerslev and Meddahi (2005) have shown that the R^2 of the Mincer-Zarnowitz regression (11), based on the realized volatility, underestimates the true predictability of the competing models. To overcome this problem, they propose a simple methodology (based on the recent non-parametric asymptotic distributional results in Barndorff-Nielsen and Shephard 2002) to obtain an adjusted R^2, denoted $\overline{R}^2$, that takes into account the measurement errors in the realized volatility.[12]

Table 2 reports the estimated parameters of the Mincer-Zarnowitz regressions (robust standard errors are given between parentheses) as well as the $\overline{R}^2$'s and R^2's (between brackets) of both the EGARCH(1, 1) model and the SV model (without CBIs dummies) estimated on the three daily exchange rates vis-à-vis the USD.[13]

Table 2: In-sample forecast comparison

Mincer-Zarnowitz Regressions

Series	EGARCH(1,1)			SV		
	$\hat{a}$	$\hat{b}$	$\overline{R}^2[R2]$	$\hat{a}$	$\hat{b}$	$\overline{R}^2[R2]$
EUR/USD	-0.08	1.28	**0.19**	-0.10	1.34	**0.38**
	(0.04)	(0.10)	[0.11]	(0.05)	(0.12)	[0.22]
YEN/USD	-0.13	1.34	**0.23**	-0.17	1.43	**0.40**
	(0.12)	(0.26)	[0.17]	(0.13)	(0.29)	[0.30]
GBP/USD	-0.02	1.21	**0.26**	0.00	1.16	**0.40**
	(0.03)	(0.11)	[0.19]	(0.04)	(0.13)	[0.28]

Note: Estimated parameters of the Mincer-Zarnowitz regression (11), either using the in-sample forecast of the standard deviation according to the EGARCH(1, 1) model (columns 2-4) or using the SV model with unobserved components (columns 5-7). Robust standard errors are given between parentheses. The adjusted $R2$'s (à la Andersen et al. 2005), denoted $\overline{R}^2$, are reported boldface in columns 4 and 7 while the unadjusted $R2$'s are reported below between brackets.

From Table 2, one hardly sees a difference between the two competing approaches in terms of bias. Indeed, irrespective of the specification, a and b are not significantly different from 0 and 1 (at the usual 5% level), respectively for the YEN/USD and GBP/USD series. For the EUR/USD series, both models provide slightly biased estimates of the realized volatility since the β's are significantly higher than 1. However, there is no doubt about the supremacy of the unobserved components model in terms of predictability of the volatility. Indeed, the $\overline{R}^2$'s and R^2's are between 30% to almost 50% higher than the ones obtained from the EGARCH(1, 1)

[12]See Andersen et al. (2005) for more details on the construction of $\overline{R}^2$.

[13]In order to save space and due to the similarity of the results, we do not report the estimation results for each quotation time but select randomly those related to exchange rates quoted at 16h00 GMT+1 (i.e. $\theta = 16$).

specification. Note that the same conclusion applies regardless we use a simple GARCH or a more sophisticated long-memory (E)GARCH model.

Estimating using 3 or 4 currencies

For the extraction of the currency level and volatility factors three exchange rates, involving 4 currencies, are used as input. In Section 3.2 it was explained how 3 currencies are the bare minimum for extracting the factors, and that adding the fourth can be expected to add extra information and precision in the measurement of the factors. To illustrate the effect, the SV model (without interventions) was estimated both using the 3 currencies USD, EUR and YEN, and adding the British Pound to the mix.

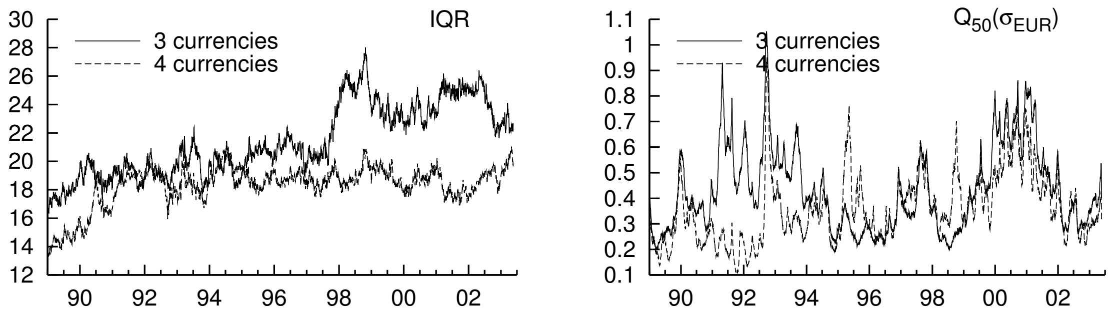

Figure 4: Average interquartile range of the currency level factors (left panel) and the median of the volatility factor σ_{EUR} (right panel) extracted using 3 or 4 currencies, respectively.

The left panel of Figure 4 displays the average interquartile range (IQR) of the posterior density of the currency level factors of USD, EUR and YEN. Overall, the level factors are estimated more precisely, with a smaller IQR, when a fourth currency is taken into account. This effect is especially strong starting in 1998, when the Asia crisis results in a jump in uncertainty for the Japanese Yen. The information included in the GBP/USD exchange rate is of great worth in that period to get a higher level of precision for the currency factors of the other countries.

