Effects of the Bank of Japan's Intervention on Yen/Dollar Exchange Rate Volatility*

Toshiaki Watanabe†
Faculty of Economics, Tokyo Metropolitan University

Kimie Harada‡
Graduate School of International Accounting, Chuo University

Latest Revision: June 2004

Abstract

This paper examines the effects of the Bank of Japan (BOJ)'s intervention on the volatility as well as the level of the yen/dollar exchange rate. Specifically, the conventional GARCH model proposed by Bollerslev (1986) and the component GARCH model proposed by Engle and Lee (1999), where the volatility consists of short-run and long-run components, are estimated using the BOJ's and the Federal Reserve system (Fed)'s official intervention data. Results based on the component GARCH model provide new evidence on the effects of the BOJ's intervention on the volatility of the yen/dollar exchange rate. The BOJ's intervention only reduces the short-run volatility component from the late 1990s to 2003, while it does not have an impact on volatility (both the short- and long-run volatilities) at all in the early 1990s. The BOJ's intervention has some positive effects only in the short run. The stabilizing effect of the BOJ's intervention in the late 1990s and the first few years of the 2000s is not enhanced by the Fed's coordinated intervention. Meanwhile, the Fed's coordinated intervention has statistically significant effects only in the short run.

JEL classification: F31
Keywords: Exchange rate volatility; Central bank intervention; Component GARCH

*We thank Colin Mckenzie, Gunther Schnabl, and seminar participants at Keio University and Tokyo Metropolitan University for their useful comments. We gratefully acknowledge Gunther Schnabl for providing data on the Federal Reserve's intervention. We also appreciate the suggestive comments of the referees.This research was partially supported by Grants-in-Aid for the 21st century COE program and Science Research, both from the Ministry of Education, Culture, Sports, Science and Technology of the Japanese Government.

†*Address for correspondence:* Faculty of Economics, Tokyo Metropolitan University, 1-1 Minami Ohsawa, Hachioji-shi, Tokyo 192-0397, JAPAN. Email address: twatanab@bcomp.metro-u.ac.jp

‡*Address for correspondence:* Graduate School of International Accounting, Chuo University, 42-8 Honmura-cho, Ichigaya, Shinjuku, Tokyo 162-8473, JAPAN. Email address: kimieh@tamacc.chuo-u.ac.jp

1 Introduction

This paper examines the effects of the Bank of Japan (BOJ)'s intervention on the behavior of the yen/dollar exchange rate. Recent empirical studies on the effects of foreign exchange intervention by central banks have analyzed the effects of intervention on the volatility as well as the level of the exchange rate. It is well known that exchange rate volatility changes randomly over time. Taking this fact into account, several researchers such as Chang and Taylor (1998) and Dominguez (1998) have employed the most widely used model of exchange rate volatility, the generalized autoregressive conditionally heteroskedastic (GARCH) model proposed by Bollerslev (1986) to investigate the effects of intervention. In particular, Chang and Taylor (1998) and Dominguez (1998) introduce intervention variables as explanatory variables into the mean and volatility equations in the GARCH model.

The use of a GARCH model, however, has an important drawback. It is the well-known phenomenon called volatility clustering, that shocks to exchange rate volatility are highly persistent. Incorporating intervention variables into the GARCH volatility equation is equivalent to assuming that the effects of intervention are also persistent. If the effects of intervention on exchange rate volatility are transitory, this approach is not valid. Beine et al. (2002) use fractionally integrated GARCH (FIGARCH) to model volatility, and show that the traditional GARCH model tends to underestimate the effects of intervention. In this paper, to overcome the problem, we use the component GARCH model proposed by Engle and Lee (1999). This model assumes that the volatility consists of two components: one is the long-run volatility component whose shocks are highly persistent, and the other is the short-run volatility component whose shocks are less persistent. By entering the intervention variables into both long-run and short-run volatility equations, we can capture the effects of intervention whether the effects are persistent or not.

