CENTRAL BANK FOREX INTERVENTIONS ASSESSED USING REALIZED MOMENTS*

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Preliminary Draft

Abstract

This paper studies and assesses the impact of G3 Central Bank interventions on the DEM/USD exchange rate properties using daily realized moments of exchange rate returns (obtained from intraday data) for the period 1989-2001. Boxplots of the realized moments for the intervention day, the days preceding and following the intervention day illustrate the shape of this impact. Rolling regressions results for an ARFIMA model for realized moments are used to measure the intervention impact and characterize its significance.

Our analysis allows to confirm previous findings but also to highlight new ones including the timing and the persistence of coordinated interventions on exchange rate volatility, important volatility spillovers, impact on exchange rate cross-moments like covariance and correlation as well as significant responses in terms of realized skewness.

JEL Classifications: C22, E44, F31, G15.

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1 Introduction

This paper belongs to the growing literature using intraday information to study and assess the impact of Central Bank Interventions (CBI) on forex markets. Previous studies have used daily or weekly forex (FX) data to document level and variance effects of CBI's. Among the more recent literature using intraday data, Dominguez (2003) pays particular attention to the influence of intraday market conditions on effectiveness of the CBI's.

The objective of the paper is twofold. First, by conducting event studies of the periods preceding and following CBI’s our aim is to document various effects of CBI’s, whether desired or not. Using the daily realized moments (see a.o. Andersen, Bollerslev, Diebold and Labys 1999, 2001) obtained from hourly FX data on the DEM/USD rates for the period from January 4, 1989 to February 28, 2001, the paper analyzes the shape of the impact of CBI’s on mean returns, volatility and higher moments as well as on several spillover measures. Using boxplots covering the intervention day, the two preceding days and the two days after we carry out an event study describing the pattern of the market reactions to interventions. We distinguish between unilateral interventions by the Bundesbank and the US Federal Reserve respectively and coordinated interventions of these Central Banks on the DEM/USD rate. To study the impact of spillovers, we also consider the impact on the DEM/USD rate of unilateral interventions of the Bank of Japan and the US Federal Reserve respectively and coordinated interventions of these Banks in the YEN/USD market.

Second, the paper goes beyond describing the impact of CBI’s. Using rolling regressions it attempts to explain movements in realized moments by relating these moments to the type of intervention and to dummy variables for the day of the week. This analysis is carried out to measure sign, size and significance of the various types of interventions. This analysis could be extended further by accounting for the state of the market at the time of the intervention along the lines of Dominguez (2003) who finds that the timing of interventions matters. For instance, she finds that interventions which occur when trading volume is large or when a macroeconomic announcement has been scheduled are expected to have big effects. Another possible extension could consist of a joint analysis of realized moments. These two extensions are left for future work.

While Dominguez’s (2003) study is close to ours in some respects, there are important differences. Dominguez (2003) analyzes returns and squared returns to assess the impact of interventions. We rely on up to the third daily realized moments to graphically illustrate and to measure the effects of CBI’s in rolling regressions. Doing so, we hope to measure all relevant types of effects of CBI's on the exchange rate distribution. In particular, we also pay attention to spillover effects of interventions in the YEN/USD market to the DEM/USD exchange rate, both by conditioning on interventions on the YEN/USD rate and by looking at the covariances and correlations between the two exchange rates studied. Interestingly, under appropriate conditions, daily realized moments yield consistent and highly efficient estimates of return moments and superior forecasts (see e.g. Andersen, Bollerslev, Diebold and Labys, 2002, on realized volatility). Moreover they have the advantage to correct for specific hour-of-the-day effects. Finally, the observation periods differ. Dominguez (2003) studies the period 1987-1995 whereas we analyze more recent data for the period 1989-2001.

The paper is organized as follows. In Section 2, we shall report boxplots of various realized moments for the different types of interventions mentioned above, starting two days before the day
when the intervention occurred and including realized moments up to the end of the second day after the intervention. After this visual and model free inspection, rolling regressions (rolled over the various hours of the day) are estimated on the realized moments to quantify (and test) the impact of CBI’s across hours of the day. In Section 3 we shall discuss the modelling implications of our empirical findings. Section 4 draws some general lessons both for modelling and for policy interventions from our analysis.

2 The Impact of CBI’s on Daily Realized FX Moments

2.1 Introduction

As they convey a large piece of information about fundamentals and future monetary policies (see Mussa 1981), direct CBI’s in the FX markets are expected to exert important effects on exchange rate dynamics. While the core of the empirical literature is devoted to studying the impact of CBI’s thereby focusing mostly on returns and volatility (see for recent surveys Baillie et al. 2001 and Sarno and Taylor 2001), the CBI’s may have other possibly unintended side-effects on exchange rates. As we will show, the effects also highly depend on the type of CBI. Possibly, they also differ depending on the state of the market when the intervention takes place, as has been shown by Dominguez (2003) for returns and Beine et al. (2002b) concerning volatility. However this latter aspect will not be investigated here but left for future research.

Focusing on the two major exchange rate markets (DEM/USD and YEN/USD), we distinguish between six different types of official interventions:¹

1. unilateral interventions conducted by the Bundesbank (ECB after 1999) on the DEM/USD market denoted BBU,

2. unilateral interventions by the US Federal Reserve on the DEM/USD market denoted FEDU,

3. coordinated interventions defined as interventions conducted on the DEM/USD market the same day and in the same direction by the two involved central banks denoted COORD,

4. unilateral interventions conducted by the Bank of Japan (BoJ) on the YEN/USD market denoted BoJU,

5. unilateral interventions by the US Federal Reserve on the YEN/USD market denoted FE-DUY,

6. coordinated interventions defined as interventions conducted on the YEN/USD market the same day and in the same direction by the two involved central banks denoted COORDY.²

Note that sometimes we make the distinction between CBI’s involving purchases or sales of USD. For instance, unilateral purchases (resp. sales) of the Bundesbank are denotes BBUp (resp. BBUs).