In the right hand panel, the median of the posterior density of the standard deviation of the Euro currency returns is shown.[14] Overall, the estimate of volatility does not differ strongly whether two or three exchange rates are used. However, especially in the period of stability in the EMS (10/90-9/92), the inclusion of GBP in the estimation indicates that volatility in the EUR/USD exchange rate in this period is not so much due to the EUR as to the USD. Therefore, with four currencies the evaluation of risk related to the EUR is lower than when the one estimated when GBP is left out of the estimation.

4 Estimation and results

4.1 Central bank intervention data

Our CBIs data capture daily official interventions (interventions disclosed by the central banks themselves) conducted by the three major central banks over the same period ranging from

[14]We get similar conclusions for the other currencies.

January 1 1989 to June 30 2003. The CBIs expressed on a daily basis as net purchases or sales of foreign currencies expressed in USD. These data were obtained either through bilateral contacts with the central banks (Fed and Bundesbank) or through downloading the data from the website (Bank of Japan). Note that the official interventions concerning the British Pound are not available, at least to external researchers; this currency is taken along in the estimation in order to facilitate the estimation of the currency factors for levels and volatilities.

The data set excludes spurious reports of interventions. As usual in the literature, we distinguish between coordinated interventions (operations conducted by the two involved central banks on the same markets, the same day and in the same direction) from unilateral ones. The CBIs are captured by dummy variables as done in most papers of the empirical litarature and in a consistent way with the signalling channel which is the underlying theoretical framework used to rationalize the impact of these operations on exchange rates.

We consider eight different types of interventions:

- Coordinated operations by the Fed and the Bundesbank (**BB-Fed**) on the **EUR/USD** market;
- Coordinated operations by the Fed and the Bank of Japan (**BoJ-Fed**) on the **YEN/USD** market;
- Unilateral operations by the **Fed** on the **EUR/USD** market;
- Unilateral operations by the **Fed** on the **YEN/USD** market;
- Unilateral operations by the the Bundesbank (**BB**) or the ECB on the **EUR/USD** market;
- Operations conducted by the Bundesbank (**BB**) against other European currencies in the context of the European Monetary System (**EMS**);
- Unilateral operations by the **BoJ** on the **YEN/USD** market;
- Unilateral operations by the **BoJ** on the **EUR/YEN** market.

Table 3 reports the number of interventions days broken down by type of operation and by currency market.

4.2 Quotation time

While our analysis is conducted at the daily frequency, we pay particular attention to the choice of the quotation time of the exchange rates S_{tij}. This importance stems from the recent findings of the literature (Dominguez 2003 and 2004; Payne and Vitale 2003; Beine et al. 2004) suggesting that the impact of CBIs on the moments of exchange rate returns are of short-run duration and mean-reverting. As emphasized by Beine et al. (2004), such evidence stresses the importance of choosing an appropriate and separate quotation time to study the impact of each type of operation. Another approach is to conduct a pure intraday analysis on the impact of CBIs but this is not feasible at present. First, the exact timings of the operations conducted by the three central banks studied here are not available. Secondly,

Table 3: Number of interventions days (1/1/1989-30/6/2003)

	YEN/USD	EUR/USD	EMS	EUR/YEN
BB-FeD	-	58	-	-
BoJ-FeD	72	-	-	-
Fed	31	64	-	-
BoJ	227	-	-	18
BB/ECB	-	33	33	-

Note: the figures report the number of (official) interventions days on each market. BB-FeD, BoJ-FeD, Fed, BoJ and BB/ECB denote concerted interventions of the Bundesbank (before 1998) or ECB (after 1998), concerted interventions of the BoJ and the Fed, unilateral Fed interventions, unilateral BoJ and unilateral Bundesbank/ECB interventions respectively; For the BoJ interventions, due to unavailability of official data before May 1991, the data capture the days of reported interventions for the first part of the sample.

conducting a purely intraday analysis may be cumbersome since intraday FX data are known to exhibit a complex seasonality. This intraday periodicity gives rise to a striking repetitive (U-shape) pattern in the autocorrelations of the absolute or squared returns (proxies for the volatility) While theoretically feasible, extracting both the unobserved country specific volatilities and their seasonality using the Bayesian methods developed by Bos and Shephard (2004) is beyond the scope of the paper. Due to unavailability of the exact timing of these official interventions, it is necessary either to use auxiliary information or to make assumptions on the time range of the operations. Appendix B discusses in details the choice of the optimal quotation time relative to each type of operation.

4.3 EGARCH estimates

For the sake of comparison, we complement our analysis in terms of country factors by a traditional GARCH analysis aimed at capturing the impact of interventions on the two first moments of the exchange rate returns. As surveyed by Humpage (2003), this type of approach has been extensively used in the empirical literature and might be considered as a useful benchmark to assess the contribution of our analysis. To this aim, we rely on the EGARCH$(1,1)$ specification presented in equations (6)–(9) with CBIs introduced both in the conditional mean and variance equations.

4.4 Results

Table 4 reports the estimates of the impact of CBIs. Columns 4-6 (labelled 'EGARCH') give respectively the estimates of the impact of CBIs on the exchange rate moments using the EGARCH approach ($beta^\dagger$ and $gamma^\dagger$ parameters), their robust standard errors (s) and the p-value for a one-sided test of significance of the parameters (p). Columns 7-10 (labelled 'Bayesian SV') report the estimates of the impact of CBIs on the currency components of these exchange rates (β and γ parameters), their standard deviation (s) and the p-value for a one-sided test of significance of the parameters (p). The upper panel (labelled 'Mean equation') reports the findings relative to the mean (first moments on either the exchange rate returns or the country factors) while the lower panel (labelled 'Variance equation') provides the results relative to the volatility side (second moment of either the exchange rate returns or the country factors).

