Preliminary

Signaling Effects and the Timing of Foreign Exchange Interventions

Kentaro Iwatsubo [a,*] and Junko Shimizu [b]

[a] *Institute of Economic Research, Hitotsubashi University, Tokyo, Japan*
[b] *Graduate School of Commerce and Management, Hitotsubashi University, Tokyo, Japan*

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Abstract

This paper empirically examines whether timing foreign exchange interventions can enhance central banks' signaling effects. Classifying the Japanese and the US intervention operations against the yen/dollar exchange rate into (1) officially announced, (2) unannounced but reported and (3) perfectly secret interventions, we find that announced interventions outperformed the latter two. Even official announcements, however, were quite effective only for the short sub-sample period when a former vice minister of finance for international affairs Eisuke Sakakibara, nicknamed "Mr. Yen" by NY Times, was in charge. Then we explore whether the efficacy of intervention announcements is associated with market conditions. We show strong evidence that announced interventions had a more significant influence on exchange rate when implied volatility and trading volume on the last trading day were high. This is consistent with the conjecture by Peter B. Kenen (1987) that intervention is more effective when traders' exchange rate expectations are heterogeneous. These findings are explained in a noise trading framework.

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[*]Corresponding author. Tel.: +81-42-580-8348; fax: +81-42-580-8333.

Email address: iwatsubo@ier.hit-u.ac.jp (K. Iwatsubo)

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1. Introduction

The traditional view in the literature suggests that sterilized interventions operate through a signaling channel if they cause private agents to change their expectations about the exchange rate by altering their views about the likely future actions of the central bank or of other private agents. Alternatively, although perceptions of the future actions of the central bank remain unchanged, agents might alter their views about the likely impact of present actions on future values of the exchange rate.[1] Although there are considerable debates in both academic and policy circles about the effectiveness of sterilized interventions, the signaling channel has received ambiguous empirical support (Dominguez and Frankel, 1993abc; Bosner-Neal and Tanner, 1996; Baillie and Osterberg, 1997; Beine, et al., 2002).

Part of the reason for the differing results is that studies focus on different central banks, different exchange rates and different time periods. It is also due to the different ways in which researchers define the success of an intervention. But, in the large part, the differences in results across studies reflect the fact that market reaction to interventions differs according to the situations, even for the same central banks and the same exchange rates. Actually, intervention operations sometimes work and sometimes do not.

When are central bank interventions likely to influence exchange rates? One approach to tackle this old question is the recently advanced "market microstructure" approach, which puts an emphasis on information heterogeneity among traders. Bacchetta and van Wincoop (2003) argue that trader heterogeneity, based on differences in information that traders receive or differences in the interpretation of information, might lead to short-run price and volatility effects in reaction to information revelation.[2] If

[1] The existing literature offers two channels through which sterilized interventions can affect exchange rates, the 'portfolio-balance channel' and the 'signaling channel'. The former comes from the fact that the sterilized intervention changes the composition of portfolios and thus the risk premia. There is a consensus, however, that this effect is empirically weak and cannot be easily exploited by the monetary authority. Thus, subsequent studies have emphasized the signaling hypothesis (Mussa, 1981; Lewis, 1988; Dominguez and Frankel, 1990).

[2] See Lyons (2001) for a thorough discussion of market microstructure in foreign exchange markets. For a more general treatment of market microstructure see O'Hara (1995).

exchange rate movements are affected by trader heterogeneity, then central banks should time market interventions to exploit it. The recent literature actually suggests that the market reaction to a central bank intervention depends on the degree of heterogeneity across trader beliefs about the fundamentals as well as the intervention signal (Bhattacharya and Weller, 1997; Vitale, 1999). To my knowledge, Peter B. Kenen (1987) is the first to raise the issue on the relationship between expectation heterogeneity across traders and the efficacy of foreign exchange interventions. Kenen (1987) notes that "[w]hen expectations are heterogeneous and especially when a bubble appears to be building, intervention may be quite effective."

This paper explores this conjecture. Our theoretical argument is based on the model of De Grauwe and Grimaldi (2003). In their model, the existence of chartists produces speculative noise which leads to systematic deviations of the exchange rate from its fundamental. Intervention can be effective in reducing noise since it reduces the profitability of noise trading. Intervention can be especially effective when it is easily understood by fundamentalist because they take advantage of the signal of intervention but chartists do not.

In this paper, we empirically test for the following two hypotheses. One is the signaling hypothesis and the other concerning the relationship between the efficacy of intervention signal and expectation heterogeneity among traders. These hypotheses are tested for using the daily intervention data recently disclosed by the Japanese government and daily exchange rate in the yen/dollar market.

The signaling hypothesis of foreign exchange interventions is tested for in order to examine whether official announcement and newswire reports can enhance the effectiveness of interventions. Recent empirical research on foreign exchange rate interventions investigates the significance of the signaling hypothesis using news reports. These studies split the amount of interventions into the reported and secret intervention volume (Dominguez, 1998; Beine, Benassy-Quere and Lecourt, 2002), or include reported and secret intervention dummies as independent variables (Dominguez and Frankel, 1993c).

We address two shortcomings with these studies. First, as suggested in Klein (1993) and Frenkel, Pierdzioch and Stadtmann (2004), the likelihood of an intervention

being reported increases with the size of an intervention. The positive correlation between volume and the probability of being reported may lead us to mistake the volume effect for the signaling effect if one runs a regression using reported intervention volume and secret intervention volume as independent variables. Second, intervention volume plays a role in affecting exchange rates not only through the portfolio balance channel but through the signaling channel, while intervention dummies (reported and secret) are related only to the signaling channel.[3] It is necessary to control for the volume to examine the exact impact of signals. Hence, we include intervention volume and dummies (officially announced, unannounced but reported, and secret) separately in the estimation equation.

We next investigate whether intervention signals are more effective when heterogeneous traders hold different beliefs on the exchange rate. The growing strand of empirical literature of the market microstructure explores the interrelationships among volatility, trading volume and heterogeneity and finds their positive relationships (Frankel and Froot, 1990; Chionis and MacDonald, 1997; MacDonald and Marsh, 1996). We use implied volatility and trading volume as proxies for the dispersion of expectations across traders for the hypothesis due to a lack of the daily data on exchange rate expectations. We provide new evidence on the appropriate timing of interventions from the viewpoint of trader heterogeneity.[4]

The experiences of Japanese interventions provide a natural experiment to test for our hypotheses for some reasons. First, as Dominguez (2003) suggests, the Bank of Japan (BOJ thereafter) is the most active intervener of the G-3 in the foreign exchange market in the 1990s. The number of interventions by the BOJ is the largest among the G-3, and the total volume of BOJ interventions exceeded those by both Fed and Bundesbank by over 13 times. Second, more interestingly, intervention policy has changed frequently

[3] Although market traders do not know the exact volume during the days of interventions, they can guess its approximate size based on market rumors and their trading activities. Hence intervention volume can function as central banks' signals to the market.

[4] To my knowledge, Dominguez (2003) is the only paper to investigate the timing of intervention operations. Using intra-daily data, she finds that interventions have large effects when trading volume is high, when they are closely timed to scheduled macro announcements and when they are coordinated with another central bank. She does not, however, consider the relationship between the timing of interventions and central banks' signals.

according to the persons of the Ministry of Finance (MOF thereafter) in charge of foreign exchange interventions. These characteristics of the Japanese interventions enable us to investigate the effect of intervention techniques on exchange rate.

The empirical results reveal that officially announced interventions have larger effects than unannounced but reported interventions and perfectly secret interventions. Even official announcements, however, are quite effective only for the short sub-sample period when a former vice minister of finance for international affairs Eisuke Sakakibara, nicknamed "Mr. Yen" by NY Times (Sep 16, 1995), was in charge. We also find that announced interventions have a more significant influence on exchange rate when implied volatility and trading volume on the last trading day are high. This suggests that the expectation heterogeneity among traders plays a significant role in enhancing the efficacy of interventions.

The remainder of the paper is organized as follows. Section 2 discusses the theoretical background of our hypotheses. Section 3 describes the intervention data and the sampling scheme. Section 4 explains the empirical methodology. Section 5 presents the estimation results. Section 6 concludes.

2. Theoretical background

In this section, we theoretically explore the relationship between the signaling effects and expectation heterogeneity among traders and draw some testable implications.

Our discussion is based on the argument of De Grauwe and Grimaldi (2003). In their model, two types of traders have heterogeneous beliefs about the future exchange rate: fundamentalists and chartists (noise traders). They have distinct forecasting methods on the future exchange rate. Fundamentalists forecast the exchange rate to return to the fundamental rate in the future. In this sense they use a negative feedback rule that introduces a mean reverting movement in the exchange rate. On the other hand, chartists compute a moving average of the past exchange rate changes and they extrapolate this into the future exchange rate change. Similarly, they receive the risk in a different way. Chartists evaluate risk defined as weighted average of the squared forecasting errors, while fundamentalists are assumed to take into account the misalignment of the exchange rate from the fundamental in addition to the forecasting errors. With the same utility

function and the same budget constraint, these traders evaluate the risk-adjusted profitability of their forecasting rules and decide ex post whether or not to switch to the more profitable one.

