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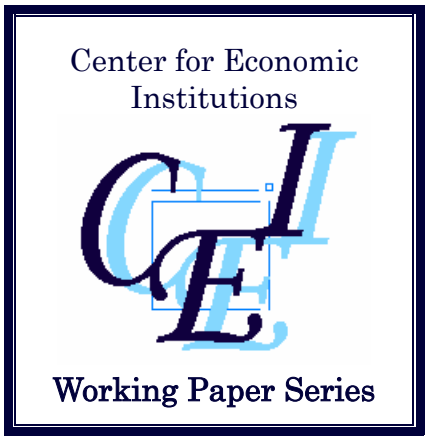

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Signaling Effects of Foreign Exchange Interventions and Expectation Heterogeneity among Traders

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Abstract

This paper explores whether official intervention signaling effects on short-run exchange rate movements depend on market conditions. We find evidence that announced interventions significantly affect the level and reduce the volatility of the yen/dollar rate when traders' expectations of future exchange rates are relatively heterogeneous. To compensate for the lack of daily exchange rate expectation survey data, we use implied volatility as a proxy since these are highly correlated. These results are consistent with predictions from the market microstructure models with asymmetric information across agents and the signaling hypothesis of foreign exchange interventions. Our findings indicate that the efficacy of intervention hinges not only on the firmness of signals but also on the degree of expectation heterogeneity among traders.

JEL classification: F31
Keywords: Foreign exchange intervention; Announcements; Expectation heterogeneity

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1. Introduction

The Bank of Japan (BOJ hereafter) intervened in the foreign exchange markets during the 1990s more actively than the U.S. Federal Reserve and the German Bundesbank. The total volume of BOJ interventions exceeded those by the Fed and the Bundesbank by more than a factor of 13 (Dominguez, 2003a). Although policy makers seem to view sterilized interventions as an additional policy tool beyond the usual mix of fiscal and monetary policy, the existing literature has failed to find a reliable connection between official transactions in foreign exchange markets and associated exchange rate movements. Using recently released Japanese intervention data, Ito (2003) shows that Japanese interventions produced the intended effects on the yen during the second half of the 1990s, but were not effective in the first half of the decade.

Overall, the empirical evidence on the effect of sterilized interventions on the level of exchange rates is rather mixed, attributable in part to different methodologies, different foreign exchange markets, different time-periods and different definitions of intervention success. Many researchers also consider the second moment of the exchange rate process and find that interventions typically increase exchange rate volatility. They often interpret such findings as evidence of a perverse or destabilizing effect of interventions.

Recent studies reconcile these seemingly contradictory findings by suggesting that central banks may at times possess private information about future fundamentals and target values of foreign currencies. Accordingly, interventions might reveal such information and, depending on prevailing market sentiments, influence market expectations and affect exchange rates (Baillie, Humpage and Osterberg, 2000). This "information signaling channel" (Fatum and Hutchison, 2002) can be seen as nesting the "classical signaling channel", through which interventions function as a signal of future monetary policy. This broad signaling channel can explain the increase in volatility following interventions as well, since volatility may be associated with transmission of information. Higher volatility is not necessarily incompatible with interventions having the desired effect on the level of the exchange rate (Humpage, 2003).[1]

[1] The 'portfolio-balance channel' and the 'signaling channel' are two traditional channels through

The current paper contributes to this strand of literature by exploring the market conditions under which intervention signals are likely to influence exchange rates. Specifically, we test the hypothesis that announced interventions can affect the level and reduce the volatility of exchange rates when traders' expectations of future exchange rates are heterogeneous. This holds if information asymmetry across traders leads to excess volatility and short-run deviations from the fundamental values of exchange rates. In addition, if an intervention signals unambiguous information about future market fundamentals, it can coordinate traders with asymmetric information and hence move the market rate back towards its fundamental value. We show that not only central bank signals but also heterogeneity in traders' expectations due to information asymmetry plays a key role in the literature's lack of robust evidence on the efficacy of intervention.

The empirical tests are conducted using Japanese and U.S. intervention data and the daily yen/dollar exchange rate. We also make use of news reports by Reuters and Bloomberg to distinguish among 'announced', 'unannounced but reported' and 'completely secret' interventions. The Japanese intervention strategy has not been consistent in terms of volume and frequency. As a matter of fact, Japan's intervention policy has changed frequently in accordance with who is in charge of foreign exchange interventions at the Ministry of Finance (MOF hereafter). These features of the Japanese interventions enable us to investigate the effect of intervention policy on exchange rates.

The results reveal that, even though we control for the volume effect, official announcements regarding interventions significantly affect the movements of exchange rates, supporting the signaling hypothesis. However, when this is divided into distinct phases, we find that announcements were quite effective only for the sub-sample period when former Vice Minister of Finance for International Affairs Eisuke Sakakibara, nicknamed "Mr. Yen" by the NY Times (Sep 16, 1995), was in charge. We then examine whether the effect of central bank signals is associated with market conditions. Indeed,

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which sterilized interventions can affect exchange rates. The former comes from the fact that the sterilized interventions change the composition of portfolios and thus the risk premium. There is a consensus, however, that this effect is empirically weak because intervention transactions are miniscule relative to the stock of outstanding assets. Thus, subsequent studies have emphasized the signaling hypothesis. (Mussa, 1981; Dominguez and Frankel, 1990) However, Lewis (1995), Kaminsky and Lewis (1996) and Fatum and Hutchison (1999) find that U.S. interventions have not conveyed a clear signal about future monetary policy actions.

announced interventions have a more significant influence on the level and reduce the volatility of exchange rates when implied volatility on the previous trading day is high. Given the high correlation between implied volatility and the dispersion of exchange rate expectations in the survey data, this suggests that the effectiveness of official interventions depends not only on the firmness of central bank signals but also on the heterogeneity of expectations among traders.

Recent studies on foreign exchange intervention have investigated the significance of the signaling hypothesis using news reports and yield mixed results on the efficacy of reported and secret interventions to date. Dominguez (1998) suggests that secret interventions generally increase volatility, while reported interventions sometimes reduce it. By contrast, Beine, Benassy-Quere and Lecourt (2002) show that secret interventions have almost no impact on volatility, but reported interventions clearly increase the volatility of exchange rates. In this paper, we make use of recently disclosed data on Japanese interventions. This allows us to obtain more precise estimates than previous papers were able to in the absence of official Japanese intervention data.

Some researchers have investigated whether the impact of interventions depends on market conditions. Using intra-daily data, Dominguez (2003a) 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 other central banks. She does not, however, consider the effect of trader heterogeneity. The most closely related paper to ours is Beine (2003). He estimates a Markov switching model to show that after the Louvre Agreement, when expected volatility was relatively high, central bank interventions in the DEM/USD market were not necessarily destabilizing. We take a different approach and estimate the effects of interventions on both the level and volatility of exchange rates.

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 contains our conclusions.

2. Theoretical background

The exchange rate literature has been confronted with three challenging findings. First, since the seminal work by Messe and Rogoff (1983), it has been generally accepted that all the standard macro models of exchange rate determination are empirically unsuccessful. Second, a substantial number of studies find that technical trading rules, including *ex ante* rules, can generate excess profits in spot exchange rates, suggesting the existence of asymmetric information across traders (LeBaron, 1999; Neeley and Weller, 2001). Third, Evans and Lyons (2001) show that most short-run exchange rate volatility is related to order flow, which in turn is associated with investor heterogeneity. These findings have increased interest in the role of information in the microstructure of foreign exchange markets, and it seems useful to view recent work on interventions within this framework.

Grossman and Stiglitz (1980) argue that if information is costly, then market participants either will not have full information or will not completely understand its implications, and market exchange rates cannot continuously reflect all available information about their future distributions. Exchange rates will reflect information up to the point where the marginal benefit from acquiring and trading information equals the marginal cost.

