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Bank of Japan Interventions and the Volatility of the Dollar/Yen Exchange Rate

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Abstract

We analyse the impact of Bank of Japan's (BoJ) intervention on the volatility of the USD/JPY exchange rates under a regime switching framework. We find that the Yen intervention decreases the volatility, and the impact is only significant when market volatility is low.

Die Interventionen der japanischen Zentralbank und die Volatilität des Dollar/Yen-Wechselkurses

Zusammenfassung

Der Beitrag analysiert den Effekt von Interventionen der japanischen Notenbank (BoJ) auf die Volatilität des USD/JPY-Wechselkurses im Rahmen eines Regime-Switching Modells. Die Ergebnisse zeigen, dass Interventionen die Volatilität senken. Allerdings ist der Effekt nur dann signifikant, wenn die Marktvolatilität niedrig ist.

Keywords: Foreign Exchange Intervention, Exchange Rate Volatility, Regime Switching GARCH

JEL classification: F31,G15

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I. Introduction

Foreign exchange intervention has been a commonly used tool by central banks to influence exchange rates and the Bank of Japan (BoJ) is one of those central banks that has intervened in the foreign exchange market the most frequently. Acting as the agent of the Ministry of Finance, the BoJ conducts interventions as a means for achieving exchange rate stability,[1] which is in line with the guiding principles for intervention policies provided by the IMF.

Given the frequency of official interventions in the Japanese market, it is reasonable to assume that interventions affect the exchange rates through the signalling channel, which can be at work when the market is aware of the intervention occurs. The signalling channel assumes that the intervention intends to signal a change in the monetary policy. Thus the market participants interpret the intervention as information released into the market, and alter their expectations and actions regarding the exchange rate. The effect of central bank interventions (CBIs) through a signalling channel, however, depends on whether the signal is unambiguous and consistent with official goals. The prevailing state of the market, however, plays an important role in determining whether the signal is unambiguous or not (*Dominguez,* 1998). As earlier research shows, market participants seem to differentiate less between good and bad news when they are in the more volatile period (*Ane* and *Ureche-Rangau*, 2006). The market reacts to the news (in our case, the intervention) differently under turbulent and calm states, and we hypothesize that the effect of intervention on exchange rates may depend on the level of volatility (high/low).

Numerous studies have sought to evaluate the effects of the BoJ's interventions on the exchange rate volatility, including *Dominguez* (1998), *Galati* et al. (2005), *Nagayasu* (2004), *Beine* et al. (2009), *Hoshikawa* (2008), *Hassan* (2012), *Kim* and *Le* (2010). These studies, however, assess the impact of interventions under a single market regime. In this paper, we differentiate the intervention effect on volatility under different market states. Exchange rate volatility is time-varying and usually highly persistent. The source of volatility persistence may arise from structural changes in the variance process, i.e., volatility regime switching. Indeed, regime-switching in nominal exchange rates has been well documented in the literature, by *Engel* and *Hamilton* (1990), *Bekaert* and *Hodrick* (1993), and *Bergman* and *Hansson* (2005) among others.

The conventional way of assessing the impact of CBIs on volatility is to model the intervention variable using a standard volatility model, such as the GARCH model. The structural form of conditional means and variances in standard GARCH models, however, is held fixed throughout the whole sample

[1] Bank of Japan. http://www.boj.or.jp/en/intl_finance/outline/index.htm/.

period and as a result, any shift in unconditional variance is likely to lead to misestimating the parameters. Since the GARCH model cannot distinguish high and low volatility periods and assigns all volatility persistence to individual shocks, it suffers from an upward bias in persistence estimation (*Lamoureux* and *Lastrapes*, 1990). Given the inability of the single regime GARCH model to account for changes in the economic environment, the impact of CBIs captured by this type of model is based on an inflexible structural form of volatility. Therefore, when the regime of the economy changes the dynamics of the intervention's impact cannot be observed. Limited evidence exists on the impact of CBIs in regime-switching framework. *Beine* et al. (2003) take account of the changes in the economic environment when evaluating the impact of CBIs on exchange rate volatility. The use of weekly data, however, implies constant variance within regimes and therefore it does not allow to address the impact of interventions under different volatility regimes. *Hassan* (2012) uses a regime change model to examine the impact of frequency and size of intervention on volatility. Nevertheless, the regime changes considered refer to the pattern of the interventions and not to volatility.