This paper is also different from previous studies in that we use the BOJ's official intervention data. Previous researchers used the BOJ's intervention data collected from the financial press because the official BOJ intervention data was not available until July 2001.[1] Recently, some studies have examined the effects of intervention using the BOJ official intervention data. Ito (2002) examined the effects of the BOJ's intervention on the level of the

[1] See Dominguez (1998) and Chang and Taylor (1998). Baillie and Osterberg (1997) estimate the effects of central bank intervention on the yen/dollar exchange rate volatility, but they only use data on the Fed's intervention.

yen/dollar exchange rate using the official intervention data. Frenkel et al. (2003) investigate the accuracy of financial press reports of intervention, and find that they are inaccurate indicators of the actual level of intervention. We examine the effects of intervention on the volatility as well as the level of the yen/dollar exchange rate using the official intervention data with a new methodological tool.

The main findings are as follows. First, with respect to the effect of intervention on the level of the yen/dollar exchange rate, the GARCH and the component GARCH models lead to the same result, that the BOJ's intervention is effective in the second half of the sample period, from the late 1990s to 2003, and its effectiveness is enhanced by the Fed's coordinated intervention.[2] However, the BOJ's intervention is not effective in the early 1990s. We identify new evidence on the effects of the BOJ's intervention on the yen/dollar exchange rate volatility based on the component GARCH model. Second, the BOJ's intervention reduces the short-run volatility component in the second half of the sample period, while it does not have an impact on the volatility at all in the first half of the sample period. Third, the stabilizing effect of the BOJ's intervention in the whole period is not enhanced by the Fed's coordinated intervention. Fourth, using the component GARCH model, we also find that the BOJ's intervention reduces the short-run volatility component in the second half, while it does not have an impact on the long-run volatility at all in either the first or second periods. This implies that the BOJ's intervention is not successful in terms of its effect on volatility because it could not maintain shocks.

The rest of this paper is organized as follows. Section 2 describes our data. Section 3 presents estimates of the effects of the BOJ's intervention using the conventional GARCH model, while Section 4 presents estimates of the effects using the component GARCH model. Conclusions are given in Section 5.

2 Data Description

We used the following data to test for the effects of the BOJ's intervention on the level and volatility of the yen/dollar exchange rate: the yen/dollar exchange rate, the amount of intervention by the BOJ and the Fed, and interest rates. The yen/dollar exchange rate data

[2] In this paper, the sample period is divided into two halves based on the discussion in Ito (2002). There, the sample period is divided at June 1995 since a chronological analysis shows clearly that the style of intervention in terms of frequency, preintervention amount, and predicability, has changed before and after that time.

are the daily closing spot prices in the New York market. The BOJ and Fed intervention data are daily official yen/dollar transactions measured in yen and dollars, respectively. The daily closing spot price of the yen/dollar exchange rate is plotted with the daily amount of BOJ intervention in Figure 1, and the daily amount of Fed intervention in Figure 2, respectively. While most of the BOJ's interventions are unilateral, there is no unilateral Fed intervention and the Fed's interventions are always accompanied by BOJ interventions. The Fed intervention data is used to capture the effects of coordinated intervention.[3]

The observation period in this study ranges from April 1, 1991—when the first data on the BOJ official intervention data become available—to March 31, 2003. Papers that analyze the effectiveness of intervention using the same sample period and official intervention data are limited. Former studies that used GARCH-type models were mostly based on perceived intervention reported by newspapers or wire services, and they did not analyze the effectiveness of intervention in the late 1990s. Hillebrand and Schnabl (2003) identify two subperiods, from 1991 to 1998 and from 1998 to 2003, based on the impacts of foreign exchange intervention on the yen/dollar exchange rate. Ito (2002) divides the sample period at June 1995 based on the findings that the intervention styles of the Japanese authorities were different before and after June 1995 in terms of frequency and per-intervention amount. The evidence for this is also obvious from Figure 1. Ito (2002) has pointed out that predictability of the market also changed over the period, and has found that BOJ intervention was not effective in the first half of the 1990s, but was effective in the second half. We analyze the two subsamples separately, based on the findings in Ito (2002). One is from April 1, 1991 to June 20, 1995, which we call the first half, and the other is from June 21, 1995 to March 31, 2003, which we call the second half of the sample period. Our choice is, therefore, not arbitrary.

