Volatility and Spillover Effects of Yen Interventions

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Abstract

We consider the Bank of Japan’s (BoJ) interventions’ effects on the intraday volatility of the USD/JPY exchange rates and their spillovers to the Euro/JPY exchange rates. We use 15-minute data during the period 2000 to 2004 and employ multivariate GARCH modelling, quartile plots of intraday volatility, and equal variance tests to analyse the intraday effects of the BoJ interventions on exchange rate volatility. The results indicate that the BoJ interventions decrease the volatility of the USD/JPY exchange rate but increase the volatility of the euro/JPY series. Intraday returns are less heteroskedastic on the intervention day.

Keywords: Foreign Exchange Intervention, Bank of Japan, Exchange Rate Volatility, Spillover Effect, High Frequency data

JEL classification: F31,G15

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1. Introduction

Despite the move to floating exchange rates in the post Bretton Woods era, many central banks and governments rely extensively on foreign exchange intervention to influencing exchange rates. The guiding principles for intervention policy provided by the IMF to its member countries include the disapproval of exchange rate manipulation for balance of payments adjustment purposes and/or for gaining unfair competitive advantages but encourages interventions for countering disorderly market conditions. While the Plaza Accord (1985) guided concerted interventions towards strengthening particular currencies over other (specifically depreciating the USD), the Louvre Accord’s (1987) stated objectives also included the potential role of intervention in decreasing excessive exchange rate volatility. In practice central banks may intervene for different purposes, such as countering disorderly market conditions, reducing excessive exchange rate volatility or counteract deviations from long-run equilibrium exchange rates (Neely, 2005).

In Japan, the Minister of Finance authorizes the BoJ to act as its agent and conduct interventions as a means for achieving exchange rate stability. Indeed, the Bank of Japan (BoJ) has frequently intervened in the foreign exchange market, and many studies have sought to evaluate the efficiency of its interventions. Two main streams of studies on central bank interventions exist, focusing on the interventions effect on the exchange rate level and on the exchange rate volatility respectively. The findings, however, vary depending on the type of intervention, the data used and the sample period considered. In general, most studies find that publicly announced and coordinated interventions are more effective than non-announced and unilateral interventions in influencing the level of exchange rates. At the same time interventions increase exchange rate volatility (e.g., see Beine et al., 2005; Baillie and Humpage, 1992; Nagayasu, 2004; etc.).

A number of studies investigate the success of the massive interventions in terms of levels for the period under consideration. In general, they produce evidence that the interventions were effective, in spite of Yen’s appreciation by 14% from 2003 to 2004 (see Spiegel, 2003; Fatum and Hutchison, 2005). Spiegel (2003) argues that in the absence of intervention activity, the Yen’s value could have risen further. Nevertheless, scant evidence

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1 IMF executive Board Decision no. 5392-(77/63), adopted April 1977.
3 A number of studies investigate the effects of the BoJ’s interventions both on the exchange rate level and its volatility. For example, Chang and Taylor (1998), Frenkel et al. (2003), Galati et al. (2005), Fatum and Hutchison (2005), and Nagayasu (2004).
4 For example see Fatum and Hutchison (2003), Dominguez and Frankel (1993), and Sarno and Taylor (2001).
exists regarding the BoJ intervention effects on exchange rate volatility for that period and this is the focus of the present paper.

The sample periods used in the existing literature on the BoJ intervention cover either the entire period from the earliest date that official intervention data is available (1991) to the new millennium or a subsection of the 1990s. During 2000 to 2004, however, there has been a shift in the BoJ’s strategy, as revealed in the magnitude and frequency of interventions. Spiegel (2003) suggests that this has been motivated by the perception that rapid appreciation of the Yen would reduce the competitiveness of Japanese export.

This paper focuses on the period from 2000 to 2004, which represents a unique era for both the pattern of intervention and the economic environment in Japan. This different environment is manifested in several ways. Firstly, the magnitude and the frequency of interventions increased substantially during this period. The overall amount of intervention in the USD/JPY exchange rates by the BoJ from 1991 to 1999 totalled 23,107.4 billion Japanese Yen, while in 2003 alone it reached 20,246.5 billion Japanese Yen, only slightly less than the total sum of 8 years during the 1990s. The frequency of interventions has also increased. While interventions were not very frequent in the 1990s and no interventions have been reported from March 2004 until September 2010, in 2003 alone occurred 82 interventions. Thus, the period 2000 to 2004 represents the most frequent official interventions from BoJ in the history.

In addition, the period 2000 to 2004 covers the ‘zero interest rate policy’ era in Japan. During this time, hopes are developed that the Japanese economy was just beginning to recover from a long, painful recession which lasted for ten years. Due to the loss of interest rates as a policy tool the BoJ explored alternative tools for stimulating Japan's economy. Given these circumstances, the purpose and possibly the impact of interventions may have had different qualitative features as compared to previous practice. Furthermore, during this period, the U.S. Federal Reserve (Fed) has not intervened in the USD/JPY market either unilaterally or in co-ordination with the BoJ, which allows to exclude the impact of intervention by other authorities and focus solely on the effect of interventions by the BoJ.\(^5\)

The above considerations, along with data issues that we discuss below, motivate our focus on the BoJ interventions that occurred during 2000 to 2004. We also do not include the two recent interventions of September 2010 and March 2011 March for a number of

\(^5\) Humpage and Shenk (2008), suggest that the reasons for which the Fed stopped intervening include the potential of conflict between foreign-exchange-market interventions and monetary policy, the danger of generating uncertainty about the ultimate objectives of monetary policy, and the unsuccessful record of interventions.
reasons. Given the long period of inactivity between 2004 and 2010 the interventions may reflect different qualitative features. First, while in the early millennium the interventions are highly frequent (147 interventions) those of 2010 and 2011 are ad hoc episodes. Second, considering the 200 to 2004 interventions we can focus on unilateral interventions from the Japanese authorities (while the 2011 intervention is a joint intervention from G-7 countries). Third, the last two interventions happened in the new economic and financial environment that follows the global financial crisis of 2007-2008, which is very different from the economic environment in the early 2000’s. Moreover we focus only on reported official interventions by BoJ and do not consider the possibility of ‘secret’ or unreported interventions, which have different qualitative features.

In addition to examining the exchange rate volatility implications of the BoJ interventions the paper contributes to the literature in three other respects. In particular, intervention cannot be regarded as successful if it causes turbulence in other markets, even if it effectively calms volatility in the market that central bank intervenes. Thus we not only evaluate how the BoJ’s interventions affect the USD/JPY exchange rate volatility, but also investigate their spillover effect on the euro/JPY exchange rate. We also test the effect on the covariances of two exchange rates. Finally, in order to precisely evaluate the dynamics of the intervention effect, we consider an intraday framework which allows to obtain additional insights on the intraday volatility characteristics on intervention and non-intervention days.

The following section provides an eclectic literature review on foreign exchange rate intervention. Section 3 explains the construction of our data set relating to exchange rates and intervention. Section 4 is divided into three subsections, corresponding to the methodologies used and discusses their results. Section 5 concludes.

2. Literature Review

While an extended literature exists on the impact of central bank interventions (CBIs, henceforth) on the foreign exchange market the results of these studies are not uniform. This reflects the existence of various types of intervention, the different exchange rates which reflect different structures, and different sample periods reflecting different policy environments. This section reviews the literature focusing on the impact of interventions on the USD/JPY exchange rate level, volatility, and spillover effects. Moreover, the existing literature on the impact of CBIs using intraday data is presented.

Traditionally the focus of the analysis has been on the impact of interventions on the
exchange rate level. Fatum and Hutchison (2003) use the official intervention data to test the effectiveness of the intervention by the BoJ from 1991 to 2000 utilizing an event study approach. They conclude that large-scale coordinated operations have a higher likelihood of success and that intervention is effective in influencing exchange rate movements in the short run, even without taking interest rates and the ‘news’ effect into consideration. Chaboud and Humpage (2005) separate the period 1991–2004 into different sub-periods according to the frequency of interventions. They find that interventions impact on the direction of exchange rate movements, during the period 1995-2002 but they are not successful in doing so between 2003 and 2004.