The interaction of these heterogeneous traders leads to a rich behavior with which the exchange rate is dissociated with its fundamentals most of the time (the disconnect puzzle). In addition, the volatility of the exchange rate, which is unrelated to fundamentals, increases with the number of chartists (the "excess volatility" puzzle).

In this model, intervention can be quite effective in reducing the noise and in tightening the link between the exchange rate and the fundamentals. The reason for interventions to be effective is that fundamentalists are assumed to take into account the optimal intervention rule by the monetary authorities in their expectations, while chartists use only information about past exchange rates to forecast the future. Hence, even if the intervention does not affect fundamentals, it affects the market structure, the share of fundamentalists and chartists, by making noise trading less profitable and driving out chartists from the market. For effective intervention, it should be systematic and conducted according to a rule that the fundamentalists easily understand. Furthermore, the target of intervention should be consistent with the fundamental and common knowledge.

This model provides some testable implications. First, intervention is more effective when market expectation is heterogeneous and noise trader activities bring the exchange rate away from its fundamental. Second, intervention is more effective when it is unambiguous and easy to understand for the market.

Thus, we test for the following hypotheses.

Hypothesis 1. Officially announced interventions have large effects on exchange rate than unannounced but reported interventions and secret interventions.

Hypothesis 2. The signaling effect is more significant when traders have heterogeneous expectations on exchange rates.

3. Data on Japanese interventions

3-1. Japanese interventions classified by newswire reports

In today's international financial markets a number of newswire services report news incessantly throughout the day. They include Reuter, Bloomberg, Dow Jones, the Kyodo News Service, Jiji Press, etc. Foreign exchange traders usually deal currencies watching reports on their computer screen provided by several news providers simultaneously. There might be some information gap between them, but newswire, which cannot directly obtain some information, offset their shortfalls by quoting the news reported by other news sources. Bloomberg, which we rely on as a news source in this paper, has sometimes reports obtained from other news sources. For example, it reports news in the following way; "[a]ccording to Dow Jones, the BOJ was reported to buy dollar in the London market."

We classify interventions into three categories using reports provided by Bloomberg as follows. "Announced interventions" have official statements on interventions by government officials within the same day of interventions. Usually government officials, such as minister of finance, vice minister of finance for international affairs, director general of the international bureau and governor of the BOJ, state comments just after the interventions, saying that "[t]he BOJ intervened into the market." [5] Then most news providers report their statements with their names.

"Unannounced but reported interventions" are reported by newswire but have no official statements. In most cases, they include traders' quotations or show newswires' confidence on the interventions. The examples are "[s]ome traders said that the BOJ intervened into the market around at 115 yen in the morning session" and "[t]he BOJ apparently bought dollars against yen." In contrast, "secret interventions" have no reports by newswire, but actually there are.

Some reports on interventions by newswire are recognized to be false after the intervention data are disclosed. We denote them as "false reports". Although they are not actual interventions, we also examine their impact on exchange rates because they might not be believed to be false by traders with confidence.

One may wonder if monetary authorities can make their interventions public or secret intentionally, because it is news providers that decide to report the interventions

[5] The interventions with official statements announced on the next day are not included in the announced interventions since they do not affect today's exchange rate movements.

when they do not make any official announcements. Actually the monetary authorities, however, have great deal of discretion in transmitting intervention information to the market. They can control the range, speed and ambiguity of the information by limiting and expanding the number of commercial banks to be assigned to transact currencies for the benefit of them. They can also decide the size of interventions. As described in the introduction, the probability of being reported increases with the size. Even if the monetary authorities do not announce on interventions, they can make the interventions public or secret to some degree.

Figure 3 shows the classification of interventions from June 15, 1992 to May 27, 2004. During the period, there are 323 intervention days for the yen/dollar rate by the BOJ, which account for 10.4% of the sample. On the other hand, there are 224 days (190 days correctly and 34 days incorrectly) reported to be intervened by newswire, which account for 7.2% (6.1% plus 1.1%, respectively) of the sample. Within the reported days, there are 43 days with official statements, which account for 1.4% of the full sample. When we regard the actual intervention days as 100%, the ratio of announced interventions to all intervention days is 13.3% and the ratio of unannounced but reported interventions was 45.5%. 58.8% of the Japanese interventions are reported correctly. On the other hand, there are 133 days with interventions but no reports by newswire (secret interventions), which account for 41.2% of all intervention days. At last, there are 34 days reported to be intervened but turned to be false.[6]

The disclosed intervention data indicate the daily size of interventions. Table 1 shows the relationship between the intervention techniques and volume. The number of large-sized intervention days, whose amount is above 500 billion yen per one day, is 38 days which account for 11.8% of all intervention days. The breakdown is 14 days for announced interventions, 16 days for unannounced but reported interventions and 8 days for secret interventions. On the other hand, the number of small-sized intervention days, whose volume is under 500 million yen, was 118 days which account for 36.5 % of all

[6] In this paper, the number of false days is fewer than previous studies on Japanese intervneions (Pierdzioch and Stadtmann; 2004). We exclude the days on which the newswire has little confidence on the interventions. The example is "[t]he BOJ seems to intervene into the market." To apply the conservative criteria to classify interventions, we can analyze the effect of false reports more precisely.

intervention days. They have 5 days for announced interventions, 60 days for unannounced but reported interventions and 53 days for secret interventions.

Generally, the ratio of announced interventions increases with their size and the ratios of unannounced but reported interventions and secret interventions decrease with their volume. The highest range of secret interventions was under 499 million yen, but the second and third highest ranges were between one billion to two billion yen and between two billion to five billion yen, respectively. These indicate that the relationship between the probability of secret interventions and their volume is non-linear. The ratio of unannounced interventions becomes lower with the size of interventions.

3-2. Changes of intervention policy

It is widely known that the Japanese intervention policy changed in June 1995 when Eisuke Sakakibara took over as director general of the international finance bureau. He made a deliberate decision to reduce the frequency of interventions and increase the size (Sakakibara, 2002). Accordingly some previous studies on the Japanese interventions divide their sample period in June 1995 (Ito, 2003). The intervention policy has still changed after his resignation, however, especially in terms of official announcements on interventions. Hence, we divide our sample period into 4 sub-sample periods according to the person in charge of interventions, specifically according to vice minister of finance for international affairs of the MOF, who is the most influential on interventions.[7] The sub-sample periods are Period 1 (6/15/1992 - 6/20/1995), Period 2 (6/21/1995 - 7/7/1999), Period 3 (7/8/1999 - 1/13/2003) and Period 4 (1/14/2003 - 5/27/2004). Intervention techniques are quite different depending on the person who actually decides interventions.

Table 2 shows the average size and techniques of interventions for 4 sub-periods. First, the number of intervention days in Period 1 was the highest among 4 sub-periods (145 days), which implies that one intervention per 5.4 business days. There are 15 days

[7] The MOF decides the volume and timing of interventions and the BOJ, which receives the order from the MOF, execute to intervene in the foreign exchange market. The decision makers for intervention are limited to minister of finance, vice minister and deputy vice minister of finance for international affairs, director general of the international bureau or director of the foreign exchange market division (Sakakibara, 2002).

of coordinated interventions with the Federal Reserve Bank of NY in Period 1. The average size of interventions was 48.8 billion yen, which is the smallest among 4 sub-periods. Accordingly, the frequent but small volume is the feature of Period 1. In this sub-period, only 6.2% of interventions are announced, while almost 70% of them are unannounced but reported interventions. This suggests that the Japanese monetary authority took the intervention technique which was easily recognized by market participants and newswire, which might lead to many false reports (20days).

The number of interventions in Period 2, when Dr. Sakakibara was assigned as director general of the international bureau, was the fewest among 4 sub-periods. It had only 24 intervention days, which were interpreted as one intervention per 40 business days. Despite their few interventions, the average size of interventions is 5.1 billion yen per day, which is the largest. Thus large-sized but infrequent interventions are the feature of Period 2. The ratio of both officially announced and unannounced but reported interventions was high (91.6%). In addition, there were 4 days of coordinated interventions with Federal Reserve Bank of NY. It means that the halves of announced interventions in Period 2 were accompanied with Federal Reserve Bank of NY.

In Period 3, there were only 25 intervention days, which were interpreted as one intervention per 37 business days. It was remarkable that all were announced interventions in Period 3. The average size of interventions is 5.3 billion, which is the largest among 4 sub-periods. There is only 1 false reported day.

Period 4 has much more interventions than Period 2 and Period 3. The number of interventions in Period 4 is 129 days, which are interpreted as one intervention per 2.8 business days. The average amount of interventions is 2.7 billion yen. These indicate that the intervention policy changed dramatically from infrequent and large-sized interventions to frequent but medium-sized interventions. Another big change was the highest ratio of secret interventions, which are 74% of all interventions in Period 4. After Mr. Mizoguchi was appointed as vice minister of finance for international affairs, government officials declined to make comments on any interviews. Instead of making announcements, the MOF started to reveal the monthly volume of interventions at the end of months and the size of daily interventions every three months. In response to changing the intervention technique, reports by newswire turned to be vague, saying that “[t]he

market participants were keeping watch on a possible intervention," and "[t]he BOJ seemed to be in the market."