In an extreme case of imperfect information, when a substantial portion of market participants base trades on extrapolations of past exchange-rate movements, exchange rates might remain misaligned from their fundamental values, even when the more informed traders feel that the current exchange rates are inappropriate. The chartists and fundamentalists model originally proposed by Frankel and Froot (1986) has been frequently utilized both theoretically and empirically. De Grauwe and Grimaldi (2005) show that this model is capable of reproducing the empirical puzzles of exchange rates such as the disconnect puzzle, excess volatility, fat tails and volatility clustering. Survey evidence also suggests that technical trading is widely used as a guide to short-term exchange rate behavior when traders form their expectations (Taylor and Allen, 1992; Cheung and Chinn, 2001).

The recent exchange rate microstructure model developed by Baccheta and van Wincoop (2003) introduces trader heterogeneity, based on differences in the possession

of information or the interpretation of information, into an otherwise standard monetary model of exchange rate determination. They demonstrate that information dispersion leads to magnification and endogenous persistence of the impact of non-fundamental trades on exchange rates.

In such a market characterized by information asymmetries, a monetary authority with an information advantage regarding prospective market fundamentals could influence exchange rates if the authority conveys private information to the market through its intervention. A monetary authority typically maintains ongoing relationships with a select group of major banks (domestic and foreign) and uses these banks as counterparties for their foreign exchange transactions. In exchange for exclusivity, these dealers inform the monetary authorities about the conditions of foreign exchange markets, perceived reasons for market movements and the dealer's customer order flows. These operations indicate that the monetary authorities gather information from a group of dealers and use it in making intervention decisions.[2]

Interventions are especially effective if they can coordinate traders with asymmetric information and push the current market rate towards its fundamental value. Popper and Montgomery (2001) emphasize the information sharing role of interventions. Since uninformed foreign exchange dealers can benefit from the monetary authority's information on future fundamentals, intervention can influence exchange rates by transmitting such information and reducing information asymmetries among market participants.

The above argument provides some testable implications. Firstly, interventions are more effective when market participants have heterogeneous information and the information asymmetry has pulled the exchange rate away from its fundamental value. Secondly, to effectively transmit credible information to the market, interventions should be unambiguous and easy to understand for the market.

Given that interventions operate through a signaling channel, it would seem that monetary authorities would declare their intentions and actions with as much publicity as possible. Yet, there are many recorded instances in which interventions are undertaken

[2] Bhattacharya and Weller (1997) and Vitale (1999) present theoretical models in which central banks maintain an information advantage and disseminate it to the market.

under the cloak of secrecy. While there are some compelling reasons for the secrecy of interventions, research has not yet reached a consensus on the importance of secrecy (Dominguez and Frankel, 1993; Hung, 1997; Bhattacharya and Weller, 1997; Vitale, 1999; Chiu, 2003).

Thus, we test the following hypotheses:

Hypothesis 1 (Signaling hypothesis)

Officially announced interventions have larger effects on exchange rate than unannounced interventions.

Hypothesis 2 (Heterogeneity hypothesis)

The signaling effect is more significant when traders have heterogeneous expectations of exchange rates.

3. Data

3.1. Japanese interventions classified by newswire reports

We classify interventions into three categories using news reports provided by Bloomberg and Reuters. 'Announced interventions' are those accompanied by official statements from government officials on the intervention day. The government officials may include the Minister of Finance, the Vice Minister of Finance for International Affairs, the Director General of the International Bureau and the Governor of the BOJ. They often confirm interventions by publicly stating that the BOJ intervened in the market. Then the statements are broadcast within few minutes by newswires along with the name of the official making the announcement. 'Unannounced but reported interventions' are reported by newswires but without any corresponding official statements. Newswire reports sometimes quote traders as saying, "[s]ome traders said that the BOJ intervened in the market at around 115 yen during the morning session" or "[t]he BOJ apparently bought dollars against yen." 'Secret interventions' are not reported by the newswires, but do actually take place.

Figure 1 displays monthly time-series evidence on the yen/dollar exchange rate and the size of Japanese interventions from May 13, 1991 to May 27, 2004. There are neither interventions for dollar sales above the rate of 125 yen/dollars nor dollar purchases below 125 yen/dollar.

The classification of interventions is shown in Figure 2. During the sample period, there are 343 intervention days for the yen/dollar rate (10.1% of the sample). Among the intervention days, 208 (60.6%) are correctly reported by newswires, while 135 (39.6%) are not reported but have actually taken place (secret interventions). 12.8% of the intervention days are announced by government officials (announced interventions) and 47.8% are not announced but are reported by newswires (unannounced interventions).

The disclosed intervention data indicates the daily size of interventions. Table 1 shows the relationships between intervention policy and intervention volume. The number of days for large-sized interventions (more than 500 billion yen a day) is 38 (11.1%). The breakdown is 14 days of announced interventions, 16 days of unannounced but reported interventions and eight days of secret interventions. On the other hand, the number of small-sized intervention days (less than 50 billion yen per day) is 133 (36.5%). They have six days of announced interventions, 73 days of unannounced but reported interventions and 54 days of secret interventions. In general, the share of announced interventions increases with their size.

3.2. Changes in intervention policy

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 and increase the size of interventions (Sakakibara, 2002). Accordingly, some studies on Japanese interventions divide their sample period into pre and post June 1995 (Ito, 2003). The intervention policy also changed after his resignation, especially in terms of making official announcements about interventions. Hence, we divide our sample period into four sub-periods according to who is the Vice Minister of Finance for International Affairs of the MOF at the time, as he has the most influence on Japanese intervention decisions.[3] 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

[3] The MOF determines the volume and timing of interventions and the BOJ, which receives the order from the MOF, executes the intervention in the foreign exchange market. The decision makers for intervention are limited to the Minister of Finance, the Vice Minister and Deputy Vice Minister of Finance for International Affairs, the Director General of the International Bureau and the Director of the foreign Exchange Market Division. (Sakakibara, 2002)

(1/14/2003 - 5/27/2004). Intervention techniques are quite different depending on the person who actually decides on the intervention.

Table 2 shows the average size and intervention types for the 4 sub-periods. Period 1 is characterized by frequent, small interventions. In this period, frequency is the highest among 4 sub-periods (averaging an intervention every 4.77 days) and the average size of an intervention was 47 billion yen, which is the smallest among four sub-periods. There are 18 days of coordinated interventions with the Federal Reserve Bank of NY in period 1. During period 1, only 6.1% of interventions are announced, while more than 70% are unannounced but reported interventions.

In period 2, when Dr. Sakakibara was in charge of interventions, he reduced the intervention frequency (averaging 39.83 days between interventions), while increasing the average size of interventions (510 billion yen per day). The ratio of both 'officially announced' and 'unannounced but reported' interventions was high (91.6%). In addition, half of the announced interventions in period 2 were accompanied by Federal Reserve Bank of NY interventions.

In period 3 the trend of infrequent but large interventions continued. There were only 25 intervention days (averaging 36.72 days per intervention) and the average size of an intervention was approximately 530 billion yen, which is the largest among the four sub-periods. It is remarkable that all of the interventions in period 3 were announced.

In period 4 the intervention policy changed dramatically, from being infrequent and large to frequent and medium-sized. The frequency of interventions in period 4 increased to an average of an intervention every 2.78 business days. Another big change was the very high ratio of secret interventions, which made up 74.4% of all interventions in this period. After Mr. Mizoguchi was appointed as Vice Minister of Finance for International Affairs, government officials declined to make comments or give any interviews. Instead of announcing interventions as they occurred, the MOF started to reveal the monthly volume of interventions at the end of each month and the size of the interventions every three months. In response to the change in the intervention strategy, newswire reports turned to vague statements such as "market participants are keeping watch for a possible intervention" and "[t]he BOJ seemed to be active in the market."

4. Empirical methodology

The usually considered primary objectives of exchange rate interventions are directing trends in exchange rate movements and calming disorderly markets.[4] These motivations suggest that central banks aim to influence not only exchange rate values, but also exchange rate volatility. There are broadly two types of exchange rate volatility that one might address with interventions: GARCH volatility and expected volatility as implied by option prices on exchange rate futures. We choose the latter because the effect of interventions on market expectations seems more compatible with the signaling hypothesis.[5] Furthermore, the use of a GARCH model to estimate the effect of interventions on exchange rate volatility has been recently questioned. Since shocks to exchange rate volatility are highly persistent ("volatility clustering"), incorporating intervention variables into the GARCH specification is equivalent to assuming that the effects of interventions are also persistent. If the effects are transitory, this framework is not valid (Watanabe and Harada, 2005). In addition, having only a small number of classified interventions makes it difficult to estimate the volatility equation of the GARCH model especially when we include the interaction term between the intervention dummy and the expectation heterogeneity variable.