A number of studies also consider the effect of interventions on the USD/JPY exchange rate volatility, rather than just focusing on the exchange rate level. The existing evidence suggests that interventions are associated with increased exchange rate volatility and that coordinated intervention has a greater impact than unilateral intervention. Nagayasu (2004) investigates the effectiveness of Japanese foreign exchange interventions on the USD/JPY exchange rates for 1991-2001 using a GARCH(1,1) model and finds that interventions cause increased volatility. Gatati, et al. (2005) use density functions to describe market expectations and explain how the market expectations and interventions interact with each other focusing on interventions made by both the BoJ and the Fed during the period 1993-2000. They find that interventions have no significant effect on the mean of expected exchange rates and higher moments. Beine et. al. (2007) test the CBIs’ impact decomposing exchange rates into different factors for each country and estimating the unobserved components through a Bayesian procedure. Their results show that interventions do not effectively move exchange rates in the desired direction and in fact these operations can increase volatility. More importantly, they find that unilateral intervention also tends to increase volatility. Beine et. al. (2003) utilize a regime-switching modelling framework to examine the impact of CBIs on the returns and volatility of the DEM/USD and JPY/USD exchange rates at a weekly frequency. Their results reveal that the effects of interventions depend on the volatility regime of the market and the expectation of the intervention. When the market is in the low-volatility state, the intervention tends to increase volatility, while when the market is volatile, intervention has a stabilizing impact. Beine et. al. (2002) consider the short-run effect of official interventions on the level and volatility of the DEM/USD and JPY/USD exchange rates using a FIGARCH model, rather than the generally preferred GARCH model to measure volatility. The results show that official interventions increase the volatility of the exchange
rates but have no effect on the level of the exchange rate.

A more recent spate of papers shifts focus from the volatility of the exchange rates to the spillover effects of intervention on volatility. That is, they examine whether interventions in one market can also impact on the volatility of other foreign exchange markets. Beine et. al. (2005) test the impact of G3 central bank interventions on the DEM/USD exchange rate from 1989–2001 analysing daily realized moments. Their results show that although the intervention appears not to have an impact on returns, significant effects of coordinated interventions exist on volatility, covariance, correlation, and skewness. This impact, however, is typically short-lived and never lasts longer than a single day. Beine (2004) uses a multivariate GARCH model to investigate the effect of CBIs on the correlation and covariance of the JPY/USD and DM(euro)/USD exchange rates during 1991-2001. The results show that CBIs increase the conditional variances and covariances as well as the conditional correlation. Coordinated interventions have the greatest impact. Both the last two studies find significant spillover effects. Dominguez (1998) examines the effects of interventions on the USD/DM and USD/JPY exchange rates during 1977–1994. The results show that, with the exception of the mid-1980s interventions increase volatility and no significant spillover effects exist.

Given that the evidence point to a short-run only effect significant effect of intervention and as high frequency exchange rate data becomes available, more attention has been recently paid to the intraday analysis of the CBI’s impacts. Chang and Taylor (1998) provide an intraday analysis of the effects of intervention by the BOJ for the period 1992-1993. They use Reuters news headlines related to the intervention and examine the reaction of the intraday volatility and the individual banks’ responses. The results show that the intervention occurs at least one hour before the news reports. Some market makers could receive intervention information between 30 and 60 minutes before the news report. They also find that the intervention has a positive impact on volatility, while the macroeconomic news does not significantly affect volatility. Morana and Beltratti (2000) evaluate the effects of CBIs on the DM/USD exchange rates using high frequency data. They employ an unobserved component model and take intraday seasonality into account. The results indicate that interventions are not very effective, they have a 50% probability of increasing volatility, and intervention mostly affects the intraday seasonal and permanent components. Domiguez (2003) examines the impact of CBIs on intraday (5-minute interval) exchange rate volatility from 1987 to 1995, utilizing Reuters news reports. From the market microstructure point of view, the study helps to understand how traders observe and
interpret the CBIs and how CBIs influence exchange rate volatility. The results indicate that intervention operations influence the volatility only in the short run and are associated with increases in intraday and daily volatility, especially for coordinated interventions. The relationship between the effectiveness of CBIs and the market conditions at the time of intervention is the focus of Dominguez (2006) who uses intraday data and Reuters news reports. The findings suggest that Fed intervention significantly affects both returns and volatility and that these effects last at least until the end of the day. Moreover, Secondly, there exists traders who know about the intervention at least one hour prior to the news reports.

All the existing studies in an intraday framework rely on news reports of interventions. This is reasonable since official intervention data is not available in frequencies higher than daily. Some of existing studies use the time when the news is released as the proxy for the time of intervention. The accuracy, however, of using the release time as the proxy of the actual intervention time has been questioned in the literature (e.g., Fischer, 2006).

One innovation of this paper is that, we do not use a proxy of any sort for the exact time of intervention. A conventional wisdom has been developed, based on the existing empirical evidence that the intervention impact does not last for more than one day. Thus, our interest is on the dynamics of the impact within the day in order to better understand how intraday volatility reacts to interventions and how they work under different market conditions, which cannot be inferred from daily analysis. We also compare the spillover effect with the original effect on the USD/JPY exchange rates in the intraday case.

A second feature of this paper is that it focuses on a sample period which is relatively unexplored. The period considered in this paper is typically analyzed in the literature as part of a more extended data sample. Moreover, a unique characteristic of this period is the absence of intervention originated by the Fed. Previous studies normally examine different impacts of coordinated and unilateral interventions, which may give useful suggestions to policy makers. Interventions (especially BoJ interventions), however, are more likely to occur as clustered events, and sometimes both coordinated and unilateral interventions occur frequently in the same period. In this case, it is difficult to completely separate the effects of coordinated interventions from those of unilateral interventions. Therefore, using a period in which there was no coordinated intervention at all, may allow deducing more accurate inferences on unilateral interventions. It is worth noting that the Fed had not intervened at all in the USD/Yen market during the first decade of the millennium.
This paper contributes to the literature focusing on a sample period with specific features and adopts an intraday perspective to analyse the impact of the BoJ’s interventions on exchange rate volatility and the associated spillover effects. Our approach produces a more accurate characterization of the yen foreign exchange intervention volatility dynamics on two accounts at least. First, we use actual data, and thus avoid using the inaccurate release time of news reports to determine the timing of intervention. Second, we solely focus on unilateral interventions originated by the BoJ, thus excluding the effects of coordinated interventions.

3. Data Description
3.1 Exchange Rate Data

Intraday Data

The original data we use are 5-minute interval spot foreign exchange prices of the USD/JPY and euro/JPY provided by Olsen and Associates, which we transform to 15-minute interval data and the period under study runs from January 1st, 2000 to October 31st, 2004.

Although the foreign exchange market is open 24 hours a day, 7 days a week, trading volumes on weekends and holidays are very small. Thus, following Anderson and Bolleslev (1998), we remove weekend returns from the sample (i.e., from Friday 21:15 GMT to Sunday 21:00 GMT). We do not remove holiday returns, however, because Japanese holidays seldom correspond to those of Western countries. The other two major markets (New York and London) are open on Japanese holidays, while the BoJ intervenes on some Western holidays.6 Thus, in order to ensure the completeness of the intervention data we keep the holiday returns in our series. This results in a total of 120,864 observations.

We obtain the return series, \( r_t \), as:

\[
    r_t = \ln p_t - \ln p_{t-1},
\]

where \( p_t \) is the spot price at time \( t \). The actual plots of each return series are shown in Figure 1 and Figure 2, respectively.