Similarly, we study six potential effects even though other effects could also be considered:

¹In this paper, we focus on official interventions and do not make any distinction between secret and reported interventions (see Dominguez and Frankel 1993 as well as Dominguez 1998). While interesting, the so-called secret puzzle (Sarno and Taylor 2001) mostly applies to the eighties. Since the beginning of the nineties, most major central banks have increased the transparency of their FX operations. This evolution is obvious for the Fed but also for the BoJ (see Ito 2002 on this point).

²We neglect Bundesbank and BoJ interventions on the DEM/YEN market as they were very rare.
1. effects in terms of exchange rate returns,

2. effects in terms of exchange rate volatility on the market on which they take place,

3. volatility spillover, i.e. effects on the volatility of a CBI in another market,

4. effects on the covariance of exchange rates,

5. effects on the correlation between exchange rates,

6. and finally effects on higher moments of exchange rate distributions, namely skewness.

Table 1 provides a summary of the various potential effects by type of CBI.

<table>
<thead>
<tr>
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<th>BBU</th>
<th>FEDU</th>
<th>COORD</th>
<th>BoJU</th>
<th>FEDUY</th>
<th>COORDY</th>
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<tr>
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<td>1</td>
<td>2</td>
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<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Volatility spillover</td>
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<td>5</td>
<td>6</td>
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<tr>
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<tr>
<td>Higher moments</td>
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<td>11</td>
<td>12</td>
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<td>11</td>
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Table 1: Cases of Potential Effects of CBI's.

Combining CBI and effects types leads to a taxonomy of twelve different cases. In the following subsections, we report for each case a summary of the main findings of the literature. One major contribution of this paper is to provide new evidence on these various effects, using the recent results on realized moments for measuring exchange rate moments. We focus on the effects at a daily frequency using boxplots which provide evidence on the effects of CBI by focusing on the specific days for which the investigated events (CBI) took place. An important feature of our analysis is that we make use of intraday hourly exchange returns for building consistent measures of daily exchange rate moments. This allows to highlight several important findings in terms of CBI impacts, namely impact persistence and the importance of choosing the appropriate quotation time.

### 2.2 Drawbacks of Using Intradaily Data

The use of intradaily data has been found to yield interesting insights on the impact of central bank interventions, as documented for instance by Dominguez (2003). Actually, Dominguez (2003) relies on news reports provided by the wire services to capture the exact timing of the interventions. Chang and Taylor (1998) followed the same strategy to capture intraday effects of CBI in the YEN/USD markets. By contrast, no official release of the exact timing of the intervention operation is available. Therefore, one has to rely on reported rather than official interventions to assess the efficiency of FX operations conducted by the central banks. Nevertheless, there might be some discrepancy between both types of interventions. First, by using reported interventions.

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3For the sake of comparison with previous findings (Galati and Melick, 1999), we focus only on skewness and do not consider kurtosis. Nevertheless, such an investigation could easily be carried out and is left for future work.
rather than official interventions one neglects the so-called secret interventions, i.e. official interventions that are unknown to dealers in the FX markets. While the bulk of secret interventions took place mostly in the eighties, a significant number of CBI’s conducted by the BoJ in the early nineties remained secret. Our investigation period ranging from 1989 to 2001 obviously includes some secret interventions, which calls for an alternative approach to the use of intraday data. Second, there might be a significant lag between the effective operation(s) and the reporting of central bank interventions. Importantly, the lengths of these lags may be variable as the reporting depends on the dealers willingness to release the information.

Another reason why conducting a purely intraday analysis may be cumbersome is that 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 returns (proxy for the volatility). In this respect, Andersen and Bollerslev (1997) have shown that neglecting this seasonality pattern leads to obvious misspecification biases and thus to misleading economic interpretations. Consequently, relying on a standard intraday approach to fully characterize the impact of CBI’s on the first three moments would lead to a complicated and hardly manageable model. By using intraday realized moments computed over a 24-hour period one avoids having to worry about the intraday seasonality pattern (see below).

2.3 Effects on Daily Returns

Basically, intervention policies may be prompted by different objectives. Amongst these objectives, influencing trend movements in the level of exchange rate returns is obviously the most frequent one. It has been basically the objective of the Fed, the Bundesbank and the BoJ since the late seventies, with an important exception after the Louvre Agreement in February 1987 until the beginning of the nineties. One obvious recent example of a central bank aiming at reversing undesirable trends in exchange rates is provided by the very active intervention policy followed by the BoJ. As suggested by Ito (2002), interventions leading to a weaker yen belong to the set of policy measures aiming at improving the recent Japanese economic and financial situation.

Unilateral interventions aiming at influencing exchange rate returns have been used by the three major central banks (Case 1). Nevertheless, as illustrated by the Plaza Agreement in September 1985 that promotes central bank cooperation in order to depreciate the dollar, coordinated interventions are considered as more effective for influencing the level of exchange rates (Catte et al. 1992) (Case 2). On the whole, the empirical literature provides very weak evidence of systematic impacts of central bank interventions on exchange rate returns. In general, authors do not identify any robust effect in the conditional mean of exchange rate returns (Baillie and Osterberg 1997a).

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

5 Interestingly, Dominguez (1999) uses two methods in order to account for intraday seasonal patterns in exchange rate volatility. This makes the estimation procedure to capture the impact of reported interventions quite cumbersome. One question in using this approach concerns the relationship between the observed seasonal patterns and the occurrence of news or interventions. In Dominguez (2003), the author does not include seasonal filtering but compares intraday volatilities (captured by the squared 5-minutes returns) between episodes of interventions and days of non intervention and tests for the equality of the two variances. While straightforward, this procedure does not rely on regressions allowing to capture the effects in terms of volatility persistence.

6 Focusing on the Fed policies, Dominguez (1999) reports four different aims: influencing trend movements in the level of exchange rates, calming disorderly markets (i.e. eliminating excess volatility), rebalancing the foreign exchange reserves and intervening in support of other central banks.
Nevertheless, Baillie and Osterberg (1997b) find some empirical support for interventions influencing forward exchange risk premium. When some effects on the spot exchange rate returns are detected, the impact is contrary to the objectives, i.e. purchases of US dollar leading to a depreciation of the dollar (Baillie and Osterberg 1997a, Beine et al. 2002). This perverse result tends to hold for both unilateral and coordinated interventions. This result has usually been interpreted as a lack of credibility of central banks adopting a leaning-against-the wind policy.