To analyze the effect of interventions on exchange rates, 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. We would judge that an intervention is effective in controlling the exchange rate if it significantly affects daily returns in the appropriate direction.

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[4] The other reasons for interventions include rebalancing central banks' reserve holdings and supporting fellow central banks in their exchange rate operations. Of the four listed reasons, only portfolio rebalancing does not involve a desired change in the level or volatility of exchange rates. Since monetary authorities rarely provide traders with information regarding their specific goals for particular intervention operations, we assume that relatively few interventions take place for the sole purpose of portfolio rebalancing.

[5] Another drawback of using implied volatility computed from currency option prices is that the results may be sensitive to assumptions about risk neutrality.

We test the effect of interventions on the changes of exchange rates using equation (1).

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

where $r_t = 100 \ln(S_t / S_{t-1})$ is the logarithmic return of the spot exchange rate (expressed as a percentage) with S_t the being yen/dollar rate (NY close).[6] X_t denotes a vector of independent variables related to the Japanese and the U.S. interventions as well as macro variables which may affect exchange rates.

Following Bonser-Neal and Tanner (1996) and Dominguez (1998), the volatility equation is specified as follows:

$$
iv_t = a' Y_t + b' Z_{t-1} + \varepsilon_t \tag{2}
$$

where $iv_t = 100 \ln(IV_t / IV_{t-1})$ is the logarithmic return of the implied volatility (expressed as a percentage) with IV_t the implied volatility estimate derived from at-the-money option prices (one- and three-month) on the spot yen/dollar rates from the Tokyo market (5 PM). Because market participants cannot know the Fed's intervention (with certainty) at 5 PM (Tokyo time) on the same day, the variables related to the Fed's intervention are lagged by one day. These form Z_t. The variables concerning the Japanese interventions and macro variables are included in Y_t. It should be noted that all variables in the volatility equation are taken to be the absolute values of those in the level equation.

Existing empirical research testing the signaling hypothesis using news reports typically splits interventions into reported interventions and secret interventions and analyzes the significance of the coefficients for the volume of each type of intervention (Dominguez, 1998; Beine, Benassy-Quere and Lecourt, 2002). The alternative way of

[6] As explained by Ito (2003), the disclosed Japanese intervention volume is the result of interventions in the Tokyo, Europe, and U.S. 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 exchange rate changes due to interventions on a particular day can be measured by the change in the NY closing rate across consecutive days.

analyzing the difference in the effectiveness of intervention strategies is to use intercept dummies representing intervention strategies as independent variables independent of intervention volume.

Although market traders do not know the exact intervention volumes on intervention days, they can guess the approximate sizes based on market rumors and trading activity, especially when large-scale interventions are carried out. As intervention volume increases, these can function as signals from central banks to the market. This contradicts the view of shifting slopes because the difference between announced and unannounced interventions lessens as intervention volume increases. Although using intercept dummies seems preferable to shifting slopes, we would leave the choice of model specification to empirical tests. Accordingly, we estimate the model incorporating both slope and intercept dummies and test which specification is more appropriate.

Three dummies are considered in the estimation equations for announced interventions, unannounced but reported interventions and secret interventions for Japan and the U.S. (There were no secret interventions by the U.S.) Dummies take a value of +1 if such an intervention strategy is carried out for dollar purchases (yen sales), -1 for yen purchases (dollar sales) and zero otherwise. The intervention volume variable is also signed with + (dollar purchases) and – (yen purchases). If dollar purchase interventions by the U.S. and Japanese monetary authorities tend to cause the dollar to appreciate and the yen to depreciate, the coefficients would be expected to be positive.

When shifting slopes, one multiplies the intervention dummies and volumes with signs in accordance to purchases and sales of foreign currencies and use these as the independent variables. As suggested by Dominguez (1998), we also include the interest rate differential between the Japanese and U.S. overnight money market rates in the level equation in order to account for relative contemporaneous monetary policies in both countries.[7]

For the volatility equation, a holiday dummy is included which takes a value of 1 if the previous day is a holiday and 0 otherwise, following Dominguez (1998). Since variables related to interventions are all taken as absolute values, we would expect

[7] The overnight market rates are the Federal Funds rate for the U.S. and the call rate for Japan.

negative signs for the coefficients if interventions were effective in reducing expected volatility.

The problem of simultaneity has been frequently raised in the empirical research on interventions. If official intervention and exchange rate changes are simultaneously determined, interventions are not exogenous to current market conditions and may yield inconsistent and biased estimates. However, Goodhart and Hesse (1989) and Almekinders (1995) suggest that it takes at least two days for central banks to begin intervening in the foreign exchange market in response to excessively volatile spot exchange rates and deviations from target levels because of institutional features of monetary authority decision making processes. We assume that interventions are exogenous to spot exchange rate behavior on intervention days.

5. Estimation results

5.1. Is signaling effective?

The first hypothesis to test is the signaling hypothesis. Specifically, we examine whether officially announced interventions have a larger effect on exchange rates than secret interventions.

Table 3 presents the results of the estimations on the full sample period, one of which incorporates intercept dummies and differentiated slopes for announced, unannounced but reported, and secret interventions by the U.S. and Japanese monetary authorities. The Wald tests below show that the coefficients of slopes for the classified interventions are not significantly different from each other, while the intercept dummies are significantly different. This suggests that the intercept dummy model is preferable, as suggested in the previous section.

On the right hand side of the estimation results for the full sample period, the coefficient of the Japanese announced interventions dummy is significantly positive, while the coefficients of the Japanese unannounced but reported interventions dummy and the secret interventions dummy are significantly negative. The negative sign on the coefficient of unannounced interventions does not necessarily imply that interventions without official announcements cannot influence exchange rates. Taking into account the

volume effect, such strategies can be effective although their efficacy is significantly less than that of announced interventions.

During the sample period, whenever the U.S. authorities intervened, the Japanese authorities intervened on the same day. There were no unilateral U.S. interventions, while there were many by the Japanese authorities. Hence, the U.S. intervention dummy captures the impact of coordinated interventions between the U.S. and Japan. On the other hand, the Japanese intervention dummies represent the Japanese unilateral intervention effect because we take into account the effect of coordinated interventions.

Both announced and unannounced but reported U.S. interventions are significantly effective, conditional on the volume of the intervention. On the other hand, the intervention volume does not affect exchange rates if we control for the intervention dummies. For the U.S. monetary authorities, it is whether the intervention is announced and/or reported that has a significant influence on exchange rates, not the size of the intervention.

The regression results for 4 sub-sample periods are presented in Table 4. The interesting result is that the coefficient of the dummy for secret interventions is significant and negative in period 1, while that of the dummy for announcement is significantly positive in period 2. This sharp contrast suggests that Dr. Sakakibara's policy change in favor of official announcements might lead to more successful interventions. The evidence that the signaling effect is effective only in period 2 and not in other sub-sample periods is consistent with previous studies showing that signaling effects have ambiguous empirical support.

The main result from Table 4 is that announcement effects are significant only in period 2. Official announcements alone do not necessarily guarantee the success of an intervention. A natural question arises: why did Dr. Sakakibara's announcements succeed in period 2?

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

The next hypothesis to test is the heterogeneity hypothesis. We examine whether the announcement of interventions has a stronger influence when traders have heterogeneous expectations of exchange rates. In order to test this hypothesis, one

includes the interaction term between the announced intervention dummy and a variable representing the expectation heterogeneity of future exchange rates among traders. However, survey data on exchange rate forecasts are not available on a daily basis. Thus we need to find a proxy for the dispersion of exchange rate expectations across traders.

Recent research on market microstructure presents theories for explaining volatility and trading volume in connection with the concentration of information in the market (Admati and Pfleiderer, 1988). Using survey data on exchange rate forecasts, there is an increasing amount of evidence supporting these theories. They find that expectation heterogeneity leads to an increase in trading volume and exchange rate volatility, while volatility increases expectation heterogeneity (Chionis and MacDonald, 1997; Frankel and Froot, 1990). Following these studies, we use implied volatility and trading volume to test whether they are good proxies for expectation heterogeneity among traders.