Table 1 shows the distribution statistics of both exchange rate return series. Both series display similar characteristics to the stylized properties of high frequency financial

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6 For example, on December 26th, 2003, the BoJ intervened on the USD/JPY exchange rates for a volume of 191.7 billion Japanese Yen.
time series returns documented in the literature; approximately zero means, slight skewness and fat tailed distributions.

**Daily Data**

The exact times of official interventions are not available, and therefore the intraday returns cannot be modelled by the existing intervention data sets. We use daily returns as regressors in a multivariate GARCH model and in order to capture how interventions affect volatility during different times of the day we use different quotation time points to calculate daily returns. Using a 15-minute interval return series, the quotation time ranges from 00:00 to 23:45 (Japanese time) generating 96 daily return series. Each series contains 1,259 observations. We use these return series to perform rolling estimations of the multivariate GARCH model.

Let the daily return series, \( r_{t,n} \), be:

\[
r_{t,n} = \ln p_{t,n} - \ln p_{t-1,n},
\]

where \( r_{t,n} \) is the daily return at day \( t \) and at time \( n, t=1\ldots1259; \) \( n \) corresponds to different time points from 00:00 to 23:45 at 15-minute intervals. There are 96 different time points, \( n \), in each day and \( p_{t,n} \) and \( p_{t-1,n} \) are spot prices for day \( t \) and day \( t-1 \) at time \( n \).

Table 2 lists the distribution statistics of daily returns for the USD/JPY and euro/JPY exchange rates using 10 different quotation time points as examples. The mean values of the returns are approximately zero and the skewness is slightly more than zero for each series, which is similar to their high frequency counterparts. The kurtosis of the daily return series, however, is much less than that of the high frequency case, indicating that as the frequency becomes lower, the distribution of the series is closer to the normal distribution.

**3.2 Intervention Data**

We use official intervention data published on the website of the Japanese Ministry of Finance. From January 1\textsuperscript{st}, 2000 to October 31\textsuperscript{st}, 2004, there were 147 interventions by the BoJ in the USD/JPY exchange rates, and the total amount reached 45,173.5 billion Japanese Yen. All these interventions involved selling the Japanese Yen and buying the USD, with the aim of depreciating the Japanese Yen. Figure 3 shows the intervention amount against the time, and table 3 shows the summary of statistics. It appears that the interventions happened abruptly and were clustered. The intervention amount ranges from 0.1 billion to 1,666.4 billion Yen. The period of most frequent interventions is from
January 2003 to March 2004. In 2003 alone, the BoJ intervened 82 times, which is more than half of the total for the sample period. With the exception of April and August, the BoJ intervened during every month of the year. Many of these interventions happened in a continuous pattern. Another important characteristic of the intervention data is that the BoJ is the only authority to intervene in the USD/JPY exchange rate market during this period.

To carry out the event study, described in the next section, we separate the days when intervention occurs from the sample period forming two groups of data. One group contains 147 intervention days, and the other contains 1,112 non-intervention days. For each 15-minute interval, quartiles of the intraday volatility across intervention and non-intervention days are calculated, respectively. Using these sub-sample data, we compare of the intraday volatility of intervention days and non-intervention days are compared.

Overall, three different groups of data series are generated from the 15-minute return series, which are the whole sample daily returns for the multivariate GARCH model, the intraday returns for intervention days, and the intraday returns for non-intervention days. The daily return series is calculated according to different quotation time points resulting in 96 series of daily returns.

4. Methodology

4.1 The Multivariate GARCH model

Using a multivariate GARCH framework not only allows explaining the movement of conditional variances over time for each asset return series, as does the univariate model, but also captures the way that covariances vary across time. We use the VECH model because the estimated variance/covariance matrix satisfies the positive definite condition at all times and the model is less restricted. The diagonal VECH-GARCH (1,1) specification reduces the number of parameters to be estimated.

The general VECH model is proposed by Bollerslev et. al. (1988), as follows:

\[ y_t = b + \varepsilon_t \]

\[ \text{VECH}(H_t) = c + \sum_{i=1}^{d} A \text{VECH}(\varepsilon_{t-i}, \varepsilon_{t-i}') + \sum_{j=1}^{b} B \text{VECH}(H_{t-j}) \]  

\[ \varepsilon_t \mid \Omega_{t-1} \sim N(0, H_t), \]

where \( y_t \) is a \((N \times 1)\) vector of asset returns, \( b \) is a \((N \times 1)\) vector of constants, \( \varepsilon_t \) is a \((N \times 1)\) vector of innovations, \( \text{VECH}(\cdot) \) is the column-stacking operator and takes the
‘upper triangular’ portion of a matrix into a column vector, and \( C \) is a 
\(((N(N+1)/2)\times 1)\) vector containing unconditional variances and covariances. \( A_i \) and 
\( B_j \) are \((N(N+1)/2)\times(N(N+1)/2)\) matrices of GARCH process parameters. \( H_t \) is the 
\((N \times N)\) matrix of the conditional variance-covariance of the returns.

The large number of parameters makes the estimation of the general model 
cumbersome. A simpler specification has been developed, however, which restricts the 
parameter matrices \( A_i \) and \( B_j \) to the diagonal ones, significantly reducing the parameters to 
be estimated. In our case, there are two underlying assets (i.e., the USD/JPY and euro/JPY 
exchange rates), resulting in only 9 unknown parameters in the variance-covariance 
equations. Since we want to estimate the impact of the BoJ’s interventions on volatility, we 
extend the diagonal VECH model by adding the (exogenous) intervention variable into the 
variance and covariance equations, as well as in mean equations. Thus we can write the 
extended model as:

\[
\begin{align*}
    y_{1,t} &= b_1 + \delta_1 x_{t-1} + \varepsilon_{1,t} \\
    y_{2,t} &= b_2 + \delta_2 x_{t-1} + \varepsilon_{2,t} \\
    h_{11,t} &= \gamma_{11} + \alpha_{11} \varepsilon_{1,t-1}^2 + \beta_{11} h_{11,t-1} + \psi_{11} x_{t-1} \\
    h_{22,t} &= \gamma_{22} + \alpha_{22} \varepsilon_{2,t-1}^2 + \beta_{22} h_{22,t-1} + \psi_{22} x_{t-1} \\
    h_{12,t} &= \gamma_{12} + \alpha_{12} \varepsilon_{1,t-1} \varepsilon_{2,t-1} + \beta_{12} h_{12,t-1} + \psi_{12} x_{t-1} \\
    \varepsilon_t | \Omega_t &\sim N(0,H_t),
\end{align*}
\]

where \( y_{1,t} \) and \( y_{2,t} \) are the USD/JPY and euro/JPY exchange rate return series. \( h_{11,t}, h_{22,t} \) and 
\( h_{12,t} \) are conditional variances and the covariance respectively. The variable \( x_t \) denotes the 
dummy variable for interventions. Using the dummy variable corresponds to the theory of 
the signalling channel, which interprets the intervention as information released into the 
market, and therefore it can affect market expectations and actions. The variable \( x_t \) takes 
the value 1 when the intervention happens on day \( t \) and takes the value 0 in all other cases. 
Since interventions in the sample period only involve the purchase of the USD, there is no 
sign difference in the dummy variable. To capture the dynamic and persistence of the 
impact around intervention days, values of \( i \) will vary from -1 to 1 (\( i = -1, 0, 1 \)), which 
represent the day before intervention, the intervention day itself, and the day after the 
intervention.

Model 4 is estimated by the maximum log likelihood method.\(^7\) As mentioned in

\(^7\) The software used is RATS.
Section 3, the model is applied to 96 return series which are calculated by different time points. We analyze the coefficient $\psi_{i,j}$ from different time points in order to get insights on how intervention affects the intraday volatility.

