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Working Papers

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ECON2004-4

Discipline of Economics
Faculty of Economics and Business

e+b

ISBN 1 86487 654 9 ISSN 1446-3806
July 2004

Central Bank Interventions in the Yen-Dollar Spot Market

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ABSTRACT

We test the effectiveness of Bank of Japan (BOJ)'s foreign exchange interventions on conditional first and second moments of exchange rate returns and traded volumes, using a bivariate EGARCH model of the Yen/USD market from 5-13-1991 to 6-28-2002. We also estimate a friction model of BOJ's intervention reaction function based on reducing short-term market disorderliness and supplementing domestic monetary policy. We find ineffectiveness of BOJ interventions pre-1995 but effectiveness post-1995, Fed intervention amplified the effectiveness of the BOJ transactions, BOJ's interventions were based on 'leaning against the wind' motivations, and BOJ interventions were vigorously used in support of domestic monetary policy objectives post-1995.

Keywords: Foreign exchange intervention, Bank of Japan, exchange rate volatility, trade volume
JEL codes: E44, G14, G15

Acknowledgement This work was funded in part by a Sesquicentenary Research and Development Grant from the University of Sydney

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INTRODUCTION

This paper examines the relations between exchange rate changes, traded volumes and central bank interventions in the Yen/United States dollar (Yen/USD) foreign exchange market. The Bank of International Settlements reported in 2002 that the Yen/USD was the second most traded currency pair (20% of all global transactions valued at USD1.21 trillion per day in 2001, the €-USD having 30%). Further they reported that only 13% of all transactions were with non-financial customers motivated by liquidity needs, implying that 87% occurred between foreign exchange dealers and brokers. What this suggests is that the huge daily volumes traded are largely driven by the need for resolution of asymmetric information issues amongst dealers and brokers, often prompted or halted by the interventions of the Bank of Japan (henceforth the BOJ) and the United States Federal Reserve (henceforth the Fed). The BOJ has been one of the most active central bank in foreign exchange markets in the last fifteen years. It has the distinction of having made perhaps the biggest ever intervention on a day—USD26 billion sales on April 10 1998, when all East Asian currencies were depreciating, and Japan, on the brink of recession, was proposing a massive fiscal expansion package. At the end of 2002, the BOJ had accumulated USD 452 billion of foreign exchange reserves, which represented almost 19% of all official reserves held globally, and which was 57% more than the next largest central bank, China.

There is an extensive literature that examines the high frequency relations between exchange rate returns and central bank intervention—for recent examples, see Sarno and Taylor (2001), Kim and Sheen (2002), Kearns and Rigobon (2003), and Edison, Cashin and Liang (2003). This literature has tested the effectiveness of intervention by determining whether the level and volatility of exchange rate returns are affected in the desired direction, or if prominent trends are reduced. It has also tested for possible determinants of central bank responses to exchange rate returns. This literature is normally not concerned with low frequency issues—for example, whether or not the real exchange rate is under- or over-valued relative to its medium-run value, or whether there should be a fixed, floating or managed floating exchange rate regime. The focus has usually been on high frequency issues in an environment where the exchange rate is market-determined. However this singular focus is not appropriate in the case of the BOJ, which is widely believed to use foreign exchange intervention as an additional instrument to achieve its monetary policy objectives. Therefore in this paper, we examine both high and low frequency issues.

With regard to high frequency issues, the developments of financial market microstructural theory and testing over the last twenty years has stressed the relation between asset price returns and trading volumes. This suggests that interventions ought to matter for volumes, and volumes ought to matter for interventions. Intervention should affect foreign exchange trading volumes because changes in underlying market fundamentals—or beliefs about them—should cause more trading activity, as well as affecting the volatility of returns. Further, central banks are likely to value the information content of transaction volumes in making their intervention decisions. Therefore it is interesting and important to examine central bank interventions in the context of both returns and volumes. This has never been done before because data on volumes is not readily available. In this paper, we address this issue using a measure of trading volume—the daily reported trades by Tokyo foreign exchange brokers to the BOJ.

On low frequency issues, there is a growing agnosticism about the ability of a central bank to successfully influence exchange rates. For example, Schwartz (2000) claims that US and European monetary authorities no longer believe that intervention works. She challenges the Bank of Japan for its obduracy in pursuing sterilized intervention [1] as an instrument targeted to domestic objectives. The basis for this challenge is essentially that there is no hard and robust evidence from around the world that interventions successfully affect exchange rates. However, if there is going to be good evidence of successful interventions, the chances are that it will be found from the BOJ's activities post-1995 when it very actively intervened to stop the Yen appreciating (and perhaps to engineer a depreciation). Its key purpose was to prevent the exchange rate adding to domestic deflationary pressures.

The main questions we address in this paper are:

- Was the BOJ able to achieve desirable effects on the trend and volatility of returns and volumes with its interventions? Did it help when the Fed supported the BOJ in these interventions?
- Did the BOJ use intervention as another monetary policy instrument, and was it successful in doing so?

The rest of the paper is organized as follows: Section 2 outlines the theoretical relationships between exchange rates, market volumes and interventions, section 3 discusses the data and modelling issues, section 4 presents the investigation results for the efficacy of the BOJ's interventions, section 5 investigates the determinants of the BOJ's interventions, and finally section 6 offers concluding remarks.

2. TESTING THEORIES OF EXCHANGE RATE RETURNS, TRADING VOLUMES AND INTERVENTIONS

Most of the trading volume in foreign exchange markets is driven by information motives, with liquidity playing a minor role. The interventions of central banks may also contribute to changes in the price and the quantity traded, and this section focuses on how interventions can interact with information motives to generate significant effects.

In foreign exchange markets, asymmetric information amongst dealers involves both the availability of raw data for variables that may influence the exchange rate, as well as the distribution of beliefs about their effects and the future changes in those influences. The fundamental idea is that dealers with superior information can make profitable trades with those with inferior information.

In foreign exchange markets, one source of information is produced as macroeconomic data. No dealer has an information advantage about

[1] The BOJ explains in a document on its website (www.boj.or.jp/en/about/basic/etc/faqkainy.htm) that any Yen funds to be sold on foreign exchange markets are raised by issuing Financing Bills. So it appears that it is sterilizing its interventions. However in numerous official statements, it claims that it aims to ensure domestic liquidity is optimal, and these interventions may be used to help achieve that.

macroeconomic announcements. However, with regard to macroeconomic data, there is typically a spread of beliefs amongst dealers about the future evolution of these information events, as well as the importance of their effects. This belief asymmetry is crucial for exchange rate determination and is an important motivation of trading. The resulting traded volumes are not public knowledge, and dealers have to compete to get early access to this type of information. This need to trade to build knowledge about beliefs is supported by the institutional feature of the market whereby dealers that post bid and ask prices have to accept trades (up to a limit order). As a consequence, inventory risk management becomes crucial, with small imbalances in orders seen to be translated into multiple orders among dealers.[2] Thus small liquidity trades plus trades to build knowledge about the spectrum of beliefs get amplified into huge volumes.

Another critical information event is central bank interventions in the market. These interventions can be "big news" on the market. The size and persistence of interventions can make a difference to dealers, either directly or perhaps because they may signal a possible change in domestic monetary policy. If more than one central bank is involved in the intervention, there is a much larger probability of a substantial effect on dealers' portfolios. Whenever the central bank intervenes, all dealers do not necessarily know that it has occurred.[3] So once again this information vacuum can only be filled by frequent and intelligent trading. The challenge for any trader is to build knowledge about the spectrum of market beliefs and interventions, ahead of other traders, so that they might avoid making losses from being poorly informed, and even possibly make profits from being better informed. With beliefs able to change rapidly, information about the belief spectrum will become quickly out-dated. Therefore these information-motivated trades need to continue at a high frequency. It is not surprising, then, that foreign exchange markets have the highest turnover of all markets in the world.

How does trading resolve the information problem on beliefs? In their individual deals, traders can observe the responses to their own bid and ask prices, and can observe how much others are prepared to trade at the bid and ask prices they set, and how readily they change those prices. Thus transaction volume and price data are vital for building intelligence on the distribution of beliefs in the foreign exchange market place. Naturally, it makes a difference if changes in transaction volumes arise from other private dealers or from the central bank. The central bank's motives differ from those of other dealers.

Initially, volume information played no role in the micro-structural literature on financial markets. Only price signals mattered (e.g. Glosten and Milgrom 1985). Subsequently volume signals were introduced, which explained how price and volume information can together improve the learning process. Easley and O'Hara (1987) showed that informed traders would want to trade large quantities if they knew they had superior information, and so the observed volume of trade becomes a good signal of the possible existence of an informed trader. In the context of the foreign exchange market, an 'informed' trader becomes one that is a substantial step ahead in determining the key features of the distribution of information and beliefs in the marketplace. Naturally, every trader is receiving different private signals from their trades. The quality of the signals received will differ, and so in subsequent trades, the volume traded by a trader reveals to others some information about the quality of prior signals received. The greater the volume, the higher the inferred quality. This was the argument suggested by Blume, Easley and O'Hara (1994). However when central bank intervention is the reason for observed trading, it does not necessarily follow that volumes traded will increase—the central bank may be intervening specifically to calm the market.

Admati and Pfleiderer (1988) suggested another possible reason for trading volumes to be informative—transaction costs (which are surely very low in the Yen/USD foreign exchange market). Liquidity-motivated traders, usually

[2] This is known as the 'hot potato' syndrome (for example, see Lyons (2001)). It occurs when dealers sequentially unload unwanted positions, until eventually a satisfied counterparty is found.

[3] In a survey of 13 OECD central banks, Lecourt and Raymond (2003) report that 80% of central banks prefer to deal with major banks, thus ensuring high liquidity and visibility. Sometimes they do trade with brokers, to maintain their anonymity, if their interventions might be interpreted as inconsistent with current monetary policy and thus falsely signal a change.

large financial institutions acting on behalf of their private clients, will typically prefer to execute their requirements when the market is very active, thus economizing on transaction costs. In the same way, information-motivated traders will also prefer active times. This implies an equilibrium in which information acquisition is more intense when the market is active. Therefore high volumes are associated with greater learning.