4. Empirical methodology

In this section, we describe the empirical methodology. We assume that the daily rate of return of the yen/dollar exchange rate without interventions is built around the standard Martingale model with time dependent conditional heteroskedasticity. Following Bollerslev (1986) and Baillie and Bollerslev (1989), the conditional variance is modeled as a linear GARCH (1,1) process and the conditional density is Gaussian[8]. Hence, if interventions significantly affect the daily return of the exchange rate in the appropriate direction, we would judge that the interventions are effective.

The estimation equation is specified as follows.

$$\begin{aligned} r_t &= a' X_t + \varepsilon_t \\ \varepsilon_t \mid \Omega_{t-1} &\sim N(0, h_t), \\ h_t &= \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 h_{t-1} \end{aligned} \qquad (1)$$

where $r_t = 100 \ln(S_t / S_{t-1})$ is the logarithmic return of the spot exchange rate (expressed in percentage) with S_t the daily yen/dollar rate (NY close).[9] X_t denotes a vector of independent variables related to the Japanese and the US interventions as well as macro variables which may affect exchange rates.

As explained in the introduction, we include not only intervention volume but several sets of dummies as independent variables in order to disentangle the signaling effects from the portfolio balance effects. 4 dummies are included for officially interventions, unannounced but reported interventions, perfectly secret interventions and

[8] Regarding the choice of underlying distribution, De Gennaro (1990) and Pagan (1996) show that a Student's-t distribution may be appropriate to account for the leptokurticity characterizing the high frequency financial data, while Baillie et al. (1996) and Bollerslev and Wooldrige (1992) explain that the QML estimates obtained with a Gaussian assumption behave relatively well.

[9] As explained by Ito (2003), the disclosed Japanese intervention volume is the result of intervention in the Tokyo, Europe, and the US markets, either carried out directly by the BOJ or by other central banks on behalf of the BOJ. Given the disclosure constraint of daily aggregation, the best proxy for the exchange rate change due to the interventions on a day can be measured with the change in the NY closing rate between the two consecutive days.

false reports for Japan and the US. There were no secret interventions and false newswire reports for the US. Each dummy takes a value of +1 if such technique of intervention is carried out for dollar purchases (yen sales), -1 for yen purchases (dollar sales) and zero otherwise. The variables of intervention volume is also signed with + (dollar purchases) and – (yen purchases). Hence, if the dollar purchasing interventions by the US and Japanese monetary authorities tend to appreciate the dollar and depreciate the yen, the positive signs of the coefficients are expected to be obtained.

As suggested by Dominguez (1998), we also include the interest rate differential between the Japanese and US overnight money market rates in order to take into account relative contemporaneous monetary policies in these countries.[10] When central banks intervene, the evolution of the interest rate differential may also indicate whether interventions are sterilized or not. However, the interest rate differential mainly moves in response to unexpected open monetary operations.

5. Estimation results

5.1. Is signaling effective?

The first hypothesis to test for is the signaling hypothesis. Specifically, we examine whether official announcements about interventions enhance credibility of interventions, leading to have larger effects on exchange rates than keeping interventions secret does.

Table 4 presents the results of estimations with the US and Japanese intervention volumes and the interest rate differential as independent variables. The coefficients of both Japanese and US intervention volumes are significantly positive in the entire period and the sub-sample periods except for the Japanese interventions in Period 1. Exchange rate interventions are quite effective in affecting the yen/dollar exchange rate. These results are consistent with Ito (2003), which argues that the reason for ineffectiveness of the Japanese interventions in Period 1 may be due to too strong a force of yen appreciation despite repeated interventions, or due to an ineffective style of intervention

[10] The overnight market rates are the FF rate for the US and the call rate for Japan.

in the period. We investigate below whether the intervention technique matters in Period 1.

For the economic significance, it was estimated that the Japanese intervention of 100 billion yen changes the exchange rate by 0.05 %, while the US intervention of one billion dollars changes it by 1.9 %. The impact of the US interventions is much larger than that of the Japanese interventions.

Given the positive signs of the coefficients for the Japanese and US intervention volumes, we can exclude the possibility that we measure causality from the exchange rate to interventions since this would require negative signs.

To detect the signaling effects, several intervention dummies are also included as independent variables. The results are shown in Table 5. In the full sample period, conditional on the size of interventions, the coefficient of the announced intervention dummy is significantly positive, while the coefficients of the unannounced but reported intervention dummy and the secret dummy are significantly negative. Announcement effects are quite influential for interventions, which supports the signaling hypothesis. More interestingly, no official announcements have a negative signaling effect even if the interventions are reported by newswire. The false report dummy is not significant. These findings suggest that reporting by newswire does not improve the credibility of interventions, while making official announcements does.

The US interventions are significantly effective in the whole sample period, for both announced and unannounced but reported interventions, conditional on intervention volume. On the other hand, the intervention volume does not affect exchange rates if we control for the intervention dummies. It is to conduct interventions with announcements and/or reports that has a significant influence on exchange rates, not the size of interventions for the US.

Table 5 also presents the regression results for 4 sub-sample periods. The interesting result is that the coefficient of secret dummy is significantly negative in Period 1, while that of announcement dummy is significantly positive in Period 2. This sharp contrast suggests that Dr. Sakakibara's policy change might lead to more successful interventions.

However, the evidence that the announcement effects are significant only in Period 2 might cast doubts on the effectiveness of intervention announcement. Hence, we examine whether the announcement effects are specific to Period 2. Table 6 reports the results for the full sample period. We change the specification of equations by including interaction terms with the Period 2 dummy in the equation on the right hand side of the Table. We also include the US intervention dummies in stead of the announced and unannounced intervention dummies.

During our sample period, whenever the US authority intervened, the Japanese authority intervened on the same day. There was no unilateral US intervention, while there are many of them by the Japanese authority. Hence, the US intervention dummy captures the impact of coordinated intervention between the US and Japan.

The results on the left hand side of Table 6 report that the coordinated interventions are effective conditional on the size of interventions. Since we control for the coordinated intervention dummy, the Japanese intervention dummies represent the Japanese unilateral intervention effects. The results are similar to those of Table 5, although the coefficient of announced intervention dummy is higher and more significant.

On the right hand side of Table 6, the result indicates that announcement effects are not significant except for Period 2. This finding questions the efficacy of intervention announcements. Official announcements alone do not necessarily guarantee the success of an intervention. A natural question arises: why did Dr. Sakakibara succeed in interventions in Period 2?

2.2. Does expectation heterogeneity matter for the efficacy of announcements?

We next examine whether trader heterogeneity on exchange rate expectations matters for the efficacy of intervention announcement. In order to test for this hypothesis, ideally one would like to include the interaction term between the announced intervention dummy and a variable representing exchange rate expectation heterogeneity. Unfortunately, however, exchange rate forecast data are not available on the daily basis. Thus, we use implied volatility and trading volume as proxies for the dispersion of exchange rate expectations across traders.

The recent empirical studies on the market microstructure explore the interrelationships between volatility, trading volume and the heterogeneity of exchange rate expectations. Using survey data on exchange rate forecasts, they obtain strong evidence on the positive relationships among them (Frankel and Froot, 1990; Chionis and MacDonald, 1997; MacDonald and Marsh, 1996). These findings support our idea of using these proxies.

The implied volatility data we use are calculated using the at-the-money option prices at the Tokyo option market, as collected by Nikkei. For trading volume data, we use the trading volume of all active brokered interdealer trades on the yen/dollar spot exchange rates at the Tokyo foreign exchange market, as collected by Nikkei. These data are only available source of spot currency market trading volume at daily frequency over our sample period. Daily trading volume has a slight upward-trend over our sample period. In addition, the share of brokered interdealer trades might have been increasing since the electric broking system was introduced in 1993, although there is no discontinuity on data around the time of its introduction. To deal with these problems, we create the following volume variable, following Chaboud and LeBaron (1999). The variable is the ratio of today's trading volume to a sum of the previous 100 trading volumes.

$$Trading\ volume\ ratio = vol_t \Big/ \sum_{s=1}^{100} vol_{t-s} \tag{2}$$

Table 7 through Table 9 presents the results of estimations whose variables have the lagged values of implied volatility (1 month and 3 month) and trading volume ratio. To prevent simultaneity problem, the interaction terms are made of lagged values of implied volatility and trading volume ratio, instead of their current values.

The difference between the upper and lower tables is that we include the interaction terms with the US intervention volume and dummy as exogenous variables on the lower regressions. The results are similar between Table 7 and Table 8. The coefficient of the interaction term between the Japanese announcement dummy and the lagged implied volatility is positive and significant in Period 2, while those in other sub-sample periods are not. This suggests that the announcement effects in Period 2 have a non-linear relationship with implied volatility. When implied volatility on the last

trading day is sufficiently high, the effect of official announcements on exchange rate is significant.