The same rolling estimate is performed using different values for $i$. The results, however, show that patterns of the coefficients’ $\psi_{i,j}$ significance for day $t$, day $t-1$ and day $t+1$ are similar, i.e., the significant point of $\psi_{i,j}$ generally indicates similar times for different days. This also applies to day $t-2$ and day $t+2$. This phenomenon cannot be satisfactorily explained in terms of the persistence of the impact of interventions (for the days after), or the perception of interventions in the market (for the days before). Given that, during the sample period under study, interventions always occur continuously for several days or even several weeks (especially in 2003), it is not appropriate to use the lag variable method to determine the effect of interventions on other days. In addition, there is evidence in the literature, showing that the impact of the intervention does not extend beyond the intervention day (e.g., Dominguez, 2003; Beine et al., 2005). On the other hand, the similar significance pattern of impact on volatility itself may be evidence that the impact comes from the intervention of the day in question, rather than the day before or after, otherwise, the cross impact will make the pattern different. Based on the assumption above, we investigate only the impact on day $t$, that is we set $i=0$.

**Interventions’ impact on the USD/JPY exchange rate volatility**

Figure 4 shows the rolling estimation results for the intervention coefficient $\psi_{11}$. The X axis represents the time (Japanese time) used to calculate daily returns, which ranges from 00:00 to 23:45. The Y axis represents the values of the estimation that use different daily return series. Some non-convergent results have been deleted from the sample.

Firstly, one can observe from Figure 4 that in the variance equation for the USD/JPY series, coefficients $\psi_{11}$ are all negative when they are significant. In other words, BoJ interventions decrease the volatility of the USD/JPY exchange rates. This result is rather surprising because, in the literature, almost all studies which include BoJ interventions found that Japanese interventions have a positive impact on volatility. This contrary finding, however, might be explained when we consider the sample periods in these studies, none of which is the same as the one used in this study. For example, the period used in Beine

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8 The time discussed in empirical results thereafter refers to Japanese time.
9 The p-values are shown in Graph 3.5.
(2004) is from 1991 to 2001, from 1992 to 1993 in Chang and Taylor (1998), from 1985 to 1995 in Beine et al. (2002), from 1989 to 2001 in Beine et al (2005), from 1991 to 2001 in Nagayasu (2004), from 1985 to 1995 in Domiguez (2003), etc. The sample period used in this study is 2000 to 2004, which has rarely been studied separately. According to the 1987 Louvre Agreement, intervention should aim to stabilize excess volatility. The decreased volatility shows that in this period, BoJ interventions achieved some degree of success. The negative impact of BoJ interventions in this study might be explained mainly by the fact that the magnitude and the frequency of BoJ interventions have significantly increased after 2000. The amount and frequency of the interventions reached their peak during this period, suggesting that intervention might have become more powerful than during the 1990s. In addition, the continuous intervention pattern also provides the participant with more information with which to predict the intervention. It is unsurprising that when the BoJ starts to intervene in this market, it does not result in a large divergence of expectations, which is the main cause of high volatility. Although some of the studies mentioned include the period 2000 – 2001, their general results still indicate a positive impact. This may be because the long sample period from the 1990s dominates the results. It is therefore necessary to break down the long sample period focusing on the resulting sub-samples investigation.

Figure 5 shows the p-values of intervention coefficient $\psi_{11}$. The intervention coefficients appear significant only at a few time points during the day rather than at every point in the day. The first period in which coefficients are significant at the 5% level is from 1:30 to 3:45 Japanese time. It seems confusing as, during this time, the Japanese market has not opened and the intervention has not yet been executed. However, during this period, the local time of the U.S. market is from 11:30 to 13:45. One possible explanation for this puzzle is that the significant effects of the intervention during this period might come from the previous day’s intervention. As discussed before, the intervention activities in our sample period appear in a clustering pattern. In most cases, the BoJ intervenes on a daily basis for a week, or sometimes even for a month. This special intervention pattern makes it difficult to separate the intervention effects from one day and another in the model estimation. Kim (2007) split one calendar day into three parts according to the business hours of three major markets. He finds that the BoJ intervention effects on volatility are significant and exert greater influence during the period from noon to closing time in the U.S. market, which equates to early morning of the following day in Japan. This result may partially support our conjecture. After the Japanese market opens at 8:00 local
time, we can see several blocks of significant periods in the morning, which are from 8:00 to 8:45, 9:15 to 9:45 and 10:15 to 11:15. After 12:00, only 4 points are significant and after 13:15, intervention coefficients are no longer significant. This result confirms the finding of previous studies that the impact of interventions on volatility only lasts for the short run.

**Impact on the euro/JPY exchange rate volatility (spillover effect)**

The so-called spillover effect of the intervention is that CBIs in one market also affect other foreign exchange markets. In this study, we investigate whether BoJ interventions in the USD/JPY exchange rate market can also cause fluctuations in the volatility of the euro/JPY market, and in what direction these effects occur.

Figure 6 shows the values of intervention coefficient $\psi_{22}$ for the euro/JPY exchange rates. Surprisingly, although the impact of intervention on the volatility of the USD/JPY exchange rates is negative, the impact on the euro/JPY exchange rates is always positive (increased volatility). The phenomenon may be explained by the fact that when the intervention in the USD/JPY market is detected by the euro/JPY market, it induces greater uncertainty in the euro/JPY exchange rates than in the USD/JPY. Firstly, the JPY is sold against the USD by the BoJ with the apparent aim of depreciating the JPY. However, the direction in which intervention drives the USD/JPY exchange rates is not necessarily the same for the euro/JPY exchange rates. How those interventions influence the euro/JPY exchange rates and to what extent they can move are not clear to the rest of the market. Secondly, the signal of the intervention on the USD/JPY exchange rates may also cause anticipation of the BoJ’s interventions against the euro. During our sample period, the BoJ always intervenes in the JPY against the euro on the same day as it intervenes in the USD/JPY market.\(^{10}\) This anticipation may also cause uncertainty in the market. In general, the BoJ’s intervention in the USD/JPY market achieved some success in terms of stabilizing the market. However, the consequence of this was that it had to experience increased volatility in another related market.

Figure 7 shows the p-values of intervention coefficient $\psi_{22}$ of the euro/JPY exchange rates and reveals another difference between the intervention’s impact on the volatility of the USD/JPY exchange rates and its spillover effect. Intervention coefficients are significant in the USD/JPY exchange rates only for a period of several hours, while for the euro/JPY exchange rates, they are significant at the 10% level all day and at the 5% level

\(^{10}\) One exception is on September 22nd, 2000, which was a coordinated intervention with the European Central Bank

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for most of the time during the day of the intervention. From the Figure one can see that, in general, during the hours that the European market and the U.S. market are open (especially the European market), coefficients are more significant (except for two outlier points at 22:45 and 23:00). This pattern may be caused by more trading activity against the euro/JPY exchange rates when the European market opens. It is also because, when the European market opens, the BoJ intervention has occurred and the news has spread to the market.

**Impact on the covariance of two exchange rates**

Figure 8 shows the values of estimated intervention coefficient $\psi_{12}$ in the covariance equation. Another surprising result emerges with all the signs of the coefficients appearing to be negative, which means that the BoJ’s intervention in the USD/JPY exchange rates decreases the covariance between the USD/JPY and euro/JPY exchange rates. Beine (2004) finds that the CBIs actually increase the covariance between the USD/JPY and euro/USD exchange rates. Although the underlying exchange rates in this study are different from those studied by Beine (2004), the different results indicate that the CBIs do affect the covariance between the two exchange rates. The way in which they affect it, however, depends on the specific assets under study and the impact of interventions on individual assets. Beine (2004) finds that the intervention has positive effects on the volatility of both exchange rates. According to ‘the stylized fact that covariance and correlation tend to be higher during the periods of rather high volatility’ (Beine 2004), it is not surprising that the intervention also has positive effects on the covariance in that study. In our case, the BoJ’s intervention has negative effects on the volatility of the USD/JPY exchange rates, while it has positive effects for the euro/JPY exchange rates. Therefore, how the intervention affects the co-movement of the two exchange rates remains unclear until we examine the estimation results. This supports the argument that intervention should be considered as an important issue when predicting covariances and correlations among exchange rate series, a result that can be valuable for portfolio management.