For the sake of brevity, we only report the estimates of the impact of each type of operation. It should be nevertheless clear that each estimate comes from the estimation of the full model, i.e. the one admitting a specification in which all components of W_{tij} (for the EGARCH model) or W_{ti} (for SV) are included both in the mean and variance equations. The model is estimated using a quotation time for S_{tij} corresponding to the likelihood of the occurrence of the investigated operation. This timing is reported in column 3. For instance, the estimates of the impact of coordinated interventions of the Fed and the Bundesbank are drawn from the estimation of the models using S_{tij} observed at 15h GMT+1. For this particular quotation time, only the impact of coordinated interventions are reported to the extent that 15h GMT+1 is the only optimal quotation time for this type of operations. The choice of the optimal quotation time is motivated in Appendix B.[15]

It should be first emphasized that in general, the results obtained in the empirical literature using GARCH models are to a certain extent sample-specific (Humpage 2003). This partly reflects that intervention policies change over time. This explains why our EGARCH results are representative of this literature only to some degree and that there exists some discrepancies with previous studies. The choice of the 'optimal' quotation time, the use of a specific GARCH model and the type of interventions might also explain these discrepancies.[16]

4.4.1 Mean results

If one defines an efficient operation as the one moving the exchange rate in the desired direction, i.e. net purchases of dollars leading to an appreciation of the dollar, an efficient operation implies positive coefficients of CBIs in the mean equation of the EGARCH model (i.e. μ_{ij}), positive coefficients on the non-US (Euro or Yen) component (i.e. $\beta_i > 0$, $i \neq 0$) and negative coefficients on the US component (i.e. $\beta_j < 0$).[17] An important exception concerns the impact of the so-called auxiliary interventions (BB within the EUR, and the BoJ on the EUR/YEN market). Since all exchange rates are expressed in terms of USD, it is impossible to define an expected coefficient in the EGARCH model for these operations. In this sense, the significantly positive coefficient associated to unilateral interventions of the BoJ on the EUR/YEN obtained in the EGARCH specification is difficult to interpret. In contrast, given the definions of these interventions, efficiency in the factor approach implies a positive coefficient on the Euro component associated to EMS interventions, a negative coefficient on the Euro component associated to interventions on the EUR/YEN and a positive coefficient on the YEN component associated to interventions on the EUR/YEN.[18]

In line with the literature, our EGARCH estimates for the impact on the level of exchange rate returns suggest that CBIs are poorly efficient instruments, at least at a daily frequency. Coefficients relative to the impact of the mean are either insignificant at the

[15] We report one sided p-values. This choice is motivated by the fact that in a Bayesian perspective, one-sided p-values correspond to the probability mass of the parameter distribution above or below zero. For the sake of consistency, one-sided p-values are also used for the Egarch results.

[16] For instance, using reported interventions of the BoJ before 1991, Beine et al. (2002) find some significant impact of the coordinated interventions on the YEN/USD over the 1985-1995 period.

[17] As discussed by several authors like Fatum (2002), such a definition of efficiency might be restrictive. It nevertheless conveys the advantage of simplicity and delivers a testable proposition.

[18] By convention, EMS intervention dummy takes 1 for DEM sales. The EUR/YEN intervention dummy takes 1 for yen sales.

Table 4: Impact of central bank interventions, 1989-2003

Mean equation

Banks	FX	GMT+1	EGARCH $\beta_1^\dagger$	s	p	Bayesian SV Cur	β	s	p
BB-Fed	EUR/USD	15	−0.138	0.161	0.20	USD	0.100	0.113	0.19
						EUR	0.023	0.042	0.29
BoJ-Fed	YEN/USD	3	−0.311	0.122	0.01	USD	−0.041	0.098	0.34
						YEN	0.041	0.063	0.26
BB	EUR/USD	12	−0.277	0.184	0.07	USD	0.042	0.119	0.36
						EUR	0.057	0.059	0.17
BB	EMS	14	0.009	0.136	0.49	EUR	0.168	0.115	0.07
Fed	EUR/USD	17	−0.095	0.067	0.08	USD	0.078	0.084	0.18
						EUR	0.036	0.036	0.15
Fed	YEN/USD	17	−0.192	0.129	0.07	USD	0.249	0.158	0.06
						YEN	0.018	0.066	0.39
BoJ	YEN/USD	3	−0.279	0.060	0.00	USD	0.002	0.035	0.48
						YEN	−0.017	0.041	0.34
BoJ	EUR/YEN	3	0.275	0.130	0.02	EUR	−0.222	0.141	0.06
						YEN	0.151	0.189	0.21

Variance equation

Bank(s)	FX	GMT+1	EGARCH $\gamma_1^\dagger$	s	p	Bayesian SV Cur	γ	s	p
BB-Fed	EUR/USD	15	0.918	0.299	0.00	USD	0.790	0.253	0.00
						EUR	0.198	0.296	0.25
BoJ-Fed	YEN/USD	3	0.444	0.056	0.00	USD	0.412	0.237	0.04
						YEN	0.962	0.236	0.00
BB	EUR/USD	12	0.098	0.122	0.40	USD	0.382	0.319	0.12
						EUR	0.463	0.339	0.09
BB	EMS	14	0.166	0.078	0.02	EUR	0.774	0.365	0.02
Fed	EUR/USD	17	−0.040	0.043	0.17	USD	0.603	0.249	0.01
						EUR	−0.381	0.384	0.16
Fed	YEN/USD	17	−0.170	0.122	0.09	USD	0.530	0.347	0.06
						YEN	−0.048	0.361	0.45
BoJ	YEN/USD	3	0.051	0.037	0.09	USD	0.026	0.139	0.43
						YEN	0.324	0.138	0.01
BoJ	EUR/YEN	3	−0.220	0.124	0.04	EUR	0.433	0.448	0.17
						YEN	0.850	0.425	0.02