To measure traders' expectation heterogeneity, we use survey data collected by the Japan Center for International Finance (JCIF) in Tokyo, Japan.[8] Since May 1985, the JCIF has been conducting telephone surveys twice a month, on the second and last Wednesdays. Point forecasts of the yen/dollar exchange rate for the one-, three- and six-month horizons are obtained from foreign exchange experts in forty-four companies.[9] The JCIF calculates the average, the standard deviation, the maximum and the minimum for the responses. Of these, we use the standard deviation and the coefficient of variation (the standard deviation divided by the sample mean forecasts).

We use the trading volume of all active brokered interdealer yen/dollar spot exchange trades on the Tokyo foreign exchange market, as collected by the Nikkei. This is the only available source of daily spot currency market trading volume data over our sample period. Daily trading volume has a moderate upward-trend over the sample period. In addition, the share of brokered interdealer trades may have increased since an electronic broking system was introduced in 1993, although there is no discontinuity in the data around the time of its introduction. To address these issues, we create the

[8] For the details of the data, see Ito (1990).

[9] These companies are 15 banks and brokers, four securities companies, six trading companies, nine export-oriented companies, five life insurance companies and five import-oriented companies.

following volume variable, following Chaboud and LeBaron (1999). The variable is the ratio of today's trading volume to a sum of the previous 30, 50 and 100 trading volumes.

$$Trading\ volume\ variable_t = vol_t \Big/ \sum_{s=1}^{i} vol_{t-s}, \quad i = 30,50,100$$

The exchange rate forecast survey data is provided on a bimonthly basis, while implied volatility and trading volume data are provided on a daily basis. We then collect bimonthly data for implied volatility and trading volumes corresponding to exchange rate forecasts. The correlation coefficients are presented in Table 7. The standard deviation of forecasts is highly correlated with implied volatility (0.6～0.7), while the correlation between the heterogeneity of expectations and the trading volume variable is low (0.1～0.2). This result is robust if we use the standard deviation of heterogeneity measures divided by the sample mean (the coefficient of variation). Therefore, we make use of implied volatility as a proxy for the heterogeneity of exchange rate expectations among traders.

Tables 6 and 7 report the results of whether the effects of official interventions on the level and the volatility of exchange rates depend on expectation heterogeneity. The independent variables include the interaction terms between the intervention dummies and implied volatility (one- and three-month). To prevent a simultaneity problem, the interaction terms consist of the one period lagged values of implied volatility. Since implied volatility is highly persistent, the one period lag is a proxy for the implied volatility just before an intervention.

In the first column of Table 6 (results for the whole sample period), the result of the estimation with one-month implied volatility is displayed. The coefficient of the interaction term between the Japanese announcement dummy and the lagged implied volatility is positive and significant, while that of the Japanese announced dummy is significantly negative. This suggests that the announcement effects have a non-linear relationship with exchange rate changes, which depends on implied volatility. Based on these coefficients, we can state that official announcements influence exchange rates if the lagged implied volatility is greater than 11.347%. Furthermore, the significantly positive coefficient of the interaction term between the Japanese intervention volume and the lagged implied volatility shows that large-scale interventions are effective when the

lagged implied volatility is sufficiently high (more than 11%). By contrast, keeping interventions secret (both the unannounced but reported interventions and the secret interventions) has no significant impact on the exchange rates themselves. The results in the period 2 shows that lagged implied volatility of more than 10.187% is required for announced interventions to be effective. When implied volatility on the last trading day is sufficiently high, the effect of official announcements on exchange rate is significant. This result is robust even when we use the three-month implied volatility presented at the bottom of Table 6.

Table 7 shows the effect of interventions on the volatility of exchange rates. Like Table 6, there is a non-linear relationship between interventions and official announcements which depends on the implied volatility. The result for the whole sample period suggests that when the lagged implied volatility is more than 13.986%, official announcements can reduce volatility because the interaction term has a negative coefficient. However, the coefficient of the interaction term between intervention volume and the lagged implied volatility is significantly positive, mitigating the effect on volatility. We then consider both volume effect and announcement effect simultaneously. For example, suppose the intervention volume is 200 billion yen (the average for the whole sample period). We find that a lagged implied volatility of more than 15.119% is needed for an announced intervention to reduce the volatility of exchange rates. This indicates that lagged implied volatility, serving as a proxy for expectation heterogeneity, is an important factor in the efficacy of interventions on both the level and volatility of exchange rates.

6. Conclusion

This paper contributes to the central bank intervention literature by showing that the effectiveness of official interventions in the foreign exchange market depends not only on the firmness of signals but also on the heterogeneity of expectations across agents. Consistent with previous studies, intervention announcements do not always affect exchange rates. Once expectation heterogeneity is considered, however, the effectiveness of announcing interventions improves significantly. These findings are explained by

market microstructure theories in addition to the signaling channel of foreign exchange interventions.

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Table 1. Intervention policy and volume (5/13/1991-5/27/2004)

Intervention volume (100 million yen)	No. of days	Announced interventions	Unannounced but reported interventions	Secret interventions
1～499	133	6	73	54
	100.0%	4.5%	54.9%	40.6%
500～999	64	4	40	20
	100.0%	6.2%	62.5%	31.3%
1000～1999	48	7	14	27
	100.0%	14.6%	29.2%	56.2%
2000～4999	60	13	21	26
	100.0%	21.7%	35.0%	43.3%
5000～26201	38	14	16	8
	100.0%	36.8%	42.1%	21.1%
Total	343	44	164	135
	100.0%	12.8%	47.8%	39.4%

Source: the Ministry of Finance of Japan, Bloomberg and Reuters.

Table 2. Intervention policy in Japan and the US

Period	JP Interventions				US Interventions			
	No. of days	Announced interventions	Unannounced but reported interventions	Secret interventions	No. of days	Announced interventions	Unannounced but reported interventions	Secret interventions
＜Full sample period : 3119days＞								
5/13/1991-5/27/2004	343	44	164	135	22	11	11	0
		12.8%	47.8%	39.4%		50.0%	50.0%	0.0%
Average volume of interventions per day (JPY 100 million/USD 1million)	1991	4225	1735	1573	358	398	318	0
＜Period 1 : 787days＞								
5/13/1991-6/20/1995	165	10	118	37	18	7	11	0
		6.1%	71.5%	22.4%		38.9%	61.1%	0.0%
Average volume of interventions per day (JPY 100 million/USD 1million)	470	642	514	281	328	344	318	0
＜Period 2 : 956days＞								
6/21/1995-7/7/1999	24	8	14	2	4	4	0	0
		33.3%	58.3%	8.3%		100.0%	0.0%	0.0%
Average volume of interventions per day (JPY 100 million/USD 1million)	5105	4598	6025	683	492	492	0	0
＜Period 3 : 918days＞								
7/8/1999-1/13/2003	25	25	0	0	0	0	0	0
		100.0%	0.0%	0.0%				
Average volume of interventions per day (JPY 100 million/USD 1million)	5282	5282	0	0	0	0	0	0
＜Period 4 : 358days＞								
1/14/2003-5/27/2004	129	1	32	96	0	0	0	0
		0.8%	24.8%	74.4%				
Average volume of interventions per day (JPY 100 million/USD 1million)	2719	10667	4359	2090	0	0	0	0

Source: The Ministry of Finance of Japan, Quarterly Review of Federal Reserve Bank of NY, Bloomberg and Reuters.
Note. The US interventions during the sample period were all coordinated with the Japan.