Figure 9 reveals that the intervention coefficient $\psi_{12}s$ are only significant for some short periods and become insignificant during most of the day. The longest period in which coefficients are significant at the 5% level is from 1:45 to 3:00 Japanese time, which is in accord with the significant period of variance equations of the USD/JPY and euro/JPY exchange rates. It should be noted that, during this period, the U.S. market is open and
there is also some overlap time with the European market. After the Japanese market opens, intervention coefficients are only significant at the 5% level at 4 or 5 time points, and they are not significant after 10:30. In addition, even when we look at the 10% significance level, the significance point is still between 8:00 and 11:15. The results indicate that the BoJ’s intervention in the USD/JPY exchange rates only affects the covariance between the USD/JPY and euro/JPY exchange rates in the short run. It is interesting to note that the effects on the covariance are most significant when the U.S. and European markets are active. As mentioned earlier, this could possibly be traced back to the previous day’s intervention. However, the intervention affects the covariance only at the 10% level and only in the morning during the Japanese market opening time on the intervention day.

In short, the BoJ intervention on the USD/JPY exchange rate from 2000 to 2004 has resulted to decreased market volatility. This is a short-run effect and is mainly apparent on the morning of the day of intervention. The spillover effect of BoJ interventions on the euro/JPY exchange rates is significant. It increases, however, the volatility of the euro/JPY exchange rates and the effect lasts for the whole day. In addition, the BoJ’s intervention in the USD/JPY exchange rates decreases the covariance between the USD/JPY and euro/JPY exchange rates and the effect is short-lived, not extending beyond the morning of the intervention day.

4.2 Intraday volatility plots of intervention days and non-intervention days

The results from the multivariate GARCH model provide a general overview of how BoJ interventions affect the volatility of exchange rates, as well as their covariance. The estimation, however, covers the whole sample period and it is unable to distinguish the differences in volatility patterns between intervention and non-intervention days. In order to obtain clearer information about this, we use an event study method where intervention days are separated from the rest of the sample data. It results in two sub-samples: intervention and non-intervention days. From Figures 10 – 15 we can compare two sub-samples and discover how interventions function in relation to intraday volatility under different market conditions. The plots use absolute returns as the indicator of volatility. Figures 10 -12 show the third quartile, the median and the first quartile of the intraday volatility of the USD/JPY exchange rates across intervention and non-intervention days. Figures 13 -15 show those of the euro/JPY series. The X axis shows the time intervals during the day and the Y axis indicates the values of the quartiles. The different quartiles represent the high volatility, median volatility and low volatility periods, respectively.
The intraday volatility of the USD/JPY exchange rates

Observing Figures 10 – 12, we can discern a seasonal pattern of intraday volatility. There is an increase in volatility shortly after the Japanese market opens. After the volatility achieves a peak, it starts to decline and reaches the lowest point at around 12:00. As closing time approaches, the volatility increases again. This pattern is in accordance with the stylized seasonality pattern of the high frequency intraday volatility, which shows an approximate U-shape.

Although the intraday volatility on intervention days shows similar seasonal patterns to that of non-intervention days, the Figures reveal that there is a difference. Firstly, three quartiles all show sharp increases in volatility on non-intervention days at around 9:00 Japanese time, about one hour after the market opens. For intervention days, there are also increases in volatility at around 9:00. The increases, however, are much smoother and there is no spike like that observed on non-intervention days. One of the explanations for the U-shape intraday volatility pattern is the clustered arrival of public and private information. After the information has accumulated or is released overnight, once the market opens, many trading activities in the market are prompted in reaction to the information. This will lead to high volatility around the market opening time. It is easier to account for the spikes of volatility at opening time on non-intervention days. However, how can the different pattern (no spike) on intervention days be explained? As mentioned previously, the intervention occurred on a daily basis in most cases in our sample; the pattern may make it easier for the market to predict the intervention. As ‘predicted’ news, when the intervention news is released, it might cause less volatility than on non-intervention days where more unexpected news arrives. Whether there is more evidence for this conjecture is a matter for further study.

Secondly, the volatility on intervention days is lower than the volatility on non-intervention days. It is consistent with the results from the multivariate GARCH model that the intervention decreases the volatility of the USD/JPY exchange rates. In Figures 10 – 12, there is a significant distance between the volatility on intervention days and non-intervention days. In addition, during the high volatility and median volatility periods (Figures 10 and 11), the volatility patterns of intervention days are similar and the movements of volatility are in line with those of non-intervention days. For the same time interval, the extent to which the volatility has been decreased on intervention days is similar for both high and median volatility periods. However, for the low volatility period
(Figure 12), some different characteristics are apparent. On the one hand, the volatility on intervention days does not move in the same direction as that of non-intervention days for many time points. Although the volatility on intervention days is lower, the pattern is very different from that of high and median volatility periods. On the other hand, when the volatility reaches the lowest point of the day, such as from 5:00 to 8:00 and from 12:00 to 14:00, the volatility on intervention and non-intervention days is almost identical. This result indicates that the intervention affects volatility differently under different market conditions, and in our case, the low volatility period shows different features. It provides an incentive for investigating the dynamic of the impact of intervention within different volatility regimes.

Thirdly, for all three volatility regimes, there is a common period during which the volatility of intervention days is not significantly lower and sometimes even exceeds the volatility of non-intervention days. It is a short period from about 4:00 to 8:00 in the morning, when there is the least overlap in opening times of the three major markets (New York, Tokyo and London). That could be because of the relatively low level of trading activity, meaning that intervention has less impact on volatility.

**The intraday volatility of the euro/JPY exchange rates**

The plots of the intraday volatility of the euro/JPY exchange rates share some similar features with those of the USD/JPY series. Firstly, they both have U-shape seasonal patterns, which are well documented in the high frequency volatility literature. Secondly, there are sharp increases at the opening time on non-intervention days, which also occur at around 9:00 Japanese time. As mentioned earlier, it may be caused by the market reactions to the large amount of information released at the opening of the market. In addition, the movements of volatility on intervention days match very closely with those on non-intervention days, in both the high and median volatility periods.

There are some patterns, however, which differ significantly from the plots of the USD/JPY exchange rates, indicating the different impact of the intervention on the euro/JPY series. Firstly, the levels of volatility on intervention days are quite similar to those on non-intervention days. We cannot discern any significant differences between them from the Figures. According to the result of the multivariate GARCH model, the spillover effect of interventions on the euro/JPY exchange rates increases volatility. However, we can see that, during the day, the volatility of intervention days sometimes surpasses that of non-intervention days. It reminds us that even if the average effect from
the model estimation indicates a positive impact of the intervention on volatility, it does not mean the volatility increases throughout the day. In some intraday intervals, the volatility decreases. The result emphasizes the importance of intraday analysis on the intervention impact.

Secondly, Figures 13–15 show that in the low volatility period, there are more time points that the volatility of intervention days is higher than that of non-intervention days and the values of volatility from two sub-samples are mostly close in comparison with those of the other two volatility regimes. In addition, there are fewer points where the volatility of intervention days is higher than that of non-intervention days, when the volatility regime becomes high. In the high volatility period (Figure 13), it is apparent that for most of the time, the volatility of intervention days is slightly lower than that of non-intervention days. This result clearly shows that the intervention affects volatility differently in different volatility regimes. Based on the results from the model estimation in the previous section, i.e., interventions have positive spillover effects on the euro/JPY exchange rates, from the plots we can see that the effects are mainly observed in the low volatility period.