Table 9 presents the similar results, which are obtained using the trading volume ratio as a proxy for expectation heterogeneity. The announcement on interventions is more influential on exchange rate when trading volume is high.

In sum, using Japanese daily intervention data, we find that making official intervention announcements does not necessarily have an influence on exchange rate. Actually, the significance of announcement effects depends on the time period. A successful intervener Dr. Sakakibara provided a key to solve this puzzle: market conditions are crucial to enhance the efficacy of announcement. We show evidence that intervention announcement is more effective when implied volatility and trading volume on the last trading day are sufficiently high. This is consistent with the view that expectation heterogeneity improves the signaling effects.

6. Conclusion

This paper empirically examines whether timing foreign exchange interventions can enhance central banks' signaling effects. Classifying the Japanese and the US intervention operations against the yen/dollar exchange rate into officially announced, unannounced but reported and perfectly secret interventions, we find that announced interventions outperformed the latter two. Even official announcements, however, were quite effective only for the short sub-sample period when Dr. Eisuke Sakakibara was in charge. Then we explore whether the efficacy of official announcements about interventions is associated with market conditions. We show strong evidence that announced interventions had a more significant influence on exchange rate when implied volatility and trading volume on the last trading day were high. This is consistent with the conjecture by Peter B. Kenen (1987) that intervention is more effective when traders' exchange rate expectations are heterogeneous.

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Figure 1. Japanese interventions and yen/dollar rate
(June 1992－May 2004)

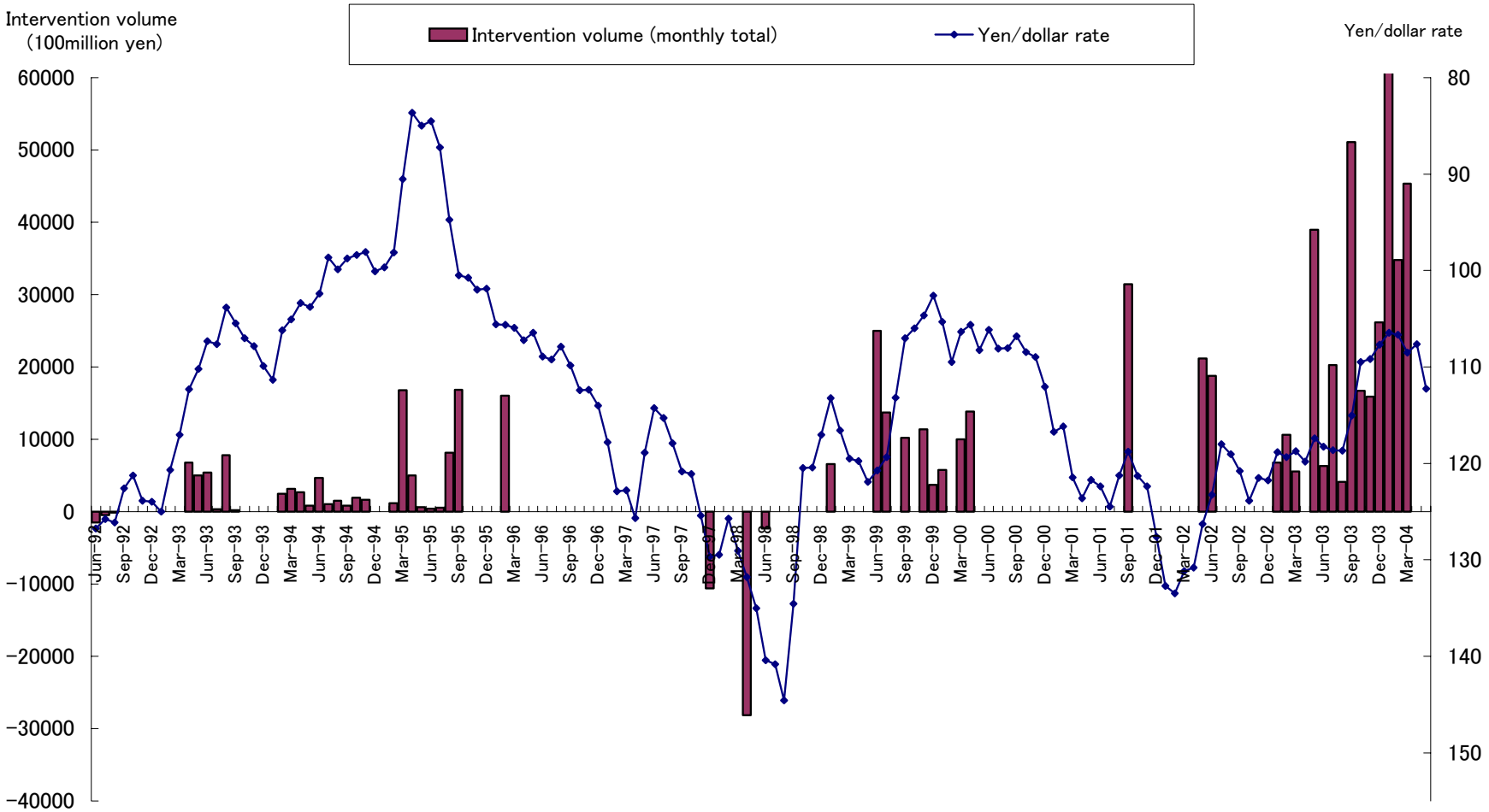


Figure 2. Japanese interventions and implied volatility
(June 1992－May 2004)

