Interventions in the Yen-Dollar spot market: A story of price, volatility and volume

Author/Contributor:

Kim, Suk-Joong; Sheen, Jeffrey

Publication details:

Journal of Banking and Finance

v. 30

Chapter No. 11

pp. 3191-3214

0378-4266 (ISSN)

Publication Date:

2006

Publisher DOI:

<http://dx.doi.org/10.1016/j.jbankfin.2005.12.005>

License:

<https://creativecommons.org/licenses/by-nc-nd/3.0/au/>

Link to license to see what you are allowed to do with this resource.

Downloaded from <http://hdl.handle.net/1959.4/40146> in <https://unsworks.unsw.edu.au> on 2023-04-26

Interventions in the Yen-Dollar Spot Market: A Story of Price, Volatility and Volume**

Suk-Joong Kim*

School of Banking and Finance
The University of New South Wales
UNSW SYDNEY
NSW 2052 Australia
Tel: +61 2 9385-4278
Fax: +61 2 9385-6347
Email: s.kim@unsw.edu.au

Jeffrey Sheen

School of Economics and Political Science
The University of Sydney
NSW 2006 Australia
Tel: +61 2 9351-3075
Fax: +61 2 9351-4341
Email: jeffs@econ.usyd.edu.au

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 3-30-2004. We also estimate a friction model of BOJ's intervention reaction function based on reducing short-term market disorderliness and supplementing domestic monetary policy. Important finding of this study are that: i) we find ineffectiveness of BOJ interventions in influencing exchange rate trends pre-1995, in general, but effectiveness post-1995; ii) FED intervention amplified the effectiveness of the BOJ transactions; iii) interventions amplified market volatility and volumes through a 'learning by trading' process; iv) BOJ's interventions were based on 'leaning against the wind' motivations on the exchange rate trend and volumes; and v) BOJ interventions were vigorously used in support of domestic monetary policy objectives post-1995. Though some of our findings confirm recent studies, our analysis goes deeper to provide new findings with important implications for central banks and foreign exchange market participants.

Keywords: Foreign exchange intervention, Bank of Japan, exchange rate volatility, trade volume

JEL Classification: E44, G14, G15

Published in Journal of Banking and Finance, Vol. 30, No. 11, pp. 3191–3214, 2006.

* Corresponding author

** We wish to thank two anonymous referees for their invaluable comments. The remaining errors, if any, are our own.

1. Introduction

We examine the relations between exchange rate changes, traded volumes and central bank interventions in the Japanese Yen/United States dollar (Yen/USD) market. The Yen/USD was the second most traded currency pair (17% of all global transactions valued at USD1.88 trillion per day in 2004, the €USD having 28%) in 2004 (BIS, 2005). Further, 83% of transactions occurred between foreign exchange dealers and brokers. This suggests 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 (BOJ) and the United States Federal Reserve (FED). The BOJ has been one of the most active central banks in the foreign exchange markets in the last fifteen years. It has the distinction of having made the biggest ever intervention on a day—USD20.3 billion sales on April 10 1998, when all East Asian currencies were depreciating, and Japan, on the brink of a full scale financial crisis, was proposing a massive fiscal expansion package. At the end of 2003, the BOJ had accumulated USD 653 billion of reserves, which represented nearly 22% of all official reserves held globally.

Since the release of the historical intervention data by the BOJ in July 2001, a long list of researchers have investigated various aspects of the BOJ interventions. This literature has tested the intervention effectiveness by determining whether the level and volatility of exchange rate returns are affected in the desired direction, or if prominent trends are reduced (Chaboud and Humpage, 2003, Fatum and Hutchison, 2003, Beine, 2004, Nagayasu, 2004, Frenkel *et al.*, 2005). Possible responses of BOJ's interventions to exchange rate returns have been examined (Ito, 2002, Beine and Bernal, 2004, Frenkel *et al.*, 2004, and Ito and Yabu, 2004). This literature has focused on higher frequency issues in a market environment (Dominguez, 2003). However this focus needs extending in the case of the BOJ, which has used foreign exchange intervention as an alternative instrument to achieve its domestic monetary policy objectives (for example, see (Fatum and Hutchison, 1999, Sellon, 2003, Vitale, 2003). With short-term interest rates close to zero from 1995, intervention to stop the Yen appreciating (and perhaps to engineer a depreciation) was used to prevent further deflationary pressures.

However, there is a growing agnosticism about the ability of a central bank to successfully influence exchange rates. For example, Schwartz (2000) claimed that US and

European monetary authorities no longer believe that intervention works. She challenges the BOJ for its obduracy in pursuing sterilized intervention¹ 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. What evidence exists suggests that interventions sometimes work because of the ‘presence’ effect of a central bank rather than the size of its operations and if it surprises the market. However, if there is going to be good evidence of successful size effects of transparent interventions, the chances are that it will be found from the BOJ’s activities post-1995 when it very actively intervened as a non-traditional alternative to monetary policy implementation. In fact, we report such findings.

Microstructural modelling of financial markets has stressed the relation between asset price returns and volumes. In foreign exchange markets, this suggests that intervention analysis should be extended to incorporate volume processes: interventions ought to matter for volumes, and volumes ought to matter for interventions. Interventions should affect foreign exchange trading volumes because they change underlying market fundamentals—or beliefs about them—and should be reflected in trading activity. Further, central banks are likely to value the signal or information content of transaction volumes in making their intervention decisions. An examination of central bank interventions in the context of both exchange rate returns and volumes has never been done before because data on volumes is not readily available. We address this issue using a measure of trading volume—the daily reported trades by Tokyo foreign exchange brokers to the BOJ. Our joint estimation of exchange rate returns and volumes using a bivariate EGARCH model should not only yield more efficient results than separate estimations, but provide insights into the dynamics of the return-volatility-volume relationships.

The main questions we address are: Was the BOJ able to achieve desirable effects on the trend and volatility of returns and volumes with its interventions? What were the main factors driving the BOJ’s intervention reaction function? Did the BOJ use intervention as a monetary policy instrument, and was it successful in doing so? The main findings of this paper are:

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.