Note: The entries report the estimated impact of the corresponding CBIs (see columns 1 and 2), based on the EGARCH model (columns 4–6, using QMLE estimation) and the Bayesian SV model (columns 7–10). The column GMT+1 indicates the quotation time of the exchange rate used to estimate the EGARCH of the Bayesian SV models. The columns marked by s and p report the robust standard errors and the p-value for a one-sided test of significance of the parameters, for the EGARCH model; for the SV model the posterior standard deviation and corresponding quasi-p value are given. As the posteriors of the intervention parameters for the Bayesian estimation are almost normal, the classical significance level can be used in a Bayesian setting.

5% critical level (BB-Fed:EUR/USD, BB:EUR/USD, Fed:EUR/USD) or significantly negative (BoJ:YEN/USD, Fed:YEN/USD). Consistent with those findings, our factor approach also points to poor efficiency, although emphasizing less counterproductive impacts of these interventions. The poor efficiency of CBIs in terms of exchange rate levels has been rationalized by several theoretical analysis. For instance, Bhattacharya and Weller (1997) model the interaction process between the central bank and market participants in the presence of interventions. They discuss the conditions under which the impact of CBIs might be close to zero or even perverse. This might occur when a central bank puts an important weight in its intervention reaction function on its own exchange rate target.

Regarding the efficiency of the CBIs, an interesting contribution of our factor approach nevertheless lies in the estimated impact of the intra-EMS interventions conducted by the Bundesbank. Looking at impact in terms of the Euro component, the results points to some (weakly) efficient operations of the Bundesbank since in general DEM sales tended to lower the value of the German currency. The same holds for the sales of YEN against the Euro carried out by the BoJ which tended to appreciate the European currency. These results illustrate that auxiliary interventions are easier to interpret in a currency factor model. They show that they turn out to be important control variables to be taken into account in an econometric analysis aimed at capturing the effect of CBIs.

4.4.2 Volatility results

The results in terms of volatility in the EGARCH approach illustrate several well-known stylized facts documented in the literature. First, interventions are clearly found to raise rather than to lower exchange rate volatility. This has been extensively documented by numerous authors including the early contributions of Baillie and Osterberg (1997) and Dominguez (1998). Consistent with the previous literature, we find no evidence of negative significant impact, either in terms of exchange rate or in terms of currency component.[19] Second, in general, coordinated interventions (see BB-Fed:EUR/USD and BoJ-Fed:YEN/USD operations) are found to exert stronger effects than unilateral operations. This result, consistent with many other previous findings (Catte, Galli and Rebecchini 1992, Beine et al. 2002, among others) confirms that the impact depends on the information conveyed by those operations as argued by the signalling theory. Nevertheless, results in Table 4 show that unilateral interventions may also exert some weaker direct impact, in line with some previous studies (Dominguez 1998, Beine et al. 2004).

With respect to the volatility side, the factor approach adopted in this paper allows to shed some interesting light on the impact of these interventions. The distinction between currency components allows to identify significant impacts which are not captured in the classical approach in terms of exchange rates. The discrepancy in terms of findings between the two approaches is partly due to the fact that the impact in terms of exchange rates is a non-linear combination of the impacts in terms of currency components. The coordinated interventions between the Fed and the BoJ are found to affect the volatility of both currency components. Such an evidence is weaker for the coordinated interventions between the Fed and the Bundesbank for which the effect on the DEM component is less important. In a more general perspective, the CBIs are not found to affect more the volatility of the USD rather than the other currencies involved in the FX operation. In this respect, the results are

[19] Once again, the coefficient obtained in the EGARCH specification for the EUR/YEN interventions is difficult to interpret.

not supportive of the existence of any USD-bias in the investigation of CBIs and suggest a negative answer to Question 2 relative to the existence of a specific dollar effect.

The results of the factor approach also allow to document interesting asymmetric effects of CBIs in terms of volatility. Two new insights emerge from these estimates. First, the results of Table 4 suggest that unilateral interventions tend to exert highly asymmetric effects in terms of currencies. Interestingly, it is found that unilateral CBIs tend to impact the volatility of the currency of the central bank conducting the intervention. In other terms, a unilateral intervention conducted by the Fed tends to primarily impact the uncertainty of the US currency (see the coefficients of the Fed:EUR/USD and Fed:YEN/USD). Strikingly, the same result holds for the BoJ on the YEN/USD as well for the Bundesbank (on EUR/USD). These results question the usual conclusion of the empirical literature emphasizing the absence of any impact of unilateral interventions. They suggest that operations of this type not only fail to deliver the desired effect in terms of level of the currency but also involve some significant costs in terms of uncertainty.[20] These results are also clearly supportive of an operating signalling channel for the FOREX interventions in the sense that the operations mostly affect the expectations of agents regarding the currency of the central bank present in the market and not the other currency component. Combined with the evidence concerning the effect of concerted operations, our results suggest that depending on the type of operation, intervention induces different impacts on the currency market. Hence, the answer to Question 1 relative to the evidence of asymmetric effects between unilateral and concerted operations in terms of currency dynamics, is affirmative.