Using intraday hourly exchange rate returns (see Appendix 1 for details on data), we provide some evidence supporting the previous results. Let us first denote $y_{t,\theta}$ the realized return of day $t$ quoted at hour $\theta$ ($\theta = 0, 1, \ldots, 23$). Making use of returns defined on an hourly basis, $y_{t,\theta}$ can be computed as:

$$y_{t,\theta} = \sum_{j=0}^{23} r_{t,\theta-j}$$

in which $r_{t,j}$ denotes the hourly intraday return of the corresponding exchange rate peculiar to day $t$ between time $j - 1$ and $j$ and by convention $r_{t,-j} = r_{t-1,24-j}$ for $j = 1, 2, \ldots, 23$.

Once the daily realized returns are computed, an event study can be performed to assess the impact of the CBI's on this realized moment. For instance, in order to evaluate the effects of unilateral USD purchases by the Bundesbank (Case 1), Panel 1 of Figure 1 plots the median as well as the first and third quartiles of the subsample of daily realized returns $y_{t,\theta}$ for each intervention day, the two preceding days and the two days after. Since we have no precise information about the timing of the official interventions, we vary $\theta$ between 0 and 23 to describe the pattern of the market reactions to interventions. This gives a set of 24 points on each figure (ranging from 0 to 1 on the graph for the intervention day), each tick corresponding to an increment of $\theta$ (starting at 0 each day). Furthermore, to give a more comprehensive overview of the impact of CBI's, we extend the boxplots for the two days preceding (from -2 to 0 on the graphs) and following the intervention days (from 1 to 3 on the graphs).

Figures 1 and 2 present respectively the boxplot corresponding to unilateral and coordinated interventions. On the whole, the evidence is fully consistent with the previous findings in favour of weak impact of CBI in terms of returns.\footnote{Appendix 1 describes the sources of CBI data. Over our investigation period, we observe the following numbers of FX operations: 33 unilateral USD sales of the Bundesbank (no unilateral purchase on the investigated period), 26 unilateral sales by the Fed, 38 unilateral purchases by the Fed, 14 coordinated purchases and 44 coordinated sales. On the YEN/USD market, we also observe 31 unilateral Fed interventions, 178 unilateral BoJ interventions and 72 coordinated interventions.}

Somewhat surprisingly, there is no or very little effect of unilateral purchases or sales on the median and the lower and upper quartiles of the returns during the intervention days. Coordinated interventions also have little impact on the median return during the intervention days.

The interquartile ranges however sharply increase in the second part of the intervention day and remain large during part of the day following the intervention day. This latter effect is due to the moving average feature of realized intraday returns. Here again, we may conclude that while materializing quickly any effect of interventions is of a temporary nature too. The increase of the interquartile ranges is consistent with the finding documented in the literature that CIB’s tend temporarilily increase uncertainty in the FX market. This finding will be confirmed when we study the impact of CBI’s on volatility measures.
2.4 Effects on Daily Volatility

Examples of explicit attempts to smooth exchange rate volatility through unilateral interventions (Case 3) are provided by the policy followed by the Bank of Canada before 1995 (see Murray et al. 1996). Indeed, the Bank of Canada adopted the rule of an automatic intervention when absolute daily changes of the CAD/USD exchange rate (often used in the past together with squared daily returns as a noisy proxy of the volatility) exceeded some threshold. The Louvre Agreement which took place in February 1987 promoted central bank cooperation in order to counteract excess exchange rate volatility on the major FX markets. This agreement resulted in heavy coordinated intervention operations of the Bundesbank and the Fed between February 1987 and the end of 1990 (case 4).

In general, the literature provides some clear cut evidence that a CBI tends to increase exchange rate volatility. Furthermore, such a finding is robust to the measurement of exchange rate volatility: this holds for 	extit{ex post} volatility captured by univariate GARCH models (Baillie and Osterberg 1997a, Dominguez 1998, Beine et al. 2002); this is also the case when focusing on 	extit{ex ante} or expected volatility measured by implied volatilities extracted from currency option prices (Bonser-Neal and Tanner 1996, Dominguez 1998, Galati and Melick 1999).

With respect to exchange rate volatility, we investigate the effects using boxplots. Following recent works of Andersen et al. (2001), we rely on daily realized volatility ($\sigma^2_{t,\theta}$) built from the squared intraday hourly returns:

$$\sigma^2_{t,\theta} = \sum_{j=0}^{23} r^2_{t,\theta-j}.$$  \hspace{1cm} (2)

Therefore $\sigma^2_{t,\theta}$, the daily volatility of day $t$ observed at time $\theta$, is built from the sum of the current and the 23 previous squared hourly returns. Unlike the daily squared returns that provide unbiased but very noisy volatility proxies, the daily realized volatility yields consistent and highly efficient estimates of the volatility (see Andersen et al. 2001 for more details about the properties of the realized volatility in a continuous time framework).

As in Subsection 2.3, an event study is first performed to visualize the impact of the CBI’s on the realized volatility. Looking at the boxplots reported in Figure 3, one identifies an important increase of volatility related to FX interventions. This result obviously holds for coordinated interventions of the Fed and the Bundesbank, which is fully consistent with the literature. Nevertheless, two additional interesting features emerge from this picture. First, for coordinated interventions, one identifies a sharp increase in FX realized volatility between 14:00 and 15:00 GMT, i.e. one hour after the beginning of the overlap period, i.e. simultaneous opening of both markets. Notice that the time lag between the European FX market (in Frankfurt) and the US market ranges between 5 and 7 hours. As reported by several authors including Dominguez (1998, 2003), coordinated interventions between the Fed and the BB (ECB) primarily occur during the opening overlap period. Therefore, this means that the response of FX volatility to coordinated interventions is

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8Such a positive impact of CBI is also confirmed by Beine (2002) in a multivariate GARCH framework. Some noticeable exceptions to this positive impact are provided by Beine, Laurent and Lecourt (2003) using volatility regime switching approach and by Mundaca (2001) accounting for exchange rate bands and simultaneity bias.