The daily returns for the yen/dollar exchange rate, which are denoted by r_t in what follows, are the continuously compounded returns calculated as the difference in the logarithm of the closing prices for two consecutive days. The descriptive statistics are summarized in Table 1. The statistics reported are the sample size, mean, standard deviation, skewness, kurtosis, and the Ljung–Box (LB) statistics corrected for heteroskedasticity following Diebold (1988). The sample sizes for the first and second halves are 1064 and 1953, respectively. The

[3] The Fed intervention data are provided courtesy of one of the authors of Hillebrand and Schnabl (2003).

mean for the first half is significantly below zero, indicating that, on average, the yen was appreciating. The mean for the second half is positive but statistically insignificant. The skewness and kurtosis show that the distribution of the daily returns for the yen/dollar exchange rate is nonnormal in both periods. The LB(12) statistics have an asymptotic distribution that is a $\chi^2(12)$, under the null hypothesis of no autocorrelation. The results in Table 1 indicate that the null hypothesis of no autocorrelation for the return of the yen/dollar exchange rate is not rejected at the 5% significance level in the first half and at the 10% level in the second half, while the null hypothesis for the squared return, which can be considered as a proxy for volatility, is rejected at the 1% level in both periods. We may conclude that the return for the yen/dollar exchange rate is serially uncorrelated, while its volatility is serially correlated, which is consistent with the well-known phenomenon of volatility clustering, that shocks to exchange rate volatility are highly persistent.

3 An Analysis Based on the GARCH Model

3.1 GARCH Model

We first estimate the effects of the BOJ's intervention using the GARCH model proposed by Bollerslev (1986). Specifically, we estimate the following GARCH(1,1) model with the BOJ's and the Fed's official intervention data:

$$r_t = a + b(i_t - i_t^*) + c_1 I_t + c_2 I_t^* + \epsilon_t, \tag{1}$$

$$\epsilon_t = \sqrt{h_t} z_t, \quad z_t \sim \text{i.i.d.} N(0,1), \tag{2}$$

$$h_t = \omega + \beta h_{t-1} + \alpha \epsilon_{t-1}^2 + \theta_1 |I_t| + \theta_2 |I_t^*|, \tag{3}$$

where i_t and i_t^* are the Japanese and the US overnight interest rates, respectively,[4] and I_t and I_t^* are the BOJ's and the Fed's net purchases of dollars, respectively.[5] The reason for including the spread between the Japanese and the US interest rates in equation (1) is to take into account the relative contemporaneous monetary policies in the two countries (see Dominguez 1998 and Beine et al. 2002).[6] The right hand side of (1) does not contain

[4] The Japanese interest rate is the uncollateral overnight call rate, and the US interest rate is the effective Federal Fund's rate (Federal Reserve Bank of New York).

[5] If $I_t > (<) 0$, it means that the BOJ purchased (sold) dollars in period t.

[6] We have also estimated a model in which a weekend dummy variable that takes one on the day following weekends and holidays, and zero otherwise, has been included in equation (3), but the dummy was not statistically significant.

any lagged r_t's because the return for the yen/dollar exchange rate is found to be serially uncorrelated in the previous section.

We estimate all the parameters in equations (1)–(3) simultaneously using the quasi maximum likelihood method assuming that z_t follows the standard normal distribution; since the true distribution of z_t may not be normal, we calculate the standard errors using the method proposed by Bollerslev and Wooldridge (1992) that is robust to the nonnormality of z_t.[7]

3.2 Estimation Results

The results of estimating the model that consists of equations (1)–(3) are presented in Table 2. The effects of the BOJ's and the Fed's interventions on the level of the yen/dollar exchange rate are captured by c_1 and c_2, respectively. If $c_1 > 0$ ($c_2 > 0$), it means that the BOJ's (Fed's) intervention is effective in the sense that intervention in support of the dollar (yen) leads to an appreciation of the dollar (yen). For the first period, the estimate of c_1 is significantly below zero, while it is significantly above zero for the second period. This result suggests that the BOJ's intervention is not effective in the early 1990s, while it is effective in the late 1990s through to 2003. A negative effect on the level of the yen indicates that supporting the dollar results in a decline in the dollar. This result is not intuitive since it says that intervention is effective but the effect is in the wrong direction. However, Ito (2002) and Hillebrand and Schnabl (2003) also obtain the same effect during a similar period which includes 1994–1995. Ito (2002) suggests that the failure of intervention in 1994 and 1995 may be due to too strong a force of yen appreciation despite repeated intervention. The Fed's intervention is effective in both periods because the estimates of c_2 are significantly above zero. The total effect of the BOJ's and the Fed's joint intervention is measured by $c_1 + c_2$. Joint intervention was not effective in the first period (the combined coefficient was -0.2720), however it turned out to be effective in the second period (the combined coefficient was -0.7190). [8]

For the spread between Japanese and US overnight interest rates, $(i_t - i_t^*)$, we expect that

[7] We have also estimated a model assuming that z_t follows a Student's-t distribution whose variance is normalized to one, but the results are qualitatively unaltered.