Another interesting insight concerns the impact of auxiliary interventions. Unlike the approach of exchange rates, the decomposition in terms of currency components succeeds in capturing volatility effects of these interventions. The rationale for this result might be the following. Referring to the signalling channel which has by far received the most important empirical support, there is no theoretical reason why we should expect some intra-EMS interventions or intervention on the DEM/YEN market to impact the volatility of the USD. As a result, the variation of the exchange rate expressed in USD is likely to be smoothed. In contrast, the identification of the currency component allows to abstract from this drawback and permits a clear identification of the increase of the volatility. These results imply that auxiliary interventions tend to have some indirect impact on the exchange rate and should be accounted for in future investigations of the impact of CBIs as relevant control variables. In this sense, they lead to a positive answer to Question 3, 'Should one account for interventions on auxiliary markets when analysing the impact of FX operations in the major markets?'

5 Conclusion

In this paper, we assess the impact of foreign exchange interventions carried out by the G-3 central banks over the recent period. Unlike the traditional approaches in terms of exchange rates, we propose to investigate the impact of these operations on the two first moments of the currency components of these exchange rates. The identification of these components is carried out through the estimation of a recent Bayesian stochastic volatility model proposed by Bos and Shephard (2004) augmented by explanatory variables both in the mean and the volatility parts. Through the analysis of the effects of the central bank interventions, our

[20] We adopt here the usual view that central banks tend to dislike bursts of volatility of their currencies. This view has nevertheless been scarcely questioned by a couple of authors (e.g. Hung 1997).

paper provide a first attempt to capture asymmetric effects of financial news in the foreign exchange markets in terms of currencies.

Our results provide new insights on the impact of these interventions. First, they confirm that in general, central bank operations do not succeed in moving the exchange rate in the desired directions and tend to lead to more uncertainty. Second, our results do not support the existence of some USD bias in the sense that US currency would be impacted more by direct purchases or sales operated by the major central banks. Third and most importantly, while the traditional approaches do not identify clear effects in terms of exchange rate volatility, we find that unilateral interventions obviously tend to primarily raise the volatility of the currency of the central bank involved in these operations. Finally, our approach allows to capture in a more rational way the impact of operations carried out by the central banks on other but related markets.

This paper could be extended to an intra-daily analysis. Nevertheless, one should overcome the fact that the exact timings of official interventions are not available. This could be done by relying on the timings extracted from the newswire reports as used by Dominguez (2004). Another hurdle concerns the application of the estimation techniques to high-frequency data as well as the way to account for intra-daily seasonality patterns.

A Statistical background

The model presented in Section 3 is built up from unobserved components e_{it} for the level and h_{it} for the volatility of the exchange rates. The relation between (log-) exchange rates s_{ijt} and the respective volatilities h_{it}, h_{jt} is clearly non-linear. In such a case, convenient classical state space estimation methods are not available. In this paper we apply Bayesian methods developed by Bos and Shephard (2004).

In their paper, a Bayesian sampling procedure is proposed for models with stochastic volatility and a conditionally Gaussian State Space form (GSSF-SV). The variant of the algorithm applied here samples from the augmented parameter space $\theta = (\sigma_\xi, \phi, \gamma, \beta, \mathbf{e}, \mathbf{h})$ in the following steps:

1. Initialise u, θ, and compute $\sigma^2 = f(u, \sigma_\xi, \phi, \gamma)$ as a function of u.
2. Update draw from $\theta, \alpha | y, u$ by
   (a) Sampling from $\theta | y, u$;
   (b) Sampling from $\alpha | y, \sigma^2(u, \sigma_\xi, \phi, \gamma), \theta$ using the generic GSSF simulation smoother (Frühwirth-Schnatter 1994, Carter and Kohn 1994, De Jong and Shephard 1995, Durbin and Koopman 2002).
3. Recompute σ^2 from u and θ, sample from $\sigma^2 | \alpha, y, \theta$, and reconstruct $u = f^{-1}(\sigma^2, \lambda)$. The sampling is performed using the method in Kim, Shephard and Chib (1998).
4. Repeat from 2.

where $u_{it} \equiv \xi_{it}/\sigma_{\xi i}$ are the normalised disturbances in the volatility equations.

Bos and Shephard (2004) discusses a range of possibilities for step 2a. In this paper we use a number of measures to increase the speed of convergence of the algorithms:

1. The level intervention parameters β are taken up into the state using an augmented state vector (see Durbin and Koopman 2001). In this manner, the posterior density of the β's follows without any additional sampling (at the cost of a larger state vector).

2. Parameters of the volatility equations are sampled separately per country. As the persistence of volatility in the U.S. is purportedly not related to the persistence in the Euro area, i.e. the parameters can be supposed largely independent, sampling can be done separately without introducing extra correlation in the chain of drawings.

3. The level of the volatility, governed by γ_i, is sampled from it's full conditional density $(\gamma_i|\phi_i, \sigma_{i\xi}, u_i)$. This density can be closely approximated by a multivariate normal density, with mean and variance closely related to a convolution of Gumbel Extreme Value densities.

4. The remaining parameters, ϕ_i and $\sigma_{i\xi}$ are sampled using a random walk Metropolis algorithm, see Chib and Greenberg (1995).