The empirical literature has documented the existence of a strong positive correlation between trade volumes and the volatility of returns. The 'mixture of distribution hypothesis' (MDH) developed by Clark (1973) and then Epps and Epps (1976) suggests the existence of underlying latent (information) variables that lead to an observed joint dependence of volumes and returns. New information will affect both unpredictable volumes and the volatility of returns. This latent information may include 'secret' central bank intervention, which will affect both volumes and returns.

Results from tests involving the joint distribution of returns and volume in the foreign exchange market have been few and varied[4]. Glassman (1987) and Bessembinder (1994) used volumes on foreign exchange futures from the Chicago International Money Market as a proxy for spot volumes. They do not find significant effects from their derivative volume variable when trying to explain bid-ask spreads. Hartmann (1999) uses the volume data that we use in this paper—the reported volume transactions of Japanese foreign exchange brokers to the BOJ. He finds that unpredictable volumes do have a significant positive impact on bid-ask spreads in the Yen/USD market. He also shows that the volume data exhibits significant conditional heteroscedasticity.

[4] The evidence from tests of the mixture of distributions hypothesis using stock market data also varies. Lamoureux and Lastrapes (1990) showed that volume had a significant positive effect on the conditional variance of returns. Hiemstra and Jones (1994) in an EGARCH context do not find support for the hypothesis. On the other hand, Andersen (1996) does find support for MDH with a model of stochastic volatility. He also finds that the estimate of the volatility persistence of returns is significantly lowered when volume data is included. He conjectures that this could be because there are some information events that induce heavy trading, but with little effect on daily returns.

These Hartmann (1999) results suggest that a GARCH model for volumes might be appropriate, and that unpredictable volumes are likely to have an impact on the exchange rate returns process. It is now well-established that the exchange rate returns are efficiently modelled as an EGARCH(1,1) process using a Student-*t* distribution (for example, see Hsieh 1989, Baillie and Bollerslev 1989, and Kim and Sheen 2002). The 'mixture of distributions' hypothesis suggest that a way to proceed is to set up a bivariate EGARCH model for exchange rate returns and volumes. We can test whether unpredictable volumes have an impact on the conditional means and variances of the returns process, and whether unexpected returns have an impact on the conditional means and variances of the volume process. In this context, it is also possible to test whether foreign exchange interventions by the central bank have any impact on that bivariate process.

The empirical literature that tests for the effectiveness of central bank intervention is plagued by the problem of simultaneity. If the exchange rate is thought to be depreciating excessively on a day, the central bank may choose to begin to sell foreign currency that day. It will continue its operations through the day if it perceives that it has slowed the exchange rate trend, or better still if it reverses it. But reversal is not a necessary condition of effectiveness, and so it is likely that there will be many days of intervention sales (purchases) of foreign currency when the exchange rate has actually depreciated on the day. What we need to know is whether the exchange rate would have depreciated more without the intervention. This problem will apply equally when we are testing whether intervention has a stabilizing effect on trade volumes. So far there have been three approaches to resolving this problem. The first simply assumes that intervention affects the exchange rate with a lag, which is unsatisfactory because interventions happen in real time (for example, see Baillie and Osterberg (1995) and Lewis (1995)). In a second approach, Kim and Sheen (2002) introduce dummy variables for cumulative, large-sized and coordinated interventions to see whether the isolation of these unusual interventions can overcome the downward bias induced by simultaneity. In a third approach, Kearns and Rigobon (2003) use simulated GMM estimates, making an identifying assumption that the central bank intervention policy has an exogenous structural shift within the sample.

The last two of these approaches have provided evidence indicating that interventions have been stabilizing. In this paper, we take the second approach and extend it to a bivariate model of exchange returns and volumes. Since the BOJ significantly raised the intensity of its interventions after mid-1995, it is quite possible that the simultaneity problem will be overwhelmed, and that we might obtain transparent evidence of the desirable effectiveness of intervention.

When central banks intervene infrequently, their primary objective is usually to eliminate any perceived disorderliness in the foreign exchange market. In the previous literature, this disorderliness has been framed in terms of exchange rate realizations—the correction of an undesired trend, the reduction of abnormally high volatility of returns, the pricking of a bubble, or perhaps the moderation of an excessive overshoot.[5]

However the significant developments from microstructural theories of financial markets have alerted analysts to the importance of volume measures. It would therefore seem sensible for a central bank to extend its measure of disorderliness by also using information on traded volumes. Thus we suggest that a central bank might want to intervene if volumes are unexpectedly high, or if the volatility of those trade volumes were felt to be excessively large. Even if indicators on exchange rate returns are not yet suggesting a disorderly market, unusual volume outcomes may be a useful early predictor of future disorderliness. If apparently excessive exchange rate changes are occurring without any unusual volume effects, then the central bank ought to doubt its judgement that these exchange rate changes are undesirable. If both returns and volume indicators are giving unusual signals, the central bank should be more convinced that an intervention is appropriate.

Since trading volumes are likely to be very informative for the intervention decision of the central bank, it needs to be able to obtain this information. The central bank, like any other dealer in the market, needs to participate in the market to get this information. Therefore it should not be surprising if there are many days when the central bank is in the market, but not having any apparent or expected effect. By these innocuous trades, it is able to gather information about the market. However some central banks also gather information by requiring reports of broking or dealing activities of institutions under their supervision. For example, the BOJ requires brokers to provide a daily report of their actual trades (in volumes and prices) and this is the source of our volume data. This is an incomplete source of volumes since it only accounts for onshore and brokered transactions. Nevertheless it is apparently useful to the BOJ, and it is important to test whether it plays a significant role in their intervention activity.

Market disorderliness, whether manifested through exchange rate or traded volume measures, is not necessarily the only motivating factor for interventions. As explained in the introduction, foreign exchange intervention can be and often is used to help achieve domestic monetary policy objectives. When short-term interest rates are changed, a central bank may decide to intervene in foreign exchange markets in support of this change in its principal monetary policy instrument. In the case of the BOJ, both motivations[6] are likely to be important.

3. DATA AND MODELING ISSUES

The Yen/USD exchange rate is the mid-point rate collected at 5pm London time (GMT) and the volume data is the volume of spot market transactions in Tokyo foreign exchange market as reported by brokers to the BOJ and measured in billions of Yen. These data were collected from Datastream. We chose the London market closing rate for the exchange rate so that not only the BOJ interventions but also the US Fed interventions are relevant when calculating daily returns. Figure 1 shows the time-line of market operating hours for both the Tokyo and the New York foreign exchange markets. The Tokyo market opens and closes before the New York market, and any Yen

[5] There is a large literature studying the determinants of intervention. For example, see Dominguez and Frankel (1993), Lewis (1995), Almekinders and Eijffinger (1996), Dominguez (1998), Baillie and Osterberg (1998), Kim and Sheen (2002), and Kearns and Rigobon (2003).

[6] There are other minor determinants such as profitability and the replenishing and rebalancing of central bank foreign exchange inventories.

interventions by the BOJ and the US Fed on calendar date t would be completed by noon New York time (which is 5pm GMT)[7]. Daily exchange rate return calculated over the horizon between GMT 5pm at date $t-1$ and date t would thus include both the BOJ and the Fed intervention on the Yen/USD exchange rate at date t. The daily exchange rate returns are measured as continuously compounding returns, $R_t = \ln(S_t / S_{t-1}) \times 100$, where S_t is the spot exchange rate between the US dollar and the Japanese Yen (Yen/USD) measured as units of Yen per US Dollar.

Trading volume used is the spot market broker volume measured in USD millions in the Tokyo market. This data has to be reported to the BOJ by brokers every day between opening time and 3:30pm JST. As Hartmann (1999) notes, it is very difficult to get foreign exchange turnover data series. This broker volume data is informative as an indicator of overall spot volumes in Japan if the broker share of the market remains constant or grows. In fact the Bank of International Settlements (2002) reported that the proportion of brokered transactions has been increasing globally because of the advent of low-cost electronic broking. A further issue is that brokered trades tend to be used for larger transactions because of the greater need for anonymity. Again the increased use of electronic broking has reduced this potential size bias. The trading volume series contain significant but small positive (linear and non-linear) trends, and so the residuals from a quadratic-detrending regression are used as the detrended (and de-meaned) volume, VM_t.[8]

Table 1 reports the summary statistics of exchange rate return and daily volume. It is evident that both daily returns and daily volumes are non-normal and leptokurtic. Negative skewness is observed for the exchange rate returns while volumes are positively skewed. Significant linear and non-linear serial correlations are observed in both cases, and bivariate correlations between the two are also significant. Tests of Granger causalities reveal more details on the nature of this bivariate relationship. The causality runs only from volume to returns, but there is a bi-directional causality between volume and squared returns, which is consistent with the mixture of distributions hypothesis. Thus, modeling of the daily exchange rate returns and trading volume must account for these observed characteristics.

The intervention data cover the period 13 May 1991 to 28 June 2002 containing 213 BOJ interventions in the Yen/USD market. The Yen interventions by the BOJ is normally carried out in the Tokyo market, however, if the BOJ feels further intervention is required after the close of business in Tokyo at 5pm JST, it would request other central banks to conduct interventions on its behalf. The US Fed has been performing this role and there were 22 such intervention activities in the Yen/USD exchange rate in the New York market by the Fed during the sample.

The BOJ's and the Fed's intervention in the Yen market are publicly available[9] and they are recorded as net market purchase of US dollar assets in billions of Yen. The full sample can be split into two sub-samples to account for the two distinct periods of BOJ interventions. The emergence of Dr. Sakakibara (better known as 'Mr. Yen' in the Western markets) as the new Director of International Finance Bureau at the Ministry of Finance and Economics in 1995 marked a new era of interventions where interventions were less frequent but substantially larger in size. In order to account for this structural break we split the sample on the 20 June 1995 (see Ito 2002).