9We make use of the fact that at an hourly frequency, FX returns remain serially uncorrelated.
very fast, less than 1 hour, which is fully consistent with the findings of Dominguez(2003). The issue of whether this effect is highly persistent may be best tackled by investigating the pattern of estimates drawn from rolling regressions (see below). This emphasizes the importance of quotation time of exchange rates for capturing the impact of FX interventions in a consistent way. Second, from the boxplot, we see that the pattern of FX volatility changes display some asymmetry, i.e. the size of the increases in the volatility during intervention days are not symmetrically distributed around the median.

While the boxplots provide numerous details about the timing and the persistence of the CBI’s on the investigated realized moment, it is not suited to make inference. For this reason and to complete our study, rolling over all the possible value for $\theta$ ($\theta = 0, \ldots, 23$), we regress the realized FX volatilities on the daily central bank intervention data. We pay attention to the statistical properties of the FX realized volatilities. Preliminary investigation and results reported in the literature suggest that the log of FX daily realized volatility is nearly gaussian, displays some long memory (Andersen et al. 1999) and is sensitive to a day of the week effect (Hsieh 1989). More precisely, DEM/USD realized volatilities tend to be higher on Monday compared to the other trading days of the week. In order to account for these features, we follow Andersen et al. (1999) in estimating an ARFIMA$\{1, d, 0\}$ model but extend this specification by including a Monday dummy and more importantly dummy variables accounting for the CBI’s as additional explanatory variables:

$$(1 - \phi L)(1 - L)^d \left[ \ln(\sigma_{t,\theta}^2) - \mu_I \right] = \epsilon_t \quad (3)$$

where

$$\mu_t = \mu + \beta_0 I_{m,t} + \beta_1 I_{BBU,t} + \beta_2 I_{FEDU,t} + \beta_3 I_{COORD,t}$$
$$+ \beta_4 I_{FEDUY,t} + \beta_5 I_{BoJU,t} + \beta_6 I_{COORDY,t}$$

in which $d$ (the fractional integration parameter), $\phi$, $\mu$, and the $\beta_j$’s, ($j = 0, \ldots, 6$) are parameters to be estimated, $I_{m,t}$ is a dummy variable taking 1 if day $t$ is Monday, 0 otherwise. $I_{FEDU,t}$, $I_{BBU,t}$, $I_{COORD,t}$, $I_{FEDUY,t}$, $I_{BoJU,t}$, $I_{COORDY,t}$ are dummy variables taking 1 if respectively a unilateral intervention of the Fed on the DEM/USD market, a unilateral intervention of the Bundesbank/ECB on the DEM/USD market, a coordinated intervention on the DEM/USD market, a unilateral intervention of the Fed on the YEN/USD market, a unilateral intervention of the BoJ on the YEN/USD market, a coordinated intervention on the YEN/USD market took place on day $t$, 0 otherwise. $\epsilon_t$ is the error term which is assumed to be normally and identically distributed. Estimating model (3) for each combination of the various possible values of indexes $i$ ($i = -2, -1, 0, 1, 2$) and $\theta$ ($\theta = 0, \ldots, 23$) one ends up with a sequence of estimates of coefficients $\beta_j$ ($j = 1, \ldots, 6$), allowing to capture the evolution of the impact and the persistence of interventions across hours and days. The models are estimated over the period January 4 1989 to February 28, 2001 (3061 points). Figure 4 reports the sequence of point estimates of respectively $\beta_3$, $\beta_1$ and $\beta_2$ as well as their confidence intervals at a 95% confidence level. Note that the information on the confidence intervals allows one to test the significance of the slope coefficients for specific values of $\theta$.

Estimation of the ARFIMA models is carried out by exact maximum likelihood (Sowel 1992) under the normality assumption using ARFIMA 1.01 (see Doornik and Ooms 1999).
Rolling regressions reinforce the previous conclusions drawn from the investigation of the boxplots but also bring new insights. First, Figure 4 shows that unilateral interventions also exert significant effects on FX volatility, albeit less important than those exerted by coordinated interventions. Second, the timing on which they impact on FX volatility is quite different from the one particular to coordinated interventions: FX volatility seems to react to BB intervention in the morning (European time) while Fed interventions impact in the afternoon (US Eastern time). This is fully consistent with the fact that, without the need to coordinate and thus to take advantage of the market overlap, American and German authorities choose to conduct FX operations when only their local market is opened. Third and importantly, rolling estimates allow to characterize the persistence of coordinated and unilateral intervention. This is an important point, as there is a striking lack of consensus (both among academics and practitioners) about the typical horizon over which CBI’s exert some significant impact (see the survey of Neely 2001 on this point). For coordinated interventions, in line with the evidence drawn from the boxplots (Figure 3), the pattern of $\beta_3$ estimates shows a sharp increase at 15:00 GMT, i.e. one hour after the opening of the US market, confirming that the response to CBI is very fast. The significance of the $\beta_3$ estimates at time $t+1$ sharply drops after 16:00 GMT, i.e. after the closing of the German market. Given that a particular squared hourly return $r^2_{t,j}$ will be included in the next 24 measures of realized FX volatility, this means that this impact is of short duration, at most 2 hours. This finding has strong implications for approaches based on daily data. Choosing a wrong quotation time of the exchange rate is likely to lead to underestimation of the impact of CBI on exchange rate volatility. This point will be illustrated further in Section 4.