This sampling scheme delivers draws from the posterior density of the parameters in θ and of the unobserved components e_t, h_t. Note that all the sampled values are based on all exchange rates, over the full time period. In terms of the state space model, the samples correspond to 'smoothed' estimates, instead of filtered estimates. In case full filtered estimates are requested, the particle filter can be used (Pitt and Shephard 1999).

B Timing of CBIs

As explained in the main core of the text, the choice of the quotation time of the exchange rate is of primarily importance for assessing the impact of CBIs on the dynamics of exchange rates as well as currency components. In this appendix, we discuss for each type of operation the choice of the optimal quotation time, i.e. the quotation time necessary to capture, if any, the potential impact of these operations. Basically, we can rely on a set of elements which, together, suggest a likely time range:

- Opening hours of the local markets. As documented by Dominguez (1998) and Dominguez (2003), most central banks tend to operate on their own local markets, providing orders to the domestic commercial banks;

- Need to coordinate or not with another central bank; a good example is provided by the concerted operations on the EUR/USD market;

- Empirical distributions of the timings of reported interventions for each central banks by Dominguez (1999) and Dominguez (2003). These distributions involve the timing of the interventions perceived by the FX traders using newswire reports (Reuters). They nevertheless ignore the secret (unreported interventions)[21] and do not account for the possible lags between the effective operations and the trader reports.[22] The moments

[21] Dominguez (2003) mentions that over the 1989-1995 period, 25% of the Fed interventions were not reported by Reuters.

[22] Such a presumption is confirmed by the recent results obtained by Payne and Vitale (2003) showing that using reported interventions of the Fed they find that exchange rates react up to 45 minutes ahead of Reuters intervention reports. Importantly, the lengths of these lags may be variable as the reporting depends on the dealers willingness to release the information.

of these distributions nevertheless provide useful insight in the possible timing of the operations.

B.1 Coordinated interventions on the EUR/USD

Following the discussion of Dominguez (1998) and Dominguez (2003) as well as the evidence of Beine et al. (2004) with respect to their impact on volatility, we assume that the coordinated interventions of the Fed and the Bundesbank take place during the overlap period (ranging between 13h and 17h GMT+1). Such a choice is consistent with the distribution over time provided by Dominguez (1999) using Reuters reports. We therefore pick up the middle of the time range for the exchange rate quotation, i.e. 15h00 GMT+1. This choice is consistent with the evidence provided by Beine et al. (2004).

B.2 Coordinated interventions on the YEN/USD

Unlike for coordinated interventions between the ECB and the Fed, there is no overlap period between the Japanese and the US market. Therefore, assuming that most interventions are carried out by central banks on their own local markets (see Dominguez, 1999 on this particular point), a coordinated intervention on this market takes the form of an intervention of the BoJ followed by an intervention of the Fed. An initial BoJ intervention will therefore induce some reaction of the markets during Japanese trading time. We therefore investigate the impact using the middle of the time range for the exchange rate quotation, i.e. at 3h GMT+1.

B.3 Unilateral interventions of the BB on the EUR/USD

When carrying out a unilateral operation, the Bundesbank (ECB) does not need to take advantage of the simultaneous opening of the US and the European market. Therefore, the operation can take place either before of after the opening of the US market (13h GMT+1). Such a procedure is consistent with the evidence provided by Dominguez (1999) documenting an average time of occurrence of BB operations around 12h30 GMT+1. We therefore use the quotation at 12h00 GMT+1.

B.4 EMS interventions of the BB on the EUR/USD

All EMS interventions are coordinated interventions in the sense that they involve the same operation on the part of the other European central banks. Notice that we do not have the counterpart EMS currency against which the German Mark was traded, and therefore do not know which European central bank was involved in these operations. Given the fact that these operations can occur all over the day, we choose 14h00 GMT+1 as our exchange rate quotation.

B.5 Unilateral interventions of the Fed on the EUR/USD and the YEN/USD

When carrying out a unilateral operation, the Fed does not need to take advantage of the simultaneous opening of the US and the European market. Therefore, the operation can take place either before of after the close of the European market (17h00 GMT+1). Such a procedure is consistent with the evidence provided by Dominguez (1999) documenting an average time of occurrence of Fed operations around 15.57 GMT+1 and the distribution over time (Figure 2) showing a significant part of the operations occurring after 16h00 GMT+1. The same line of reasoning can apply to the unilateral interventions of the Fed on the YEN/USD market.

B.6 Unilateral interventions of the BoJ on the YEN/USD and the EU/YEN

Given the stylised fact that most central banks use a network of domestic commercial banks to carry out their interventions, it might be inferred that the vast majority of BoJ interventions are carried out between 0h00 and 7h00 GMT+1. This is confirmed by the evidence given by Dominguez (1999), with an average BOJ intervention time around the Tokyo Lunch, i.e. at 4:56 GMT+1. Like for the coordinated interventions, we choose 3h00 GMT+1 as our quotation time.

C Posterior sampling

Using the method exposed in Appendix A, a collection of the posterior density of the parameters $\sigma_\xi, \phi, \gamma, \beta$ (and factors **e** and **h**) is sampled. While the main interest lies into the sampled factors, the model parameters $\sigma_\xi, \phi, \gamma, \beta$ play their own role in modelling persistence of the stochastic volatility, and the size of the influence of each type of the CBIs.

For the results on the extracted factors themselves, in Section 3.4, Figures 2–3 and the Mincer-Zarnowitz regressions of Table 2, a sample of size 100,000 was collected, after a burn-in period of 20,000 iterations. This sample did not include any interventions, the only parameters in the model are the ones governing the stochastic volatility processes of the factors.