- i) From a model that jointly estimates exchange rate returns and volumes, large and infrequent BOJ interventions after 1995 successfully corrected undesired exchange rate movements. However this came at the price of higher market volatility and volumes.
- ii) 'Coordinated' interventions with the FED were successful only after 1995.
- iii) From estimates of the intervention reaction function, the BOJ did intervene to correct deviations from an exchange rate trend, but this was moderated when there was high unexpected volume (but not exchange rate volatility)
- iv) Lower interest rates had no effect on exchange rate returns before 1995, as the BOJ sold US dollars to stop depreciation of the Yen, but they did cause depreciation (or reduce appreciation) after 1995. Japan found itself in a liquidity trap situation with deflation and a growth slump, and so the BOJ bought USD in unsterilized interventions to encourage depreciation of the Yen.

The results in i) and ii) are largely consistent with the recent literature (Ito, 2002, Chaboud and Humpage, 2003, Nagayasu, 2004), however, we provide further significant insights into the nature of the effectiveness, putting to rest many of the concerns raised in Schwartz (2000). Our reaction function estimations for the BOJ intervention determinants substantially extend those considered by Ito and Yabu (2004), thus providing a more complete analysis of intervention in the Yen/USD market. Accordingly, the results in iii) and iv) represent new and important findings. The results discussed in the paper have important implications for central banks, and for foreign exchange market participants alike.

2. Modelling trading volumes, exchange rate returns and interventions

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. Dealers with superior information can make profitable trades. While no dealer has an information advantage about macroeconomic announcements, 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

for trading. The resulting traded volumes are not public knowledge, and dealers have to trade to get early access to this type of information. This need to trade to build knowledge about the distribution of 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)². As a consequence, inventory risk management becomes crucial, with small order imbalances seen to be translated into multiple orders.³ Thus small liquidity trades plus trades to build knowledge about the spectrum of beliefs get amplified into huge volumes. We shall call this the ‘learning by trading’ story, and will test for its validity.

It makes a difference if changes in transaction volumes arise from other private dealers or from a central bank, since the latter’s motives and influence are quite different. Central bank interventions can be “big news” on the market, especially if they are coordinated. 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. Whenever an intervention occurs, all dealers do not necessarily know. The resulting information vacuum can only be filled by frequent and intelligent trading, leading to price and volume discovery.

Initially, volume information played no role in the microstructure theory. 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. Blume, Easley and O’Hara (1994) argued that the greater the volume, the higher the inferred signal quality⁴. 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.

The empirical literature has documented the existence of a strong positive correlation

² This is also referred to as order flow in the literature, and detailed discussion on this issue can be found in Evans and Lyons (2002) and Bacchetta and Wincoop (2003).

³ 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.

⁴ Admati and Pfleiderer (1988) suggested another possible reason for trading volumes to be informative—transaction costs. However these are surely very low in the Yen/USD foreign exchange market.

between 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 affects both unpredictable volumes and volatility. In our context, this latent variable can be ‘secret’ central bank interventions, which affect both volumes and returns⁵. Results on the joint distribution of returns and volume in the foreign exchange market have been few and varied⁶. Glassman (1987) and Bessembinder (1994) used futures volume from the Chicago International Money Market as a proxy for spot volume, but found no significant effects on bid-ask spreads. Hartmann (1999) used the volume data that we use in this paper—the reported volume transactions of Japanese foreign exchange brokers to the BOJ, and found that unpredictable volumes have a significant positive impact on bid-ask spreads in the Yen/USD market. He also showed that the volume data exhibits significant conditional heteroskedasticity. These results suggest a GARCH model for volumes, and that unpredictable volumes are likely to have an impact on the exchange rate returns process. It is well-established that the exchange rate returns are efficiently modelled as an EGARCH(1,1) process using a Student- t distribution (Hsieh 1989, Baillie and Bollerslev 1989, and Kim and Sheen 2002)^{7, 8}. The evidence on the MDH hypothesis suggests proceeding with a bivariate model for exchange rate returns and volumes. To

⁵ In a survey of 13 OECD central banks, Lecourt and Raymond (2003) reported 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. Some central banks, such as the Swiss National Bank, always choose to announce their intervention activities. For the rationales of secret and announced interventions, and corresponding empirical evidence, see *inter alia* Neely (2001), Dominguez (1998), Kim et al, (2000), and Beine and Bernal (2004).

⁶ Lamoureux and Lastrapes (1990) showed that stock market volume had a significant positive effect on the conditional variance of returns, but Hiemstra and Jones (1994) in an EGARCH context disagreed. Andersen (1996) did find support for MDH with a model of stochastic volatility, showing that the volatility persistence of returns is significantly lowered when volume data is included.

⁷ Though Ito (2002) and Nagayasu (2004) have used GARCH (1,1) models for Yen exchange rate returns, the EGARCH approach provides more efficient estimates.

⁸ EGARCH modeling allows asymmetric volatility responses and we report significant negative asymmetry of exchange rate volatility to shocks (as shown by negative and significant $b_{\varepsilon_{er1}}$) in sample 2 reported in Table 2. This asymmetry is the basis of the ‘leverage effect’ reported in the literature. However, the standard ‘leverage effect’ has less obvious application in the case of exchange rate estimation due to the symmetric nature of exchange rates. However, the literature reports significant volatility asymmetry in the GARCH family of estimations on exchange rates (e.g. Hsieh, 1989, Kim, 1999, Kim et al 2000, McKenzie, 2002), including our own. Movements of exchange rates at times can be determined mostly by developments in one country rather than both. For example, the Yen may depreciate against the USD in response to worsening domestic conditions in Japan with no material changes in the U.S. In addition, if exchange rates are determined mostly by capital flows in the short run, asymmetric investment flows may lead to observed asymmetric volatility effects. For instance, foreign investors might at times determine the movements of the target market currency, and then increased volatility necessitates additional returns—hence the leverage effect.

see if the 'learning by trading' hypothesis is valid, we can test whether unpredictable volumes impact on the conditional means and variances of the returns process, and vice-versa⁹. We can also test whether foreign exchange interventions 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, which biases the estimates *downward*. 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 intervention¹⁰. This problem will apply equally when we are testing whether intervention has a stabilizing effect on trade volumes. In this paper, we use dummy variables for large-sized, cumulative and coordinated interventions to try to identify effectiveness in episodes when the bias is minimal¹¹. However, since the BOJ significantly raised the intensity of its interventions after mid-1995, it is quite possible that the downward bias from the simultaneity problem will be overwhelmed, and that we might obtain evidence of the desirable effectiveness of intervention.

When central banks intervene in a high frequency context, their primary objective is usually to eliminate any perceived disorderliness in the 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

⁹ Since the volume measures are 'unsigned' in the sense that we do not know if trades were buyer- or seller-initiated, we should not expect significant correlation between unexpected exchange rate returns and volumes.