In this paper, we utilize a Markov Regime-Switching (MRS) GARCH model, which allows for conditional heteroskedasticity within the regimes, to assess the effects of BoJ's interventions on the USD/JPY exchange rate volatility. The intervention variable is modelled on both the mean and variance equations in the MRS-GARCH models. As the regimes shift, the coefficients of interventions change as well. By this means we can observe how the BoJ's interventions affect exchange rate volatility differently under different market states. To our knowledge, there has been no other attempt in the literature to use the MRS-GARCH model to evaluate the impact of CBIs on exchange rate volatility.

II. Data and Methodology

The official intervention data is available on the website of the *Japanese Ministry of Finance* for the period starting from May, 1991. We focus on the period spanning from January 1st 2000 to October 31st 2004, which represents a unique era for interventions in Japan. First, the BoJ has intervened in the USD/JPY exchange rate market with substantially greater magnitude and higher frequency during this period as compared to 1990s, which makes the data of this period a typical example that intervention influences the foreign exchange markets through the signalling channel.[2] Second, the interventions that occurred during

[2] 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, only slightly less than the total sum of 8 years during the 1990s. The frequency of interventions was also high, occurring 82 times in 2003.

this period are all unilateral ones conducted solely by the BoJ. Therefore our analysis is not affected by joint or coordinated interventions on the USD/JPY exchange rate. Third, intervention activities during that period were restricted to buying USD and selling Yen, therefore the intention of the intervention is consistent over the sample period.[3] In addition, the period 2000 to 2004 covers the 'zero interest rate policy' era in Japan. It provides a unique institutional background for investigating the effectiveness of sterilized intervention when monetary policy options are constrained (*Fatum*, 2015). Under these circumstances, both the purpose of intervention and its impact tend to differ from previous practice.

In this paper we use a time series model and the continuity of the data is crucial. We do not include recent interventions conducted in 2010 and 2011 to avoid the discontinuity of the intervention data, given that there is no intervention from March 2004 until September 2010.[4] *Fatum* and *Yamamoto* (2014) consider the BoJ interventions from 1991 to 2011, however they use sub-sample methods and separate the years 2004 and 2011 as two sample periods. During the period we consider in this paper there were 147 interventions by the BoJ in the USD/JPY exchange rates, and the total amount reached 45,173.5 billion Japanese Yen. Figure 1 shows the plot of the intervention activities.

Most of the literature uses intraday data for the analysis of volatility. Compared to daily data, intraday data contains more information on daily transactions and is less noisy (e.g., see *Chortareas* et al., 2011; *Jiang* et al., 2016; *Kenourgios* et al., 2015a; *Kenourgios* et al., 2015b). In our case, the use of intraday data is particularly useful since the intervention effects are short-lived and the impact of the intervention does not extend beyond the intervention day (e.g., *Dominguez*, 2003; *Beine* et al., 2009, *Kim*, 2007; *Kim* and *Le*, 2010). In addition, empirical evidence shows that the effects of BoJ interventions on volatility are mostly significant from noon to closing time in the U.S. market (*Kim*, 2007). The daily closing price of exchange rates in Japanese market may not capture the short-term impact of interventions.

The exact times of official interventions, however, are not available. Therefore we construct a set of daily return series which are obtained from different trading times within the day in the Japanese market, and we use each of them as dependent variable in model estimation in order to capture the timing of the interventions' effect on volatility. For a one-hour interval, the quotation time ranges from 00:00 to 23:00 (Japanese time), which generates 24 daily return series. Each series contains 1,259 observations.

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[3] There are interventions involved the opposite direction: selling USD and buying Yen in 1991, 1992 and 1997.

[4] There are 7 interventions in total from September 2010 to November 2011 conducted by the BoJ. No intervention event happens since then till the third quarter of 2016.