Table 2 reports the intervention statistics for the full and the two sub-samples. For the full sample, there were 213 interventions (180 positives and 33 negatives) by the BOJ and most of the interventions were positive, that is, intervention purchases of USD (sales of Yen) assets. The widely-held belief is that the BOJ was mostly attempting to reduce the level of excess demand for the Yen in the market by these interventions. The average size of the intervention is Yen 149.9 billion and it ranges from as low as Yen 5.1 (3.2) to 1405.9 (2620.1) billion for intervention purchases (sales) of the USD for Yen.

[7] See Bank of Japan (2000)

[8] We have replicated our regressions using the logarithm of volume. We find that our parameter estimates are qualitatively similar, though the equation diagnostics deteriorate when using the logarithm.

[9] The BOJ data are available at www.mof.go.jp/english/e1c021.htm. The Fed data is available from www.newyorkfed.org/pihome/news/forex/. The intervention statistics are released 30 days after the end of each financial quarter.

Interventions were often followed by reinforcing interventions in the same direction. Given that there was a BOJ intervention, the probability of another intervention in the same direction the following day is 53%. The probability of a three successive interventions is 34%. Most of the interventions were concentrated in sub-sample one, accounting for 166 out of 213 days. However, the size of transactions increased drastically, with the average Yen sale (purchase) increasing from Yen 50.2 (29.2) to 488 (684.4) billion in sub-sample two. The US Fed interventions were modest in size compared to the BOJ transactions, and were designed to support BOJ transactions initiated in the Tokyo market shortly before the New York market opening, as shown by the probability of the Fed intervention being coordinated with a prior BOJ intervention being one. As with BOJ activities, the Fed interventions were concentrated in the first sub-sample (18 out of total of 22 transactions).

4. MODELING THE EFFECTIVENESS OF BOJ INTERVENTION

The time-varying volatility and the leptokurtosis of the distributions of the daily exchange rate returns and volumes may be effectively modelled by a suitably specified GARCH model with a non-normal conditional density for the residuals. The asymmetric effects, if any, of unexpected changes can be handled by applying Nelson (1991)'s Exponential-GARCH approach that explicitly models the effects of positive and negative innovations separately. EGARCH models also have the advantage of not having to impose positivity restrictions on the coefficients in the conditional variance equation. Indeed, negative coefficients for included exogenous variables (such as the intervention variable) will have a special meaning in this paper. The significant linear and non-linear correlations between the daily returns of Yen/USD exchange rate and the spot market trade volume can be jointly modelled by a bivariate EGARCH model of the two variables with a bivariate *t* distribution for the residuals used to account for the excess kurtosis shown in the data. To simplify the analysis and economise on the number of parameters to be estimated, the conditional correlations are assumed to be constant through time (see Bollerslev 1990).

The bi-directional causations between the exchange rate returns and trade volume documented in Table 1 are modelled by including feedback effects in the conditional mean and variance equations. These include lagged error terms (own and the other) included in both the conditional mean and variance equations, and contemporaneous variances (own and the other) in the conditional mean equations.

In addition, a holiday dummy is included to account for possible seasonal effects on the conditional mean and variance of the daily returns and volume. These may be due to significant differences in the volume of information relevant for trading on particular days, leading to consistently different patterns in the conditional mean and variance movements. The holiday dummy takes as values the number of days between two successive trading days. It is one for week days, three for Mondays and one or more for days immediately following public holidays.

The effectiveness of the interventions are examined by including daily intervention variables in the conditional mean and variance of the bivariate EGARCH model and examining the sign and the significance of the intervention variables. The effectiveness of the daily intervention on the exchange rate may be dependent on a number of features, however.

First, the response of the foreign exchange market may depend on whether the intervention on the day is large enough to have a significant effect on the current trend. The size of the intervention matters. Given the relatively large turnover in the Japanese foreign exchange market—the BIS (2002) reports a daily average of 147 billion in USD equivalents in April 2001, out of which 101 billion were accounted for by Yen/USD transactions—the size of intervention has to be substantial enough to be able to move the 'equilibrium' exchange rate. Second, it is important to determine whether the intervention transaction for the day is a one-off episode, or a part of a series of interventions over many days. The BOJ may spread out the intervention transactions over a number of days to maximize its effects through the signaling channel. An intervention stance may be perceived to be more credible to market participants if they see a series of intervention transactions in the same direction rather than a one-off entry into the market. The market perception of the different effects of intervention is modeled in this paper by allowing the intervention coefficient to differ depending on the features of the intervention on the day. This is accomplished by incorporating two slope dummy variables into the coefficient for the intervention variable in the conditional mean and variance equations. These are: a *size dummy* that takes the value of one for interventions of larger in amount than the average daily intervention for each of the three samples (Yen 149.6, 46.8 and 513 billion in the full sample, and the first and second sub-sample, respectively) and zero otherwise; and a *cumulative intervention dummy* that takes the value of one for days of intervention that are preceded by at least two previous days' intervention in the same direction and zero otherwise.

In addition to the intervention carried out by the BOJ, the US Fed also intervened in the Yen/USD market. However, without exception, the Fed interventions were carried out in the morning (New York) after the overnight BOJ interventions, and always in the same direction. It is fair to say, therefore, that the Fed's interventions were an extension of that by the BOJ and were designed to reinforce the effectiveness of the BOJ interventions. We model this separately from the BOJ interventions.

The bivariate EGARCH(1,1) model to be tested is as shown below:

Conditional Mean Equations

$$\Delta ER_t = a_c + a_{erma} e_{t-1} + a_{vmma} \varepsilon_{t-1} + a_{erh} \sqrt{h_{er,\,\mathrm{t}}} + a_{vmh} \sqrt{h_{vm,\,\mathrm{t}}} + a_{hol} D_{hol,t} + a_{idiff}\, Idiff_t \qquad \text{(1a)}$$
$$(a_{\mathrm{int}v} + a_{cum} I_{CUM_t} + a_{size} I_{SIZE_t}) \cdot Intv_t + a_{fed}\, IntvFED_t + e_t$$

$$VM_t = \alpha_c + \alpha_{vmar} VM_{t-1} + \alpha_{erma} e_{t-1} + \alpha_{vmma} \varepsilon_{t-1} + \alpha_{erh} \sqrt{h_{er,\,\mathrm{t}}} + \alpha_{vmh} \sqrt{h_{vm,\,\mathrm{t}}} + \alpha_{hol} D_{hol,t} \qquad \text{(1b)}$$
$$+ (\alpha_{\mathrm{int}v} + \alpha_{cum} I_{CUM_t} + \alpha_{size} I_{SIZE_t}) \cdot Intv_t + \alpha_{fed}\, IntvFED_{t-1} + \varepsilon_t$$

Conditional Variance Equations

$$\ln h_{er,t} = b_c + b_h \ln h_{er,t-1} \qquad \text{(2a)}$$
$$+ \left[b_{\varepsilon\_er1} \frac{e_{t-1}}{\sqrt{h_{er,t-1}}} + b_{\varepsilon\_er2} \left(\frac{|e_{t-1}|}{\sqrt{h_{er,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right]$$
$$+ \left[b_{\varepsilon\_vm1} \frac{\varepsilon_{t-1}}{\sqrt{h_{vm,t-1}}} + b_{\varepsilon\_vm2} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{vm,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right]$$
$$+ b_{hol} D_{HOL,t} + (b_{\mathrm{int}v} + b_{cum} I_{CUM_t} + b_{size} I_{SIZE_t}) |Intv_t| + \alpha_{fed} |IntvFED_t|$$

$$\ln h_{vm,t} = \beta_c + \beta_h \ln h_{vm,t-1} \qquad \text{(2b)}$$
$$+ \left[\beta_{\varepsilon\_er1} \frac{e_{t-1}}{\sqrt{h_{er,t-1}}} + \beta_{\varepsilon\_er2} \left(\frac{|e_{t-1}|}{\sqrt{h_{er,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right]$$
$$+ \left[\beta_{\varepsilon\_vm1} \frac{\varepsilon_{t-1}}{\sqrt{h_{vm,t-1}}} + \beta_{\varepsilon\_vm2} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{vm,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right]$$
$$+ \beta_{hol} D_{HOL,t} + (\beta_{\mathrm{int}v} + \beta_{cum} I_{CUM_t} + \beta_{size} I_{SIZE_t}) |Intv_t| + \beta_{fed} |IntvFED_{t-1}|$$

$$h_t^{er,ma} = \rho \sqrt{h_{er,t} \times h_{ma,t}} \qquad \text{(3)}$$

$D_{hol,t}$ =	Seasonal dummy that takes the number of days between two successive observations. 1 for normal weekdays, 3 for Mondays and 2 or higher for days immediately following market closures due to holidays.
$Idiff_t$ =	Interest rate differential between US and Japanese overnight interest rates.
$Intv_t$ =	Net market purchase of USD assets with Yen by the BOJ, in 100 billions of Yen
$IntvFED_t$ =	Net market purchase of USD assets with Yen by the FED, in 100 billions of Yen
$ICUM_t$ =	Cumulative BOJ intervention dummy variable that takes the value of one if BOJ intervention at day *t* is preceded by intervention in the same direction at day *t-1* and *t-2*, and zero otherwise.
$ISIZE_t$ =	BOJ intervention size dummy variable that takes the value of one if the absolute amount of intervention at day *t* is greater than the sample average daily net market purchase of Yen (149.65, 46.75 and 513.05 billion for the full sample, sub-sample one and sub-sample two, respectively) and zero otherwise.
$h_{er,t}$ =	Conditional variance of daily exchange rate changes.
$h_{vm,t}$ =	Conditional variance of daily detrended trading volume in the Tokyo FX market.