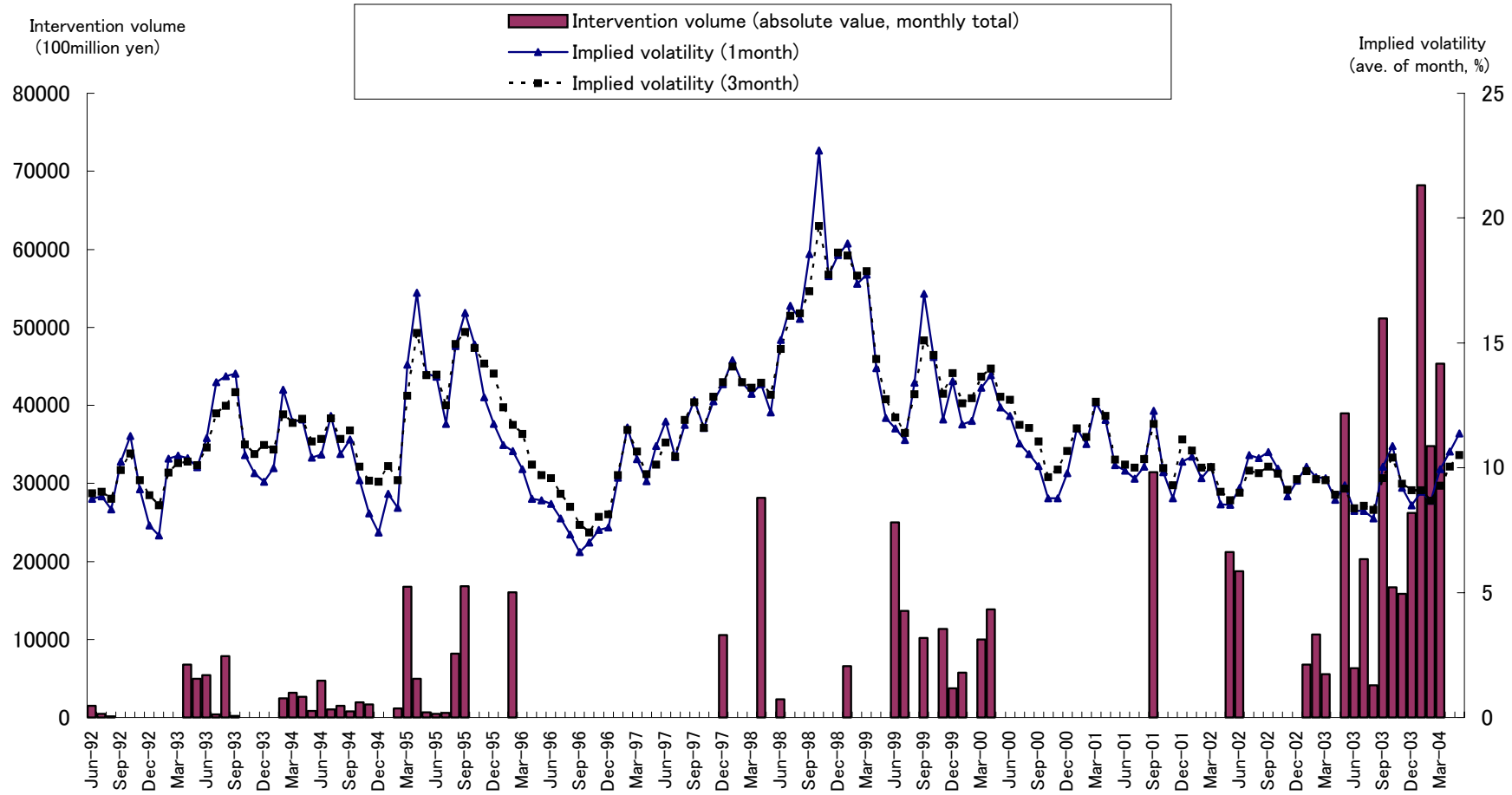
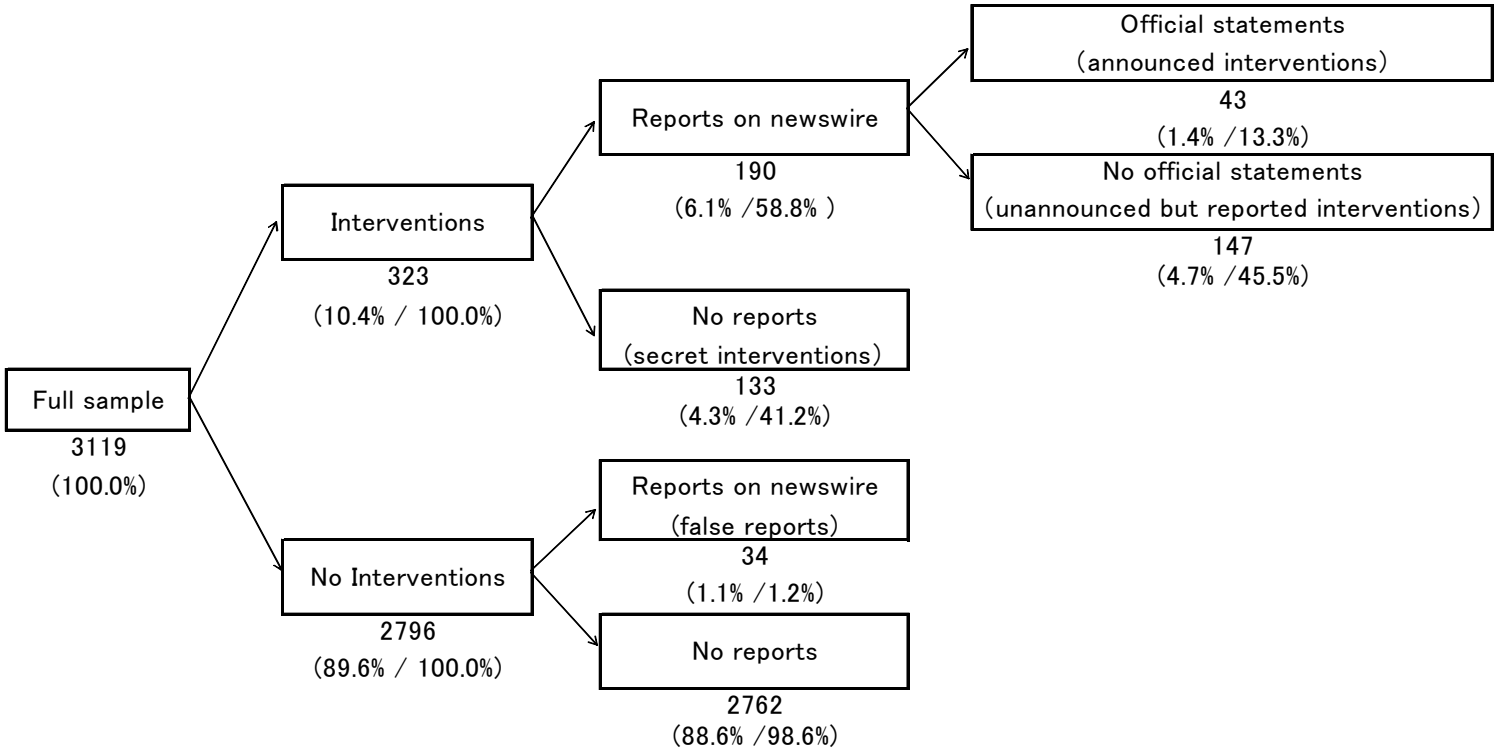


Figure3. Practices of intervention in Japan (6/15/1992-5/27/2004)



Source: the Ministry of Finance of Japan and Bloomberg
1. "Announced interventions" have official statements about the interventions during the same day of interventions.
2. "Unannounced but reported interventions" have some reports on newswire but no official statements.
3. "Secret interventions" have no reports about the interventions on newswire.
4. "False reports" have reports on newswire, but there are actually no interventions.
5. The percentage of each practice of interventions against the whole samle days and against whole intervention days are in parenthesis, respectively.

Table 1. Practices and intervention volume (6/15/1992-5/27/2004)

Intervention volume (100 million yen)	No. of days	Announced interventions	Unannounced but reported interventions	Secret interventions
1～499	118	5	60	53
	36.5%	11.6%	40.8%	39.9%
500～999	59	4	36	19
	18.3%	9.3%	24.5%	14.3%
1000～1999	48	7	14	27
	14.9%	16.3%	9.5%	20.3%
2000～4999	60	13	21	26
	18.6%	30.2%	14.3%	19.5%
5000～26201	38	14	16	8
	11.8%	32.6%	10.9%	6.0%
Total	323	43	147	133
	100.0%	13.3% / 100%	45.5% / 100%	41.2% / 100%

Source: the Ministry of Finance of Japan and Bloomberg

1. "Announced interventions" have official statements about the interventions during the same day of interventions.
2. "Unannounced but reported interventions" have some reports on newswire but no official statements.
3. "Secret interventions" have no reports about the interventions on newswire.

Table 2. Changes of intervention policy in Japan

Period	Unilateral Interventions (JP)					Coordinated Interventions (US)	
	No. of days	Announced interventions	Unannounced but reported interventions	Secret interventions	False reports	Announced interventions	Unannounced but reported interventions
＜Full sample period : 3119days＞							
6/15/1992-5/27/2004	323	43 13.3%	147 45.5%	133 41.2%	34	10	9
Average volume of interventions per day (JPY 100 million/USD 1million)	2093	4321	1897	1591		478	378
＜Period 1 : 787days＞							
6/15/1992-6/20/1995	145	9 6.2%	101 69.7%	35 24.1%	20	6	9
Average volume of interventions per day (JPY 100 million/USD 1million)	488	699	544	273		468	378
＜Period 2 : 956days＞							
6/21/1995-7/7/1999	24	8 33.3%	14 58.3%	2 8.3%	13	4	0
Average volume of interventions per day (JPY 100 million/USD 1million)	5105	4598	6025	683		492	0
＜Period 3 : 918days＞							
7/8/1999-1/13/2003	25	25 100.0%	0 0.0%	0 0.0%	1	0	0
Average volume of interventions per day (JPY 100 million/USD 1million)	5282	5282	0	0		0	0
＜Period 4 : 358days＞							
1/14/2003-5/27/2004	129	1 0.8%	32 24.8%	96 74.4%	0	0	0
Average volume of interventions per day (JPY 100 million/USD 1million)	2719	10667	4359	2090		0	0

Source: The web site of the Ministry of Finance of Japan, Quarterly Review of Federal Reserve Bank of NY and Bloomberg

1. "Announced interventions" have official statements about the interventions during the same day of interventions.
2. "Unannounced but reported interventions" have some reports on newswire but no official statements.
3. "Secret interventions" have no reports about the interventions on newswire.
4. "False reports" have reports on newswire, but there are actually no interventions.
5. The US interventions during our sample period were all coordinated with the BOJ.
6. The scales are 100 million yen for JP interventions and million dollars for US interventions.

Table 3. Descriptive Statistics

	Exchange rate (Yen/Dollar)	Excahnge rate return (%)	Interest rate differencial (%)	Implied volatility (1month, %)	Implied volatility (3month, %)	Trading volume ratio (%)
＜Full sample period : 6/15/1992-5/27/2004＞						
Average	114.10	-0.01	-3.27	11.25	11.44	1.01
Median	114.37	0.00	-4.39	10.60	10.80	0.96
Max	147.25	4.14	1.85	39.50	28.80	3.36
Minimum	80.63	-7.69	-7.30	6.20	6.70	0.07
Std. dev.	11.33	0.71	2.17	2.95	2.52	0.38
＜Period 1 : 6/15/1992-6/20/1995＞						
Average	107.31	-0.05	-1.13	10.73	10.90	1.02
Median	105.95	-0.03	-0.62	10.35	10.60	0.95
Max	128.03	4.14	1.85	18.70	16.70	2.92
Minimum	80.63	-5.42	-4.95	6.70	8.30	0.19
Std. dev.	11.61	0.72	1.79	2.40	1.65	0.43
＜Period 2 : 6/21/1995-7/7/1999＞						
Average	116.99	0.04	-4.94	12.55	12.80	1.01
Median	117.15	0.04	-4.94	12.20	12.70	0.98
Max	147.25	3.95	-3.75	39.50	28.80	3.21
Minimum	84.10	-7.69	-7.30	6.20	6.70	0.13
Std. dev.	12.40	0.83	0.31	3.77	3.19	0.37
＜Period 3 : 7/8/1999-1/13/2003＞						
Average	116.82	0.00	-4.04	10.93	11.18	0.98
Median	118.74	0.00	-4.87	10.50	10.70	0.95
Max	134.81	2.05	-1.12	21.60	18.30	2.95
Minimum	101.60	-2.85	-7.01	7.50	8.30	0.07
Std. dev.	8.75	0.64	1.91	1.99	1.75	0.33
＜Period 4 : 1/14/2003-5/27/2004＞						
Average	113.53	-0.03	-1.09	9.39	9.29	1.03
Median	114.50	0.00	-1.02	9.30	9.20	0.96
Max	121.69	1.39	-0.86	16.10	12.60	3.36
Minimum	103.76	-1.75	-1.45	7.30	7.90	0.21
Std. dev.	5.30	0.42	0.13	1.28	0.80	0.40

Source: Datastream, Nikkei Financial Quest and AMUSAS of Nikkei QUICK.