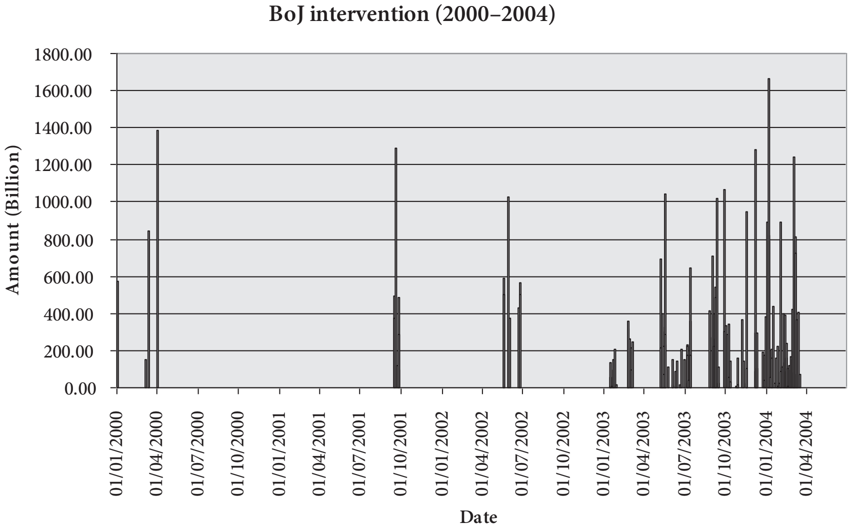

Figure 1: The Plot of Intervention Activities During 2000 to 2004 (The Intervention Amount is Reported in Billion Japanese Yen)

Let the daily return series $r_{t,n}$ be:

$$r_{t,n} = 100 * (\ln e_{t,n} - \ln e_{t-1,n}), \quad (1)$$

where $e_{t,n}$ is the USD/JPY exchange rates at day t and at time n, $t = 1 \ldots 1259$, and n corresponds to time points from 00:00 to 23:00 at one-hour interval, in total 24 different values in each day.

The MRS-GARCH model combines the standard GARCH model and Hamilton's (1989) Markov Regime-Switching model. It allows the unconditional mean and variance of dependent variable to take different values according to the economic state. Two regimes are assumed in this study, i.e., a high volatility regime and a low volatility regime. According to the Markov regime-switching model, the latent state variable s_t which controls the regime shifting follows a first-order Markov-chain with transition probability:

$$\Pr(s_t = j \mid s_{t-1} = i) = p_{ij} \quad (2)$$

which indicates the probability of switching from state i at time $t - 1$ into state j at time t. In our case, $i, j = 1, 2$ and p_{ij} can be gathered into a transition probability matrix P where

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} = \begin{bmatrix} p_{11} & 1 - p_{11} \\ 1 - p_{22} & p_{22} \end{bmatrix} \tag{3}$$

In the regime-switching context, the standard GARCH (1,1) model becomes state-dependent :

$$\begin{aligned} r_t &= \mu_{s_t} + \gamma_{s_t} r_{t-1} + \varepsilon_t \mid \Omega_{t-1} \sim f(0, h_{s_t,t}) \\ h_{s_t,t} &= \omega_{s_t} + \alpha_{s_t} \varepsilon_{t-1}^2 + \beta_{s_t} h_{s_t,t-1} \\ s_t &= 1, 2 \end{aligned} \tag{4}$$

where the return series r_t is the return series calculated from equation (1), following a mixture of distributions:

$$r_t \mid \varsigma_{t-1} \sim \begin{Bmatrix} f(r_t \mid s_t = 1, \varsigma_{t-1}; \theta_1)\, w.p. & p_{1t} \\ f(r_t \mid s_t = 2, \varsigma_{t-1}; \theta_2)\, w.p. & 1 - p_{1t} \end{Bmatrix}, \tag{5}$$

with ς_{t-1} being the information set at time t – 1, $f(\cdot \mid s_t = i)$ is the conditional distribution given that regime i occurs at time t, and $\theta = (\theta_1, \theta_2)$ is the set of parameters. The conditional probability is specified as

$$p_{jt} = P(s_t = j \mid \varsigma_{t-1}) = \sum_{i=1}^{2} p_{ij} P(s_{t-1} = i \mid \varsigma_{t-1}) \tag{6}$$

Let $P(s_t = j \mid \varsigma_t)$ be the probability of falling in regime j at time t and define

$$P(s_t = j \mid \varsigma_t) = \frac{f(r_t \mid s_t = j, \varsigma_{t-1}) P(s_t = j \mid \varsigma_{t-1})}{\sum_{i=1}^{2} f(r_t \mid s_{t-1} = i \mid, \varsigma_{t-1}) P(s_t = i \mid \varsigma_{t-1})} \tag{7}$$

The conditional state probabilities can be obtained recursively. Thus, the log likelihood function can be written as:

$$L = \sum_{t=1}^{T} \log \sum_{j=1}^{2} f(r_t \mid s_t = j, \varsigma_{t-1}) P(s_t = j \mid \varsigma_{t-1}), \tag{8}$$

where $f(r_t \mid s_t = j, \varsigma_{t-1}) = \exp\{l_{jt}\}$, and l_{jt} is the t^{th} term from the relevant case of L_T.