[8] We have divided the sample period at breaks in the exchange rate cycle as shown in Figure 1 and estimated the effect of intervention. Specifically, for 1995 末 2003, we divided the sample into four subsamples; namely yen depreciation from June 95 to August 98, appreciation from August 98 to January 2000, depreciation from January 2000 to February 2002, and the remainder. The effect of intervention on the yen level was positive, indicating that intervention in support of the dollar resulted in a rise in the dollar. Therefore, our results are not dependent on the choice of subsample. Even after dividing the sample into four periods, intervention had a strong positive effect on the yen/dollar rate for the second period.

$b < 0$ since a rise in the Japanese interest rate compared with the US interest rate will lead to an appreciation of the yen. The estimates of b are negative, but statistically insignificant in both periods.[9] During the second subsample period, which includes the financial crisis in the late 1990s, the interest rate fell nearly to zero and stayed at that level for years. The so-called "zero interest rate" might have made b ineffective.

Next, we turn to the estimation results of equation (3). The effects of the BOJ's and the Fed's interventions on the volatility of the yen/dollar exchange rate are captured by θ_1 and θ_2. The estimate of θ_1 in the first half of the sample period is positive but insignificant, meaning that in the first half, the BOJ's intervention increases volatility; however, the effect is not significant. The estimate of θ_2 in the first period is, contrarily, negative but insignificant, meaning that the Fed's intervention decreases daily volatility but the magnitude is negligible. The estimates of θ_1 and θ_2 in the second half are statistically insignificant. The degree of persistence in volatility can be measured by $\alpha + \beta$. The sum of the estimates of α and β in the first half is 0.9382, which is a little low, but in the second half it is 0.9912. They indicate that the volatility shocks are highly persistent, which is consistent with the literature using GARCH models. In summary, the effect of intervention on volatility is insignificant and positive in the regressions and intervention did not reduce volatility.

4 An Analysis Based on the Component GARCH Model

4.1 Component GARCH Model

In this section, we analyze the effects of the BOJ's and the Fed's interventions on the yen/dollar exchange rate's volatility using a different GARCH model. Specifically, we employ the component GARCH model developed by Engle and Lee (1998). This model decomposes the volatility, h_t, into a short-run component, s_t, and a long-run component, q_t, as follows:

$$h_t = q_t + s_t. \tag{4}$$

Engle and Lee (1998) specify the dynamics of the short-run and long-run volatility components as follows:

$$s_t = (\alpha + \beta) s_{t-1} + \alpha(\epsilon_{t-1}^2 - h_{t-1}), \tag{5}$$

$$q_t = \omega + \rho q_{t-1} + \varphi(\epsilon_{t-1}^2 - h_{t-1}). \tag{6}$$

[9] We follow Dominguez (1998) by adding the interest rate spread in addition to the intervention variables to control for relative monetary policies between two countries.

Persistence of the short-run and long-run volatility components can be captured by $\alpha+\beta$ and ρ, respectively. It is assumed that $0<\alpha+\beta<1$ and $0<\rho<1$ to ensure that the both components will converge to their means 0 and $\omega/(1-\rho)$. Since the long-run volatility component is more persistent than the short-run volatility component, it is also assumed that

$$0<(\alpha+\beta)<\rho<1. \tag{7}$$

In addition, the following constraints are required to ensure that total volatility h_t is non-negative. (See the Appendix in Engle and Lee (1998) for details.)