1. Foreign exchange rates are the closing rate of NY market (18:00 of NY time). Foreign exchange returns are daily % change in exchange rate.
2. The interest rate differential is the difference in ovrernight interest rate between Japan and the US.
3. The implied volatility is calculated from yen/dollar option price (at the money).
4. The trading volume ratio is the % ratio of the intervention day's spot trading volume in the Tokyo market to the sum of trading volume from 100 days prior to the intervention day to 1day.

Table 4. Effects of intervention volume on exchange rate

＜Dependet variable：% change in exchange rate	Full sample period	Period 1	Period 2	Period 3	Period 4
Method：GARCH-ML	6/15/1992-5/27/2004	6/15/1992-6/20/1995	6/21/1995-7/7/1999	7/8/1999-1/13/2003	1/14/2003-5/27/2004
＜Explanatory variables＞					
Mean Equation					
Constant	−0.05549 *** (0.01986)	−0.01579 (0.02930)	−0.00493 (0.29721)	−0.03497 (0.05203)	−0.82643 (0.75334)
Interest rate differential	−0.01514 *** (0.00512)	−0.00113 (0.01498)	−0.01003 (0.05985)	−0.00652 (0.01147)	−0.27287 (0.26460)
JP intervention volume	0.00005 *** (0.00001)	−0.00049 *** (0.00010)	0.00009 *** (0.00002)	0.00007 *** (0.00002)	0.00003 *** (0.00001)
US intervention volume	0.00188 *** (0.00014)	0.00158 *** (0.00031)	0.00601 *** (0.00079)		
Varivance Equation					
Constant	0.00827 *** (0.00118)	0.01561 *** (0.00347)	0.00972 *** (0.00273)	0.75621 *** (0.05370)	0.07104 ** (0.03289)
ARCH(1)	0.04139 *** (0.00305)	0.05204 *** (0.00813)	0.06181 *** (0.00782)	−0.02076 ** (0.01027)	0.12942 *** (0.04190)
GARCH(1)	0.94323 *** (0.00440)	0.92172 *** (0.00946)	0.92459 *** (0.01028)	−0.83086 *** (0.11971)	0.63707 *** (0.13399)
Adjusted R-squared	0.0163	0.0089	0.0756	0.0047	0.0056
obs.	3119	787	1056	918	358

1. Standard deviations are in parenthesis. *、** and *** denote statistical significance at the 10%、5% and 1% levels, respectively.

2. There were no US interventions in Period 3 and 4.

3. The scales are 100 million yen for JP interventions and million dollars for US interventions.

Table 5. Signaling effects of exchane rate interventions

＜Dependet variable: % change in exchange rate＞	Full sample period		Period 1		Period 2		Period 3		Period 4	
Method：GARCH-ML	6/15/1992-5/27/2004		6/15/1992-6/20/1995		6/21/1995-7/7/1999		7/8/1999-1/13/2003		1/14/2003-5/27/2004	
＜Explanatory variables＞										
Mean Equation										
Constant	-0.02756	(0.02160)	-0.00747	(0.02990)	-0.14878	(0.30934)	-0.03461	(0.05208)	-0.35345	(0.25794)
Interest rate differential	-0.00992 *	(0.00534)	-0.00112	(0.01464)	-0.03900	(0.06259)	-0.00642	(0.01147)	-0.29141	(0.23490)
JP intervention volume	0.00006 ***	(0.00001)	-0.00033 ***	(0.00011)	0.00006 **	(0.00003)	0.00007 **	(0.00003)	0.00005 ***	(0.00002)
US intervention volume	0.00010	(0.00044)	-0.00072	(0.00064)	0.00401	(0.00413)				
JP announced intervention dummy	0.18979 *	(0.10553)	0.70629	(2.36843)	1.07293 ***	(0.20094)	-0.02226	(0.20493)	0.13442	(14808.9)
JP unannounced but reported intervention dummy	-0.19444 ***	(0.05869)	-0.15049	(0.09414)	0.11569	(0.18273)			-0.07951	(0.12349)
JP secret intervention dummy	-0.17682 ***	(0.06439)	-0.23426 *	(0.13027)	0.50328	(0.65416)			-0.12876	(0.07860)
JP false report dummy	0.12040	(0.13827)	0.09175	(0.21841)	0.11980	(0.17811)	0.26663	(21861.2)		
US announced intervention dummy	1.16440 ***	(0.28037)	0.01199	(2.42842)	-0.06104	(1.40029)				
US unannounced but reported intervention dummy	0.79602 ***	(0.15200)	1.32357 ***	(0.22017)						
Varivance Equation										
Constant	0.00902 ***	(0.00134)	0.01394 ***	(0.00348)	0.00980 ***	(0.00274)	0.75559 ***	(0.05521)	0.06599 **	(0.02725)
ARCH(1)	0.04508 ***	(0.00374)	0.04966 ***	(0.00748)	0.06688 ***	(0.00848)	-0.02090 *	(0.01095)	0.14277 ***	(0.04114)
GARCH(1)	0.93804 ***	(0.00533)	0.92598 ***	(0.01050)	0.91985 ***	(0.01067)	-0.82926 ***	(0.12534)	0.64170 ***	(0.11398)
Adjusted R-squared	0.0235		0.0011		0.0774		0.0027		0.0028	
obs.	3119		787		1056		918		358	

1. Standard deviations are in parenthesis. *、** and *** denote statistical significance at the 10%、5% and 1% levels, respectively.

2. There were no US interventions in Period 3 and 4.

3. The scales are 100 million yen for JP interventions and million dollars for US interventions.

Table 6. Signaling effects in the Sakakibara era

＜Dependet variable： % change in exchange rate＞ Method：GARCH-ML				Full sample period 6/15/1992-5/27/2004		
＜Explanatory variables＞				＜Explanatory variables＞		
Mean Equation				Mean Equation		
Constant	−0.02742		(0.02156)	Constant	−0.02519	(0.02141)
Interest rate differential	−0.00988	*	(0.00533)	Interest rate differential	−0.01005	* (0.00532)
JP intervention volume	0.00006	***	(0.00001)	JP intervention volume	0.00006	*** (0.00001)
US intervention volume	0.00011		(0.00036)	US intervention volume	−0.00034	(0.00050)
JP announced intervention dummy	0.23903	**	(0.09717)	JP announced intervention dummy	0.00393	(0.12911)
				JP announced intervention dummy＊period 2 dummy	1.07434	*** (0.18740)
JP unannounced but reported intervention dummy	−0.20277	***	(0.05846)	JP unannounced but reported intervention dummy	−0.17968	*** (0.05762)
JP secret intervention dummy	−0.17659	***	(0.06449)	JP secret intervention dummy	−0.17476	*** (0.06369)
JP false report dummy	0.11353		(0.13790)	JP false report dummy	0.11497	(0.13746)
US intervention dummy	0.91344	***	(0.14687)	US intervention dummy	0.80155	*** (0.17804)
				US intervention dummy*period 2 dummy	1.19767	*** (0.33680)
Varivance Equation				Varivance Equation		
Constant	0.00888	***	(0.00131)	Constant	0.00885	*** (0.00131)
ARCH(1)	0.04470	***	(0.00357)	ARCH(1)	0.04509	*** (0.00372)
GARCH(1)	0.93865	***	(0.00512)	GARCH(1)	0.93813	*** (0.00526)
Adjusted R-squared	0.0228			Adjusted R-squared	0.0372	
obs.	3119			obs.	3119	

1. Standard deviations are in parenthesis. *、** and *** denote statistical significance at the 10%、5% and 1% levels, respectively.