For the joint distribution of the two error processes, a conditional bivariate standardized *t* distribution with variance-covariance matrix $\mathbf{H_t}$ and *d* degrees of freedom is used instead of the customary bivariate normal, thus accounting for possible leptokurtosis in the joint conditional densities (see Bollerslev 1987; Hamilton 1994). The virtue of using this distribution is that the unconditional leptokurtosis observed in most high frequency asset price data sets can show up as conditional leptokurtosis, and yet have the important property that it converges asymptotically to the Normal distribution as *d* approaches infinity (or alternatively, *1/d* is statistically indistinguishably from zero)[10], which appears to be appropriate with low frequency data. The *t* conditional density is as below (k=2 for the bivariate case):

$$f(\varepsilon_t) = (2\pi)^{-\frac{k}{2}} \left(\frac{d-2}{d}\right)^{-\frac{1}{2}} |\mathbf{H}_t|^{-\frac{1}{2}} \left(\frac{d}{2}\right)^{-\frac{k}{2}} \Gamma\left(\frac{d+k}{2}\right) \Gamma^{-1}\left(\frac{d}{2}\right) \left(1+\frac{\varepsilon'_t \mathbf{H}_t^{-1} \varepsilon_t}{d-2}\right)^{-\frac{d+k}{2}}$$

where, $\varepsilon_t = \begin{bmatrix} e_t \\ \varepsilon_t \end{bmatrix} \sim (\mathbf{0}, \mathbf{H_t})$, $\mathbf{H_t} = \begin{bmatrix} h_{er,t} & h_{vm,er,t} \\ h_{er,vm,t} & h_{vm,t} \end{bmatrix}$

[10] *d* is the degree of freedom parameter in the student-*t* distribution and it is negatively related to the fourth moment of the distribution.

4.1 Empirical Results

The maximum likelihood estimations of the bivariate EGARCH models for both the daily Yen/USD exchange rate returns and the Tokyo foreign exchange market trade volume are reported in Table 3. Full-sample and two sub-sample estimation results are shown. The effects of the Yen interventions carried out by the BOJ and the Fed are investigated by examining the sign and the magnitude of the coefficients of the intervention variables included in the conditional mean and variance equations.

Full-Sample

The contemporaneous effect of intervention on the return is picked up by a_{intv}. For effectiveness of intervention, a positive sign is expected as this would imply net market purchases of USD with Yen would lead to a USD appreciation (or a Yen depreciation). The estimated contemporaneous intervention effect (-0.3674), however, is negative and significant. This suggests a USD depreciation against the Yen was associated with an intervention purchase of USD assets. This is in line with other researchers who report similar contemporaneous results (for example, see Baillie and Osterberg 1997, Dominguez 1998, Kim, Kortian and Sheen 2000). Although it is tempting to conclude against the effectiveness of central bank interventions, as some have, this result is affected by the well-known simultaneity between exchange rate movements and intervention activities. The identification problem is not easy to resolve because it is hard to think of good instruments for intervention.

One approach to the problem is to introduce dummy variables to test whether cumulative or particularly large interventions have distinct effects on returns. The coefficient for a cumulative intervention dummy, a_{cum}, that picks up the effects of interventions that continued for at least three days, is smaller in magnitude than the contemporaneous coefficient but also negative in sign (-0.0911). Thus, it adds to the simultaneity problem of interventions on exchange rate movements. Large interventions, however, had an offsetting effect as shown by the positive and significant coefficient, a_{size} (0.4263). The magnitude of the size dummy coefficient is larger than that of the contemporaneous coefficient, suggesting that on the days of large interventions the overall effect of large interventions was positive—the purchase (sale) of each Yen 100 billion led to a 0.03% Yen appreciation (depreciation), provided the intervention exceeded Yen 150 billion . This suggests that interventions were effective on these days in moving the Yen/USD rate in the desired direction.

As for the Yen interventions carried out by the US Fed, they had the effect of reinforcing the positive effect on the exchange rate of the above-average purchase interventions of the BOJ. The coefficient, a_{fed}, is significantly positive and nearly three times the size of the coefficients for the contemporaneous and the size dummy effects. Thus, those BOJ interventions that were followed by Fed interventions had the desired effect of moving the exchange rate in the right direction. This suggests that markets give credibility to interventions, particularly when they are large and involve two of the world's biggest central banks.

Intervention also has a significant effect on the conditional variance of exchange rate returns. Although the contemporaneous effect, b_{intv}, on this volatility measure is positive, once again this could be due to the simultaneity problem. That is, the observed association of higher volatility with interventions may be because those interventions were prompted by high exchange rate volatilities. Applying our dummy technique, we find the cumulative intervention effect is insignificant, while the size effect and the Fed intervention effect are significant and negative. The parameter estimates imply that, although normal interventions were associated with higher conditional volatility of exchange rate returns, this contemporaneous effect was nearly offset on the days of larger interventions. If the BOJ interventions were followed by Fed interventions, a significant drop in the conditional volatility is observed.

The effects of the interventions on trade volumes, α_{intv}, are shown to be similar to the exchange rate volatility effect. That is, the contemporaneous effect is positive, but the other dummy intervention coefficients are negative. The effect of a normal intervention was to raise the trading volume, however, if interventions were large and continued on a number of days, a slight fall in the volume occurred. The Fed intervention also added to this offsetting influence. This is similar to the volatility effects reported above. Lower volumes (and volatility of volumes) on those unusual intervention days indicate a successful calming operation by the central bank.

The feedback variables in the conditional mean equations are all significant except for the effect of the lagged error of volume on exchange rate returns. However, the responses of conditional variances to lagged errors (own and the other variable's) are generally insignificant. It is widely believed that volumes and the returns volatility are positively correlated. However our EGARCH results indicate that unexpected volumes have an asymmetric effect on the conditional variance of returns. If volumes are unexpectedly low, then the conditional variance is significantly lower. However, unexpectedly high volumes do not lead to higher conditional variance when that volume is very high.

The holiday effect is strongly present in all cases. In general, the Yen depreciated and the volatility was higher on the trading days following a market closure. Interestingly, both the first and second moments of detrended volume were significantly lower on these days. Finally, the effect of the interest rate differential is positive and significant as expected—a higher interest rate differential in favour of the US led to a USD appreciation on the day.

Sub-Sample One

The first sub-sample was a period of frequent and small interventions. The contemporaneous effect on exchange rate returns is still negative and significant. While cumulative intervention is now positive and significant, it is insufficient to outweigh the contemporaneous effect. The size dummy is now not significant, suggesting that BOJ activity did not reach critical size in this sub-sample. However those BOJ interventions that were followed by the US Fed interventions in the same direction produced the desired effect (a Yen appreciation (depreciation) from an intervention purchase (sale) of Yen). Once again, coordinated interventions are seen to achieve the goal of affecting Yen movements in the desired direction.

The volatility-increasing effect of contemporaneous interventions on returns is still observed, as is the volatility dampening effect of cumulative interventions. Interestingly, the Fed intervention failed to have any influence on the volatility of returns. Thus, only the unilateral interventions, if carried out over a number of days, had the desired volatility-reducing influence, but on the whole, both unilateral and coordinated interventions were associated with a rise in the conditional variance of the Yen/USD returns.

The effects of intervention on the first and second moments of the detrended trade volume are similar to those observed for the full sample. That is, contemporaneous rises in the volume and the volatility of volume were offset by the cumulative and large interventions. The Fed intervention effect is significant only in the volume volatility. The asymmetric effects of unexpected volume on the conditional variance of returns remain.

Sub-Sample Two

The second sub-sample represents a shift in the BOJ's intervention philosophy. Interventions became less frequent but significantly larger in magnitudes, and therefore had the potential for a more enhanced signalling effect. The contemporaneous effect of the intervention on exchange rate returns is now positive and significant. This is somewhat unexpected considering the full and the first sub-sample estimations exhibited the opposite results[11]. In addition, the size dummy is significant and negative, indicating that the contemporaneously positive impact on intervention is offset on the days of above average interventions. The effects of the Fed intervention are still positive. The overall effects of intervention are thus positive for both unilateral and coordinated interventions. These results suggest that the BOJ's normal intervention activities had reached critical size, but excessively large interventions now became counter-productive.

On the conditional volatility of returns, BOJ interventions failed to elicit any volatility response. However, the US Fed intervention again had a market calming effect, and so on the days of coordinated interventions, the conditional volatilities fell significantly in response to the intervention.

As for the intervention effects on trade volume, both the contemporaneous BOJ and Fed effects are significantly present in both the conditional mean and variance equations, while the Fed effect is also significant in the conditional variance of the trade volume. In short, the intervention activities raised the volume and volume volatility. Finally we still observe a significant asymmetric effect of unexpected volume on returns volatility.

5. REACTION FUNCTIONS OF THE BOJ

In this section we examine the possible determinants of the BOJ interventions. An optimal intervention rule follows from the minimization of

[11] However, similar results are reported by Ito (2002).

a central bank loss function subject to the constraints in equations (1) - (3) and perhaps a constraint on profitability of the central bank. The loss function is assumed to be linear-quadratic in expected deviations and the variance of the exchange rate from a moving target and of deviations of traded volume from its expected value.[12] In general, the optimal intervention rule will depend on features of the exchange rate and trade volume processes, and perhaps on profitability.

A central bank intervenes if it believes it can reduce short-term market disorderliness and if it regards intervention as a monetary policy instrument. Therefore the moving exchange rate target, in the loss function needs to be a weighted average of a short-term trend (or moving average) and a lower frequency target driven by the objectives of monetary policy.

With regard to minimizing short-term disorderliness in the foreign exchange markets for its currency, a central bank might intervene for a number of inter-related reasons—perceived trend correction, volatility smoothing, unexpected high traded volumes, and excessive exchange rate overshooting. Firstly, the central bank might wish to reduce disorderliness by returning the exchange rate to what it perceives to be the appropriate short-term trend. The aim would be to moderate any high frequency speculative bubbles or bandwagon surges. This requires the central bank to be convinced that it knows the underlying trend. This high frequency activity can be associated with the widely used term, 'leaning against the wind'. However if the 'wind' blows too fiercely, we might expect the central bank to recognize that its intervention may be futile.