To capture the impact of interventions on foreign exchange rates and their volatility, we add an exogenous intervention variable into the variance equation as well as the mean equation of the standard model. The parameter in the variance equation measures the degree of the impact on volatility. We use a dummy variable x_t as intervention variable, which takes the value 1 when the intervention happens on day t and the value 0 otherwise. The extended model is as follows:

$$
\begin{aligned}
& r_t = \mu_{s_t} + \gamma_{s_t} r_{t-1} + \delta_{s_t} x_t + \varepsilon_t \mid \Omega_{t-1} \sim f(0, h_{s_t,t}) \\
& h_{s_t,t} = \omega_{s_t} + \alpha_{s_t} \varepsilon_{t-1}^2 + \beta_{s_t} h_{s_t,t-1} + \lambda_{s_t} x_t \\
& s_t = 1, 2.
\end{aligned} \tag{9}
$$

III. Empirical Results

We start the analysis by examining the impact of intervention without distinguishing market states. If the intervention significantly affects market volatility in general, we further investigate whether it works differently when market experiences different level of volatility. As discussed before, the intervention effects are short-lived and the impact of the intervention does not extend beyond the intervention day. Thus we first need to identify the timing when the intervention has significant impact on volatility. We estimate a single regime GARCH (1,1) model with intervention dummy variable in the mean and variance equation (equation 9 when $s_t = 1$) for each of the 24 daily return series. We find that the impact of interventions is systematically significant between 1:00 and 5:00 Japanese time, when the U.S. exchange market is still open, and between 11:00 and 13:00, when the Japanese exchange market is open. Outside these two periods, the impact of interventions does not appear to be continuous or systematically significant.[5] The possible explanation of why the impact takes place in the early morning in Japan is as following: The intervention activities appear to be clustered during certain periods. During these periods, lasting a week or even a month, the BoJ interventions take place on a daily basis (see Figure 1). The intervention works during the same day when Japanese market opens, and also has impact on exchange rate volatility when the U.S. market opens, e.g. next day early morning Japanese time. These results are consistent with findings in other studies, e.g. *Kim* (2007) and *Chortareas* et al. (2013). Based on the results from the single regime model, hence, we focus on daily return series constructed by times between 1:00 to 5:00 and 11:00 to 13:00, when the intervention has significant impact on volatility, as dependent variables to estimate the MRS-GARCH model with intervention variable (equation 9).

[5] The results from the single regime GARCH model are available upon request.

Table 1

Estimation Results of the MRS-GARCH Model with the Intervention Variable

	Regime H	Regime L
$\hat{\mu}$	–1.52 (–0.57)	0.02 (0.96)
$\hat{\gamma}$	0.87 (4.07***)	–0.10 (–3.31***)
$\hat{\delta}$	–0.80 (–2.21**)	0.004 (0.11)
$\hat{\alpha}$	0.02 (0.78)	0.024 (2.42**)
$\hat{\beta}$	0.96 (44.90***)	0.89 (16.90***)
$\hat{\lambda}$	–0.08 (–0.30)	–0.075 (–2.06**)
$\hat{\sigma}$	2.42	1.37
$\hat{p}_{ii}$	0.89	0.93
Log likelihood	–1107.52	
Q(12)	6.48 (0.84)	
$Q^2(12)$	15.46 (0.22)	

The table shows the estimation result of the MRS-GARCH model with the intervention variable in both mean equations and variance equations for two regimes. The sample period is January 1st 2000–October 31st 2004. The daily return series is calculated by prices at 2:00am of Japanese time for the USD/JPY exchange rates. Coefficient estimations are shown in the first panel with t-statistics presented in parentheses. *** and ** denote statistical significance at the 1% and 5% significance levels respectively. Instead of intercepts $\hat{\omega}$, the standard errors of the returns conditional on each volatility regime (unconditional volatility) are reported, $\hat{\sigma} = (\hat{\omega}/1-\hat{\alpha}-\hat{\beta})^{\frac{1}{2}}$. The second panel reports the log likelihood and diagnostic test results for the residuals. Q(12) and $Q^2(12)$ are the Ljung-Box test statistics of up to 12 lags for the standardized residuals and their squares. The numbers in parenthesis are test p-values. Regime H and Regime L represent the high volatility regime and low volatility regime respectively.