2.5 Daily Volatility Spillover Effects

In general, in the literature not much attention is devoted to volatility spillover effects, i.e. changes of FX volatility on a particular market related to some intervention on another market. Nevertheless, in line with the extensive evidence of volatility spillovers between international stock markets (see for instance Koutmos and Booth, 1994), major exchange rate markets are likely to be highly interdependent. Therefore, news and financial events particular to a market are likely to exert volatility effects on the other markets. Using univariate GARCH models of DEM/USD and YEN/USD exchange rates over the 1985-1995 period, Dominguez (1998) does not detect any robust effect of this type. By contrast, in a multivariate GARCH framework, Beine (2002) finds that coordinated interventions on the YEN/USD market tend to increase exchange rate volatility on the DEM/USD market.

Focusing on the sequence of estimates of parameters $\beta_4, \beta_5$ and $\beta_6$ allows to document of these volatility spillover effects. Figure 5 suggests the presence of important volatility spillovers. Volatility spillover effects are detected for all types of interventions, albeit less significant for unilateral Fed interventions. Once more, Figure 5 documents the intra-day variation of these effects. Volatility spillover effect of unilateral BoJ interventions ($\beta_5$) shows up at 1:00 GMT, i.e. one hour after the opening of the Japanese market. Interestingly, like for volatility effects, the

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Note that one could of course also study the spillover effects on FX returns and higher moments. This has not been done as the impact of direct CBI’s on these statistical measures are not found to be substantial.
pattern of $\beta_5$ estimates suggest that the response to CBI is very fast, at least one or two hours. Not surprisingly, the timing of BoJ impact contrasts with the one related to coordinated interventions ($\beta_6$) which show up in the US afternoon trading time. Basically, due to the absence of overlap between the Japanese and the US market and given that central banks generally prefer to intervene on their own market, coordinated interventions exert some impact when the Fed follows the BoJ, i.e. during the opening of the US market.

2.6 Daily Effects on Covariances and Correlations

As suggested by the extensive literature on market contagion (see among others Forbes and Ribo- gon 1999), CBI could also exert some significant spillovers in terms of covariance and correlation between exchange rates. One obvious reason is related to two distinct pieces of evidence. First, as reported by the core of empirical literature and fully confirmed by previous evidence reported above, CBI’s tend to increase exchange rate uncertainty. Second, there is also strong evidence that correlation and/or covariance between asset prices are not constant over time (Engle, 2000). Furthermore, there seems to exist a positive link between correlation and volatility pattern (see Andersen et al. 2001 for empirical evidence about exchange rates). Therefore, one might expect that CBI’s that tend to induce increases in FX volatility also lead to a positive impact on cross-moments of exchange rates. There has been very little investigation of that particular point in the literature. The only evidence we are aware of is Beine (2002) showing from a multivariate GARCH model estimated on daily data that coordinated interventions on the YEN/USD market (Case 8 of Table 1) induced strong and positive impact on both the covariance and the correlation between the YEN and the DEM against the USD. This result does not hold for unilateral intervention.

Empirical investigation in this particular field is highly constrained by the difficulties in handling and estimating multivariate GARCH models. In this perspective, realized covariances and correlations directly built from the intraday returns are of particular usefulness for capturing such impacts. Realized covariance between the DEM/USD and the YEN/USD (denoted $\sigma_{t,0}^{dy}$) may then be computed in a similar way as realized variance:

$$\sigma_{t,0}^{dy} = \sum_{j=0}^{23} c_{t,j} - j,$$

where $c_{t,j}$ denotes the instantaneous covariance (cross-product) between the DEM/USD and the YEN/USD peculiar to interval $j$ of day $t$. Realized correlation ($\rho_{t,0}$) may also be directly computed as:

$$\rho_{t,0} = \frac{\sigma_{t,0}^{dy}}{\sigma_{t,0}^x \sigma_{t,0}^y}$$

in which $\sigma_{t,0}^x$ and $\sigma_{t,0}^y$ are the realized standard deviations of respectively the DEM/USD and the YEN/USD (see Subsection 2.4).

Figures 6 to 9 report the boxplots with respect to patterns of DEM/USD-YEN/USD covariances and correlations associated to coordinated and unilateral interventions. Boxplots reported in Figures 6 and 7 suggest a strong positive response to coordinated interventions on covariance and to a lesser extent on correlation. Interestingly, the timing of the response of covariance is fully
in line with those associated to exchange rate volatility (see Figure 4). Panel 1 of Figure 6 suggests
that coordinated interventions on the DEM/USD also tend to increase exchange rate correlation.
At first sight, the positive increase of cross-moments does not hold for unilateral interventions (see
Figures 8 and 9). On the whole, these results are fully consistent with the one obtained by Beine
(2002) using a multivariate GARCH model on daily data. Nevertheless, once more, these results
show that the impact displays much of intradaily time variation.

In order to complement the evidence of the boxplots, we run also rolling regressions for the
patterns of covariance responses to the different types of CBI. The hyperbolic decay of the auto-
correlations of the covariance calls for the use of a long memory model similar to the one fitted
for variances (see again Andersen et al. 2001). Therefore, replacing \( \ln(\sigma^2_{t,\theta}) \) by \( \sigma^d_{t,\theta} \), we estimate
model (3). Like for the volatility analysis, we introduce simultaneously the different kind of interventions occuring on both currencies. The patterns of coefficient estimates \( (\beta_3, \beta_1, \beta_2) \) related to interventions conducted by the Bundesbank and/or the Fed as well as their confidence interval are reported in Figure 10.\(^{11}\) Panel 1 of this figure confirms the positive impact of coordinated interven-
tions on the DEM/YEN covariance \( (\beta_3) \). Interestingly, both the timing and the persistence of this
effect are similar to those related to exchange rate volatility. The patterns of estimates reported
in Panels 2 and 3 suggest that positive responses to unilateral interventions tend to hold, albeit
that they are much lower in terms of size than coordinated ones. As claimed by Beine (2002),
accounting for these effects in terms of cross-moments is of high importance in many applications
in portfolio and risk management of currencies.