Disorderliness may show up as excessive fluctuations in exchange rates through higher volatility or through unexpectedly high traded volumes that arise in periods of greater uncertainty. The central bank may intervene to calm the market, by trying to reduce the uncertainty. Again, we might expect that there is a threshold of disorderliness beyond which a central bank would back away from the market. In these circumstances, the volatility and trading volumes may be sufficiently large to swamp any attempts by the central bank to calm the market. In these circumstances, their interventions would be ineffective, and would be likely to inflict serious losses on the central bank. We test to see whether derived measures of conditional volatility of the spot exchange rate changes and unexpected traded volumes have this non-linear influence on intervention.

Even if the central bank acts from time to time to reduce disorderliness, it may choose to use intervention as an additional instrument to achieve domestic monetary policy objectives. This manifests from our assumption that a component of the moving exchange rate target in the loss function is associated with monetary policy objectives. Since we cannot identify this component, we model it in our intervention function by including daily changes of the US and Japanese overnight interest rates, which are the major instruments of monetary policy. However these measures may also pick up the possibility that the central bank reacts to curb excessive over-shooting in the exchange rate brought on by changes in the interest rate differential.

In addition to the trend correction and volatility/volume reducing motives, cumulated profits/losses generated as a result of continued intervention activities may act as a constraint (or an incentive) for continued loss-making interventions. Thus, an appropriately defined cumulative profit/loss measure may prove to be important in modelling the BOJ intervention activities.

5.1 Measurement and the Effects of Short-term Trend Deviations

Central banks do appear to undertake 'leaning against the wind' interventions, whenever current exchange rate movements deviate significantly from a short-term trend. This trend might be modelled as a moving average. Following LeBaron (1999), who justifies his choice of 150 days as being commonly used by market traders, we use a 150 day window. The short-term trend deviation, $ERDEV_t$, becomes the difference between the current Yen/USD exchange rate (ER_t) and its 150 day moving average as below:

$$ERDEV_t = ER_t - \tfrac{1}{150}\sum_{i=0}^{149} ER_{t-1} \qquad (4)$$

[12] Almekinders and Eijffinger (1996) explain the steps for solving for an intervention rule, but without volume effects.

The time series plot of $ERDEV_t$ is shown in Figure 3 (Panel A). We expect that a positive deviation (or a depreciation of the Yen relative to the trend) would lead to a negative intervention (purchase of Yen) by the BOJ to try and correct the movement away from the short-term trend. We would expect the estimated parameter of the effect of trend deviations to be negative. Furthermore, the BOJ may be expected to engage more intensively (or perhaps less, if size has an overwhelming effect on the central bank) if deviations are sizeable.

5.2 Measurement and the Effects of Conditional Volatility

We generate a series for conditional volatility (h_t) from the bivariate EGARCH model discussed above, and use it in subsequent estimations as a possible determinant of intervention behavior (see Panel B of Figure 3). If the Yen is depreciating on a particular day, and the measure for the volatility of returns rises, we expect the central bank to attempt to calm the market by purchasing Yen. Conversely on days of a strengthening Yen, it will sell Yen to calm the market. Therefore we expect the estimated parameter for the effect of volatility to be negative. Once again, we admit the possibility of above-normal size effects on the central bank's response.

5.3 Measurement and the Effects of Unexpected Volume

Detrended volume is also potentially useful for modeling the intervention behaviour of a central bank. Volume movements may have enough information content for a central bank to initiate or moderate intervention activities. In line with the mixed distributions hypothesis (discussed in the introduction), a distinction would be made between expected and unexpected volume changes. A central bank would not activate or modify its intervention activities in response to expected volume changes. Only unexpected changes in volume would gain the attention of the central bank. We further conjecture that only positive unexpected changes would matter. Negative changes, which represent days when volumes are unexpectedly low, would be of little concern to the central bank. Therefore we use the estimated positive residuals, $\hat{\varepsilon}_t^{+}$ from the E-GARCH regressions of (1)-(3) as our measure of unexpected volume, $UnexpVM_t$. If this measure goes up, and the Yen is depreciating, the central bank will be particularly concerned about the rapid selling off of the Yen, and so it will reduce its Yen sales. If the Yen is appreciating on a day of unexpected high volume, Yen sales will be increased. Therefore we expect the estimated parameter of the effect of unexpected volume to be negative. Again abnormal size effects may matter.

5.4 Measurement and the Effects of Interest Rate Changes

Interest rate changes are daily change in overnight interest rates of the US and Japan. These overnight rates are proxies for monetary policies in each country—changes in these rates signal adjustments in the monetary policy stance. They are shown in panel C and D of Figure 3, respectively. Consider two arguments why interest rates may matter.

The first is that the interest rate differential may lead to overshooting exchange rates, which may be excessive if there are perceived to be band-wagon effects. This would suggest that the estimated coefficient of the Japanese interest rate on intervention would be positive (and negative for the US interest rate).

The second argument is that foreign exchange intervention may operate as a support for domestic monetary policy. In the first sub-sample, short-term interest rates in Japan and the US fell together until mid-1993, but for the next two years, they changed little in Japan (having reached 2%) but rose substantially in the US to reduce inflationary pressures. Throughout this sub-period, the appreciating Yen created a problem for the Japanese economy that had already begun (in 1992) its protracted slump in output growth. In the latter part of the first sub-period, the BOJ began to buy USD assets rather than reduce its interest rate, and so there was a positive correlation between its intervention and the rising US interest rates. For Japan in the second sub-sample, the overnight interest rate gradually approached zero, suggesting a liquidity trap. Therefore we conjecture that foreign exchange intervention became an increasingly viable alternative to domestic open-market operations for achieving the objectives of monetary policy. As the Japanese interest rate fell towards the zero bound, Yen sales for USD by the central bank were likely to have increased to weaken the exchange rate to help stimulate the slumping Japanese economy. Thus this argument leads us to expect the estimated parameter on the Japanese interest rate to be negative, in the second sub-sample

5.5 Measurement and the Effects of the Profitability of Intervention

In general, central banks do not disclose full information on their portfolio of international reserve assets and liabilities. It is therefore difficult for outsiders to properly assess the profitability of their operations. However the trend towards disclosing the size of their daily interventions on foreign exchange markets has made it possible to get some perspective on the issue. We measure the conditional profit of all past interventions, starting at an arbitrary point (which we choose as the beginning of the sample), by computing the current net value of every past intervention and summing them up:

$$CPROFIT(t) = \sum_{i=1}^{m} Intv_{t-i}\left[\prod_{j=1}^{i}(1+i_{t-j}^{US})ER_t / ER_{t-i} - \prod_{j=1}^{i}(1+i_{t-j}^{J})\right] \quad (5)$$

The cumulative intervention profits for BOJ are shown in panel E of Figure 3. If the exchange rate was depreciating when profitability rose, one might expect a central bank to feel comfortable about defending the currency. Conversely, in an appreciating scenario, it would sell the currency. This suggests that the estimated parameter for the effect of profitability should be negative. If positive, it would provide evidence that the central bank sometimes behaves like any other dealer in the foreign exchange market.

The resulting intervention function is as below.

$$\begin{aligned} Intv_t &= (\alpha_c \cdot I_{dev,t-1} + \alpha_{ERsize} \cdot I_{ERsize,t-1}) \cdot \left|ERDEV_{t-1}\right| \\ &+(\beta_c \cdot I_{ds,t-1} + \beta_{hsize} \cdot I_{ds,t-1} \cdot I_{hsize,t-1}) \cdot h_{t-1} \\ &+(\gamma_c \cdot I_{ds,t} + \gamma_{VMsize} \cdot I_{ds,t} \cdot I_{VMsize,t}) \cdot UnexpVM_t \\ &+\psi_{JP} \cdot \Delta i_t^{JP} + \psi_{US} \cdot \Delta i_{t-1}^{US} + \phi \cdot I_{ds,t-1} \cdot CPROFIT_{t-1} + \varepsilon_t \\ &= f(...) + \varepsilon_t \end{aligned} \quad (6)$$

where

$I_{dev,t}$ = An indicator variable that takes the value of positive (negative) one if $ERDEV_t$ is positive (negative) and zero otherwise. If positive, the Yen is on a down-trend and is depreciating against the USD.

$I_{ERsize,t}$ = An indicator variable that takes the value of positive (negative) one if $ERDEV_t$ is positive (negative) and by more than 5%, and zero otherwise.

$I_{ds,t}$ = An indicator variable that takes the value of positive (negative) one if the daily exchange rate change (ΔER_t) is positive (negative), and zero otherwise. If positive, the Yen is depreciating against the USD.

$I_{hsize,t}$ = An indicator variable that takes the value of one if the current conditional variance is higher than the unconditional (or average conditional) variance for each sample.

$I_{vmsize,t}$ = An indicator variable that takes the value of one if the trading volume on day t is higher than the sample average for each sample

Δi_t^{JP} = Daily change of Japanese official discount rate.

Δi_{t-1}^{US} = Daily change of the US federal fund rate.

$CPROFIT_t$ = Conditional profits of intervention against the USD in domestic currency

ε_t = Standard normal error

The intervention function shown in (6) represents the BOJ's desired intervention in the absence of fixed costs of intervention. Since we observe that there is zero intervention on most days (about 93% of days excluding weekends) and very few small interventions, it is reasonable to test for these fixed costs by considering upper and lower thresholds for intervention. Labeling these threshold values as θ^+ and θ^-, actual positive intervention will take place if the expected value of the intervention function in (6) is greater than θ^+, and negative intervention if the value is less than θ^-. Otherwise actual intervention is zero. This threshold model, which is called a friction model due to the fixed costs, can be estimated using quasi-maximum likelihood with the likelihood function given by:

$$L = \prod_{Intv_t>0} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\varepsilon_t+\theta^+)^2}{2\sigma^2}\right) \cdot \prod_{Intv_t=0} \left(\Phi\left(\frac{\theta^+ - (Intv_t - \varepsilon_t)}{\sigma}\right) - \Phi\left(\frac{\theta^- - (Intv_t - \varepsilon_t)}{\sigma}\right)\right) \cdot \prod_{Intv_t<0} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\varepsilon_t+\theta^-)}{2\sigma^2}\right)$$

where Φ is the standard normal cumulative density function.