$$0<\varphi<\beta, \quad \alpha>0, \quad \beta>0, \quad \omega>0. \tag{8}$$

Using the intervention variables, I_t and I_t^*, and the spread between the Japanese and US interest rates, $i_t - i_t^*$, we estimate the following model:

$$r_t = a+b(i_t-i_t^*)+c_1 I_t + c_2 I_t^* + \epsilon_t, \tag{9}$$

$$\epsilon_t = \sqrt{h_t} z_t, \quad z_t \sim \text{i.i.d.} N(0,1), \tag{10}$$

$$h_t = q_t + s_t, \tag{11}$$

$$s_t = (\alpha+\beta)s_{t-1}+\alpha(\epsilon_{t-1}^2 - h_{t-1}) + \psi_1|I_t| + \psi_2|I_t^*|, \tag{12}$$

$$q_t = \omega+\rho q_{t-1}+\varphi(\epsilon_{t-1}^2 - h_{t-1}) + \theta_1|I_t| + \theta_2|I_t^*|. \tag{13}$$

We estimate all the parameters in equations (9)–(13) simultaneously using the quasi maximum likelihood method again. The standard errors are calculated using the method proposed by Bollerslev and Wooldridge (1992) to take account of the possibility that the distribution of z_t may be nonnormal.

4.2 Estimation Results

The estimation results of the component GARCH model that consists of equations (9)–(13) are presented in Table 3. First, we examine the estimation results for equation (13). The effects of the BOJ's and the Fed's interventions on the long-run component of the yen/dollar exchange rate volatility are captured by θ_1 and θ_2, respectively. They are, however, positive and statistically insignificant in both periods. Therefore, over the entire period, de facto intervention did not reduce long-run volatility. If intervention could reduce volatility significantly, then it is said that intervention is effective on volatility. The degree of persistence in the long-run volatility component is measured by ρ. The estimate of ρ is 0.9626 in the first half and 0.9897 in the second half, indicating that the long-run volatility component is highly persistent. That is, the BOJ's and the Fed's interventions do not have an impact on volatility, as their effects are not reflected in the long-run component. These results are the same as those of the conventional GARCH model.

Next, we turn to the estimation results for equation (12). The effects of the BOJ's and the Fed's interventions on the short-run component of the yen/dollar exchange rate volatility are captured by ψ_1 and ψ_2, respectively. In the first half, they are both statistically insignificant, indicating that neither of the BOJ's or the Fed's interventions influence the short-run component of the yen/dollar exchange rate volatility. In the second half, however, the estimate of ψ_1 is significantly below zero, while the estimate of ψ_2 is still insignificant. This implies that in the first period the BOJ's intervention reduces the volatility of the yen/dollar exchange rate, but the Fed's coordinated intervention does not enhance this stabilizing effect. The degree of persistence in the short-run volatility component is represented by $\alpha + \beta$. The estimates of α and β in the first half are 0.1208 and 0.0203, which are so small that they are statistically insignificant. The estimates in the second half are 0.0000 and 0.9343, respectively, and they indicate that shocks to short-run volatility are not as persistent as those to long-run volatility, but they are still persistent in the second half. To obtain some intuition about the degree of persistence, it may be useful to calculate the half-life, h, of a shock. The estimates $\rho = 0.9897$ and $\alpha + \beta = 0.9343$ imply that the estimated half-life, h, of a shock to long-run volatility is about 67 trading days, while that of a shock to short-run volatility is about 10 trading days. That is, the stabilizing effect of the BOJ's intervention is halved by 10 days after the intervention. Therefore, intervention only reduces short-run volatility and does not have any impact on long-run volatility.

The estimation results for the mean equation (9) are almost the same as those obtained using the GARCH model. That is, the effects of the BOJ's and the Fed's interventions, which are captured by c_1 and c_2, are positive and significant at the 5% significance level for the second period. This shows that interventions are effective on the level of the yen/dollar exchange rate. For the first period, the estimate of c_1 and c_2 are insignificant. The estimate of c_1 is below zero and the estimate of c_2 is positive in the Component GARCH model too. Therefore, the failure of intervention in the early 1990s suggests that the BOJ's intervention is not effective on the level of the exchange rate owing to a sharp appreciation of the yen as mentioned in section 3.2. The total effect of the BOJ's and the Fed's joint intervention measured by $c_1 + c_2$ is still negative (the combined coefficient was -0.0758). One key difference is that the estimate of b in the second half using the component GARCH model is significantly negative at the 5% significance level, while it is insignificant using the GARCH model. Therefore, the spread between Japanese and US overnight interest rates is negative, which indicates that a decrease (or an increase) in the Japanese interest rate causes a depreciation (or an appreciation) of the yen. The Japanese authority's zero interest rate policy had a negative effect on the level of the yen/dollar exchange rate.