Table 3. Signaling effects of interventions (full sample period)

＜Dependet variable: % change in exchange rate＞	Full sample period			
Method: GARCH-ML	5/13/1991-5/27/2004			
＜Independent variables＞	Estimates	(Standard error)	Estimates	(Standard error)
Mean Equation				
Constant	-0.02841 *	(0.01686)	-0.02908 *	(0.01681)
Interest rate differential	-0.01029 **	(0.00444)	-0.01023 **	(0.00441)
(a) JP announced intervention dummy	0.20622 *	(0.11830)	0.16964 *	(0.10284)
(b) JP unannounced but reported intervention dummy	-0.27716 ***	(0.05577)	-0.23575 ***	(0.05291)
(c) JP secret intervention dummy	-0.08170	(0.07398)	-0.16268 ***	(0.06227)
(d) US announced intervention dummy	0.27741	(0.32715)	0.88021 ***	(0.23395)
(e) US unannounced but reported intervention dummy	1.21369 ***	(0.16220)	0.82522 ***	(0.12386)
JP intervention volume			0.00006 ***	(0.00001)
US intervention volume			0.00028	(0.00036)
(f) JP intervention volume * JP announced intervention dummy	0.00006 **	(0.00003)		
(g) JP intervention volume * JP unannounced but reported intervention dummy	0.00008 ***	(0.00001)		
(h) JP intervention volume * JP secret intervention dummy	0.00002	(0.00003)		
(i) US intervention volume * US announced intervention dummy	0.00186 ***	(0.00052)		
(j) US intervention volume * US unannounced but reported intervention dummy	-0.00079	(0.00051)		
Varivance Equation				
Constant	0.00847 ***	(0.00125)	0.00847 ***	(0.00124)
ARCH(1)	0.04183 ***	(0.00339)	0.04225 ***	(0.00340)
GARCH(1)	0.94122 ***	(0.00504)	0.94093 ***	(0.00498)
Log likelihood	-3441.867		-3447.455	
Obs.	3404		3404	

Wald tests on the coefficients	Statistic	P-value
JP intervention dummies H0: (a)=(b)=(c)	11.88 ***	0.0026
US intervention dummies H0: (d)=(e)	6.72 ***	0.0095
JP dummies with volume H0: (f)=(g)=(h)	3.49	0.1742
US dummies with volume H0: (i)=(j)	13.79 ***	0.0002

Note. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

Table 4. Signaling effects of interventions (4 sub-periods)

＜Dependent variable: % change in exchange rate＞	Period 1		Period 2		Period 3		Period 4	
Method: GARCH-ML	5/13/1991-6/20/1995		6/21/1995-7/7/1999		7/8/1999-1/13/2003		1/14/2003-5/27/2004	
＜Independent variables＞								
Mean Equation								
Constant	-0.02287	(0.02088)	-0.08063	(0.31185)	-0.03560	(0.05211)	-0.35502	(0.25780)
Interest rate differential	-0.00464	(0.01149)	-0.02597	(0.06303)	-0.00702	(0.01146)	-0.29332	(0.23486)
JP intervention volume	-0.00034 ***	(0.00010)	0.00008 **	(0.00004)	0.00007 **	(0.00003)	0.00005 ***	(0.00002)
US intervention volume	-0.00051	(0.00052)	0.00363	(0.00341)				
JP announced intervention dummy	0.71887	(2.20465)	0.98002 ***	(0.22459)	0.00146	(0.21008)	0.13401	(1410422.0)
JP unannounced but reported intervention dummy	-0.13588 *	(0.07932)	-0.21027	(0.24231)			-0.07833	(0.12260)
JP secret intervention dummy	-0.04024	(0.12817)	0.61182	(0.96955)			-0.12982 *	(0.07849)
US announced intervention dummy	-0.19043	(2.24582)	0.24045	(1.24923)				
US unannounced but reported intervention dummy	1.21644 ***	(0.16579)						
Varivance Equation								
Constant	0.01458 ***	(0.00314)	0.00867 ***	(0.00269)	0.78552 ***	(0.03472)	0.06685 **	(0.02742)
ARCH(1)	0.04485 ***	(0.00625)	0.06651 ***	(0.00846)	0.01408	(0.00895)	0.14402 ***	(0.04131)
GARCH(1)	0.92437 ***	(0.00998)	0.92195 ***	(0.01052)	0.92162 ***	(0.06338)	0.63744 ***	(0.11435)
Log likelihood	-1062.058		-1161.028		-890.183		-283.995	
Obs.	1072		1056		918		358	

1. Standard errors 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. Correlation Coefficients

	Implied volatility(1M)	Implied volatility(3M)	Trading volume variable (30days)	Trading volume variable (50days)	Trading volume variable (100days)
S.d. of forecasts (1M)	0.6687 ***		0.1552 ***	0.1607 ***	0.1712 ***
S.d. of forecasts (3M)		0.5813 ***	0.1545 **	0.1202 **	0.1418 **
Coefficient of variation (1M)	0.7045 ***		0.2040 ***	0.1694 ***	0.1604 ***
Coefficient of variation (3M)		0.6434 ***	0.1844 ***	0.1350 **	0.1358 **

1. The s.d. of forecasts is the standard deviation of foreign exchange forecasts and the coefficient of variation is the standard deviation devided by the sample mean of forecasts.

2. The trading volume variables are the % ratios of spot trading volumes on intervention days in the Tokyo market to the sum of trading volume from 30, 50, and 100 days prior to the intervention day to 1day, respectively.