Table 1 shows the results for the return series calculated at 2:00 am as example. At this time point the intervention has significantly negative impact on the volatility. We can see the existence of two regimes of volatility, i.e., a high and a low regime. The intercepts in the mean equations are not significant. However, the intercepts are positive in one regime and negative in the other, corresponding to 'good state' economy and a decreasing market. In addition, the regime corresponding to the negative conditional mean ('bad state' economy) is with a higher unconditional variance than the other. Most of the parameters in the variance equations are highly significant in both regimes. The transition probabilities $\hat{p}_{ii}$ show that low volatility regime is more persistent than the high volatility regime.

The most interesting result in Table 1 is that the interventions perform differently in high/low volatility regimes. The intervention coefficient $\hat{\lambda}$ is significant in the low volatility regime (at 5 % significant level), but not for the high volatility regime. In other words, the market reacts to the intervention depending on market conditions. One possible reason for this is that when the volatility is low or the market is calm, market participants are more likely to treat the intervention operation as an event that could affect the exchange rate market and take action to respond. The signal of interventions sent to the market can be understood clearly. Activities of participants in the market thus affect the exchange rate volatility. However, when the volatility is high and the market is in a turbulent and chaotic situation, participants seem to have less confidence in central banks' operation and less belief in their ability to affect the exchange rates. Therefore, the response from market is not significant. In addition, high volatility of a market is usually accompanied by the flow-in of a large volume of information, which may divert traders' attention from specific news or events. In this case, intervention operations will have less 'news effect' on the market than in a quiet one (low volatility market). Apparently, the single regime model can't distinguish this different impact of the intervention. Table 1 also reveals that the sign of $\hat{\lambda}$ is negative for the USD/JPY series, indicating that interventions operated by the BoJ have a calming-down effect on the USD/JPY exchange rate market, i.e., decreasing the volatility. This finding is consistent with the result from *Chortareas* et al. (2013).

Table 2

Estimation Results of the MRS-GARCH Model with the Intervention Variable for Return Series Constructed at Different Time Points

Time	Regime H			Regime L		
	$\hat{\lambda}$	$\hat{\sigma}$	$\hat{p}_{ii}$	$\hat{\lambda}$	$\hat{\sigma}$	$\hat{p}_{ii}$
1:00	–0.05 (–0.25)	2.69	0.22	–0.07 (–1.81*)	1.90	0.75
3:00	–0.06 (–0.30)	11.07	0.29	–0.09 (–2.26**)	0.56	0.76
4:00	–0.02 (–0.12)	1.32	0.11	–0.11 (–2.61***)	0.57	0.79
5:00	–0.12 (–0.71)	5.20	0.99	–0.08 (–2.01**)	2.23	0.77
11:00	–0.37 (–1.03)	4.34	0.36	–0.06(–1.36)	2.71	0.93
12:00	0.15 (1.63)	4.47	0.92	–0.54 (–2.17**)	0.31	0.26
13:00	0.07 (0.93)	3.28	0.86	–0.08 (–2.64***)	1.38	0.38

The table shows the estimation results for the intervention variable in variance equation, unconditional volatility and transition probabilities from the MRS-GARCH model for two regimes. The sample period is January 1st 2000-October 31st 2004. Time points at which the return series are constructed are shown in the first column. Coefficient estimates are shown with t-statistics presented in parentheses. *** and ** denote statistical significance at the 1 % and 5 % significance levels respectively. Regime H and Regime L represent the high volatility regime and low volatility regime respectively.

To check the robustness of our results, we also perform the estimation using return series constructed at other time points, at which the BoJ interventions have significant impact on volatility in a single regime framework. To save space, only intervention coefficients on volatility, unconditional volatility, and transition probabilities for each regime are reported.[6] The results are consistent with those from Table 1, e.g. The BoJ intervention decreases the USD/JPY exchange rate volatility, and the impacts are only significant in the low volatility regime, with exception of the daily return series calculated by prices at 11:00.

IV. Conclusion

This study evaluates the impact of intervention on volatility by a Markov regime-switching GARCH model, which allows distinguishing the possible different impact on volatility when the market state changes. The results show that there are clearly two volatility regimes existing in the market, corresponding to high and low volatility. The BoJ interventions only have impact on volatility when market is calm. The results indicate that market condition is an important factor that affects the impact of intervention and the volatility regime-switching should not be ignored when evaluating the impact of intervention.