¹⁰ There have been three imperfect approaches to resolving this problem. The first assumes that intervention affects the exchange rate with a lag (for example, see Baillie and Osterberg, 1995, Lewis, 1995 and Beine, 2004), but this is unsatisfactory because interventions happen in real time. In a second approach, Kim and Sheen (2002) introduced dummy variables for cumulative, large-sized and coordinated interventions to see whether the isolation of these unusual interventions can sidestep the downward bias induced by simultaneity. In a third approach, Kearns and Rigobon (2005) used simulated GMM estimates, making an identifying assumption that central bank intervention policy had an exogenous structural shift of greater response intensity within the sample. Their moment-adding approach is promising, but the identifying policy shift is assumed to be an exogenous process, and also it ignores exchange rate heteroskedasticity. The last two of these approaches have provided evidence indicating that interventions have been stabilizing.

¹¹ Given the large turnover in the Japanese foreign exchange market—the BIS (2005) reported a daily average of USD199billion in USD equivalents in April 2004, with the Yen/USD accounting for 18.8% of all USD transactions—the size of an intervention has to be big enough to be able to move the 'equilibrium' exchange rate.

perhaps the moderation of an excessive overshoot.¹² However, significant developments from the microstructure literature have alerted analysts to the possible importance of volume measures. It seems sensible that a central bank might extend its signals for disorderliness to include information on traded volumes. Thus we suggest that a central bank might want to intervene if volumes are unexpectedly high. Even if indicators on exchange rate returns are not yet suggesting a disorderly market, unusual volume may be a useful early predictor of future disorderliness. If apparently excessive exchange rate changes are occurring without any unusual volume effects, this would suggest market agreement, and a central bank would be less likely to regard these exchange rate changes as undesirable. If both returns and volume are giving unusual signals, a central bank should be convinced that an intervention is appropriate.

Since volumes might be informative for the intervention decision of the central bank, it needs to be able to obtain this information. It can do this by acquiring regular transaction reports from private dealers or brokers under their supervision, and/or it can do it by trading directly in the market. The BOJ does both. Regarding the former, 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. For intra-daily intelligence, a central bank, like any other dealer, needs to participate in the market. Therefore, it should not be surprising if there are many days when a central bank is in the market, but not having any apparent effect. By these seemingly innocuous trades, it is able to learn about market conditions.

3. Data characteristics

The Yen/USD exchange rate is the Tokyo opening spot rate and the volume data is the spot market transaction volume in the Tokyo foreign exchange market as reported by brokers to the BOJ and measured in USD millions. The Yen/USD rate data is sourced from Bloomberg and the volume data from Datastream. The Bank of Japan (2000) states that the Ministry of Finance in

¹² 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, 2003), Baillie and Osterberg (1998), Kim and Sheen (2002), Ito (2002), Kearns and Rigobon (2005), and Ito and Yabu (2004).

consultation with BOJ officials make intervention decisions on the basis of overnight and daily exchange rate developments and so the known exchange rate just before the interventions is the Tokyo opening rate. Thus, we use the Tokyo opening rate so that not only the BOJ interventions but also the US FED interventions are relevant when calculating daily returns. The relevant daily holding period that will contain both the BOJ and FED interventions on calendar day t is from the opening rate at t to the opening at $t+1$ ¹³. 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 interventions by the BOJ (both in the Tokyo and foreign – European and the US - markets) and the US FED interventions are enclosed in the daily holding period we use. The daily exchange rate returns are then measured as continuously compounding returns, $R_t = \ln(S_{t+1}^{Open} / S_t^{Open}) \times 100$, where S_t^{Open} is the spot Yen/USD rate measured as units of Yen per US Dollar and observed at the market opening in Tokyo.

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 JST¹⁴. 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-meanned) volume, VM_t ¹⁵.

Panel A of 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, leptokurtic, and linearly and non-linearly serially correlated. Granger 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.

The intervention data cover the period 13 May 1991 to 16 March 2004 containing 344

¹³ As a robustness check, we also examined an intradaily holding period (Tokyo open to close on day t). Apart from slightly larger magnitudes of intervention coefficients, there is little difference from the daily estimations we report in section 4. We thank an anonymous referee for pointing this out.

¹⁴ The daily average of our broker volume in 2003-4 represented just over 70% of the daily turnover in Japan reported by the BIS (2004). 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. 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.

¹⁵ 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.

BOJ and 22 US FED interventions in the Yen/USD market. The BOJ's and the FED's intervention in the Yen market are publicly available¹⁶ and they are recorded as net market purchase of USD assets in billions of Yen. The full sample is split into two (sub-) samples on 20 June 1995 (see Ito, 2002) 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. Panel B of Table 1 reports the intervention statistics for the full and the two sub-samples. For the full sample, there were 344 interventions (311 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 average size of the intervention is Yen 198.5 billion. Given BOJ intervention on a day, the probability of another intervention in the same direction the following day is 62%, and 44% the next day. 78% of the interventions were concentrated in sample one, but the average size of transactions increased drastically, with Yen sales (purchases) increasing from Yen 50.2 (29.2) to 328 (684.4) billion in sample two. The FED interventions were modest in size compared to the BOJ transactions and concentrated in the first sample.

4. Modeling the effectiveness of BOJ intervention

The statistical features of the data discussed above suggest the returns and volume may be effectively modelled by a suitably specified EGARCH model (Nelson, 1991) with a bivariate t distribution for the residuals. 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 returns and volume are modelled by including feedback effects on conditional means and variances.

The effectiveness of the interventions is examined by including daily intervention variables in the conditional mean and variance equations. The effectiveness may differ for above-average sized interventions and if it persists over a number of days. We test this using a *size*

¹⁶ The BOJ and FED data are available at www.mof.go.jp/english/e1c021.htm and www.newyorkfed.org/pihome/news/forex/. They are released 30 days after the end of each financial quarter.

dummy (that takes the value of one for above-average interventions and zero otherwise), and a *cumulative intervention dummy* (that takes the value of one for days of intervention preceded by intervention on at least two previous days and zero otherwise).

In addition to the intervention carried out by the BOJ, the 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.