2.7 Effects on Daily Higher Moments

Very little research has been conducted in order to capture the impact in terms of higher moments,
i.e. skewness and kurtosis. Skewness dynamics may be of particular interest since it captures the
evolution of downside or upside risk on a particular market. Galati and Melick (1999) are the
only ones trying to fill this gap. Using implied probability densities of market expectations at a
one-month horizon drawn from currency option prices, they do not find any significant impact
of perceived coordinated CBI’s in terms of third moment (Case 11). They do not however
focus on unilateral interventions (Case 11) which may also exert an important impact on first
and second moments of exchange rate distributions and limit their investigation to perceived
rather than official interventions.\(^{12}\) In contrast, we are not aware of any study of the impact on ex post third and/or fourth moments. The existence of such a gap is once more obviously
due to the difficulty of handling parametric models based on more general distributions than
the usual symmetric Gaussian and Student distributions. One solution would be to consider the
skewed Student density of Hansen (1994) with time-varying asymmetry parameter. Nevertheless,
estimation of such a model with explanatory variables in all conditional moments equation is
obviously empirically cumbersome.

\(^{11}\)In order to save space, we do not report the results related to interventions on the YEN/USD markets. They
are similar to the results reported in Figure 9 but are available upon request.

\(^{12}\)It is unclear whether the two series significantly differ from each others.
Alternatively, a simpler approach is to consider the realized skewness as suggested by Da-
corogna et al. (2001). Naturally, the realized skewness is defined as:

\[ Sk_{t,\theta} = \frac{\sum_{j=0}^{23} r_{t,\theta-j}^3}{\left(\sigma_{t,\theta}^2\right)^{3/2}} \]  

(6)

Boxplots of skewness dynamics (see Figure 11) suggest that skewness tends to react mainly
to coordinated USD purchases. Coordinated purchases of dollars lead to strong decreases of
realized skewness for both currencies. The timing of this effect seems consistent with the ones
previously documented for the volatilities and the cross-moments, i.e. occurring after 15.00 GMT.
By contrast, coordinated USD sales and unilateral operations do not seem to exert any significant
impact on the realized third moment.

Such an effect is fully confirmed by the results yielded by the rolling regressions. The speci-
fication used for capturing the impact of interventions on skewness differs from volatility models
defined in (3) with respect to both the type of parametric models and the way interventions are
defined. Preliminary analysis shows that there is a very fast decrease in the autocorrelations of
\( Sk_{t,\theta} \), regardless the value of \( \theta \). Therefore, a basic ARMA model seems sufficient to capture the
dynamics of the daily realized skewness. Second, like for exchange returns, the sign of the inter-
vention operation matters. Furthermore, boxplots reported in Figure 11 suggests that coordinated
purchases of USD tend to exert much more important effects than coordinated sales. This implies
than one should account for possible distinct effects of purchases and sales in the rolling regres-
sions. Basically, Figures 13 and 14 display the patterns of the \( \gamma \) coefficients estimated from the
following models \((i = 0, ..., 23; t = -2, ..., 2)\):

\[
(1 - \phi L)(Sk_{t,\theta} - \gamma_t) = \epsilon_t \]  

(7)

where

\[
\gamma_t = \gamma_0 + \gamma_1 I_{COORD_{s,t-i}} + \gamma_2 I_{COORD_{s,t-i}} + \gamma_3 I_{BBU_{s,t-i}} + \gamma_4 I_{FED_{s,t-i}} + \beta_2 I_{FEDU_{s,t-i}}
\]

The time-variation of the \( \gamma_2 \) coefficient in Figure 13 suggests that the impact of coordinated
purchases of the Fed and the Bundesbank occurs at the opening of the market overlap. Coordinated
purchases of USD lead the market to put more weight on a depreciating dollar than to a stronger
dollar, which confirms previous findings that central bank interventions can be counterproductive.
The patterns of the effect of coordinated USD sales and unilateral operations on the DEM/USD
market are much less striking (Figure 14).

Insert Figures 13 and 14 about here.

3 Implications for Modelling the Impact of CBI

One striking implication of our analysis lies in the emphasis on the importance of the quotation
time of the exchange rate for capturing daily effects of CBI. The patterns of coefficients capturing
the responses of CBI’s in terms of volatility (Figure 4) suggest that the impact is of relatively short duration. Therefore, in a traditional analysis the choice of a particular quotation time may lead to underestimation of the impact on daily data.

In order to illustrate these effects, we conduct some analysis on daily data and capture the impact of CBI through the traditional GARCH analysis proposed in the main core of the literature. We choose three different quotation times, following three representative analysis of this literature on daily data: Bonser-Neal and Tanner (1996) who rely on option prices quoted at 11.00 am on the Philadelphia market (around 17:00 GMT)\(^{13}\), Dominguez (1998) who uses New York market close data (21:00 GMT) and Beine, Bénassy and Lecourt (2002a) who use mid-day exchange rate data on the Frankfurt market (13:00 GMT). For each quotation time, we capture the impact using the following GARCH model:

\[
\begin{align*}
\sigma_t^2 &= \omega + \alpha \epsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \delta_0 I_{m,t} + \delta_1 I_{COORD,t-i} + \delta_2 I_{FEDU,t-j} + \delta_3 I_{BBU,t-h} \\
\end{align*}
\]

in which \( \epsilon_t \) is the daily return of the DEM/USD exchange rate and \( I_{COORD,t}, I_{FEDU,t}, I_{BBU,t} \) are the variables indicating intervention operations at time \( t \) as defined previously in equation (3). One well-known problem related to the use of daily data is the choice of the lag in defining the intervention variables. Basically, one must ensure that these variables are predetermined in order to control for the simultaneity bias (excess volatility causing interventions) and to make sure that the intervention operations occur before the quotation of the exchange rate. This means that depending on the time quotation, one has to lag some or all the intervention variables. For instance, the choice of the quotation time by Dominguez (1998) (21h00 GMT) ensures that all interventions of the Bundesbank and the Fed occurred before: this allows to use interventions at time \( t (i = j = h = 0) \). Nevertheless, such a quotation time might not be appropriate to capture volatility spillover effects due to unilateral BoJ interventions since that take place at the opening of the Tokyo market, i.e. after 0:00 GMT. The choice of the quotation time in Bonser-Neal and Tanner (1996) requires to lag unilateral intervention of the Fed \( (i = h = 0; j = 1) \). The lagging procedure for the coordinated interventions and the unilateral intervention of the Bundesbank is not required as the European markets are closed at that time. The same holds for the unilateral interventions of the Bundesbank when using the Beine, Bénassy and Lecourt (2002) quotation time if one assumes that most unilateral intervention of the Bundesbank occur in the morning trading time in Europe (this assumption might be too strong, of course); by contrast, it is strictly necessary to lag coordinated and unilateral interventions of the Fed \( (i = j = 1; h = 1) \).