3. The implied volatility is calculated from yen/dollar option price (at the money).

4. *,** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

Table 6. Impact on the level of exchange rates

＜Dependent variable： % change in exchange rate＞	Full sample period		Period 1		Period 2		Period 3		Period 4	
Method：GARCH-ML	5/13/1991-5/27/2004		5/13/1991-6/20/1995		6/21/1995-7/7/1999		7/8/1999-1/13/2003		1/14/2003-5/27/2004	
＜Independent variables＞										
Mean Equation										
Constant	-0.02631	(0.04994)	-0.25873 **	(0.12318)	-0.11425	(0.30864)	-0.04228	(0.10372)	-0.29945	(0.36541)
Interest rate differential	-0.00967 **	(0.00490)	0.00216	(0.01218)	-0.04234	(0.06250)	-0.00556	(0.01329)	-0.30890	(0.23609)
JP intervention volume	-0.00003	(0.00005)	0.00021	(0.00060)	-0.00025	(0.00034)	-0.00034	(0.00031)	-0.00007	(0.00023)
US intervention volume	-0.00011	(0.00036)	-0.00074	(0.00051)	-0.00082	(0.00476)				
JP announced intervention dummy	-1.57181 ***	(0.50811)	-2.97095	(1.92571)	-4.61717	(3.18750)	1.95604	(1.99689)		
JP unannounced but reported intervention dummy	-0.08796	(0.20888)	-0.14556	(0.36894)	-0.38956	(2.20585)			0.66116	(1.01010)
JP secret intervention dummy	-0.00271	(0.36922)	0.10749	(0.68229)	-8.52430	(1498.27)			0.35933	(0.70338)
US intervention dummy	0.95277 ***	(0.13555)	1.14824 ***	(0.16245)	2.05673	(1.83969)				
IV1M(-1)	0.00003	(0.00503)	0.02493 *	(0.01277)	-0.00374	(0.00639)	0.00115	(0.01039)	-0.00791	(0.02601)
JP intervention volume * IV1M(-1)	0.00001 **	(0.00000)	-0.00005	(0.00004)	0.00003	(0.00003)	0.00003	(0.00002)	0.00001	(0.00002)
JP announced intervention dummy * IV1M(-1)	0.13852 ***	(0.03957)	0.21583	(0.13807)	0.45325 *	(0.23692)	-0.15397	(0.15457)	-0.01403	(63804.6)
JP unannounced but reported intervention dummy * IV1M(-1)	-0.01397	(0.01860)	-0.00108	(0.03034)	0.01095	(0.16304)			-0.07934	(0.11188)
JP secret intervention dummy * IV1M(-1)	-0.01526	(0.03887)	-0.01818	(0.06406)	0.67754	(107.399)			-0.05289	(0.07559)
Varivance Equation										
Constant	0.00852 ***	(0.00127)	0.01498 ***	(0.00322)	0.01041 ***	(0.00310)	0.78111 ***	(0.03530)	0.06853 **	(0.02890)
ARCH(1)	0.04241 ***	(0.00351)	0.04620 ***	(0.00696)	0.07447 ***	(0.00981)	0.01603 *	(0.00953)	0.13984 ***	(0.04316)
GARCH(1)	0.94056 ***	(0.00518)	0.92209 ***	(0.01042)	0.91115 ***	(0.01231)	0.91099 ***	(0.06622)	0.63400 ***	(0.12073)
Log likelihood	-3440.337		-1060.802		-1151.408		-889.090		-283.304	
Obs.	3404		1072		1056		918		358	
＜Independent variables＞										
Mean Equation										
Constant	-0.03923	(0.06079)	-0.50221 ***	(0.19141)	-0.09809	(0.31079)	-0.06723	(0.13341)	-0.32266	(0.46624)
Interest rate differential	-0.00894 *	(0.00518)	0.01305	(0.01335)	-0.04063	(0.06233)	-0.00269	(0.01525)	-0.31468	(0.23686)
JP intervention volume	-0.00004	(0.00006)	0.00002	(0.00078)	-0.00010	(0.00049)	-0.00033	(0.00033)	-0.00010	(0.00030)
US intervention volume	-0.00018	(0.00036)	-0.00069	(0.00048)	-0.00013	(0.01522)				
JP announced intervention dummy	-2.33257 ***	(0.59075)	-3.79772	(3.17507)	-7.21467 *	(4.10557)	1.32081	(2.21997)		
JP unannounced but reported intervention dummy	0.00580	(0.28845)	0.10305	(0.51123)	-2.31101	(3.34916)			1.15995	(1.44807)
JP secret intervention dummy	-0.01553	(0.42226)	0.42541	(0.97802)	-7.15537	(423.179)			0.62308	(0.99393)
US intervention dummy	0.94631 ***	(0.13360)	1.15783 ***	(0.15861)	1.42588	(4.85990)				
IV3M(-1)	0.00147	(0.00608)	0.04841 **	(0.01919)	-0.00424	(0.00729)	0.00442	(0.01439)	-0.00605	(0.04103)
JP intervention volume * IV3M(-1)	0.00001 *	(0.00001)	-0.00003	(0.00006)	0.00001	(0.00004)	0.00003	(0.00003)	0.00002	(0.00003)
JP announced intervention dummy * IV3M(-1)	0.20538 ***	(0.04695)	0.28650	(0.24277)	0.64898 **	(0.30666)	-0.10151	(0.17698)	-0.00497	(6240.25)
JP unannounced but reported intervention dummy * IV3M(-1)	-0.02278	(0.02623)	-0.02304	(0.04354)	0.16009	(0.25207)			-0.13292	(0.16298)
JP secret intervention dummy * IV3M(-1)	-0.01360	(0.04433)	-0.04840	(0.09143)	0.56456	(30.5099)			-0.08156	(0.10739)
Varivance Equation										
Constant	0.00861 ***	(0.00127)	0.01508 ***	(0.00327)	0.01045 ***	(0.00310)	0.78313 ***	(0.03374)	0.06891 **	(0.02938)
ARCH(1)	0.04288 ***	(0.00349)	0.04601 ***	(0.00669)	0.07433 ***	(0.00979)	0.01470 *	(0.00872)	0.13952 ***	(0.04406)
GARCH(1)	0.93988 ***	(0.00516)	0.92190 ***	(0.01021)	0.91121 ***	(0.01231)	0.92136 ***	(0.06032)	0.63284 ***	(0.12286)
Log likelihood	-3463.860		-1059.322		-1151.355		-888.501		-283.249	
Obs.	3404		1072		1056		918		358	

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

2. The implied volatilities are calculated from the 1month and 3month yen/dollar option prices (at the money).

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

4. Announced intervention dummy is dropped in Period 4 due to collinearity since Period 4 had only one announced intervention.

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

Table 7. Impact on the implied volatility of exchange rates

＜Dependent variable： % change in implied volatility (1Month) ＞ Method：OLS (White(1980)'s robust standard error)	Whole sample period 5/13/1991-5/27/2004	Period 1 5/13/1991-6/20/1995	Period 2 6/21/1995-7/7/1999	Period 3 7/8/1999-1/13/2003	Period 4 1/14/2003-5/27/2004
＜Independent variables＞					
Constant	1.60325 *** (0.58613)	2.78583 *** (0.88959)	1.50555 (1.02865)	3.41512 *** (1.02003)	5.92218 (3.86109)
Holiday dummy	1.67066 *** (0.22027)	2.10783 *** (0.43275)	1.12039 *** (0.40584)	1.59795 *** (0.34845)	2.19670 *** (0.68378)
IV1M (-1)	-0.19584 *** (0.05391)	-0.35538 *** (0.08861)	-0.15448 * (0.08414)	-0.36101 *** (0.09580)	-0.67275 (0.41184)
JP intervention volume	-0.00123 ** (0.00053)	0.02015 ** (0.00809)	-0.00107 (0.00236)	0.00184 (0.00202)	-0.00067 (0.00147)
US intervention volume(-1)	-0.00536 (0.00736)	-0.00844 (0.00710)	-0.02343 (0.02023)		
JP announced intervention dummy	18.29030 *** (6.02462)	9.89727 (9.83324)	15.70027 (13.30194)	-1.28443 (12.54632)	
JP unannounced but reported intervention dummy	6.21695 ** (2.52241)	-2.56888 (4.57857)	12.69043 (14.05274)		-0.07677 (7.85854)
JP secret intervention dummy	1.80667 (2.13406)	-1.76348 (3.98475)	19.76964 *** (2.57810)		4.10002 (5.91153)
US intervention dummy(-1)	7.71190 ** (3.85237)	5.92973 * (3.47585)	24.37526 * (13.17329)		
JP intervention volume * IV1M(-1)	0.00013 *** (0.00005)	-0.00127 ** (0.00059)	0.00011 (0.00018)	-0.00006 (0.00016)	0.00008 (0.00015)
JP announced intervention dummy * IV1M(-1)	-1.30776 *** (0.47959)	-0.71599 (0.82659)	-1.17238 (0.92174)	0.03450 (1.00898)	0.67676 ** (0.31147)
JP unannounced but reported intervention dummy * IV1M(-1)	-0.43812 ** (0.21486)	0.21149 (0.36682)	-0.82513 (1.11691)		0.02871 (0.79520)
JP secret intervention dummy * IV1M(-1)	-0.21101 (0.21002)	0.11263 (0.33427)	-1.19621 *** (0.20020)		-0.53828 (0.63916)
R-squared	0.0607	0.0970	0.0569	0.0931	0.0987
Durbin-Watson d statistic	2.0023	2.0692	1.9835	1.9633	1.6604
Obs.	3404	1072	1056	918	358
＜Dependet variable： % change in implied volatility (3Month) ＞					
＜Independent variables＞					
Constant	0.96651 ** (0.38843)	1.86833 *** (0.70690)	0.95245 (0.68698)	2.36562 *** (0.77683)	5.64470 * (3.26212)
Holiday dummy	0.59117 *** (0.13607)	0.97851 *** (0.23696)	0.38082 (0.26173)	0.43107 * (0.24474)	0.50561 (0.41553)
IV3M (-1)	-0.10624 *** (0.03530)	-0.21742 *** (0.07031)	-0.08867 (0.05476)	-0.22918 *** (0.07196)	-0.61372 * (0.35298)
JP intervention volume	-0.00079 ** (0.00037)	0.01297 * (0.00670)	-0.00196 (0.00165)	0.00020 (0.00088)	-0.00048 (0.00146)
US intervention volume(-1)	-0.00335 (0.00360)	-0.00493 (0.00318)	-0.01578 (0.01446)		
JP announced intervention dummy	8.97668 ** (4.37981)	7.30466 (7.79161)	20.54609 * (11.44985)	-3.27220 (8.17312)	
JP unannounced but reported intervention dummy	3.24442 * (1.75997)	-2.37052 (3.43706)	15.04017 (9.86125)		-1.21566 (7.59332)
JP secret intervention dummy	1.13428 (1.72996)	-1.63846 (3.32618)	6.06547 *** (1.78249)		2.21941 (4.87820)
US intervention dummy(-1)	4.01334 ** (1.99582)	2.83572 * (1.51006)	15.16852 (9.86614)		
JP intervention volume * IV3M(-1)	0.00008 ** (0.00003)	-0.00089 * (0.00053)	0.00016 (0.00012)	0.00003 (0.00007)	0.00005 (0.00016)
JP announced intervention dummy * IV3M(-1)	-0.62742 * (0.36728)	-0.55516 (0.67645)	-1.54815 * (0.81109)	0.31250 (0.64482)	0.54156 ** (0.23298)
JP unannounced but reported intervention dummy * IV3M(-1)	-0.22380 (0.15581)	0.20840 (0.28880)	-1.04263 (0.77519)		0.14566 (0.81607)
JP secret intervention dummy * IV3M(-1)	-0.12460 (0.17642)	0.10060 (0.30367)	-0.27575 ** (0.13578)		-0.27723 (0.53089)
R-squared	0.0329	0.0761	0.0360	0.0541	0.0512
Durbin-Watson d statistic	2.0041	2.0415	1.9753	1.9956	1.8040
Obs.	3404	1072	1056	918	358

1. White(1980)'s heteroskedasticity-consistent standard errors are in parenthesis. *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

2. Holiday dummy takes 1 for the day one day after holidays and 0 for others.

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

4. The implied volatilities are calculated from the 1month and 3month yen/dollar option prices (at the money).

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

6. Announced intervention dummy is dropped in Period 4 due to collinearity since Period 4 had only one announced intervention.