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

Conditional Mean Equations

$$\Delta ER_t = a_c + a_{erma} e_{t-1} + a_{vmma} \varepsilon_{t-1} + a_{erh} \sqrt{h_{er,t}} + a_{vmh} \sqrt{h_{vm,t}} + a_{hol} D_{hol,t} + a_{idiff} Idiff_t \quad (1a)$$

$$+ (a_{intv} + a_{cum} I_{CUM,t} + a_{size} I_{SIZE,t}) \cdot Intv_t + a_{fed} IntvFED_t + e_t$$

$$\Delta VM_t = \alpha_c + \alpha_{vmar} VM_{t-1} + \alpha_{erma} e_{t-1} + \alpha_{vmma} \varepsilon_{t-1} + \alpha_{erh} \sqrt{h_{er,t}} + \alpha_{vmh} \sqrt{h_{vm,t}} + \alpha_{hol} D_{hol,t} \quad (1b)$$

$$+ (\alpha_{intv} + \alpha_{cum} I_{CUM,t} + \alpha_{size} I_{SIZE,t}) \cdot |Intv_t| + \alpha_{fed} |IntvFED_t| + \varepsilon_t$$

Conditional Variance Equations

$$\ln h_{er,t} = b_c + b_h \ln h_{er,t-1} + b_{hol} D_{hol,t} + (b_{intv} + b_{cum} I_{CUM,t} + b_{size} I_{SIZE,t}) \cdot |Intv_t| + b_{fed} |IntvFED_t| \quad (2a)$$

$$+ \left[b_{\varepsilon_{er1}} \frac{e_{t-1}}{\sqrt{h_{er,t-1}}} + b_{\varepsilon_{er2}} \left(\frac{|e_{t-1}|}{\sqrt{h_{er,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right] + \left[b_{\varepsilon_{vm1}} \frac{\varepsilon_{t-1}}{\sqrt{h_{vm,t-1}}} + b_{\varepsilon_{vm2}} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{vm,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right]$$

$$\ln h_{vm,t} = \beta_c + \beta_h \ln h_{vm,t-1} + \beta_{hol} D_{hol,t} + (\beta_{intv} + \beta_{cum} I_{CUM,t} + \beta_{size} I_{SIZE,t}) \cdot |Intv_t| + \beta_{fed} |IntvFED_t| \quad (2b)$$

$$+ \left[\beta_{\varepsilon_{er1}} \frac{e_{t-1}}{\sqrt{h_{er,t-1}}} + \beta_{\varepsilon_{er2}} \left(\frac{|e_{t-1}|}{\sqrt{h_{er,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right] + \left[\beta_{\varepsilon_{vm1}} \frac{\varepsilon_{t-1}}{\sqrt{h_{vm,t-1}}} + \beta_{\varepsilon_{vm2}} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{vm,t-1}}} - \sqrt{\frac{2}{\pi}} \right) \right]$$

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

- $D_{hol,t}$ = Seasonal dummy that takes the number of days between two successive observations.
- $Idiff_t$ = 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
- $I_{CUM,t}$ = Cumulative BOJ intervention dummy variable that takes the value of 1 if intervention at t is preceded by intervention in the same direction at $t-1$ and $t-2$, and 0 otherwise.
- $I_{SIZE,t}$ = BOJ intervention size dummy variable that takes the value of 1 if the absolute amount of intervention at day t is greater than the sample average (149.65, 46.75 and 513.05 billion for the full sample, sample one and sample two, respectively) and 0 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.

We consider a conditional bivariate standardized t distribution with variance-covariance matrix

$\mathbf{H}_t$ and d degrees of freedom instead of the customary bivariate normal, thus accounting for possible leptokurtosis in the joint conditional densities (see Bollerslev, 1987 and Hamilton, 1994). 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, $\varepsilon_t = \begin{bmatrix} e_t \\ \varepsilon_t \end{bmatrix} \sim (\mathbf{0}, \mathbf{H}_t), \quad \mathbf{H}_t = \begin{bmatrix} h_{er,t} & h_{vm,er,t} \\ h_{er,vm,t} & h_{vm,t} \end{bmatrix}$

4.1 Empirical Results

The maximum likelihood estimations of the bivariate EGARCH models for both the daily Yen/USD exchange rate returns and the detrended Tokyo foreign exchange market trade volume are reported in Table 2. Full-sample and two (sub-) sample estimation results are shown. Since the two samples represent fundamentally different intervention practices, the results for the full sample may not provide credible results. In fact, we find that some of the intervention variables are opposite in sign, and so the full sample results represent averages of these different results rendering the resulting analyses less meaningful. Thus, we decided not to discuss the full sample results to conserve space; however, we include them in the results tables for the record.

Sample One

The first sample was a period of frequent but small interventions. The contemporaneous effect of intervention on returns is picked up by a_{intv} . Effectiveness of intervention requires a positive sign, implying that net market purchases of USD with Yen would lead to a Yen depreciation. The estimated contemporaneous intervention effect, however, is negative and significant (-0.440), which might suggest counter-productive intervention. However this common but seemingly puzzling result might be due to simultaneity bias. To sidestep this problem, we introduce dummy variables to test whether cumulative or particularly large interventions have distinct effects on returns. The coefficient that picks up the effects of interventions that continued for at least three

days, a_{cum} , is positive and significant (0.356). This suggests that the contemporaneous effect of intervention which moved the exchange rate in the undesirable direction was partially offset on the days of interventions that were a part of a continued campaign. The net effect was to depreciate Yen by only 0.084% in response to a 100 billion Yen purchase. Larger than average interventions failed to elicit significant responses. Considering the rather tranquil nature of intervention in this sample, even above-average interventions were not large enough to be noticed by market participants. The FED's modest interventions also failed to cause any response.

Intervention also had a significant effect on the conditional variance of exchange rate returns. The contemporaneous effect, b_{intv} , is positive (1.015) and this is similar to what Frenkel et al. (2005) report. Once again, the observed association of higher volatility with interventions may be because those interventions were prompted by high volatilities. We go beyond this contemporaneous effect to find that the cumulative and size effects are both negative and significant (-0.320 and - 0.413), though the FED intervention effect is significant and positive (0.792). These parameter estimates imply that, although normal interventions were associated with higher conditional volatility of exchange rate returns, much of this contemporaneous effect was offset on the days of continued and large interventions. However, when the BOJ and FED coordinated their interventions, they added to volatility, a result also obtained by Beine (2004).