We focus here on the results peculiar to the impact of coordinated interventions.\(^{14}\) Tables 2 reports the estimation results for the various quotation times. Strikingly, the results suggest that the quotation time of the exchange rate is crucial to capture both the size and the significance of the impact of coordinated interventions in terms of exchange rate volatility. If one uses the quotes at the close of the German market \( (\theta = 16.00) \), the impact of coordinated interventions is substantial and highly significative. If one uses the quotation time of Bonser-Neal and Tanner (1996) (one hour

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\(^{13}\)Bonser-Neal and Tanner (1996) use implied volatilities drawn from currency option prices in order to capture the impact of CBI in terms of expected volatility. Nevertheless, this analysis obviously belongs to the core of studies based on daily data.

\(^{14}\)It turns out that the GARCH estimations do not capture any effect of unilateral interventions on the conditional volatility. This slightly contrasts with the results obtained from realized volatility.
\[
i = j = 1; \ h = 0 \quad i = 0; j = 1; h = 0 \quad i = 0; j = 1; h = 0 \quad i = j = h = 0
\]

\[
\begin{array}{cccc}
\theta = 13 & \theta = 16 & \theta = 17 & \theta = 21 \\
\delta_1[COORD,t-i] & 0.076 & 0.204 & 0.117 & 0.023 \\
& [0.031] & [0.057] & [0.041] & [0.022] \\
\delta_2[FEDU,t-j] & 0.000 & -0.012 & -0.011 & 0.002 \\
& [0.041] & [0.011] & [0.009] & [0.009] \\
\delta_3[BBU,t-h] & -0.003 & -0.023 & -0.013 & 0.005 \\
& [0.041] & [0.051] & [0.042] & [0.032] \\
\end{array}
\]

Table 2: CBI volatility effects in a GARCH framework and quotation times

Note: Standard errors between brackets.

later, \( \theta = 17.00 \)), while the model captures the high significance of these coordinated interventions, the impact has dramatically decreased. This is due to the short duration of volatility effects of these interventions which was previously documented through the pattern of realized volatility responses. The use of the Dominguez (1998) quotation time -which makes sense because of the issue of simultaneity- does not allow to capture -at least over our investigation period- the impact of coordinated interventions. Both the size of the impact and the significance in the GARCH specification dramatically drop with respect to the previous quotation time. Once again, the reason is that the effect does not last beyond a 3 hours duration. Therefore, these results shed a complementary light on the crucial importance of choosing the right quotation time in daily analysis of CBI. Interestingly, they suggest that due to the simultaneity bias and the short duration of the effects which was emphasized in Section 2, one single GARCH model may be insufficient to fully capture the various effects associated to each kind of intervention. This stresses one important drawback of using daily data.

4 Conclusions

In this paper we have studied the impact of CBI's on foreign exchange markets for the DEM/USD and YEN/USD. We have carried out event studies for interventions days, the two days preceding an intervention and two days following an intervention using realized intraday moments to measure the impact of CBI's. In line with the bulk of previous research documented in the literature, we have looked at the impact of interventions on returns and return volatility and we have reached similar conclusions. CBI's appear not to have a significant impact on the returns. Coordinated interventions do have an impact on return volatility. This effect appears to be significant but it is of a temporary nature, at most a few hours.

Unlike parametric models applied to daily asset returns, our approach based on realized moments allows to test the impact on cross-moments of exchange rate returns as well as higher moments. Realized daily covariances are affected by CBI's as well and the timing of the impact is consistent with the one associated to volatilities. This tends to confirm previous findings of the literature based on multivariate GARCH models but allows to document the persistence of these effects. While positive, the impact of coordinated interventions on correlations however has not been found to be substantial. Interestingly, the impact of coordinated CBI's on realized intraday
skewness measures is apparent in the boxplots as well. The impact on the kurtosis could easily be conducted using the same approach but is left for future work. A striking finding is that any impact of CBI’s appear to be of a temporary nature, which is line with the findings of Dominguez (2003) for the first two moments. The results for the boxplots are confirmed by those from the analysis of rolling regressions.

Our comprehensive empirical analysis has both implications for policy-making and for empirical modelling of foreign exchange rates. The following conclusions might be relevant for policy making at Central Banks. In the past, even through coordinated interventions Central Banks appear not to have been effective in influencing DEM/USD exchange rate returns. When coordinating their interventions Central Banks have achieved a significant, albeit temporary effect on exchange rate volatility, covariance and to a lesser extent skewness. The question whether these effects have been intended and/or have been desired can not be answered on the basis of the statistical information studied.

For a modelling purpose it is important to conclude that CBI’s do not have a impact that extends beyond the intervention day. This conclusion implies that in an analysis of daily data, the impact of CBI’s can be accounted for by including dummy variables for the (coordinated) intervention days in those moments only that have been found to be sensitive to CBI’s in the past. Notice that a CBI impact on realized moments, extending beyond the intervention day is usually due to the moving average feature of realized moments. The boxplots and the rolling regression provide more detailed information on how to model the impact of CBI’s in intradaily data.