5 Conclusions

In this paper, the effects of the BOJ's intervention on both the yen/dollar exchange rate volatility and the level of the yen/dollar exchange rate were examined with GARCH models. Traditional GARCH models tend to underestimate the effects of intervention owing to the well-known phenomenon called volatility clustering that shocks to exchange rate volatility are highly persistent. We provide new evidence on the effect of the BOJ intervention on the yen/dollar exchange rate volatility using the component GARCH model proposed by Engle and Lee (1998). This model assumes that the volatility consists of a long-run volatility component whose shocks are highly persistent and a short-run volatility component whose shocks are less persistent. Former studies employing GARCH-type models used the BOJ's intervention data collected from the financial press. In this paper, similar to other recent studies, we used official intervention data from 1991 to 2003.

The results described in sections 3 and 4 indicate that the BOJ's intervention reduced only the short-run volatility component in the second half of the sample period, while it did not have any impact on volatility at all in the first half of the sample period. Similarly, the regression estimates of the conventional GARCH model had no significant effect on volatility. The stabilizing effect of the BOJ's intervention over the whole period was not enhanced by the Fed's coordinated intervention. Therefore, this evidence indicates that intervention generally did not have a stabilizing effect on volatility. The GARCH and the component GARCH models led to similar results for the effect of intervention on the level of the yen/dollar exchange rate. The effects of the BOJ's and the Fed's interventions were, contrary to our expectation, positive for the first period. This evidence does not mean that supporting the dollar results in decline in the dollar, rather the evidence is attributed to a sharp appreciation of the yen. Intervention was effective from the late 1990s through to 2003, and its effect on the level of the yen/dollar exchange rate is observable after 1995.

References

Baillie, R.T., and Osterberg, W.P. (1997), "Central Bank Intervention and Risk in the Forward Market," *Journal of International Economics,* **43**, 483–497.

Beine, M., Bébassy-Quèrè, A, and Lecourt, C. (2002), "Central Bank Intervention and Foreign Exchange Rates: New Evidence from FIGARCH Estimations," *Journal of International Money and Finance,* **21**, 115–144.

Bollerslev, T. (1986), "Generalized Autoregressive Conditional Heteroskedasticity," *Journal of Econometrics,* **31**, 307–327.

Bollerslev, T., and Wooldridge, J.M. (1992), "Quasi-Maximum Likelihood Estimation and Inference in Dynamic Models with Time-Varying Covariances," *Econometric Reviews,* **11**, 143–172.

Chang, Y., and Taylor, S.J. (1998), "Intraday Effects of Foreign Exchange Intervention by the Bank of Japan," *Journal of International Money and Finance,* **17**, 191–210.

Diebold, F.X. (1988), *Empirical Modeling of Exchange Rate Dynamics,* New York: Springer-Verlag.

Dominguez, K.M. (1998), "Central Bank Intervention and Exchange Rate Volatility," *Journal of International Money and Finance,* **17**, 161–190.

Engle, R.F., and Lee, G.G.J. (1999), "A Long-Run and Short-Run Component Model of Stock Return Volatility," in R. Engle and H. White (eds), *Cointegration, Causality and Forecasting,* Oxford, U.K.: Oxford University Press, pp. 475–497.

Frenkel, M., Pierdzioch, C., and Stadtmann, G. (2003), "The Accuracy of Press Reports Regarding the Foreign Exchange Interventions of the Bank of Japan," *International Financial Markets, Institutions & Money*, forthcoming.

Hillebrand, E., and Schnabl, G. (2003),"The Effects of Japanese Foreign Exchange Intervention GARCH Estimation and Change Point Detection," mimeograph.

Ito, T. (2002), "Is Foreign Exchange Intervention Effective?: The Japanese Experiences in the 1990s," NBER Working Paper 8914.

Jarque, C.M, and Bera, A.K. (1987), "Test for Normality of Observations and Regression Residuals," *International Statistical Review*, **55**, 163–172.