The effects of the interventions on trade volumes, α_{intv} , were similar to the exchange rate volatility effects. That is, the contemporaneous effect is positive, but the dummy intervention coefficients are negative, with the former being larger. The variance of volume responded much the same as the mean. Interestingly, the frequent FED interventions had some influence, significantly reducing the volatility of volume on the day after their intervention activities. When the FED entered the market, the more speculative participants retreated.

The feedback variables in the conditional mean equations (shown in rows 3-6 in Table 2) are all significant except for the effect of the lagged error of volume on exchange rate returns, α_{vmma} . In addition, there are significant and asymmetric responses of conditional variances to own and the other's lagged errors (rows 15 to 18). However the estimated contemporaneous correlation of shocks to returns and volume, ρ , is insignificant. As mentioned earlier, it is widely believed that

volumes and the returns volatility are positively correlated. However our EGARCH results indicate that, while the contemporaneous shocks were uncorrelated (and see footnote 9 for an explanation), there were subsequent, positive dynamic interactions. The MDH hypothesis is thus verified in these dynamic interactions. Though the shocks to unsigned volumes and returns should be uncorrelated, the ‘learning by trading’ story suggests that there must be subsequent dynamic interaction effects on the conditional means and variances.

Interestingly, the interest rate differential between Japan and the US had no significant effect on the exchange rate. As we will see in section 5.6, this is consistent with the BOJ moderating its intervention in favour of buying Yen for USD to avoid any exchange rate effects of its declining interest rate differential.

Sample Two

The second sample represented 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 became positive and significant (0.027). This is somewhat unexpected considering our first sample results, and the results of ineffectiveness exhibited in the intervention literature. However, a similar finding is reported by Ito (2002) using a GARCH model. Interestingly, we now have insignificant cumulative and size dummies. As for the FED interventions, they reinforced the BOJ’s contemporaneous positive effect on the exchange rate. The estimate for α_{fed} is significantly positive and considerably larger than the BOJ’s contemporaneous coefficient. Thus, coordinated BOJ and FED interventions had the desired effect of moving the exchange rate substantially, and 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. This is consistent with the recent findings reported in the literature (*inter alia* Nagayasu, 2004, Ito, 2002, Fatum and Hutchison, 2003).

The volatility responses were similar to the sample one results, and the strong dynamic interaction effects again support the MDH hypothesis and the ‘learning by trading’ story. The

volume results are fairly similar, except the effects of the FED's much rarer and larger interventions on volume volatility is now positive.

Finally, the effect of the interest rate differential became positive and significant—a higher interest rate differential in favour of the US led to a USD appreciation on the day. We will see in section 5.6 that the BOJ switched to using its intervention as an alternative form of domestic monetary policy, and so it is not surprising that the interest rate differential could now display the standard market effect on the exchange rate.

In summary, the BOJ's intervention activities since 1995 have successfully turned the trends of the exchange rate in the appropriate direction without stimulating volatility. In addition, coordinated interventions with the FED added to this intervention effectiveness.

5. Reaction functions of the BOJ

In this section we examine the possible determinants of the BOJ interventions. 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 central bank's 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.

To minimize short-term disorderliness, a central bank might intervene for a number of inter-related reasons—trend correction, volatility smoothing, unexpected high traded volumes. Firstly, the central bank might wish to return the exchange rate to a more appropriate short-term trend, perhaps to moderate a high frequency speculative bubble or a bandwagon surge. This high frequency activity can be associated with the term, leaning against the wind (LATW). However if the 'wind' is too fierce, we can expect the central bank to recognize the futility of intervention. Disorderliness may also show up as excessive 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, there might be a threshold of disorderliness beyond which a central bank would back away from the market to avoid serious losses. 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.

A central bank may choose to use intervention as an additional monetary policy instrument. 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.

In addition to the above motives, cumulated profits/losses generated as a result of continued intervention activities may act as a constraint on continued loss-making interventions.

5.1 Measurement and the Effects of Short-term Trend Deviations

Following LeBaron (1999), who justifies his choice of 150 days as being commonly used by market traders, we use a 150 day moving average 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:

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

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. 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 ($h_{er,t}$) from the bivariate EGARCH model discussed above, and use its lag in subsequent estimations as a possible determinant of intervention

behavior¹⁷ (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 coefficient for the effect of volatility to be negative. Once again, we allow 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 potentially useful for modeling the intervention behavior of a central bank. Volume movements may have enough information for a central bank to initiate intervention activities. In line with the MDH, a distinction is made between expected and unexpected volume. Only unexpected volume would matter. We further conjecture that only positive unexpected changes would matter. Therefore we use the estimated positive residuals, from the EGARCH 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. 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

We use daily changes in the official target interest rates of the US and Japan, and they represent adjustments (or changes) in the monetary policy stance. They are shown in panels C and D of Figure 3, respectively. Interest rates matter firstly because the interest rate differential may lead to overshooting exchange rates, which may be excessive if there are perceived to be band-wagon effects. With the BOJ reducing interest rates throughout our sample, there would always be a fear of excessive depreciation of the Yen, which would encourage the BOJ to support the currency. Thus, we expect the coefficient for the Japanese interest rate on intervention would be positive (and negative for the US interest rate).

Secondly, foreign exchange intervention may operate directly as a support for domestic

¹⁷ By using its lagged value, this regressor contains the impact of the previous day's intervention. We recognize that our procedure may create a 'generated regressor bias'. This is the price paid for not being able to estimate the bivariate EGARCH model and the intervention friction model simultaneously.

monetary policy objectives. In the first 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. The appreciating Yen created a problem for the Japanese economy that had already begun in 1992 its protracted slump in output growth. For Japan in the second sample, the overnight interest rate gradually approached zero, suggesting a liquidity trap. Therefore unsterilized foreign exchange intervention may have become an increasingly viable alternative for achieving the objectives of monetary policy. As the interest rate fell towards the zero bound, Yen sales by the BOJ were likely to have increased to weaken the currency to help stimulate the slumping economy. Thus this argument suggests the estimated parameter on the Japanese interest rate is negative.

Which of the two arguments applies is an empirical question, which we address below.

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 the beginning of the sample, by computing the current net value of every past intervention and summing them up (for further details on this measure, see Kim and Sheen, 2002):

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

The cumulative intervention profits for BOJ are shown in panel E of Figure 3. If the Yen 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 a profit-seeking dealer.