2. The scales are 100 million yen for JP interventions and million dollars for US interventions.

Table 7. Effects of announced interventions and implied volatility (1Month)

＜Dependet variable： % change in exchange rate＞	Full sample period		Period 1		Period 2		Period 3	
Method：GARCH-ML	6/15/1992-5/27/2004		6/15/1992-6/20/1995		6/21/1995-7/7/1999		7/8/1999-1/13/2003	
＜Explanatory variables＞								
Mean Equation								
Constant	0.00038	(0.05328)	-0.16396	(0.14906)	-0.15704	(0.30514)	-0.03167	(0.10542)
Interest rate differential	-0.01032 *	(0.00579)	0.00456	(0.01493)	-0.05439	(0.06153)	-0.00564	(0.01334)
JP intervention volume	0.00000	(0.00005)	-0.00033	(0.00067)	0.00023	(0.00032)	-0.00036	(0.00031)
US intervention volume	-0.00012	(0.00042)	-0.00052	(0.00066)	-0.00135	(0.00552)		
JP announced intervention dummy	-1.44579 ***	(0.55344)	-2.45043	(2.20241)	-5.95089 ***	(1.84654)	2.07400	(1.94160)
JP unannounced but reported intervention dummy	-0.36839	(0.23246)	-0.10430	(0.42893)	-3.99061 *	(2.34582)		
JP secret intervention dummy	-0.21573	(0.37485)	-0.82899	(0.66937)	-9.52572	(781.339)		
US intervention dummy	0.97006 ***	(0.16508)	1.11896 ***	(0.22009)	2.37320	(1.84512)		
Volatility(-1)	-0.00268	(0.00518)	0.01674	(0.01497)	-0.00568	(0.00638)	0.00006	(0.01056)
JP intervention volume * volatility(-1)	0.00001	(0.00000)	-0.00001	(0.00005)	-0.00001	(0.00002)	0.00003	(0.00002)
JP announced intervention dummy * volatility(-1)	0.13383 ***	(0.04282)	0.17799	(0.15922)	0.55925 ***	(0.13724)	-0.16534	(0.15041)
JP unannounced but reported intervention dummy * volatility(-1)	0.01602	(0.01971)	-0.00085	(0.03473)	0.32958 *	(0.18277)		
JP secret intervention dummy * volatility(-1)	0.00465	(0.03926)	0.05659	(0.06332)	0.75551	(56.5368)		
Varivance Equation								
Constant	0.00898 ***	(0.00135)	0.01443 ***	(0.00365)	0.01154 ***	(0.00317)	0.74398 ***	(0.06229)
ARCH(1)	0.04542 ***	(0.00380)	0.05324 ***	(0.00861)	0.07683 ***	(0.01017)	-0.02449 *	(0.01287)
GARCH(1)	0.93766 ***	(0.00541)	0.92201 ***	(0.01097)	0.90725 ***	(0.01273)	-0.79939 ***	(0.14677)
Adjusted R-squared	0.0245		0.0053		0.0945		0.0016	
＜Explanatory variables＞								
Mean Equation								
Constant	0.00996	(0.05640)	-0.23193	(0.14747)	-0.19932	(0.31554)	-0.03167	(0.10542)
Interest rate differential	-0.00927	(0.00621)	0.01196	(0.01574)	-0.06263	(0.06220)	-0.00564	(0.01334)
JP intervention volume	-0.00021 *	(0.00011)	-0.00215 ***	(0.00058)	0.00059	(0.00053)	-0.00036	(0.00031)
US intervention volume	0.00200	(0.00207)	0.01490 ***	(0.00480)	-0.00448	(13.9642)		
JP announced intervention dummy	0.35792	(0.83745)	3.18414 *	(1.72696)	-17.3128 ***	(5.96643)	2.07400	(1.94160)
JP unannounced but reported intervention dummy	-0.35436	(0.39268)	1.05203 **	(0.44328)	-5.74891 *	(3.47214)		
JP secret intervention dummy	-0.84193	(0.58293)	0.00112	(0.75275)	-9.67704	(1865.08)		
US intervention dummy	-2.00774 **	(0.89567)	-9.26123 ***	(1.99442)	17.4977	(8116.98)		
Volatility(-1)	-0.00296	(0.00533)	0.02315 *	(0.01372)	-0.00385	(0.00633)	0.00006	(0.01056)
JP intervention volume * volatility(-1)	0.00002 **	(0.00001)	0.00014 ***	(0.00004)	-0.00004	(0.00004)	0.00003	(0.00002)
JP announced intervention dummy * volatility(-1)	-0.01696	(0.06522)	-0.27638 **	(0.12207)	1.46752 ***	(0.49092)	-0.16534	(0.15041)
JP unannounced but reported intervention dummy * volatility(-1)	0.01066	(0.03318)	-0.09961 ***	(0.03185)	0.46689 *	(0.26768)		
JP secret intervention dummy * volatility(-1)	0.05678	(0.05335)	-0.01170	(0.06512)	0.76540	(141.025)		
US intervention volume * volatility(-1)	-0.00015	(0.00015)	-0.00125 ***	(0.00037)	0.00036	(0.89079)		
US intervention dummy * volatility(-1)	0.26350 ***	(0.07255)	0.85623 ***	(0.14810)	-1.27441	(539.999)		
Varivance Equation								
Constant	0.01038 ***	(0.00171)	0.20864 ***	(0.04442)	0.05734 ***	(0.00884)	0.74398 ***	(0.06229)
ARCH(1)	0.04566 ***	(0.00441)	0.13851 ***	(0.03155)	0.17466 ***	(0.01530)	-0.02449 *	(0.01287)
GARCH(1)	0.93553 ***	(0.00651)	0.44703 ***	(0.10845)	0.74040 ***	(0.01963)	-0.79939 ***	(0.14677)
Adjusted R-squared	0.0308		0.0249		0.0941		0.0016	
obs.	3118		786		1056		918	

1. Standard deviations are in parenthesis. *、** and *** denote statistical significance at the 10%、5% and 1% levels, respectively.
2. The implied volatility is calculated from the 1 month yen/dollar option price (at the money).
3. There were no US interventions in Period 3.
4. Period 4 cannot be estimated since it had only one announced intervention.
5. The scales are 100 million yen for JP interventions and million dollars for US interventions.

Table 8. Effects of announced interventions and implied volatility (3Month)

＜Dependet variable： % change in exchange rate＞ Method：GARCH-ML	Whole sample period 6/15/1992-5/27/2004		Period 1 6/15/1992-6/20/1995		Period 2 6/21/1995-7/7/1999		Period 3 7/8/1999-1/13/2003	
＜Explanatory variables＞								
Mean Equation								
Constant	-0.01289	(0.06342)	-0.39231 *	(0.23328)	-0.16591	(0.30909)	-0.04658	(0.13533)
Interest rate differential	-0.00947	(0.00609)	0.01432	(0.01615)	-0.06018	(0.06084)	-0.00328	(0.01539)
JP intervention volume	0.00001	(0.00006)	-0.00046	(0.00089)	0.00028	(0.00052)	-0.00034	(0.00032)
US intervention volume	-0.00017	(0.00042)	-0.00056	(0.00063)	-0.00082	(0.02303)		
JP announced intervention dummy	-2.30508 ***	(0.63434)	-3.99794	(3.59244)	-8.41689 **	(3.73034)	1.36723	(2.16292)
JP unannounced but reported intervention dummy	-0.35960	(0.31889)	0.25899	(0.63659)	-5.45012	(4.05503)		
JP secret intervention dummy	-0.24768	(0.43796)	-0.91083	(0.97168)	-7.59308	(597.391)		
US intervention dummy	0.93853 ***	(0.16211)	1.12408 ***	(0.21592)	1.75169	(7.27560)		
Volatility(-1)	-0.00104	(0.00624)	0.03893 *	(0.02291)	-0.00670	(0.00721)	0.00223	(0.01460)
JP intervention volume * volatility(-1)	0.00001	(0.00001)	0.00000	(0.00007)	-0.00002	(0.00004)	0.00003	(0.00003)
JP announced intervention dummy * volatility(-1)	0.20845 ***	(0.05007)	0.30178	(0.27548)	0.74791 ***	(0.27974)	-0.10725	(0.17243)
JP unannounced but reported intervention dummy * volatility(-1)	0.01520	(0.02776)	-0.03361	(0.05347)	0.43384	(0.31007)		
JP secret intervention dummy * volatility(-1)	0.00796	(0.04575)	0.06472	(0.09202)	0.59923	(42.8082)		
Varivance Equation								
Constant	0.00901 ***	(0.00135)	0.01458 ***	(0.00374)	0.01816 ***	(0.00424)	0.74650 ***	(0.05928)
ARCH(1)	0.04558 ***	(0.00375)	0.05232 ***	(0.00824)	0.10168 ***	(0.01270)	-0.02295 **	(0.01133)
GARCH(1)	0.93742 ***	(0.00536)	0.92237 ***	(0.01080)	0.87363 ***	(0.01588)	-0.81013 ***	(0.13759)
Adjusted R-squared	0.0267		0.0114		0.0925		0.0031	
＜Explanatory variables＞								
Mean Equation								
Constant	-0.01455	(0.06314)	-0.38721 *	(0.22759)	-0.19189	(0.31577)	-0.04658	(0.13533)
Interest rate differential	-0.00994	(0.00612)	0.01339	(0.01590)	-0.06768	(0.06130)	-0.00328	(0.01539)
JP intervention volume	-0.00004	(0.00007)	-0.00098	(0.00087)	0.00087	(0.00068)	-0.00034	(0.00032)
US intervention volume	0.00153	(0.00258)	0.01613 **	(0.00790)	-0.00826	(0.82464)		
JP announced intervention dummy	-1.23336	(0.76760)	-3.20710	(3.27156)	-21.6747 ***	(6.70111)	1.36723	(2.16292)
JP unannounced but reported intervention dummy	-0.09272	(0.37260)	0.52632	(0.73125)	-8.59106 *	(4.54051)		
JP secret intervention dummy	-0.20940	(0.43626)	-0.84036	(0.96008)	-7.96146	(869.295)		
US intervention dummy	-3.04124 ***	(1.14596)	-7.42261 ***	(2.52259)	21.2887	(299.101)		
Volatility(-1)	-0.00103	(0.00621)	0.03856 *	(0.02237)	-0.00648	(0.00714)	0.00223	(0.01460)
JP intervention volume * volatility(-1)	0.00001 *	(0.00001)	0.00005	(0.00007)	-0.00006	(0.00005)	0.00003	(0.00003)
JP announced intervention dummy * volatility(-1)	0.10736 *	(0.06167)	0.21926	(0.25473)	1.78514 ***	(0.51736)	-0.10725	(0.17243)
JP unannounced but reported intervention dummy * volatility(-1)	-0.00822	(0.03247)	-0.05964	(0.06184)	0.67655 **	(0.34189)		
JP secret intervention dummy * volatility(-1)	0.00515	(0.04540)	0.05649	(0.09122)	0.62726	(65.1805)		
US intervention volume * volatility(-1)	-0.00014	(0.00020)	-0.00150 **	(0.00069)	0.00066	(0.05156)		
US intervention dummy * volatility(-1)	0.35792 ***	(0.09712)	0.76468 ***	(0.21118)	-1.56854	(19.3601)		
Varivance Equation								
Constant	0.00947 ***	(0.00146)	0.01519 ***	(0.00401)	0.04551 ***	(0.00717)	0.74650 ***	(0.05928)
ARCH(1)	0.04605 ***	(0.00418)	0.06153 ***	(0.01248)	0.16603 ***	(0.01494)	-0.02295 **	(0.01133)
GARCH(1)	0.93594 ***	(0.00602)	0.91287 ***	(0.01480)	0.76936 ***	(0.01764)	-0.81013 ***	(0.13759)
Adjusted R-squared	0.0319		0.0185		0.0916		0.0031	
obs.	3118		786		1056		918	