In general, the plots of quartiles of the intraday volatility provide us with a lot of information about the characteristics of intervention and non-intervention days. The plots for the USD/JPY and euro/JPY series clearly show that intervention in the USD/JPY market has different effects on the volatility of the USD/JPY series and euro/JPY series. The Figures support the finding from the multivariate GARCH model that intervention decreases the volatility for the USD/JPY exchange rates. The volatility of intervention days is lower than that of non-intervention days at almost any time during the day for the USD/JPY series, while that is not the case for the euro/JPY series. In addition, for both exchange rates, the intervention works differently under different market conditions, especially in the low volatility period.

4.3. The Equal Variance Test
To further explore different characteristics of intervention days and non-intervention days, we perform in this subsection an equal variance test. We use the Brown-Forsythe modified Levene test (Brown and Forsythe, 1974). It is well documented that the intraday returns are heteroskedastic across time, and this is one of the fundamental issues for understanding the movement of volatility and forecasting intraday volatility. Given the fact that the CBIs significantly affect the volatility of exchange rates in our study, it is also worth testing
whether it has any impact on the heteroskedasticity of the intraday returns. The null hypothesis of the test is that the variances at 15-minute intervals during each hour of a day are equal (homoskedastic), both on intervention and non-intervention days. For the 15-minute interval returns, there are 4 variances for each hour, and therefore the null hypothesis can be written as:

\[ H_0 : \sigma_i^2 = \sigma_2^2 = \sigma_3^2 = \sigma_4^2 \]

given

\[ H_1 : \sigma_i^2 \neq \sigma_j^2 (i,j=1,...,4) \] for at least one pair.

We use the Brown-Forsythe modified Levene test with the test statistic:

\[ F = \frac{\sum_{j=1}^{J} \sum_{i=1}^{n_j} (D_{ij} - \overline{D}_j)^2}{(N-J)(J-1)} \]

where \( D_{ij} = |r_{ij} - M_j|; r_{ij} \) is the return for day i, intraday interval j, and in our case, \( j=1,2,3,4; \) \( M_j \) is the sample median return for interval j computed over the \( n_j \) days included in the test;

\( \overline{D}_j = \frac{\sum_{i=1}^{n_j} D_{ij}}{n_j} \) is the mean absolute deviation from the median for interval j;

\( \overline{D} = \frac{\sum_{j=1}^{J} \sum_{i=1}^{n_j} D_{ij}}{N} \) is the grand mean, where \( N = \sum_{j=1}^{J} n_j \). The test statistic is approximately distributed as \( F_{J-1,N-J} \) under the null hypothesis. The test is performed 24 times (24 hours a day) for the USD/JPY and euro/JPY series, respectively, both on intervention (147 days) and non-intervention days (1,112 days).

Table 4 provides the results. There is strong evidence that intraday variances on intervention days are more homoskedastic than those on non-intervention days. For instance, on intervention days for the USD/JPY series, there are only 3 out of 24 cases in which the null hypothesis of equal variances in one hour of the day is rejected. Among them one case is rejected at the 1% significance level, another case at the 5% level and a further one at the 10% level. In the non-intervention days, however, the null hypothesis is rejected for 15 out of 24 cases at the 1% significance level, whilst there is a further case at the 5% level. This indicates that the return variance is not constant across those hours. For the euro/JPY series, the result is similar. For intervention days, there are 9 cases that reject the null hypothesis; among these only 2 cases are rejected at the 1% significance level, 4 cases at the 5% level and a further 3 at the 10% level.
We also allow a longer interval for the test period in order to compare the results. The same test is applied to the two hour interval and the hypothesis tested is that variances are equal every two hours of the day. The results are listed in Table 5. We find that the result for the two hour interval is in line with that for the one hour interval. For the USD/JPY series, 3 out of 12 cases reject the null hypothesis at the 1%, 5%, and 10% significance levels, respectively, for intervention days. However, 10 cases reject the null hypothesis for non-intervention days, all at the 1% level. For the euro/JPY series, the result of non-intervention days is the same as that of the USD/JPY, and it rejects the null hypothesis in 3 more cases than on intervention days.

The results from both one-hour and two-hour tests indicate that, for the same time period, there is a greater chance of rejecting the null hypothesis of equal variances for non-intervention days than for intervention days. In addition, according to the p-values, the rejections of the null hypothesis are more significant for non-intervention days, i.e., in almost all cases, the null hypothesis is rejected at the 1% significance level with high test statistics, while it does not apply to intervention days, for which it is rejected at the 5% significance level in most cases. This shows that during those hours on non-intervention days, the intraday returns are highly heteroskedastic.

Another interesting finding is that the results of non-intervention days for the USD/JPY and euro/JPY series are very similar. The hours for which the null hypothesis is rejected (heteroskedastic) and not rejected (homoskedastic) are almost the same for the two series, both in the one-hour test and the two-hour test. For instance, in the one-hour test, at 3:00, 7:00, 14:00 and from 16:00 to 20:00, the variances are homoskedastic for both series. Those hours are outside of the opening hours of the Japanese market and there is only one major market open (New York or London). The homogeneity of variances during these periods may result from lower levels of trading activity. However, for intervention days, the results of the euro/JPY series are different to those of the other series. There are more cases rejecting the null hypothesis for the euro/JPY exchange rates than for the USD/JPY series. It indicates that the intervention on the USD/JPY has a different impact on the homoskedasticity of the intraday variance for the USD/JPY and euro/JPY series. This can be attributed to the expectations of the market. In the USD/JPY market, because of the frequency and magnitude of interventions during our sample period, the interventions and their intentions are more easily detected by the market, and people are more likely to have an analogous understanding of them. That may not only decrease the volatility, but also drive the intraday returns towards homoskedasticity. However, although the intervention in
the USD/JPY market also makes the euro/JPY series less heteroskedastic on intervention days, there is still a degree of uncertainty about how the intervention moves or affects the euro/JPY exchange rates, and it is likely to have more divergent opinions and actions on the market. Therefore, it is not surprising that the intervention in the USD/JPY market will cause increased volatility and greater heteroskedasticity in the euro/JPY exchange rate returns than in the USD/JPY market.

To summarise, the results from the equal variance test indicate that BoJ interventions from 2000 to 2004 have an effect on the heteroskedasticity of the intraday returns. They cause the intraday returns to be less heteroskedastic on intervention days for both exchange rate series. However, the impact on the USD/JPY series is greater than the spillover effect, i.e. the impact on the euro/JPY exchange rates. This finding may be useful in the volatility forecasting field, since heteroskedasticity has been regarded as an important characteristic of returns for modelling purposes. Taking account of the impact of intervention may therefore improve the results of forecasting.

5. Conclusion

This paper contributes to the foreign exchange intervention literature by providing new evidence on the effect of BoJ interventions on exchange rate volatility. We focus on a period that has not been extensively scrutinized in previous studies and consider the intervention impact in both daily and intraday frequencies. The focus on the intraday frequencies is motivated and vindicated by the finding of the short-lived volatility effects of interventions.

We use a multivariate GARCH model to evaluate the dynamics of the intervention impact on USD/JPY exchange rate volatility, the spillover effect on euro/JPY series and the covariance of the two exchange rates. We find that the BoJ’s interventions in the USD/JPY exchange rates decrease - although only in the short-term (less than 5 hours) and in a discontinuous pattern - the volatility of the USD/JPY series. This is contrary to the findings of studies focusing on the BoJ interventions during the 1990s. Nevertheless, the interventions increase significantly the volatility of the euro/JPY series and the impact lasts for the whole of the intervention day. Our results suggest that while the interventions BoJ can decrease volatility in one market (USD/JPY) in the short run, they also cause turbulence in another market (Euro/JPY) for a relatively longer period (the entire intervention day). To judge the success of the intervention operations, one should balance
the negative and positive effects for different markets. Another inference from the results of
the multivariate GARCH model is that interventions have some impact (decrease) on the
covariance of exchange rates. The evidence produced for the spillover effect and the impact
on covariances can have direct implications for portfolio management purposes.