5.6 The Friction Model

The resulting function for desired intervention, $Intv_t$, is:

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

- $I_{dev,t}$ = An indicator variable that takes the value of positive (negative) 1 if $ERDEV_t$ is positive (negative) and 0 otherwise. If positive, the Yen is depreciating against the USD.
- $I_{ERsize,t}$ = An indicator variable that takes the value of positive (negative) 1 if $ERDEV_t$ is positive (negative) and by more than 5%, and 0 otherwise.
- $I_{ds,t}$ = An indicator variable that takes the value of positive (negative) 1 if the daily exchange rate change (ΔER_t) is positive (negative), and 0 otherwise.
- $I_{hsize,t}$ = An indicator variable that takes the value of 1 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 1 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 at the desired value in (6) will take place if the desired value is greater than θ^+ , and actual 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:

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

where Φ is the standard normal cumulative density function.

5.7 Estimation Results for the Friction Model

Table 3 reports the estimation results of the friction model. The average effect of the exchange rate deviations on the intervention activities is negative and significant in all samples. This suggests LATW intervention is at work. Other researchers report similar findings (Ito, 2002,

Frenkel *et al.*, 2004b). The magnitude of the coefficient in the second sample is about 8 times that in the first. This reflects the larger magnitudes of intervention—the average intervention was Yen 340 billion in sample two compared to 47 billion in the first.

The size effect is positive but small in sample 1 suggesting that when a deviation is of a particularly large magnitude, the central bank became less sure that it was seeing a random disturbance or that it had the resources to combat it. However, the overall effect of exchange rate deviations remained consistent with LATW. Interestingly, in the second sample, the size effect is large, negative and significant, and so the evidence suggests that the BOJ responded to exchange rate deviations, and large ones in particular. Exchange rate volatility had no significant influence on the BOJ, which 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 in all samples, and four times larger in the second sample. The size dummies were insignificant. This new volume result lends support to the LATW hypothesis. If the traded volume was unexpectedly large, the BOJ reduced its USD purchases, which would lead to an immediate decline in total trades. Unexpectedly high volume signals a problem of disorderliness, and so the central bank decides to reduce its participation to bring volumes back towards a norm. The bank knows that its reduced intervention will reduce market volumes – a result found in our EGARCH estimations. This offsetting influence of large volume movements also may suggest that trend-correcting interventions were seen to be less productive on days of especially high volume. The Bank of Japan may care about liquidity in order to intervene at low trading times. To the best of our knowledge, this paper is the first to consider trade volume and so our results represent a unique contribution to the literature.

Only Japanese interest rate changes had significant effects on BOJ intervention. The positive coefficient in sample 1 indicates that a fall in the rate led to a USD sale (Yen purchase), which is yet another evidence of LATW interventions. The Japanese discount rate changes were negative throughout the two samples and so represent continued loosening of the monetary policy stance. In sample 1 the BOJ used expansive monetary policy to stimulate the domestic economy that suffered recessionary pressures after the collapse of the stock market bubble in April 1991.

Apparently, in the face of the continued rate cuts, the BOJ chose to moderate the downward pressure on Yen. Our estimate indicates an 81 billion Yen purchase in response to a one percentage point cut in the Japanese discount rate in sample 1, but a 6,146 billion Yen sale in sample 2. The difference in the magnitudes reflects the tiny interest rate changes once inside the liquidity trap. We argue that the switch to a negative interest rate effect in sample 2 is due to the liquidity trap in which standard domestic monetary policy instruments became impotent.

The effect of cumulative profits from interventions is shown to be negative and significant in sample 2 only, indicating an intervention sale of USD as intervention profit increases. This suggests that the BOJ acted like any other profit-driven positive feedback trader that rides on a market trend. The rising cumulative intervention profit gave further impetus for the BOJ to continue the profitable intervention strategy.

The lagged intervention coefficient, δ , is significantly positive and greater than one. This suggests that the BOJ's interventions are followed by larger intervention in the same direction the day after. Both the negative and positive threshold estimates are significant¹⁸. They are approximately ten times the size in the second sample compared to the first. This suggests that the BOJ practiced more restraint in the later sample only coming into the market when a significantly higher threshold was breached on either side. Not only were interventions less frequent and considerably larger in size the estimated error variance was ten 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 volume—and to help achieve monetary policy objectives.

6. Conclusions

Our estimations of a bivariate EGARCH model of exchange returns and trading volume in the Yen/USD market lend support to the 'mixed distribution hypothesis' and a 'learning by trading story'. We found that the change of intervention philosophy by the BOJ around July 1995 resulted in successful market responses to its intervention transactions.

¹⁸ Ito and Yabu (2004) also found a significant positive coefficient for lagged interventions in their reaction function, which included threshold effects. They found that the friction cost was higher post-1995.

Before 1995, interventions were small and frequent and the contemporaneous effects of interventions appeared to be counter-productive. The effects on trade volumes were similar—volume was successfully calmed only on unusual days of sustained intervention—though interventions of above-average size also helped. The interventions by the FED were of little consequence in this sample. 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 Yen/USD rate in the desired direction. Rare, but large coordinated interventions by the US FED now added to the effectiveness of the BOJ interventions.

Overall, while small interventions could be destabilizing, large, sustained and coordinated interventions worked. However they came at a price of more market disorderliness in the form of higher volumes and volatility. Our result that ‘size matters’ is an important finding, since the literature suggests that it is the ‘presence’ of the central bank that matters, not size of the activity as such. Similarly the positive effects of sustained (and therefore expected) interventions are important because previous results tend to suggest that only ‘surprise interventions’ are effective. We argue that continued presence improve the signalling effect of intervention.

The BOJ were motivated to intervene to correct short-term trend deviations and unexpectedly high volume in both samples. This is consistent with the ‘leaning against the wind’ hypothesis, but interestingly, exchange rate volatility had no impact. Volume mattered to the BOJ, but not exchange rate volatility as a measure of disorderliness. We argue that it prefers to use an observable, rather than a statistically derived, variable as a measure of disorderliness.

Finally, BOJ intervention responded significantly but differently to changes in the Japanese interest rate before and after 1995. Before 1995, it sold US dollars when the Japanese discount rate fell, thus preventing the Yen from depreciating. After 1995, it bought US dollars as Japanese interest rates fell towards zero. Thus, as it fell into a liquidity trap, the BOJ used unsterilized foreign exchange intervention as an alternative instrument to achieve the objectives of its domestic monetary policy. It intervened to weaken the Yen, or at least to inhibit any appreciation in the face of a slumping economy. 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.