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Appendix

Amount: Billion Japanese Yen

Date	Amount	Date	Amount	Date	Amount	Date	Amount
04/01/2000	5,753	12/05/2003	3,302	01/10/2003	2,998	22/01/2004	243
08/03/2000	1,501	13/05/2003	3,037	02/10/2003	3,332	23/01/2004	1,575
15/03/2000	8,468	14/05/2003	3,971	07/10/2003	2,831	26/01/2004	21
03/04/2000	13,854	15/05/2003	2,257	09/10/2003	3,446	27/01/2004	1,881
17/09/2001	4,955	16/05/2003	698	10/10/2003	549	28/01/2004	2,264
19/09/2001	3,774	19/05/2003	10,401	13/10/2003	1,404	29/01/2004	112
21/09/2001	12,874	20/05/2003	2,283	14/10/2003	310	30/01/2004	238
24/09/2001	1,172	21/05/2003	2,882	28/10/2003	108	02/02/2004	2,512
26/09/2001	943	27/05/2003	1,086	29/10/2003	1,585	03/02/2004	8,893
27/09/2001	4,871	05/06/2003	126	30/10/2003	124	04/02/2004	884
28/09/2001	2,866	06/06/2003	1,502	10/11/2003	3,665	06/02/2004	1,090
22/05/2002	5,871	12/06/2003	70	11/11/2003	1,425	09/02/2004	30
23/05/2002	4,991	13/06/2003	869	14/11/2003	38	10/02/2004	1,160
31/05/2002	10,312	16/06/2003	1,464	18/11/2003	216	11/02/2004	4,021
04/06/2002	3,727	23/06/2003	177	19/11/2003	9,487	12/02/2004	1,336
24/06/2002	4,290	25/06/2003	2,081	20/11/2003	1,040	13/02/2004	3,863
26/06/2002	5,687	03/07/2003	1,508	21/11/2003	1	16/02/2004	842
28/06/2002	5,046	07/07/2003	2,340	08/12/2003	876	17/02/2004	1,584
15/01/2003	83	08/07/2003	2,221	09/12/2003	2,914	18/02/2004	2,410
16/01/2003	570	09/07/2003	236	10/12/2003	12,838	19/02/2004	1,000
17/01/2003	1,376	10/07/2003	1,744	11/12/2003	1,049	20/02/2004	107
20/01/2003	59	11/07/2003	412	12/12/2003	2,925	23/02/2004	1,181
23/01/2003	990	14/07/2003	3,618	26/12/2003	1,917	24/02/2004	1,211
24/01/2003	1,484	15/07/2003	6,466	29/12/2003	1,725	25/02/2004	947
27/01/2003	2,066	16/07/2003	1,726	30/12/2003	371	27/02/2004	1,695
29/01/2003	153	29/08/2003	4,124	31/12/2003	1,581	01/03/2004	1,493
24/02/2003	927	02/09/2003	2,733	02/01/2004	3,804	02/03/2004	4,219
25/02/2003	3,178	04/09/2003	7,055	05/01/2004	8,951	03/03/2004	799
26/02/2003	258	05/09/2003	3,953	06/01/2004	8,185	04/03/2003	1,974
27/02/2003	3,615	08/09/2003	2,231	07/01/2004	5,822	05/03/2004	12,446
28/02/2003	2,636	09/09/2003	2,633	08/01/2004	7,922	08/03/2004	8,090
03/03/2003	2,155	10/09/2003	5,436	09/01/2004	16,664	09/03/2004	7,236
04/03/2003	928	11/09/2003	4,872	12/01/2004	571	10/03/2004	693
07/03/2003	2,431	12/09/2003	10,178	13/01/2004	1,882	11/03/2004	3,629
10/03/2003	4	15/09/2003	271	14/01/2004	2,071	15/03/2004	4,075
08/05/2003	6,914	16/09/2003	1,087	15/01/2004	1,623	16/03/2004	678
09/05/2003	2,166	30/09/2003	10,667	16/01/2004	4,386		

Note: This table shows the date and amount of the interventions by the BoJ on Yen exchange rate against the U.S dollar for the period 2000 to 2004. For all intervention activities the dollar is bought and Yen is sold.