We also analyze the characteristics of intraday volatility on intervention (non-
intervention) days by quartile plots and use the equal variance test to further consider the
intervention impacts. The quartile plots of the intraday volatility across the intervention
(non-intervention) reveal that the interventions affect volatility differently under different
market conditions. In addition, the equal variance test presents strong evidence that
interventions cause the intraday returns to become less heteroskedastic for both exchange
rates. These findings have not been reported in the literature and they may be included as a
related factor in future exchange rate volatility forecasting.

The evidence produced in this paper shows that foreign exchange interventions by the
BoJ in the early new millennium have differ qualitatively from the past experience
regarding their effects on exchange rate volatility. This result contrasts a prevailing view in
the literature which focuses on the 1990s, that BoJ interventions increase exchange rate
volatility. In addition to the implications for policy making, the above findings on the BoJ
interventions’ impact on volatility can be utilized by financial economists for other
purposes such as volatility forecasting, and portfolio management.

References


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Economic Review*, 47, 891-911.


**Figure 1:** Plot of USD/JPY exchange rate returns (actual)

![USD/JPY 15-minute return graph](image)

Figure 1 shows the plot of the USD/JPY 15-minute interval return series from January 1st 2000 - October 31st 2004.

**Figure 2:** Plot of euro/JPY exchange rate returns (actual)

![Euro/JPY 15-minute return graph](image)

Figure 2 shows the plot of the euro/JPY 15-minute interval return series from January 1st 2000 - October 31st 2004.
Figure 3: The plot of intervention activities during 2000 to 2004

Figure 3: Plots of the official intervention data of the BoJ from January 1st 2000-October 31st 2004. The data is obtained from the website of the Japanese Ministry of Finance. The intervention amount is reported in billion Japanese Yen.

Figure 4: Intervention coefficients $\psi_{11}$ in the variance equation of the multivariate GARCH model for the USD/JPY exchange rates

\begin{align*}
y_{1,t} &= h_1 + \delta_{1}X_{t-1} + \epsilon_{1,t} \\
y_{2,t} &= h_2 + \delta_{2}X_{t-1} + \epsilon_{2,t} \\
h_{1,t} &= \gamma_{11} + \alpha_{11}\epsilon_{t-1}^2 + \beta_{11}h_{1,t-1} + \psi_{11}X_{t-1} \\
h_{2,t} &= \gamma_{22} + \alpha_{22}\epsilon_{t-1}^2 + \beta_{22}h_{2,t-1} + \psi_{22}X_{t-1} \\
h_{12} &= \gamma_{12} + \alpha_{12}\epsilon_{t-1}^2 + \beta_{12}h_{1,t-1} + \psi_{12}X_{t-1} \\
\epsilon_{t} | \Omega_t &\sim N(0,H_t) \\
\end{align*}

Intervention Coefficients in Variance Equation of USD/JPY
**Figure 5:** Intervention coefficients $\psi_{11}$'s p-values for the USD/JPY exchange rates

Figure 5 plots the intervention coefficients’ p-values for the USD/JPY exchange rates in the multivariate GARCH model. The model is estimated 96 times for 96 daily return series constructed according to different time points. The Figure shows 96 p-values against different time points. The X axis represents Japanese time and the Y axis represents the p-values. The Y axis crosses the X axis at 0.1 representing 10% significance level.

**Figure 6:** Intervention coefficients $\psi_{22}$ in the variance equation of the multivariate GARCH model for the euro/JPY exchange rates

Figure 6 plots the intervention coefficients of the euro/JPY exchange rates in the multivariate GARCH model. The model is estimated 96 times for 96 daily return series constructed according to different time points. The Figure shows 96 $\psi_{22}$s against different time points. The X axis represents Japanese time and the Y axis represents the value of estimation.
Figure 7: Intervention coefficients $\psi_{22}$'s p-values for the euro/JPY exchange rates

Figure 7 plots the intervention coefficients' p-values for the euro/JPY exchange rates in the multivariate GARCH model. The model is estimated 96 times for 96 daily return series constructed according to different time points. The Figure shows 96 p-values against different time points. The X axis represents Japanese time and the Y axis represents the p-values.

Figure 8: Intervention coefficients $\psi_{12}$ in the covariance equation of the multivariate GARCH model for the USD/JPY and euro/JPY exchange rates

Figure 8 plots the intervention coefficients for covariance of the USD/JPY and euro/JPY exchange rates in the multivariate GARCH model. The model is estimated 96 times for 96 daily return series constructed according to different time points. The Figure shows 96 $\psi_{12}$'s against different time points. The X axis represents Japanese time and the Y axis represents the value of estimation.
Figure 9: Intervention coefficients ψ'_{12} s’ p-values in the covariance equation

Figure 9 plots the intervention coefficients’ p-values for the covariance of the USD/JPY and euro/JPY exchange rates in the multivariate GARCH model. The model is estimated 96 times for 96 daily return series constructed according to different time points. The Figure shows 96 p-values against different time points. The X axis represents Japanese time and the Y axis represents the p-values. The Y axis crosses the X axis at 0.1 representing 10% significance level.
**Figure 10:** The third quartile plot of intraday volatility of USD/JPY exchange rate returns

The Third Quartile of intraday volatility of USD/JPY exchange rates

![Graph showing the third quartile of intraday volatility for intervention and non-intervention days.](image)

Figure 10 shows the third quartile of 15-minute interval intraday volatility on both intervention days and non-intervention days for the USD/JPY exchange rates. The absolute returns are used as the indicator of volatility. The light line represents the volatility on intervention days and the dark line represents the volatility on non-intervention days. Times shown in X-axis are Japanese time.

**Figure 11:** The median quartile plot of intraday volatility of USD/JPY exchange rate returns

The Median of intraday volatility of USD/JPY exchange rates

![Graph showing the median of intraday volatility for intervention and non-intervention days.](image)

Figure 11 shows the median of 15-minute interval intraday volatility on both intervention days and non-intervention days for the USD/JPY exchange rates. The absolute returns are used as the indicator of volatility. The light line represents the volatility on intervention days and the dark line represents the volatility on non-intervention days. Times shown in X-axis are Japanese time.

**Figure 12:** The first quartile plot of intraday volatility of USD/JPY exchange rate returns
Figure 12 shows the first quartile of 15-minute interval intraday volatility on both intervention days and non-intervention days for the USD/JPY exchange rates. The absolute returns are used as the indicator of volatility. The light line represents the volatility on intervention days and the dark line represents the volatility on non-intervention days. Times shown in X-axis are Japanese time.

**Figure 13:** The third quartile plot of intraday volatility of euro/JPY exchange rate returns

Figure 13 shows the third quartile of 15-minute interval intraday volatility on both intervention days and non-intervention days for the euro/JPY exchange rates. The absolute returns are used as the indicator of volatility. The light line represents the volatility on intervention days and the dark line represents the volatility on non-intervention days. Times shown in X-axis are Japanese time.

**Figure 14:** The median quartile plot of intraday volatility of euro/JPY exchange rate returns
The Median of intraday volatility of Euro/JPY exchange rates

Figure 14 shows the median of 15-minute interval intraday volatility on both intervention days and non-intervention days for the euro/JPY exchange rates. The absolute returns are used as the indicator of volatility. The light line represents the volatility on intervention days and the dark line represents the volatility on non-intervention days. Times shown in X-axis are Japanese time.

Figure 15: The first quartile plot of intraday volatility of euro/JPY exchange rate returns

Figure 15 shows the first quartile of 15-minute interval intraday volatility on both intervention days and non-intervention days for the euro/JPY exchange rates. The absolute returns are used as the indicator of volatility. The light line represents the volatility on intervention days and the dark line represents the volatility on non-intervention days. Times shown in X-axis are Japanese time.