References

- Admati, A., and Pfleiderer, P., 1988. A Theory of Intraday Patterns: Volume and Price Variability. *Review of Financial Studies* 1, 3-40.
- Almekinders, G.J., and Eijffinger, S.C.W., 1996. A friction model of daily Bundesbank and Federal Reserve intervention. *Journal of Banking and Finance* 20, 1365-1380.
- Andersen, T.G., 1996. Return Volatility and Trading Volume: An Information Flow Interpretation of Stochastic Volatility. *Journal of Finance* 51, 169-204.
- Bacchetta, P., and Wincoop, E.v., 2003. Can Information Heterogeneity Explain the Exchange Rate Determination Puzzle? NBER Working Paper 9498,
- Baillie, R.T., and Bollerslev, T., 1989. The message in daily exchange rates: A conditional-variance tale. *Journal of Business and Economic Statistics* 7, 297-305.
- Baillie, R. T. and Osterberg, W. P. (1997) "Why do central banks intervene?" *Journal of International Money and Finance*, 16:6, 909-919.
- Beine, M., 2004. Conditional Covariances and Direct Central Bank Interventions in the Foreign Exchange Markets. *Journal of Banking and Finance* 28, 1385-1411.
- Beine, M., and Bernal, O., 2004. Why do central banks intervene secretly? SSRN Working paper,
- Bessembinder, H., 1994. Bid-ask Spreads in the Interbank Foreign Exchange Markets. *Journal of Financial Economics* 35, 317-48.
- BIS, 2005. Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity in March 2005, <http://www.bis.org/publ/rpfx05.htm>.
- Blume, L.E., Easley, D., and O'Hara, M., 1994. Market Statistics and Technical Analysis: The Role of Volume. *Journal of Finance* 49, 153-82.
- BOJ, 2000. Outline of the BOJ's Foreign Exchange Intervention Operations.
www.boj.or.jp/en/about/basic/etc/faqkainy.htm,
- Chaboud, A.P., and Humpage, O.F., 2003. An analysis of Japanese foreign exchange interventions, 1991-2002. Federal Reserve Bank of Cleveland Working Paper: 0309.
- Clark, P., 1973. A Subordinated Stochastic Process Model with Finite Variance for Speculative Prices. *Econometrica* 41, 135-155.
- Dominguez, K.M., 1998. Central bank intervention and exchange rate volatility. *Journal of International Money and Finance* 17, 161-190.
- Dominguez, K.M.E., 2003. The Market Microstructure of Central Bank Intervention. *Journal of International Economics* 59, 25-45.
- Dominguez, K.M., and Frankel, J.A., 1993. Does foreign exchange rate intervention work? Institute for International Economics,
- Easley, D., and O'Hara, M., 1987. Price, Trade Size, and Information in Securities Markets,

Journal of Financial Economics. 19 69-90

- Epps, T., and Epps, M., 1976. The Stochastic Dependence of Security Prices and Transaction Volumes: Implications for the Mixture of Distributions Hypothesis. *Econometrica* 44, 305-21.
- Evans, M., and Lyons, R., 2002. Time-varying liquidity in foreign exchange. *Journal of Monetary Economics* 49, 1025-1051.
- Fatum, R., and Hutchison, M., 1999. Is Intervention a Signal of Future Monetary Policy? Evidence from the Federal Funds Futures Market. *Journal of Money, Credit, and Banking* 31, 54-69.
- Fatum, R., and Hutchison, M., 2003. Effectiveness of Official Daily Foreign Exchange Market Intervention Operations in Japan. National Bureau of Economic Research Inc NBER Working Papers: 9648.
- Frenkel, M., Pierdzioch, C., and Stadtmann, G., 2004. On the Determinants of "Small" and "Large" Foreign Exchange Market Interventions: The Case of the Japanese Interventions in the 1990s. *Review of Financial Economics* 13, 231-43.
- Frenkel, M., Pierdzioch, C., and Stadtmann, G., 2005. The Effects of Japanese Foreign Exchange Market Interventions on the Yen/U.S. Dollar Exchange Rate Volatility. *International Review of Economics and Finance* 14, 27-39.
- Glassman, D., 1987. Exchange Rate Risk and Transaction Costs: Evidence from Bid-ask Spreads. *Journal of International Money and Finance* 6, 4.
- Glosten, L., and Milgrom, P., 1985. Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders. *Journal of Financial Economics* 13 71-100
- Hamilton, J., 1994. *Time Series Analysis*. Princeton University Press, Princeton.
- Hartmann, P., 1999. Trading Volumes and Transaction Costs in the Foreign Exchange Market. Evidence from Daily Dollar-yen Spot Data. *Journal of Banking and Finance* 23 801-824
- Hiemstra, C., and Jones, J.D., 1994. Testing for Linear and Non-linear Granger Causality in the Stock Price-Volume Relation. *Journal of Finance*, 1639-1664.
- Hsieh, D.A., 1989. Modeling heteroscedasticity in daily foreign-exchange rates. *Journal of Business and Economic Statistics* 7, 307-317.
- Ito, T., 2002. Is Foreign Exchange Intervention Effective? The Japanese Experiences in the 1990s. National Bureau of Economic Research Inc NBER Working Papers: 8914.
- Ito, T., and Yabu, T., 2004. What promotes Japan to intervene in the forex market? A new approach to a reaction function. NBER Working Paper 10456,
- Kearns, J., and Rigobon, R., 2005. Identifying the Efficacy of Central Bank Interventions: Evidence from Australia and Japan, *Journal of International Economics* 66 31-48