TABLE 1. Descriptive Statistics of Daily Returns (%) for the Yen/Dollar Exchange Rate

Statistics	April 2, 1991–June 20, 1995	June 21, 1995–March 31, 2003
Sample size	1064	1953
Mean	-0.0468	0.0171
	(0.0210)	(0.0172)
St. dev.	0.6858	0.7615
Skewness	-0.4615	-0.7117
	(0.0751)	(0.0554)
Kurtosis	8.0716	10.0642
	(0.1502)	(0.1109)
LB(12)	20.69	4.05
$LB^2(12)$	27.03	45.66

NOTE: Numbers in parentheses are standard errors. The asymptotic estimates of standard errors of the skewness and the kurtosis are $\sqrt{6/T}$ and $\sqrt{24/T}$, respectively (see Jarque and Bera (1987)). LB(12) is the heteroskedasticity-corrected Ljung–Box statistic for the return series computed twelve lags. $LB^2(12)$ is the heteroskedasticity-corrected Ljung–Box statistic for the squared return series computed using twelve lags. The corrected Ljung–Box statistic is calculated following Diebold (1988). The asymptotic distribution of LB(12) under the null is a $\chi^2(12)$, and the critical values are: 18.55 (10%), 21.03 (5%) and 26.22 (1%).

TABLE 2. Estimation Results of the GARCH Model with Intervention Variables

$$
\begin{aligned}
r_t &= a + b(i_t - i_t^*) + c_1 I_t + c_2 I_t^* + \epsilon_t, \\
\epsilon_t &= \sqrt{h_t} z_t, \quad z_t \sim \text{i.i.d.} N(0,1), \\
h_t &= \omega + \beta h_{t-1} + \alpha \epsilon_{t-1}^2 + \theta_1 |I_t| + \theta_2 |I_t^*|,
\end{aligned}
$$

Parameter	April 2, 1991–June 20, 1995	June 21, 1995–March 31, 2003
a	-0.0317	-0.0459
	(0.0196)	(0.0756)
b	-0.0036	-0.0144
	(0.0104)	(0.0164)
c_1	-0.3886	0.0851
	(0.1483)*	(0.0146)*
c_2	0.1166	0.6339
	(0.0460)*	(0.0679)*
ω	0.0226	0.0049
	(0.0105)*	(0.0029)
β	0.8880	0.9595
	(0.0422)*	(0.0133)*
α	0.0502	0.0317
	(0.0286)	(0.0109)*
θ_1	0.1071	-0.0042
	(0.0641)	(0.0041)
θ_2	-0.0238	0.0453
	(0.0377)	(0.0313)
Log-likelihood	-1057.56	-2059.83

NOTE: (1) Numbers in parentheses are asymptotic standard errors computed by Bollerslev and Wooldridge 痴 (1992) method. (2) * denotes statistically significantly different from zero at 5% level using a two-tail test.

TABLE 3. Estimation Results of the Component GARCH Model with Intervention Variables

$$\begin{aligned}
r_t &= a + b(i_t - i_t^*) + c_1 I_t + c_2 I_t^* + \epsilon_t, \\
\epsilon_t &= \sqrt{h_t} z_t, \quad z_t \sim \text{i.i.d.} N(0,1), \\
h_t &= q_t + s_t, \\
s_t &= (\alpha + \beta) s_{t-1} + \alpha(\epsilon_{t-1}^2 - h_{t-1}) + \psi_1 |I_t| + \psi_2 |I_t^*|, \\
q_t &= \omega + \rho q_{t-1} + \varphi(\epsilon_{t-1}^2 - h_{t-1}) + \theta_1 |I_t| + \theta_2 |I_t^*|.
\end{aligned}$$

Parameter	April 2, 1991–June 20, 1995	June 21, 1995–March 31, 2003
a	-0.0250	-0.0549
	(0.0207)	(0.0435)
b	-0.0010	-0.0166
	(0.0093)	(0.0097)
c_1	-0.2736	0.0852
	(0.1503)	(0.0125)*
c_2	0.1978	0.6249
	(0.1495)	(0.0653)*
α	0.1208	0.0000
	(0.0908)	(0.0306)
β	0.0203	0.9343
	(0.1474)	(0.0737)*
ω	0.0121	0.0049
	(0.0054)*	(0.0025)
ρ	0.9626	0.9897
	(0.0134)*	(0.0060)*
φ	0.0203	0.0319
	(0.0228)	(0.0143)
ψ_1	0.2060	-0.0153
	(0.1690)	(0.0071)*
ψ_2	1.0555	-0.0964
	(1.4789)	(0.0928)
θ_1	0.0503	0.0021
	(0.0348)	(0.0062)
θ_2	0.0085	0.0881
	(0.0557)	(0.0719)
Log-likelihood	-1040.58	-2055.51

NOTE: (1) As for Table 2.