Table 1: Summary statistics of the 15-minute returns
Distribution statistics of 15-minute returns of the USD/JPY and euro/JPY exchange rate series.

### Table 2: Summary Statistics of Daily Returns calculated by Different Quotation Times

<table>
<thead>
<tr>
<th>Quotation Time (Japanese Time)</th>
<th>8:00</th>
<th>8:15</th>
<th>8:30</th>
<th>8:45</th>
<th>9:00</th>
<th>9:15</th>
<th>9:30</th>
<th>9:45</th>
<th>10:00</th>
<th>10:15</th>
</tr>
</thead>
<tbody>
<tr>
<td>USD/JPY Mean (x10^-5)</td>
<td>-0.772</td>
<td>3.51</td>
<td>5.13</td>
<td>12.7</td>
<td>5.12</td>
<td>19.3</td>
<td>3.08</td>
<td>3.86</td>
<td>4.25</td>
<td>3.54</td>
</tr>
<tr>
<td>S.D. (x10^-3)</td>
<td>6.020</td>
<td>5.98</td>
<td>6.05</td>
<td>7.16</td>
<td>6.04</td>
<td>7.30</td>
<td>6.00</td>
<td>5.81</td>
<td>5.85</td>
<td>5.80</td>
</tr>
<tr>
<td>Skewness</td>
<td>-0.122</td>
<td>-0.0685</td>
<td>-0.155</td>
<td>-0.172</td>
<td>-0.0676</td>
<td>-0.0146</td>
<td>-0.0636</td>
<td>-0.0296</td>
<td>0.0415</td>
<td>0.0418</td>
</tr>
<tr>
<td>Kurtosis</td>
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<td>4.33</td>
<td>4.67</td>
<td>4.18</td>
<td>4.34</td>
<td>5.26</td>
<td>4.23</td>
<td>4.09</td>
<td>4.87</td>
<td>4.05</td>
</tr>
</tbody>
</table>

Distribution statistics of daily returns calculated by 10 different quotation time points as examples. Using 15-minute interval return series, the time points range from 00:00-23:45 in Japanese time. A total of 96 daily return series generated.

### Table 3: Statistics of Intervention Data (1/1/2000-31/10/2004)

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Mean</td>
<td>307.3</td>
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<tr>
<td>Standard Error</td>
<td>26.60</td>
</tr>
<tr>
<td>Median</td>
<td>206.6</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>322.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>1666.4</td>
</tr>
<tr>
<td>Sum</td>
<td>45173.5</td>
</tr>
<tr>
<td>Count (times)</td>
<td>147</td>
</tr>
</tbody>
</table>

Source: Japanese Ministry of Finance. The numbers are in bn of Japanese Yen (except the last row).
Table 4: Results of the equal variance test for one-hour intervals

\[ H_0: \sigma^2 = \sigma^2 = \sigma^2 = \sigma^2 \]

against

\[ H_1: \sigma^2 \neq \sigma^2 (i, j = 1, \ldots, 4) \text{ for at least one pair} \]

\[ F = \frac{\sum_{j=1}^{N} (\bar{D}_j - \bar{D})^2}{\sum_{j=1}^{N} (D_j - \bar{D})^2 (J-1)} \]  

(14)

<table>
<thead>
<tr>
<th>Time</th>
<th>3D/JPY Intervention</th>
<th>3D/JPY Non-intervention days</th>
<th>10/JPY Intervention</th>
<th>10/JPY Non-intervention days</th>
</tr>
</thead>
<tbody>
<tr>
<td>00.00</td>
<td>14</td>
<td>023</td>
<td>28</td>
<td>043</td>
</tr>
<tr>
<td>00.00</td>
<td>14</td>
<td>044</td>
<td>66</td>
<td>90</td>
</tr>
<tr>
<td>00.00</td>
<td>162</td>
<td>37</td>
<td>44</td>
<td>80</td>
</tr>
<tr>
<td>00.00</td>
<td>163</td>
<td>025</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>00.00</td>
<td>58</td>
<td>025</td>
<td>11</td>
<td>27</td>
</tr>
<tr>
<td>00.00</td>
<td>03</td>
<td>010</td>
<td>11</td>
<td>27</td>
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<tr>
<td>00.00</td>
<td>90</td>
<td>024</td>
<td>11</td>
<td>27</td>
</tr>
<tr>
<td>00.00</td>
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<td>163</td>
<td>16</td>
<td>24</td>
</tr>
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<td>00.00</td>
<td>176</td>
<td>070</td>
<td>14</td>
<td>37</td>
</tr>
<tr>
<td>00.00</td>
<td>162</td>
<td>109</td>
<td>5</td>
<td>37</td>
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<tr>
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<td>028</td>
<td>9</td>
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<td>119</td>
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<td>37</td>
</tr>
</tbody>
</table>

The table shows the t-statistics and p-values of the equal variance test for one-hour intervals. For each exchange rate series, tests were carried out for both intervention days and non-intervention days. The null hypothesis is that for 15-minute interval returns, the variances in one hour are statistically equal. The symbols ***,** and * indicate, respectively, that the null hypothesis is rejected at the 1%, 5% and 10% significance levels. Times shown in the first column are Japanese time.
Table 5: Results of the equal variance test for two-hour intervals

\[ H_0 : \sigma_1^2 = \sigma_2^2 = \ldots = \sigma_8^2 \]

against

\[ H_1 : \sigma_i^2 \neq \sigma_j^2 (i,j = 1, \ldots, 8) \text{ for at least one pair} \]

\[
F = \frac{\sum_{j=1}^{8}(D_j - \bar{D}_j)^2}{\sum_{j=1}^{8}(\bar{D}_j - \bar{D})^2} \frac{(N-j)}{(J-1)}
\]

<table>
<thead>
<tr>
<th>Hours</th>
<th>USD/JPY Intervention days</th>
<th>USD/JPY Non-intervention days</th>
<th>euro/JPY Intervention days</th>
<th>euro/JPY Non-intervention days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>1.31</td>
<td>0.242</td>
<td>17.5***</td>
<td>0.000</td>
</tr>
<tr>
<td>2:00</td>
<td>0.459</td>
<td>0.865</td>
<td>5.91***</td>
<td>0.000</td>
</tr>
<tr>
<td>4:00</td>
<td>2.45**</td>
<td>0.017</td>
<td>14.7***</td>
<td>0.000</td>
</tr>
<tr>
<td>6:00</td>
<td>4.22***</td>
<td>0.000</td>
<td>12.8***</td>
<td>0.000</td>
</tr>
<tr>
<td>8:00</td>
<td>0.934</td>
<td>0.479</td>
<td>65.0***</td>
<td>0.000</td>
</tr>
<tr>
<td>10:00</td>
<td>0.879</td>
<td>0.522</td>
<td>26.9***</td>
<td>0.000</td>
</tr>
<tr>
<td>12:00</td>
<td>0.518</td>
<td>0.821</td>
<td>16.4***</td>
<td>0.000</td>
</tr>
<tr>
<td>14:00</td>
<td>0.718</td>
<td>0.657</td>
<td>17.4***</td>
<td>0.000</td>
</tr>
<tr>
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<td>0.547</td>
<td>0.799</td>
<td>1.32</td>
<td>0.237</td>
</tr>
<tr>
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<td>0.269</td>
<td>1.28</td>
<td>0.256</td>
</tr>
<tr>
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<td>0.079</td>
<td>20.3***</td>
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</tr>
<tr>
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<td>1.48</td>
<td>0.199</td>
<td>4.92***</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The table shows the t-statistics and p-values of the equal variance test for two-hour intervals. For each exchange rate series, tests were taken for both intervention days and non-intervention days. The null hypothesis is that for 15-minute interval returns, the variances within two hours are statistically equal. The symbols ***, ** and * indicate, respectively, that the null hypothesis is rejected at the 1%, 5% and 10% significance levels. Times shown in the first column are Japanese time.