5.6 Estimation Results for the Friction Model

Table 4 reports the estimation results of the friction model. The two sub-samples as well as the full sample results are reported.

The average effect of the exchange rate deviations on the intervention activities is negative and significant in all samples. This is what one expects if a 'leaning against the wind' type of intervention is at work. Evidently the BOJ reacted to overnight deviations from a short-term (150 day) trend and stepped in to correct these. The magnitude of the coefficient in the second sub-sample is about 7 times that in the first. This reflects the larger magnitudes of intervention—the average intervention of was Yen 502 billion in sub-sample two compared to 47 billion in the first).

In the full sample, these 'leaning against the wind' interventions were partially offset by the positive coefficient for above-normal deviations. This is consistent with the idea that when a deviation is of a particularly large magnitude, the central bank becomes less sure that it is seeing a random disturbance or that it has the resources to combat the disturbance. However, the overall effect of exchange rate deviations remained consistent with a 'leaning against the wind' motive for intervention. When we examine the two sub-samples, the size effect was significant in the first only, and halved the response of the BOJ. These results support our rationale for a structural break in mid-1995.

Exchange rate volatility had a significant negative influence on intervention in the full sample and in sub-sample one. This indicates that a combination of a Yen depreciation (in excess of the short-term trend) and a high conditional volatility encouraged BOJ purchases of Yen. There were no significant size dummy effects on conditional variance. We found no volatility effects in the second sub-sample. This might suggest that the BOJ was not concerned with the general state of the foreign exchange market. However the next result that we report suggests otherwise.

Unexpected trading volume had a significant negative effect on intervention only in sub-sample two. This result lends support to a 'leaning against the wind' stance. If the traded volume was unexpectedly large on a day of a depreciating Yen, the BOJ purchased Yen. This was partially offset by the positive size dummy coefficient, which was marginally significant (at .08). This implies that trend-correcting interventions were seen to be less productive on the days of especially high volume, and so the BOJ backed off the foreign exchange market.

The Japanese interest rate changes had a significant negative effect on BOJ intervention in the second sub-sample only. The negative coefficient indicates that a rise in the rate led to a USD sale (Yen purchase), which suggests that BOJ interventions were used in support of the domestic objectives of Japanese monetary policy. The magnitude of the coefficient, suggests a Yen 5.569 trillion sale of Yen in response to a one percentage point cut in the Japanese discount rate. This large value is not surprising due to the combination of the very large magnitudes of interventions (average of Yen502 billion) and very low discount rates (0.5% for the most of sub-sample two). In short, changes in the official interest rate were supplemented by large BOJ interventions in the direction of the desired exchange rate movements.

US interest rate changes were marginally significant (at 0.08) only in the first sub-sample. The positive coefficient suggests an intervention purchase of USD (sale of Yen) in response to a rise in the US Federal funds rate—thus this intervention was governed, as conjectured, by the objectives of Japanese monetary policy. A one percentage point (100 basis points) rise in the US interest rate led to a Yen 18.6 billion sale by the BOJ. This is a small response compared to that in the second sub-sample in response to the Japanese interest rate. It does imply that the BOJ acted on foreign exchange markets (but not in domestic asset markets) to try to depreciate the exchange rate, thus amplifying the desired effects of the tightening US monetary policy stance.

The cumulative profits from interventions are shown to be positive and significant in the full sample and in sub-sample two. The positive sign indicates an intervention sale of Yen when a higher profit is associated with a Yen depreciation. This might suggest that the BOJ acted like any other profit-driven dealer that reduces its exposure to a weakening asset. As its profitability rose, the BOJ was encouraged to use intervention more for its monetary policy objectives than for the purpose of stabilizing the foreign exchange market.

Both the negative and positive thresholds are significant in all three samples. They are considerably larger in magnitude in the second sub-sample (approximately 30 times the size) compared to the first. This suggests that the BOJ practiced more restraint in the later sub-sample only coming into the market when a significantly higher threshold was breached on either side. Not only were the less frequent interventions considerably larger in size in sub-sample two, the estimated error variance was seventeen times larger.

In short, our evidence suggests that BOJ interventions were motivated by both a desire to correct market disorderliness—via exchange rate deviations from short-term trends, higher volatilities (in sub-sample one only) and higher volume (in sub-sample two)—and to help achieve monetary policy objectives.

6. CONCLUSIONS

The BOJ's intervention activities in the Yen/USD foreign exchange market have been investigated in this paper. We found that the change of intervention philosophy by the BOJ around July 1995 resulted in successful market responses to its intervention transactions.

Before 1995, BOJ interventions were small and frequent and the contemporaneous daily movements of the Yen/USD exchange rate in response to intervention transactions were in the wrong direction (intervention purchases of the Yen depreciated it). However, the desired effect occurred on days with both large denomination interventions and those reinforced by the US Fed. The positive effect of these small unilateral interventions does not necessarily mean that these interventions were counter-productive, but it adds to the agnosticism about the desirability of intervention. The effects on trade volumes were similar—volume was successfully calmed only on unusual days of large, sustained and coordinated intervention.

After 1995, interventions were less frequent and substantially larger in size. In contrast to results widely obtained in the literature, the contemporaneous effects of these large interventions were to move the exchange rate in the desired direction. The US Fed again added to the effectiveness of the BOJ interventions. The contemporaneous effect on the conditional volatility of the exchange rate was positive in both sub-samples, suggesting a higher volatility was associated with interventions. However, an offsetting influence was found on the days of cumulative interventions in the first sub-sample, and the US Fed interventions had market calming effects in sub-sample two. In this period, intervention had no significant effect on volume levels, but it did significantly exacerbate the conditional variance of volumes. Overall our results suggest that while small interventions could be destabilizing, large, sustained and coordinated interventions work.

The BOJ interventions were motivated by short-term trend-correction in both sub-samples, and there is evidence that on days of persistent deviations the BOJ stayed out of the market in the first sub-sample. Higher conditional volatility or volume also elicited 'leaning against the wind' interventions. In general, the BOJ seemed to have consistently responded to correct short-term disorderliness.

Finally, after mid-1995, BOJ intervention responded significantly to changes in the Japanese interest rate—a reduction in the rate was accompanied by sales of Yen. Thus, with interest rates approaching zero, the BOJ used foreign exchange intervention in support of the objectives of its monetary policy. We are thus able to conclude that the BOJ's intense interventions post-1995 had significant desirable effects on the foreign exchange market, and these successful actions were in part motivated by domestic monetary policy objectives.

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APPENDIX

Figure 1: Market Opening Hours of the Tokyo and New York Foreign Exchange Markets