Figure 1 Yen/Dollar Exchange Rate and Bank of Japan Intervention

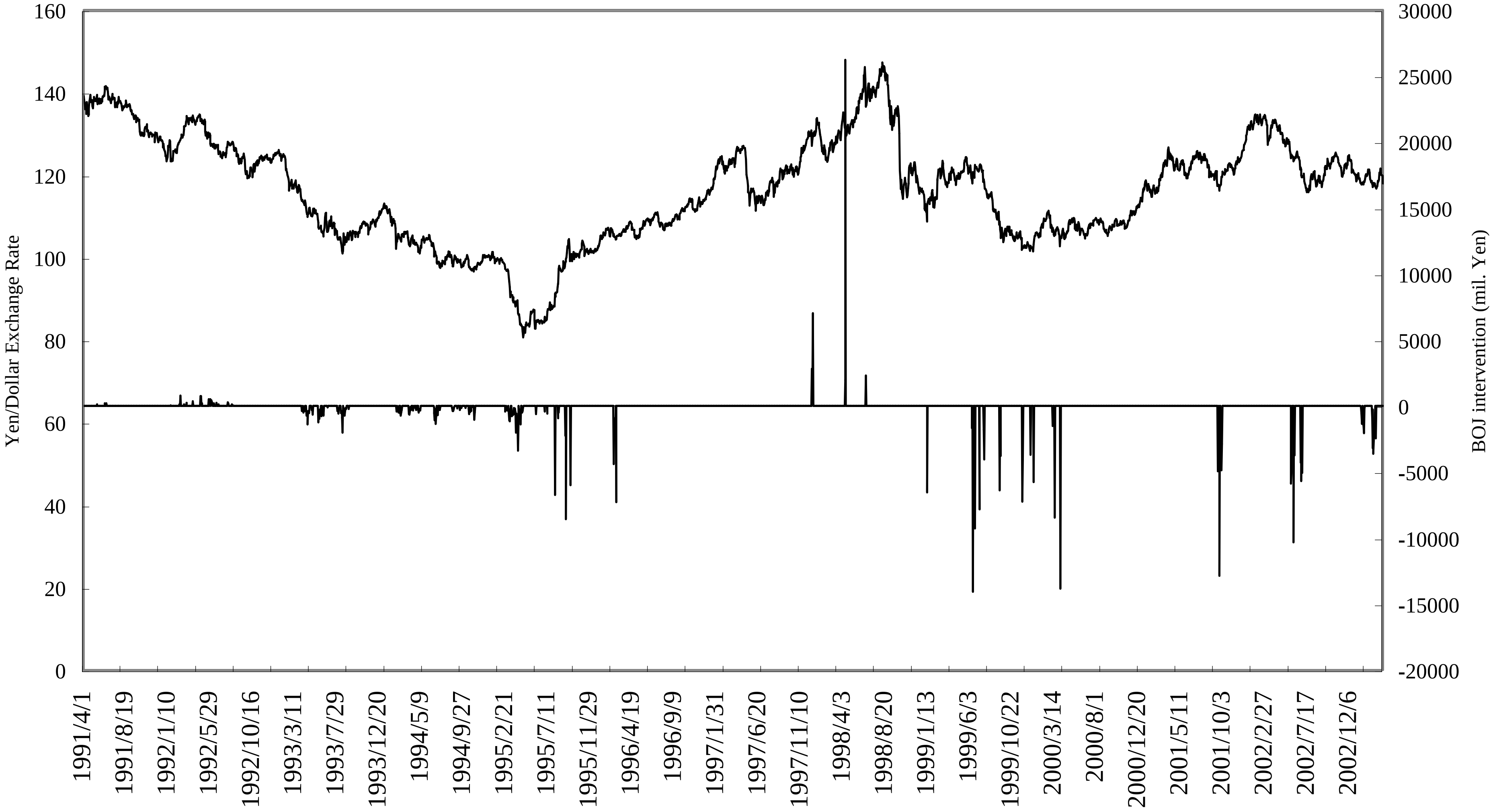

Figure 2 Yen/Dollar Exchange Rate and Intervention by the Federal Reserve System