Figure 1. Japanese interventions and yen/dollar rate
(May 1991－May 2004)

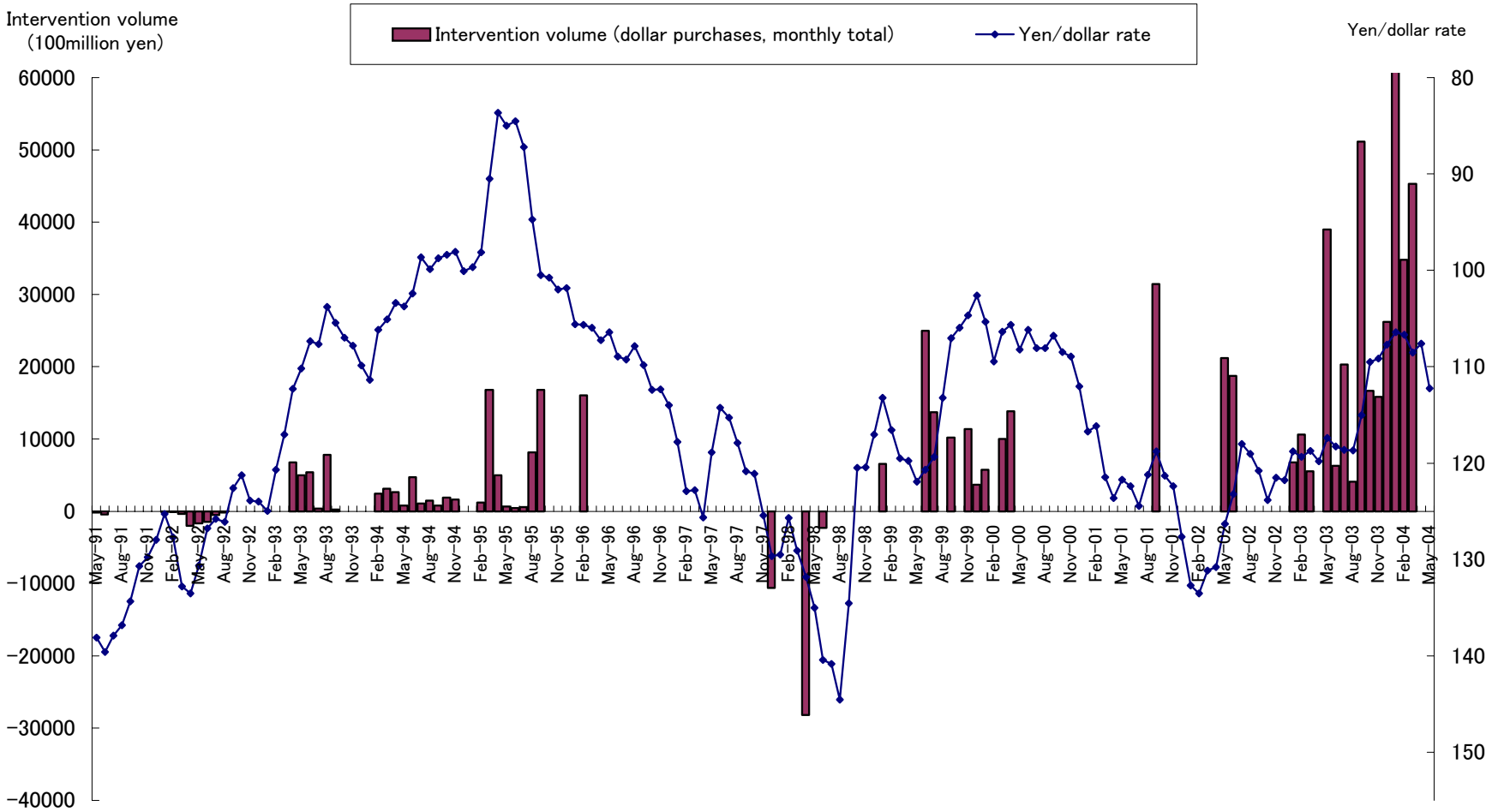
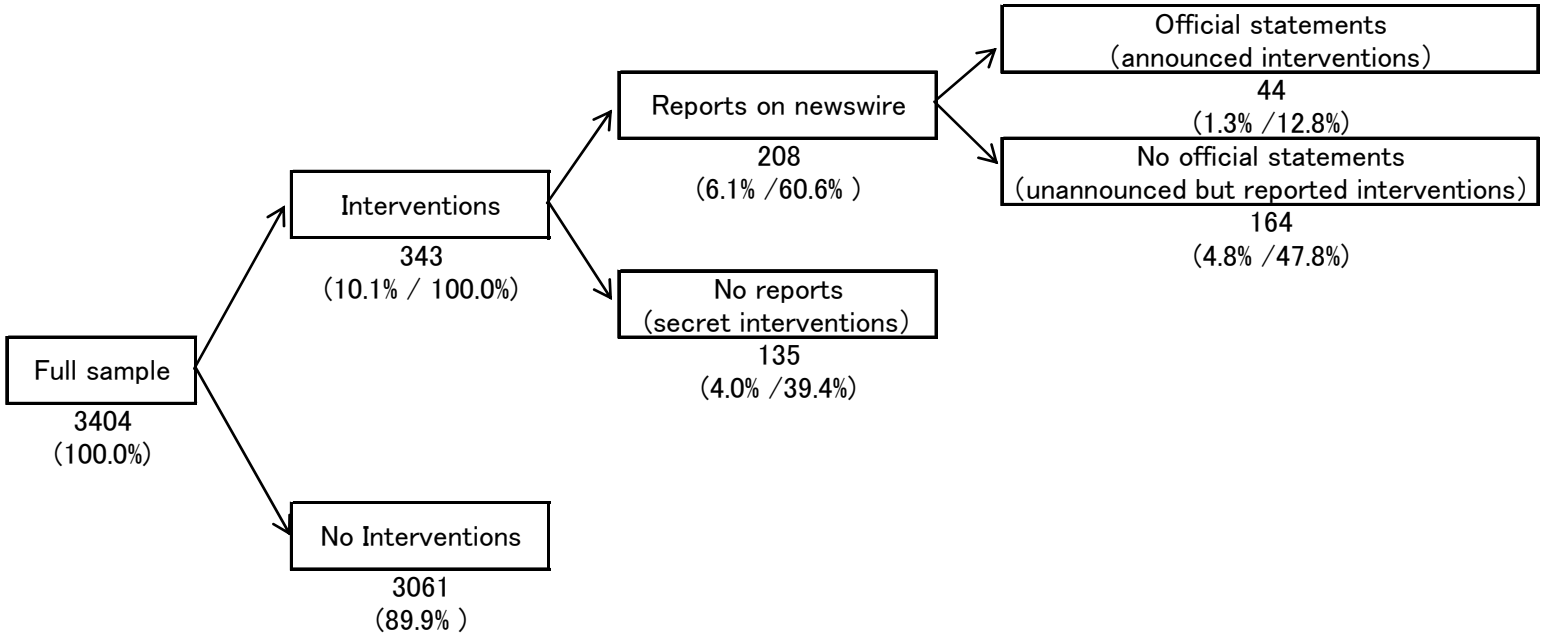


Figure2. Japanese interventions (5/13/1991-5/27/2004)



Source: the Ministry of Finance of Japan, Bloomberg and Reuters.