1. Standard deviations are in parenthesis. *、** and *** denote statistical significance at the 10%、5% and 1% levels, respectively.
2. The implied volatility is calculated from the 3 month yen/dollar option price (at the money).
3. There were no US interventions in Period 3.
4. Period 4 cannot be estimated since it had only one announced intervention.
5. The scales are 100 million yen for JP interventions and million dollars for US interventions.

Table 9. Effects of announced interventions and trading volume

<Dependet variable: % change in exchange rate> Method:GARCH-ML	Full sample period 6/15/1992-5/27/2004		Period 1 6/15/1992-6/20/1995		Period 2 6/21/1995-7/7/1999		Period 3 7/8/1999-1/13/2003	
<Explanatory variables>								
Mean Equation								
Constant	0.01359	(0.04025)	0.00085	(0.07259)	−0.15545	(0.31228)	−0.01515	(0.08760)
Interest rate differential	−0.01034 *	(0.00540)	−0.00108	(0.01493)	−0.04949	(0.06228)	−0.00624	(0.01148)
JP intervention volume	0.00007 ***	(0.00003)	−0.00019	(0.00054)	0.00008	(0.00011)	0.00004	(0.00013)
US intervention volume	−0.00005	(0.00049)	−0.00085	(0.00066)	−0.00188	(0.01307)		
JP announced intervention dummy	−0.02600	(0.20716)	−0.53535	(0.93883)	−1.06160	(1.18185)	−0.14913	(0.66229)
JP unannounced but reported intervention dummy	−0.03127	(0.14356)	0.25342	(0.33987)	0.05144	(0.54023)		
JP secret intervention dummy	−0.25246	(0.16297)	−0.48799	(0.33514)	−0.23950	(158.421)		
US intervention dummy	0.94282 ***	(0.18202)	1.13324 ***	(0.23531)	1.16098	(5.48331)		
trading volume ratio(−1)	−0.04348	(0.03580)	−0.00812	(0.06996)	−0.03784	(0.05688)	−0.01859	(0.07249)
JP intervention volume * trading volume ratio(−1)	−0.00002	(0.00003)	−0.00011	(0.00039)	−0.00001	(0.00011)	0.00003	(0.00011)
JP announced intervention dummy * trading volume ratio(−1)	0.25065	(0.21882)	0.43072	(0.73868)	3.19091 **	(1.48823)	0.11194	(0.54138)
JP unannounced but reported intervention dummy * trading volume ratio(−1)	−0.14905	(0.09820)	−0.33176	(0.26361)	0.04333	(0.28969)		
JP secret intervention dummy * trading volume ratio(−1)	0.08029	(0.13166)	0.27211	(0.33822)	0.95977	(209.840)		
Varivance Equation								
Constant	0.00848 ***	(0.00131)	0.01448 ***	(0.00379)	0.01658 ***	(0.00394)	0.75583 ***	(0.05295)
ARCH(1)	0.04355 ***	(0.00367)	0.05098 ***	(0.00875)	0.09494 ***	(0.01188)	−0.02146 **	(0.01084)
GARCH(1)	0.94046 ***	(0.00524)	0.92352 ***	(0.01206)	0.88275 ***	(0.01476)	−0.83085 ***	(0.11821)
Adjusted R-squared	0.0226		0.0066		0.0748		0.0011	
<Explanatory variables>								
Mean Equation								
Constant	0.00991	(0.04070)	0.00075	(0.07275)	−0.16834	(0.31324)	−0.01515	(0.08760)
Interest rate differential	−0.01056 *	(0.00540)	−0.00142	(0.01499)	−0.05337	(0.06274)	−0.00624	(0.01148)
JP intervention volume	0.00008 ***	(0.00003)	−0.00040	(0.00056)	0.00008	(0.00011)	0.00004	(0.00013)
US intervention volume	−0.00279 ***	(0.00101)	−0.00099	(0.00342)	0.00151	(0.24112)		
JP announced intervention dummy	−0.04912	(0.23874)	−1.05924	(1.16249)	−1.36281	(1.21977)	−0.14913	(0.66229)
JP unannounced but reported intervention dummy	−0.03879	(0.14667)	0.25925	(0.35569)	0.05972	(0.60111)		
JP secret intervention dummy	−0.25517	(0.16304)	−0.45114	(0.33627)	−0.26847	(81.6237)		
US intervention dummy	2.43003 ***	(0.48060)	2.24953 *	(1.16951)	−0.28144	(90.5836)		
trading volume ratio(−1)	−0.04012	(0.03615)	−0.00790	(0.07010)	−0.03784	(0.05781)	−0.01859	(0.07249)
JP intervention volume * trading volume ratio(−1)	−0.00002	(0.00003)	0.00006	(0.00041)	−0.00001	(0.00012)	0.00003	(0.00011)
JP announced intervention dummy * trading volume ratio(−1)	0.23026	(0.27006)	0.77926	(1.10919)	3.72787 **	(1.52123)	0.11194	(0.54138)
JP unannounced but reported intervention dummy * trading volume ratio(−1)	−0.14131	(0.10032)	−0.34776	(0.27513)	0.04391	(0.32072)		
JP secret intervention dummy * trading volume ratio(−1)	0.08061	(0.13195)	0.22680	(0.33575)	0.98236	(110.352)		
US intervention volume * trading volume ratio(−1)	0.00262 ***	(0.00080)	0.00009	(0.00366)	−0.00255	(0.13788)		
US intervention dummy * trading volume ratio(−1)	−1.43694 ***	(0.39473)	−0.94556	(1.18588)	0.93595	(103.201)		
Varivance Equation								
Constant	0.00854 ***	(0.00133)	0.01439 ***	(0.00391)	0.02943 ***	(0.00539)	0.75583 ***	(0.05295)
ARCH(1)	0.04378 ***	(0.00385)	0.05205 ***	(0.01123)	0.13055 ***	(0.01322)	−0.02146 **	(0.01084)
GARCH(1)	0.94009 ***	(0.00546)	0.92274 ***	(0.01443)	0.82936 ***	(0.01610)	−0.83085 ***	(0.11821)
Adjusted R-squared	0.0239		0.0145		0.0719		0.0011	
obs.	3118		786		1056		918	

1. Standard deviations are in parenthesis. *、** and *** denote statistical significance at the 10%、5% and 1% levels, respectively.

2. The Trading trading volume ratio is the % ratio of the intervention day's spot trading volume in the Tokyo market to the sum of trading volume from 100 days prior to the intervention day to 1day.

3. There were no US interventions in Period 3.

4. Period 4 cannot be calculated since it had only one announced intervention.

5. The scales are 100 million yen for JP interventions and million dollars for US interventions.