The parameters in the model need a prior specification. Section 3.3 already described the priors. For σ_ξ an inverted-Gamma with expectation and standard deviation of 0.2 is chosen. A priori ϕ is assumed to come from a Beta density, with expectation 0.86 and standard deviation 0.1. The intervention and mean parameters γ and β are initially drawn from $\mathcal{N}(0, 4)$.

Table 5 displays the posterior mean, the standard deviation, the range from the 5% to the 95% quantile, the autocorrelation at lag 30 and the inefficiency measure as highlighted in Shephard and Pitt (1997). The inefficiency measure indicates the amount of correlation in the chain, comparing the variation of the parameter to a measure of variation adapted for the autocorrelation at a window of the size of 2,000 lags. A theoretical value of 1 would indicate a fully efficient sample with independent drawings, whereas high values are a sign of higher correlation.

The results of the Table suggest that the posteriors of σ_ξ and ϕ are little spread out, and also the posteriors of the γ parameters governing the overall level of volatility are estimated clearly away from the prior mean, hence the data is informative on these parameters. This effect is more easily seen in Figure 5, where prior and posterior are drawn together.

Though the data is informative on the parameters, the posterior sample correlation remains high, even after applying the methods of Bos and Shephard (2004). On the other hand, the correlation was low enough for convergence to take place, and the sample at hand is large enough for the analysis in aforementioned sections.

For measuring the impact of central bank interventions, in Table 4, a different timing of the exchange rates was chosen for each of the intervention parameters. Tables 6–7 display the series of statistics for the intervention parameters. The timing of the quotations used in the estimation is the same as the one used in the core analysis (see Table 4). From these statistics

Table 5: Posterior statistics for the factor SV model

Parameter	Factor	Mean	Std. dev	$[Q_{2.5\%}, Q_{97.5\%}]$	ρ_{30}	Ineff
σ_ξ	USD	0.152	0.02	[0.11, 0.20]	0.59	218.6
	EUR	0.185	0.03	[0.14, 0.24]	0.55	213.6
	YEN	0.237	0.03	[0.18, 0.30]	0.47	118.9
	GBP	0.336	0.05	[0.24, 0.45]	0.61	251.1
ϕ	USD	0.981	0.01	[0.97, 0.99]	0.80	375.4
	EUR	0.977	0.01	[0.96, 0.99]	0.87	456.4
	YEN	0.961	0.01	[0.94, 0.98]	0.71	204.4
	GBP	0.973	0.01	[0.95, 0.99]	0.83	372.8
γ	USD	−1.689	0.14	[−1.92, −1.38]	0.89	490.8
	EUR	−2.210	0.12	[−2.45, −1.98]	0.81	340.0
	YEN	−1.321	0.10	[−1.53, −1.12]	0.70	196.6
	GBP	−3.132	0.23	[−3.61, −2.72]	0.77	294.2

Note: The table reports the posterior mean, standard deviation, 2.5 and 97.5% quantile, the 30th order autocorrelation and the inefficiency measure (Shephard and Pitt 1997), for the parameters governing the variability, autocorrelation and overall level of the stochastic volatility.

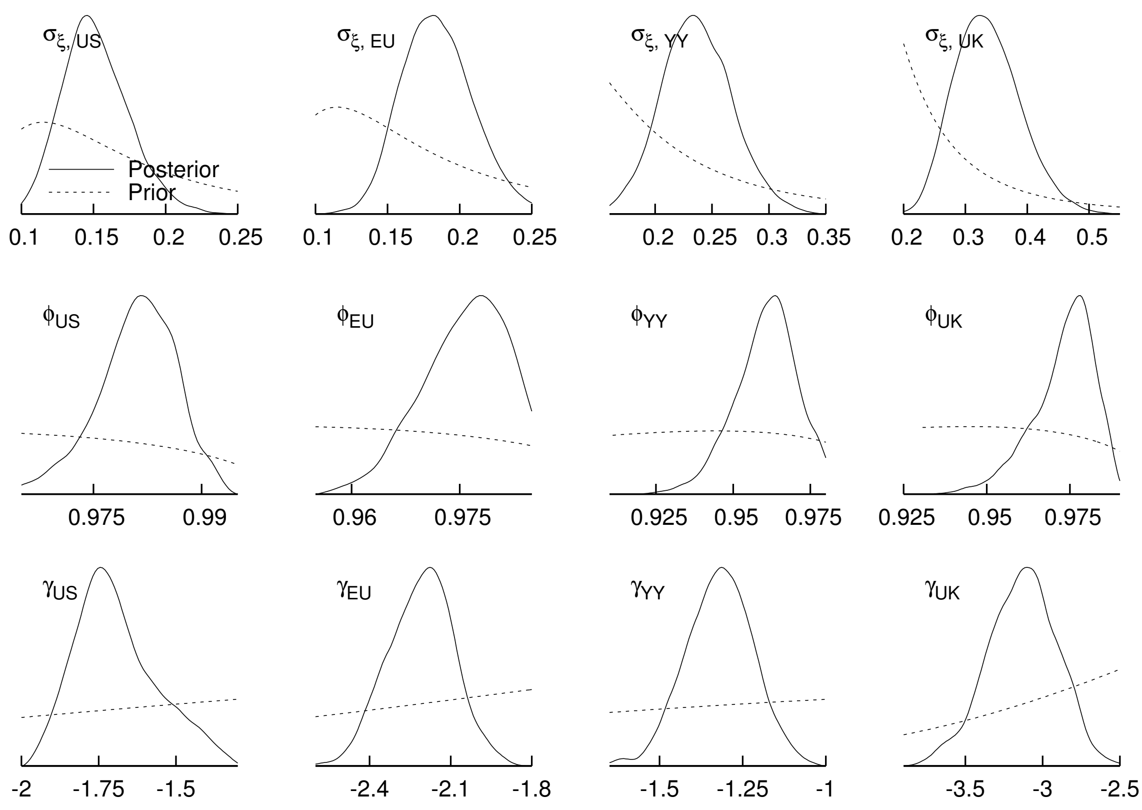

Figure 5: Posterior distribution of parameters of the factor SV model, without interventions