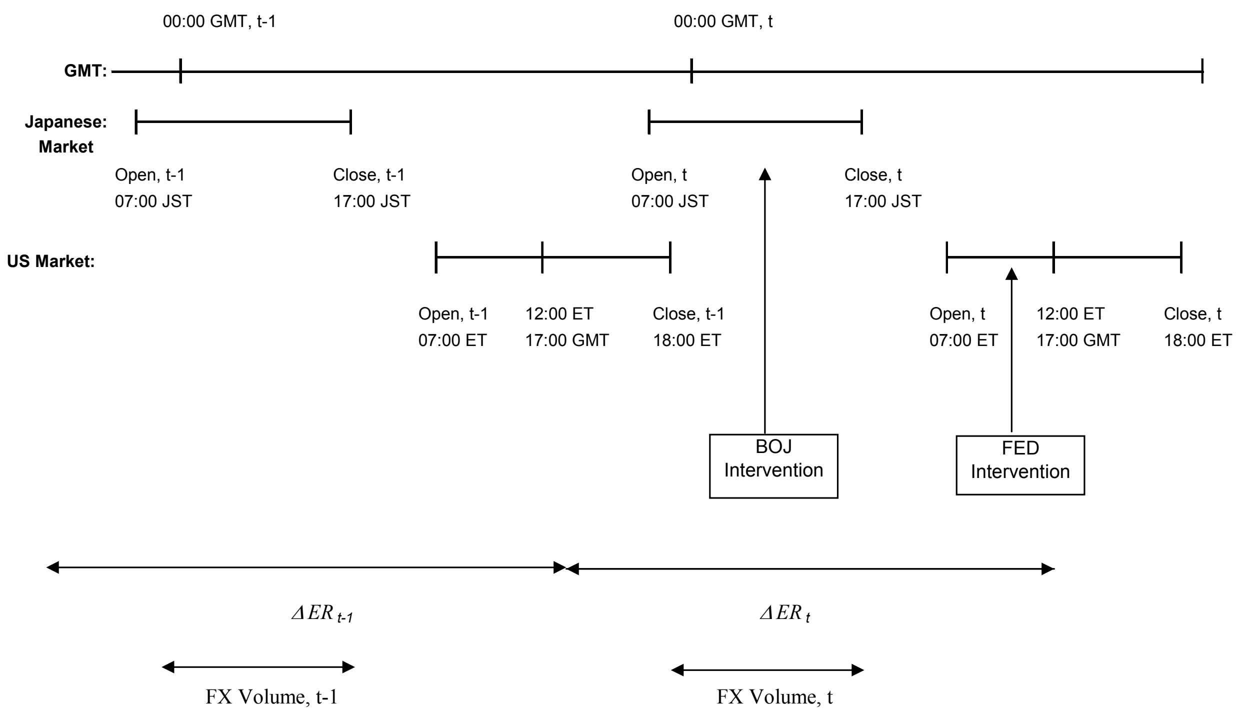

Figure 2: Yen/USD exchange rate, trade volume and Yen interventions

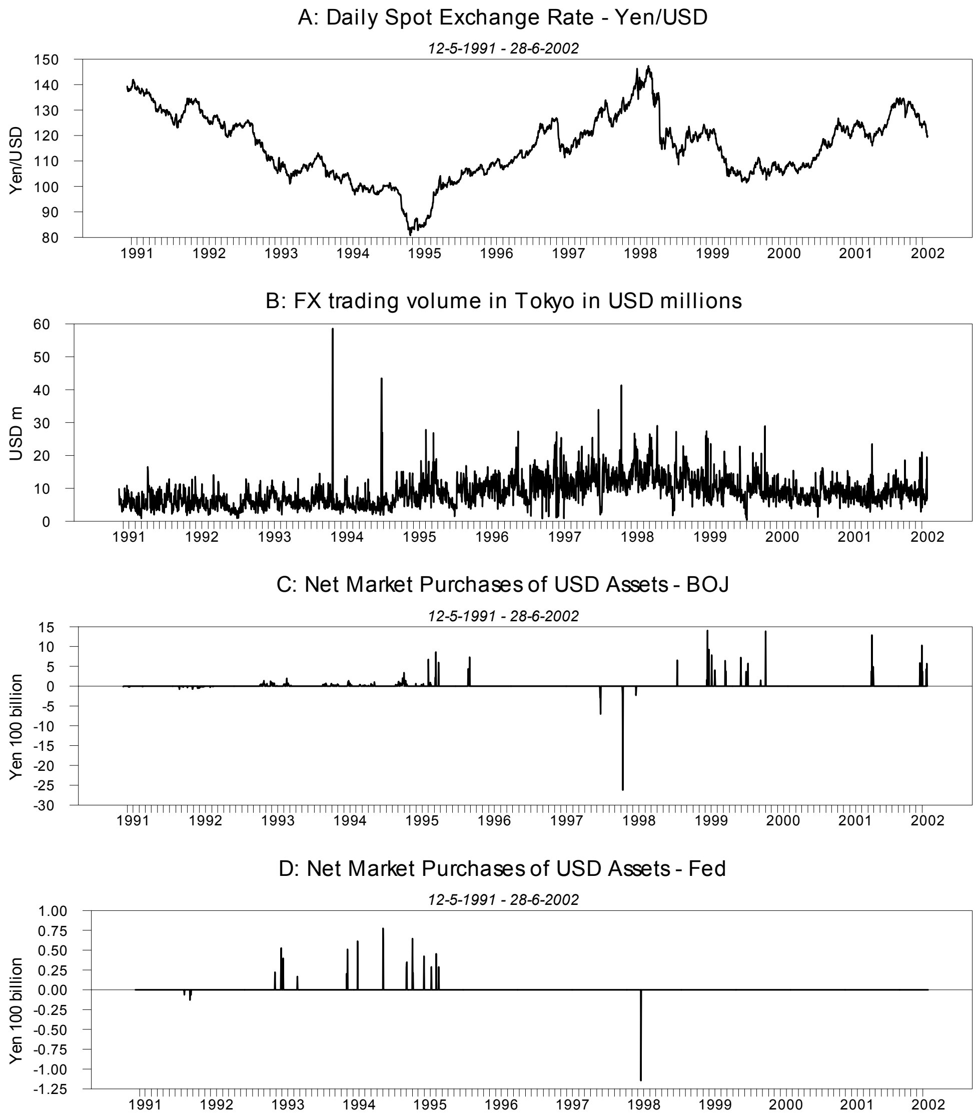

Figure 3: Determinants of Interventions

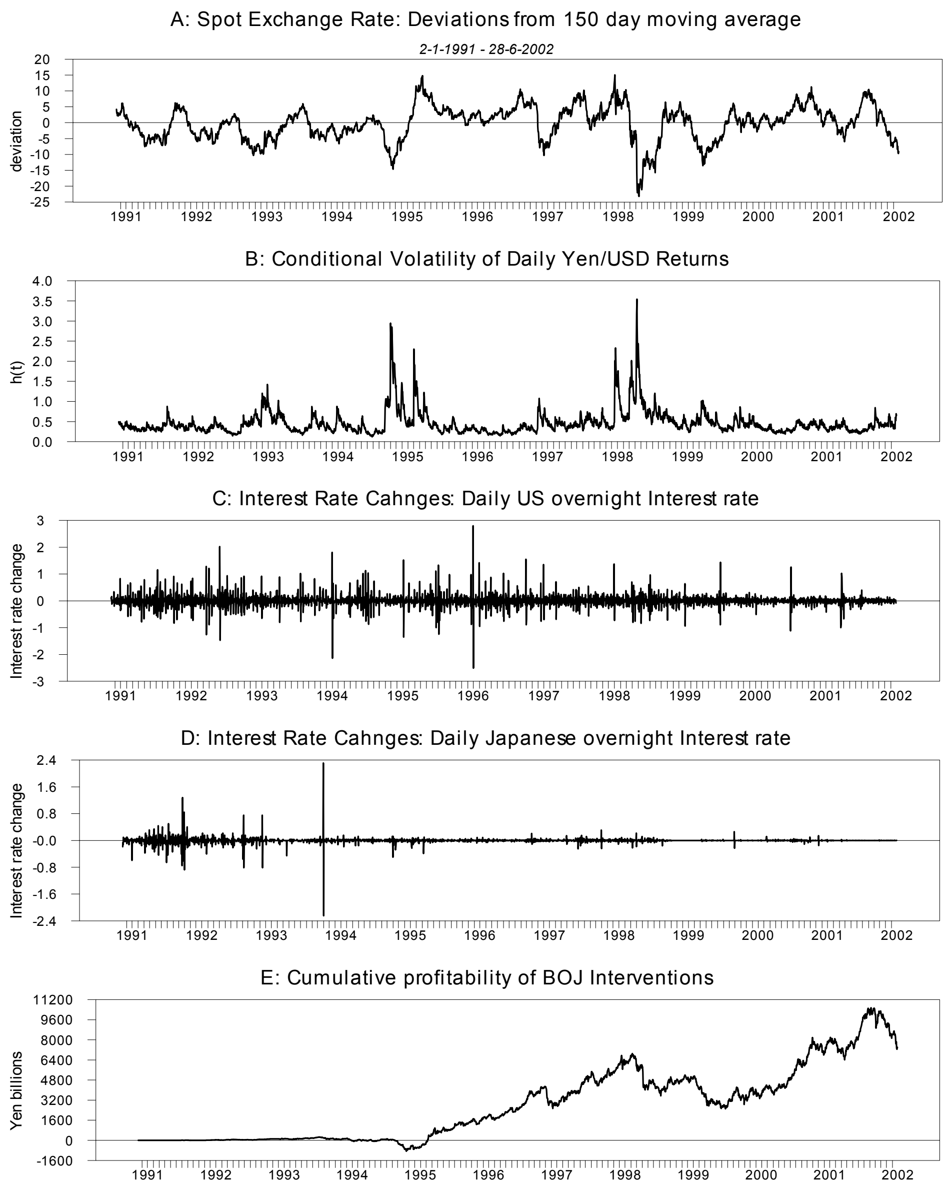

Table 1: Summary Statistics of Yen/USD returns and Detrended Volume of Tokyo Market

	Full Sample: 13 May 1991 to 28 Jun 2002		Sub-sample 1: 13 Jan 1991 to 20 Jun 1995		Sub-sample 2: 21 Jun 1995 to 28 Jun 2002	
	ΔER	Det-VM	ΔER	Det-VM	ΔER	Det-VM
Summary Statistics						
Mean	-0.005	-0.150	-0.041	-0.727	0.019	0.421
Variance	0.51	16.40	0.41	15.64	0.57	16.78
Skewness	-0.64	2.32	-0.45	3.98	-0.74	1.25
Excess Kurtosis	5.15	15.87	3.46	37.55	5.35	3.96
J-B Normality	3409	33083	620	71513	2354	1674
Tests of iid(1)						
Q(20)	22.5 **	2852.9 **	34.2 **	1655.2 **	32.7 **	2004.1 **
	{0.01}	{0.00}	{0.02}	{0.00}	{0.04}	{0.00}
$Q^2(20)$	383 ***	419 ***	101 ***	204 ***	340 ***	207 ***
	{0.00}	{0.00}	{0.00}	{0.00}	{0.00}	{0.00}
$Q_b(10) : \chi^2(40)$	5495 ***	***	1181 ***	***	2528 ***	***
	{0.00}		{0.00}		{0.00}	
$Q_b(10) : \chi^2(40)$	2234.25 ***	***	272.02 ***	***	979.87 ***	***
	{0.00}		{0.00}		{0.00}	
Unit Root Tests(2)						
ADF	-53.5	-14.2	-53.0	-31.8	-53.0	-14.1
Granger Causality Tests						
H0: ΔER does not cause VM	4.95		7.03		16.68 ***	
	{0.42}		{0.22}		{0.01}	
H0: VM does not cause ΔER	16.93 ***		7.38		6.76	
	{0.00}		{0.19}		{0.24}	
H0: $(\Delta ER)^2$ does not cause VM	15.52 ***		12.67 **		118.94 ***	
	{0.01}		{0.03}		{0.00}	
H0: VM does not cause $(\Delta ER)^2$	73.30 ***		6.56		15.46 ***	
	{0.00}		{0.26}		{0.01}	

(1) Linear and non-linear (squares) Portmanteau test (Box-Ljung)
Bivariate portmanteau test of joint white noise is carried out as below:

$$Q = T^2 \sum_{i=1}^{p} \frac{Tr(\hat{C}_i \hat{C}_0^{-1} \hat{C}_i \hat{C}_0^{-1})}{(P-i)}$$

where

$$\hat{C}_i = \frac{1}{T} \sum_{t=i+1}^{T} (\hat{\varepsilon}_t \hat{\varepsilon}_{t-i}), \quad \boldsymbol{\varepsilon}_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

T = no. of observations
P = no. of lags
Q ~ χ^2 with $d.f. = 4.P$

(2) Augmented Dickey-Fuller test with constant and trend and appropriate lags to render white noise innovations in the test equation. Lags used are 0 and 4 for ΔER and VM, respectively. Test statistic at 5% is -3.41.