Figure 3. Expectation heterogeneity

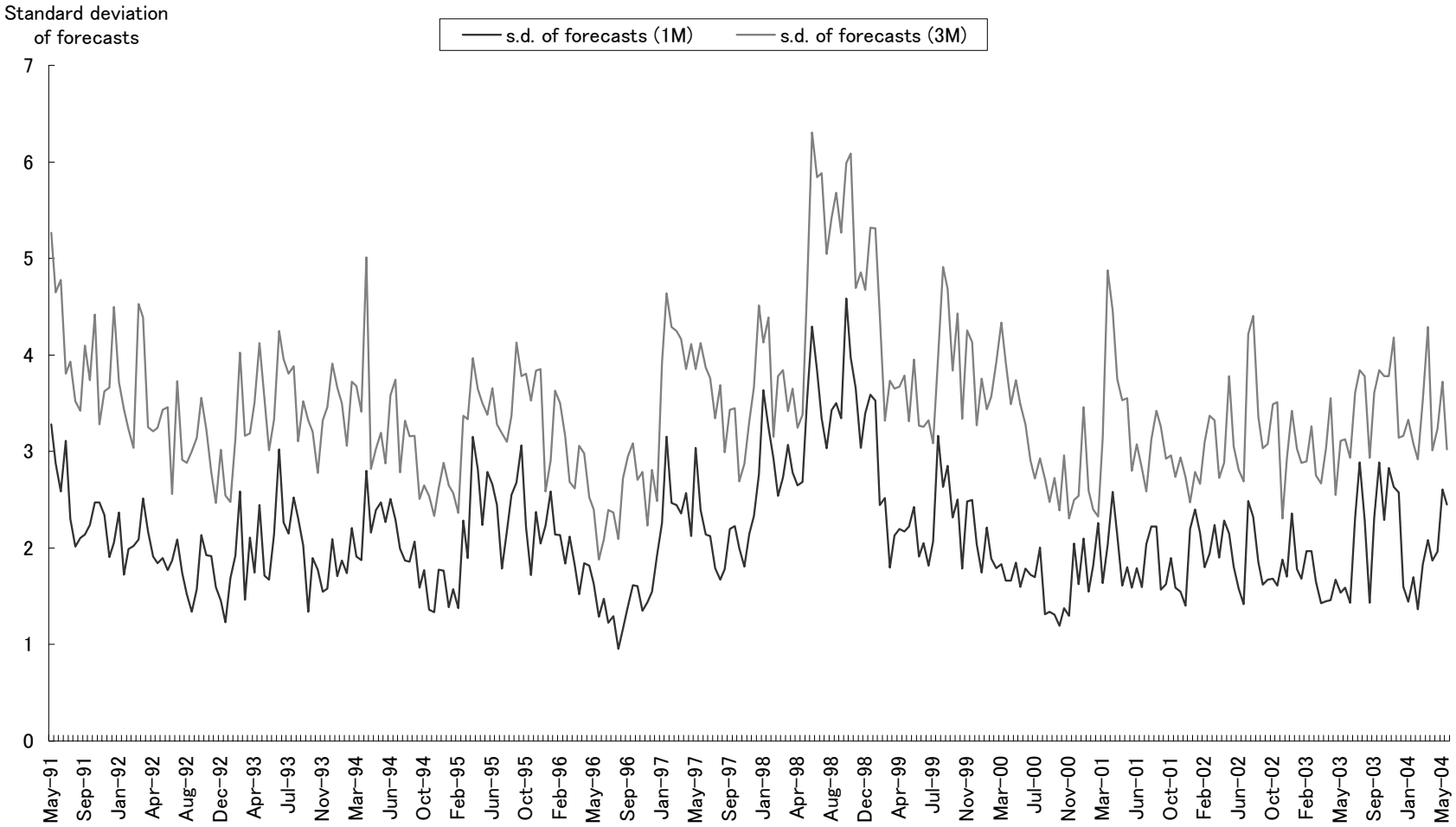


Figure 4. Implied volatility

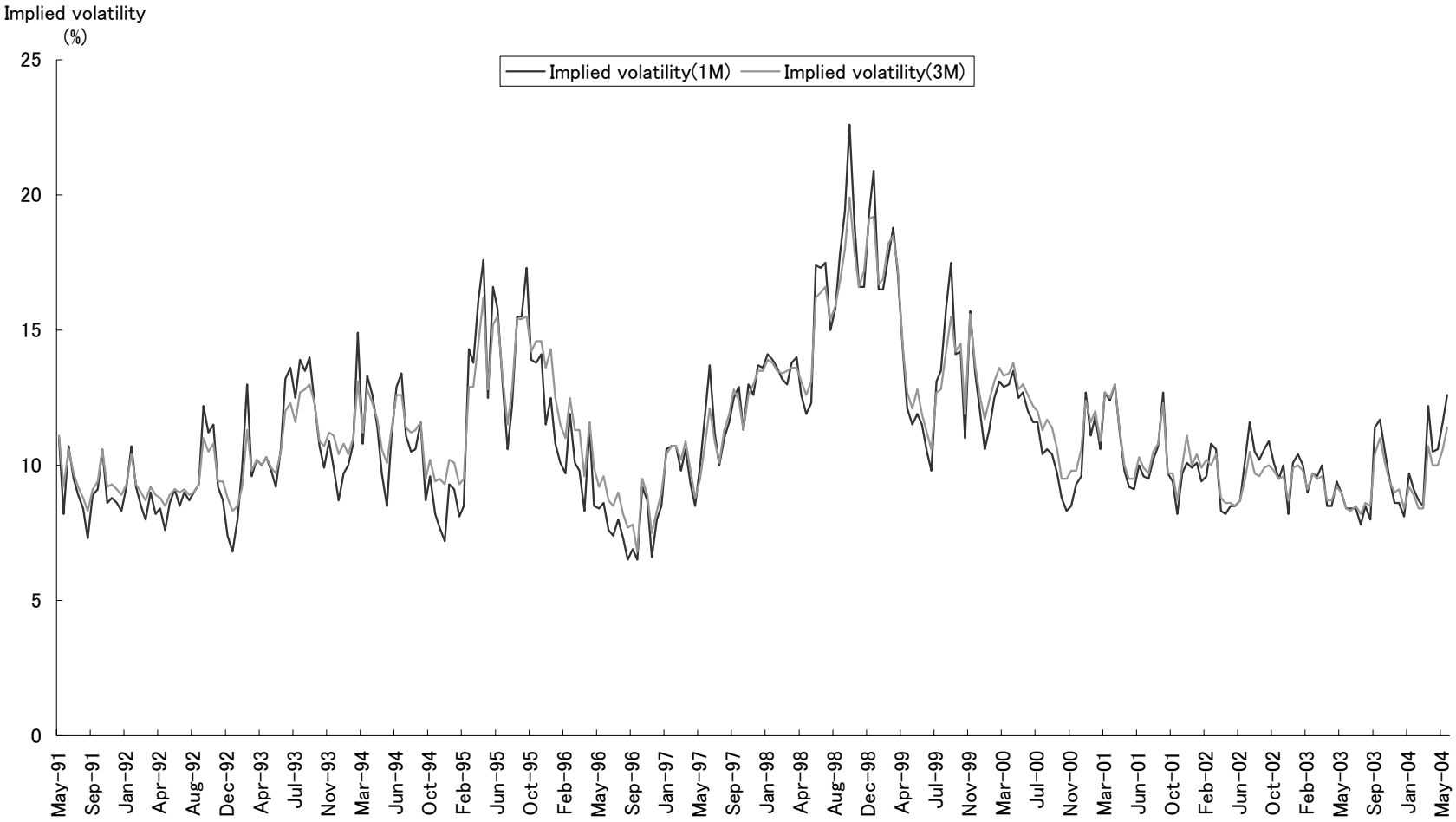


Figure 5. Trading Volume Variables