References


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Appendix 1: Data

Exchange Rate Data

Our dataset contain hourly data for two major exchange rates, the Japanese yen (YEN) and the Deutsche Mark (DEM) against the US Dollar (USD). For these two exchange rates, we have about 12 years of intraday data, from January 1989 to February 2001. The raw data consists of all interbank DEM-USD and YEN-USD bid-ask quotes displayed on the Reuters FX screen during this period. These quotes are indicative quotes but have been shown to be adequate inputs for computing intraday returns. Note that intraday FOREX returns computed from quoted bid-ask prices are subject to various market microstructure ‘frictions’, e.g. strategic quote positioning and inventory control. Such features are generally immaterial when analyzing longer horizon returns, but may distort the statistical properties of the underlying ‘fundamental’ high-frequency intraday returns. The sampling frequency at which such considerations become a concern is intimately related to market activity. For our exchange rate series, preliminary analysis based on the methods of Andersen, Bollerslev, Diebold and Labys (2002) suggest that the use of equally-spaced thirty-minute or hourly returns strikes a satisfactory balance between the accuracy of the continuous-record asymptotics underlying the construction of our realized volatility measures on the one hand, and the confounding influences from the market microstructure frictions on the other. As standard in the literature, we compute hourly exchange rate prices from the linearly interpolated logarithmic average of the 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 hourly returns as 100 times the first difference of the equally time-spaced logarithmic prices.

Official Central Bank Intervention Data (1989-2001)

The data used in this paper are official data of central bank interventions in the FX market.

- For the Fed, all data have been transmitted by the Federal reserve;
- For the Bundesbank, all data have been transmitted by the Bundesbank; the data after 1998 are reported interventions of the ECB, which nevertheless confirmed the 4 interventions carried out in September and November 2000 (but did not release the amounts);
- For the BoJ, the data after April 1 1991 are official data released by the BoJ (http://www.mof.go.jp/english/e1c021.htm). Official interventions before April 1991 are proxied by reported interventions in the Financial press (Wall Street Journal and Financial Times) (see Beine et al. 2002a for more details).
Appendix 2: ARFIMA Estimations of Exchange Rate Realized Volatility

This appendix reports examples of estimation results from which one extracts rolling estimates for \( \beta_i \) parameters reported in Figures 4 and 5. It documents on the fit of the ARFIMA models to the dynamics of realized FX volatility. Table A1 reports estimation results of model (3) with fixed \( i \) \((i = 0)\) for the intervention variables peculiar to the YEN/USD market \((I_{\text{FEDUY}_{t-i}}, I_{\text{BoJU}_{t-i}}, I_{\text{COORDY}_{t-i}})\). In other terms, only contemporaneous interventions on the YEN/USD are introduced as control variables.

\[
(1 - \phi L)(1 - L)^d \left[ \ln(\sigma_{t,\theta}^2) - \mu_t \right] = \epsilon_t
\]

where

\[
\mu_t = \mu + \beta_0 I_{m,t} + \beta_1 I_{BBU,t-i} + \beta_2 I_{\text{FEDUY}_{t-i}} + \beta_3 I_{\text{COORD}_{t-i}} + \beta_4 I_{\text{FEDUY}_{t-i}} + \beta_5 I_{\text{BoJU}_{t-i}} + \beta_6 I_{\text{COORDY}_{t-i}}
\]

Estimates reported in Table A1 confirm that the models reproduces some of the main features of FX realized volatility:

- **Long memory:** the \( d \) parameter lies between 0 and 1, in the range of 0.3 suggesting persistence of volatility shocks and a covariance stationary process; notice that the value of \( d \) is consistent with values obtained for the fractional integration parameter estimated in FIGARCH models of FX data (Tse 1998).

- **Day-of-the-week effect:** the \( \alpha \) parameter is significantly positive, confirming previous findings (Hsieh 1989) that volatility is on average relatively higher on Mondays.
\( i = 1 \quad i = 0 \quad i = -1 \)

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Table A1: Sample of rolling estimations
Figures
Figure 1: Boxplot of unilateral interventions in terms of daily realized DEM/USD returns
Figure 2: Boxplot of coordinated interventions in terms of daily realized DEM/USD returns
Case 3: unilateral Fed interventions and FX volatility

Case 4: Coordinated interventions and FX volatility

Case 3: unilateral Bundesbank interventions and FX volatility

Figure 3: Boxplot of FX interventions and realized volatility
Case 3: Unilateral Bundesbank interventions and FX volatility ($\beta_1$)

Case 4: Coordinated interventions and FX volatility ($\beta_3$)

Case 3: Unilateral Fed interventions and FX volatility ($\beta_2$)

Figure 4: Rolling regressions and DEM/USD volatility
Case 5: Volatility spillover effects of unilateral BoJ intervention on the YEN/USD ($\beta_3$)

Case 6: Volatility spillover effects of coordinated intervention on the YEN/USD ($\beta_6$)

Case 5: Volatility spillover effects of unilateral Fed intervention on the YEN/USD ($\beta_4$)

Figure 5: Rolling regressions and volatility spillover effects
Figure 6: Boxplot of coordinated interventions on the DEM/USD and FX cross-moments
Case 8: Coordinated interventions on the YEN/USD and realized DEM/YEN covariance

Case 10: Coordinated interventions on the YEN/USD and DEM/YEN Correlation

Figure 7: Boxplot of coordinated interventions on the YEN/USD and FX cross-moments
Figure 8: Boxplot of unilateral interventions on the YEN/USD and FX cross-moments
Figure 9: Boxplots of unilateral interventions on the YEN/USD and FX cross-moments
Case 10: Covariance effects of coordinated FED and Bundesbank interventions ($\beta_3$)

Case 9: Covariance effects of unilateral Bundesbank intervention ($\beta_1$)

Case 9: Covariance effects of unilateral Fed intervention ($\beta_2$)

Figure 10: Rolling regressions of FX interventions on the DEM/USD on the realized cross-moments
Figure 11: Boxplots of coordinated interventions and realized skewness of the DEM/USD
Case 11: Effect of FEDUp on the DEM/USD Skewness

Case 11: Effect of FEDUs on the DEM/USD Skewness

Case 11: Effect of BBUs on the DEM/USD Skewness

Figure 12: Boxplots of unilateral interventions and realized skewness of the DEM/USD
Figure 13: Rolling regressions of coordinated interventions and realized skewness of the DEM/USD
Figure 14: Rolling regressions of unilateral interventions and realized skewness of the DEM/USD