Table 2: Intervention Statistics

	BOJ			FED		
	Full Sample: 13 May 1991 to 28 Jun 2002	Sub-sample 1: 13 Jan 1991 to 20 Jun 1995	Sub-sample 2: 21 Jun 1995 to 28 Jun 2002	Full Sample: 13 May 1991 to 28 Jun 2002	Sub-sample 1: 13 Jan 1991 to 20 Jun 1995	Sub-sample 2: 21 Jun 1995 to 28 Jun 2002
Number of days of Interventions						
Positive	180	139	41	18	15	3
Negative	33	27	6	4	3	1
Total	**213**	**166**	**47**	**22**	**18**	**4**
Unilateral BOJ Interventions	191	148	43			
Co-ordinated interventions	22	18	4			
Average Size of Intervention (in Yen bn)						
Positive	149.9	50.2	488.0	39.3	40.3	34.4
Negative	-148.3	-29.2	-684.4	-35.0	-8.5	-114.6
Total (average of absolute values)	**149.1**	**46.8**	**513.1**	**37.2**	**38.5**	**54.5**
Largest Intervention (in in Yen bn)						
Positive	1405.9	338.8	1405.9	77.5	77.5	45.4
Negative	-2620.1	-76.9	-2620.1	-114.6	-12.7	
Smallest Intervention (in in Yen bn)						
Positive	5.1	5.1	43	16.9	16.9	28.9
Negative	-3.2	-3.2	-76.4	-6.4	-6.4	
Cumulative Intervention Probabilities						
Prb(BOJ-$I_t \neq 0$ | BOJ-$I_{t-1} \neq 0$)	0.53	0.61	0.26			
Prb(BOJ-$I_t \neq 0$ | BOJ-$I_{t-1} \neq 0$ & BOJ-$I_{t-2} \neq 0$)	0.34	0.42	0.09			
Prb(FED-$I_t \neq 0$ | BOJ-$I_t \neq 0$)				1.00	1.00	1.00

Table 3: Bivariate-EGARCH(1,1)-t Model Estimations of Intervention Effectiveness

		Full Sample: 13 May 1991 - 28 Jun 2002				Sub-sample 1: 13 Jan 1991 - 20 Jun 1995				Sub-sample 2: 21 Jun 1995 - 28 Jun 2002			
		ΔER		Detr-VM		ΔER		Detr-VM		ΔER		Detr-VM	
		Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value
ΔER	Detr-VM												
a_c	α_c	-0.028 **	{0.04}	1.699 ***	{0.00}	0.177 ***	{0.00}	4.764 ***	{0.00}	-0.051 **	{0.01}	1.633 ***	{0.00}
	α_{vmer}			0.976 ***	{0.00}			0.980 ***	{0.00}			0.925 ***	{0.00}
a_{erma}	α_{erma}	-0.046 **	{0.01}	1.998 ***	{0.00}	-0.054 **	{0.01}	2.019 ***	{0.00}	-0.033 *	{0.08}	2.466 ***	{0.00}
a_{vmma}	α_{vmma}	0.001	{0.81}	-0.711 ***	{0.00}	0.003 *	{0.09}	-0.644 ***	{0.00}	0.002	{0.65}	-0.682 ***	{0.00}
a_{erh}	α_{erh}	-0.044	{0.12}	-3.223 ***	{0.00}	-0.321 ***	{0.00}	-8.241 ***	{0.00}	-0.044 **	{0.04}	-3.016 ***	{0.00}
a_{vmh}	α_{vmh}	0.011	{0.23}	-0.030	{0.50}	0.002	{0.17}	0.029	{0.41}	0.006	{0.20}	-0.180 ***	{0.00}
a_{hol}	α_{hol}	0.009 *	{0.08}	-0.235 ***	{0.00}	-0.021 *	{0.06}	-0.615 ***	{0.00}	0.023 **	{0.01}	-0.190 ***	{0.00}
a_{idiff}	α_{idiff}	0.011 ***	{0.00}			-0.004	{0.55}			0.013 ***	{0.00}		
a_{intv}	α_{intv}	-0.367 ***	{0.00}	2.393 ***	{0.00}	-0.542 ***	{0.00}	8.342 ***	{0.00}	0.153 ***	{0.00}	0.545 ***	{0.00}
a_{cum}	α_{cum}	-0.091	{0.12}	-0.675 ***	{0.00}	0.425 **	{0.02}	-2.952 ***	{0.00}	-0.142 ***	{0.00}	-0.667	{0.36}
a_{size}	α_{size}	0.426 ***	{0.00}	-1.822 ***	{0.00}	0.089	{0.59}	-2.574 ***	{0.00}	-0.125 ***	{0.00}	-0.104	{0.59}
a_{fed}	α_{fed}	1.260 ***	{0.00}	-1.773	{0.31}	1.658 ***	{0.00}	-0.141	{0.94}	6.693 ***	{0.00}	12.885 **	{0.04}
b_c	β_c	-0.208 ***	{0.00}	0.565 ***	{0.00}	-0.467 ***	{0.00}	0.594 ***	{0.00}	-0.140 ***	{0.00}	0.587 ***	{0.00}
b_h	β_h	0.880 ***	{0.00}	0.765 ***	{0.00}	0.659 ***	{0.00}	0.678 ***	{0.00}	0.887 ***	{0.00}	0.760 ***	{0.00}
b_{ε_er1}	β_{ε_er1}	-0.040 ***	{0.00}	0.036 ***	{0.00}	0.000	{1.00}	0.002	{0.92}	-0.077 ***	{0.00}	0.055 ***	{0.00}
b_{ε_er2}	β_{ε_er2}	0.209 ***	{0.00}	0.314 ***	{0.00}	0.215 ***	{0.00}	0.342 ***	{0.00}	0.215 ***	{0.00}	0.202 ***	{0.00}
b_{ε_vm1}	β_{ε_vm1}	0.059 ***	{0.00}	-0.003	{0.83}	0.062 ***	{0.00}	0.007	{0.83}	0.040 **	{0.02}	-0.046 **	{0.05}
b_{ε_vm2}	β_{ε_vm2}	-0.083 ***	{0.00}	0.248 ***	{0.00}	-0.130 ***	{0.00}	-0.001	{0.99}	-0.056 *	{0.06}	0.312 ***	{0.00}
b_{hol}	β_{hol}	0.070 *	{0.09}	-0.085 ***	{0.00}	0.042	{0.42}	-0.124 **	{0.03}	0.045	{0.22}	-0.063 ***	{0.00}
b_{intv}	β_{intv}	0.303 ***	{0.00}	0.168 ***	{0.00}	0.826 ***	{0.00}	1.517 ***	{0.00}	0.026	{0.17}	0.164 ***	{0.00}
b_{cum}	β_{cum}	-0.007	{0.88}	-0.175 **	{0.04}	-0.424 ***	{0.00}	-0.292 *	{0.09}	0.111	{0.32}	-0.171	{0.12}
b_{size}	β_{size}	-0.294 ***	{0.00}	0.014	{0.77}	-0.108	{0.58}	-0.946 ***	{0.00}	-0.029	{0.34}	0.010	{0.52}
b_{fed}	β_{fed}	-0.310 *	{0.06}	0.638	{0.33}	0.545	{0.10}	-2.869 ***	{0.00}	-0.900 ***	{0.00}	3.683 ***	{0.00}
ρ		-0.049 ***	{0.01}			-0.073 **	{0.02}			-0.025	{0.33}		
d		34 ***	{0.00}			18 ***	{0.00}			83435 ***	{0.00}		
lnL		-10188				-3591				-6416			
$Q_b(10) : \chi^2(40)$		53 *	{0.08}			37	{0.59}			66 ***	{0.01}		
$Q^2_b(10): \chi^2(40)$		11	{1.00}			18	{1.00}			44	{0.30}		

Table 4: Friction Model Estimations of BOJ's Intervention Reaction Function

	Full sample: 13 May 1991 - 28 Jun 2002		Sub-sample one: 13 Jan 1991 - 20 Jun 1995		Sub-sample two: 21 Jun 1995 - 28 Jun 2002	
α_c	-0.291 ***	{0.00}	-0.094 ***	{0.00}	-0.657 ***	{0.00}
α_{ERsize}	0.092 **	{0.02}	0.047 ***	{0.00}	-0.138	{0.49}
β_c	-0.903 *	{0.06}	-0.264 **	{0.04}	1.549	{0.45}
β_{hsize}	0.729	{0.22}	0.097	{0.58}	-2.209	{0.34}
γ_c	-0.123	{0.51}	-0.060	{0.32}	-2.332 ***	{0.00}
γ_{VMsize}	0.092	{0.63}	0.071	{0.25}	1.371 *	{0.08}
ψ_{JP}	0.551	{0.68}	0.176	{0.39}	-55.69 **	{0.04}
ψ_{US}	0.939	{0.13}	0.186 *	{0.08}	1.917	{0.61}
ϕ	0.107 **	{0.02}	0.272	{0.11}	0.686 ***	{0.00}
σ	4.592 ***	{0.00}	0.795 ***	{0.00}	13.607 ***	{0.00}
θ^+	8.100 ***	{0.00}	1.357 ***	{0.00}	28.356 ***	{0.00}
θ^-	-10.823 ***	{0.00}	-1.490 ***	{0.00}	-40.372 ***	{0.00}
Log-L	-1115		-472		-335	