Table 6: Posterior moments of the level intervention parameters (β_1)

Banks	FX	Factor	GMT+1	Mean	Std. dev	$[Q_{2.5\%}, Q_{97.5\%}]$	ρ_{30}	Ineff
BB-Fed	EUR/USD	USD	15	0.100	0.11	[−0.12, 0.32]	0.03	3.0
BB-Fed	EUR/USD	EUR	15	0.023	0.04	[−0.06, 0.11]	0.04	7.1
BoJ-Fed	YEN/USD	USD	3	−0.041	0.10	[−0.23, 0.15]	0.05	−8.0
BoJ-Fed	YEN/USD	YEN	3	0.041	0.06	[−0.08, 0.17]	0.03	6.7
BB	EUR/USD	USD	12	0.042	0.12	[−0.19, 0.27]	0.03	45.2
BB	EUR/USD	EUR	12	0.057	0.06	[−0.06, 0.17]	0.03	5.7
BB	EMS	EUR	14	0.168	0.11	[−0.06, 0.40]	0.04	12.9
Fed	EUR/USD	USD	17	0.078	0.08	[−0.08, 0.24]	0.04	7.7
Fed	EUR/USD	EUR	17	0.036	0.04	[−0.03, 0.11]	0.03	4.8
Fed	YEN/USD	USD	17	0.249	0.16	[−0.06, 0.56]	0.05	3.4
Fed	YEN/USD	YEN	17	0.018	0.07	[−0.11, 0.15]	0.01	6.3
BoJ	YEN/USD	USD	3	0.002	0.03	[−0.07, 0.07]	0.05	29.9
BoJ	YEN/USD	YEN	3	−0.017	0.04	[−0.10, 0.06]	0.06	−1.9
BoJ	EUR/YEN	EUR	3	−0.222	0.14	[−0.51, 0.06]	0.02	0.6
BoJ	EUR/YEN	YEN	3	0.151	0.19	[−0.21, 0.53]	0.05	23.3

Note: See Table 4 for a description of the entries; these parameters concern interventions on the level intervention parameters β_1, of mentioned banks operating on the exchange rate market in column 2, measuring the effect on the currency in column 3. The parameters were sampled using the timing as in Table 4.

Table 7: Posterior moments of the volatility intervention parameters (γ_1)

Banks	FX	Factor	GMT+1	Mean	Std. dev	$[Q_{2.5\%}, Q_{97.5\%}]$	ρ_{30}	Ineff
BB-Fed	EUR/USD	USD	15	0.790	0.25	[0.30, 1.30]	0.13	31.1
BB-Fed	EUR/USD	EUR	15	0.198	0.30	[−0.38, 0.79]	0.18	68.8
BoJ-Fed	YEN/USD	USD	3	0.412	0.24	[−0.05, 0.88]	0.10	27.9
BoJ-Fed	YEN/USD	YEN	3	0.962	0.24	[0.50, 1.44]	0.20	70.0
BB	EUR/USD	USD	12	0.382	0.32	[−0.24, 1.02]	0.11	93.4
BB	EUR/USD	EUR	12	0.463	0.34	[−0.19, 1.14]	0.12	24.4
BB	EMS	EUR	14	0.774	0.37	[0.07, 1.49]	0.14	49.6
Fed	EUR/USD	USD	17	0.603	0.25	[0.11, 1.09]	0.19	82.4
Fed	EUR/USD	EUR	17	−0.381	0.38	[−1.17, 0.33]	0.19	33.9
Fed	YEN/USD	USD	17	0.530	0.35	[−0.16, 1.22]	0.15	29.6
Fed	YEN/USD	YEN	17	−0.048	0.36	[−0.75, 0.67]	0.09	1.2
BoJ	YEN/USD	USD	3	0.026	0.14	[−0.24, 0.30]	0.23	46.5
BoJ	YEN/USD	YEN	3	0.324	0.14	[0.05, 0.59]	0.16	46.8
BoJ	EUR/YEN	EUR	3	0.433	0.45	[−0.45, 1.31]	0.14	−7.0
BoJ	EUR/YEN	YEN	3	0.850	0.43	[0.03, 1.71]	0.06	18.9

Note: See Table 6 for a description of the entries; these parameters (γ_1) concern interventions on the volatility processes. The parameters were sampled using the timing as in Table 4.

it is once again apparent that the data is informative about the parameters, as the posterior distribution moves away from the prior (see Section 3.3; for the intervention parameters the prior is $\pi(\beta, \gamma) \sim \mathcal{N}(0, 2)$). The efficiency of sampling these intervention parameters is far higher, hence only a sample of size 10,000, with burn-in of 2,000 iterations, was deemed sufficient for the analysis in Section 4 and most notably Table 4. Using a larger sample size was not possible, due to the high computational burden of models of this type.

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