- Kim, S.-J., 1999. Do macro-economic news announcements affect the volatility of foreign exchange rates? Some evidence from Australia, *Applied Economics* 31 1511-1521
- Kim, S.-J., and Sheen, J.R., 2002. The Determinants of Foreign Exchange Intervention by Central Banks: Evidence from Australia, *Journal of International Money and Finance*. 21 619-649
- Kim, S.-J., Kortian, T., and Sheen, J.R., 2000. Central Bank Intervention and Exchange Rate Volatility? Australian evidence, *Journal of International Financial Markets, Institutions and Money*. 10 381-405
- Lamoureux, C., and Lastrapes, W., 1990. Heteroscedasticity in stock return data: Volume versus GARCH effects. *Journal of Finance* 45, 221-9.
- LeBaron, B., 1999. Technical trading rule profitability and foreign exchange intervention. *Journal of International Economics* 49, 125-143.
- Lecourt, C., and Raymond, H., 2003. Central Bank Interventions in the Light of Survey Results. <http://ssrn.com/abstract=419321>
- Lewis, K.K., 1995. Are foreign exchange intervention and monetary policy related, and does it really matter? *Journal of Business* 68, 185-214.
- Lyons, R., 2001. *The Microstructure Approach to Exchange Rates*. MIT Press, Boston.
- McKenzie, M., 2002. The Economics of Exchange Rate Volatility Asymmetry, *International Journal of Finance & Economics* 7 247-260.
- Nagayasu, J., 2004. The effectiveness of Japanese foreign exchange interventions during 1991–2001. *Economics Letters* 84, 377–381.
- Neely, C.J., 1998. Technical analysis and the profitability of U.S. foreign exchange intervention, *Federal Reserve Bank of St. Louis Review*. July/August 3-17
- Nelson, D., 1991. Conditional heteroscedasticity in asset returns: A new approach. *Econometrica* 59, 347-370.
- Schwartz, A.J., 2000. The Rise and Fall of Foreign Exchange Market Intervention as a Policy Tool. *Journal of Financial Services* 18, 319-339.
- Sellon, G.H.J., 2003. Monetary Policy and the Zero Bound: Policy Options when Short-term Rates Reach Zero. *Federal Reserve Bank of Kansas City Economic Review*, 5-43.
- Vitale, P., 2003. Foreign Exchange Intervention: How to Signal Policy Objectives and Stabilize the Economy. *Journal of Monetary Economics* 50, 841-70.

Figure 1: Market Opening Hours of 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, Detrended Volume and Interventions

	Sample 1: 13 Jan 1991 to 20 Jun 1995				Sample 2: 21 Jun 1995 to 16 Mar 2004				Full Sample: 13 May 1991 to 16 Mar 2004																										
	Panel A: Yen/USD and Detrended Volume of Tokyo Market																																		
	ΔER			Det-VM			ΔER			Det-VM			ΔER			Det-VM																			
	Summary Statistics																																		
	Mean			-0.047			-2.115			0.010			0.526			-0.008			-0.316																
	Variance			0.45			13.33			0.54			15.94			0.51			16.62																
	Skewness			-0.42			5.74			-1.19			1.33			-0.98			2.21																
	Excess Kurtosis			4.90			62.85			11.40			4.21			9.79			13.83																
	J-B Normality			1104			182311			12933			2367			13959			29536																
	Tests of iid ⁽¹⁾																																		
	Q(20)			20.74 {0.413}			460.12 *** {0.000}			27.81 {0.114}			2822.29 *** {0.000}			25.09 {0.198}			5262.95 *** {0.000}																
Q ² (20)			63.20 *** {0.000}			186.60 *** {0.000}			458.69 *** {0.000}			335.34 *** {0.000}			551.17 *** {0.000}			469.77 *** {0.000}																	
Q _b (10) : χ ² (40)			421.44 *** {0.000}						7860.90 *** {0.000}						7338.63 *** {0.000}																				
Q _b (10) : χ ² (40)			340.01 *** {0.000}						1629.07 *** {0.000}						1281.99 *** {0.000}																				
Unit Root Tests ⁽²⁾																																			
ADF			-15.8			-11.6			-21.5			-12.3			-26.4			-14.7																	
Granger Causality Tests																																			
H0: ΔER does not cause VM			18.64 ** {0.017}						24.32 *** {0.002}						17.12 ** {0.029}																				
H0: VM does not cause ΔER			16.61 ** {0.034}						6.14 {0.632}						6.56 {0.585}																				
H0: (ΔER) ² does not cause VM			16.07 ** {0.041}						23.18 *** {0.003}						21.07 *** {0.007}																				
H0: VM does not cause (ΔER) ²			24.01 *** {0.002}						13.31 {0.102}						6.15 {0.630}																				
															Panel B: BOJ and US FED Interventions and Detrended Volume of Tokyo Market																				
															BOJ			FED			BOJ			FED			BOJ			FED					
Number of days of Interventions																																			
Positive															139			15			172			3			311			18					
Negative															27			3			6			1			33			4					
Total															166			18			178			4			344			22					
Unilateral BOJ Interventions															148						174						322								
Co-ordinated interventions															18						4						22								
Average Size of Intervention (in Yen bn)																																			
Positive															50.2			40.3			328.1			34.4			203.9			39.3					
Negative															-29.2			-8.5			-684.4			-114.6			-148.3			-35.0					
Total (average of absolute values)															46.8			38.5			340.1			54.5			198.5			37.2					
Largest Intervention (in in Yen bn)																																			
Positive															338.8			77.5			1666.4			45.4			1666.4			77.5					
Negative															-76.9			-12.7			-2620.1						-2620.1			-114.6					
Smallest Intervention (in in Yen bn)																																			
Positive															5.1			16.9			0.1			28.9			0.1			16.9					
Negative															-3.2			-6.4			-76.4						-3.2			-6.4					
Cumulative Intervention Probabilities																																			
Prb(BOJ-I _t ≠0 BOJ-I _{t-1} ≠0)															0.61						0.62						0.62								
Prb(BOJ-I _t ≠0 BOJ-I _{t-1} ≠0 & BOJ-I _{t-2} ≠0)															0.42						0.46						0.44								
Prb(FED-I _t ≠0 BOJ-I _t ≠0)																		1.00						1.00						1.00					

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

$$Q = T^2 \sum_{i=1}^P \frac{Tr(\hat{C}_i \hat{C}_0^{-1} \hat{C}_i \hat{C}_0^{-1})}{(P-i)} \quad \text{where} \quad \hat{C}_i = \frac{1}{T} \sum_{t=i+1}^T (\hat{\varepsilon}_t \hat{\varepsilon}_{t-i}'), \quad \varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

T = no. of observations
 P = no. of lags

$Q \sim \chi^2$ with $d.f. = 4.P$

(2) Augmented Dickey-Fuller test with constant and trend and appropriate lags

Table 2: Bivariate-EGARCH(1,1)-t Model Estimations of Intervention Effectiveness

			Sample 1: 13 Jan 1991 - 20 Jun 1995				Sample 2: 21 Jun 1995 - 16 Mar 2004				Full Sample: 13 May 1991 - 16 Mar 2004			
			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										
1	a_c	α_c	-0.034 **	{0.01}	0.925 ***	{0.00}	-0.081 ***	{0.00}	2.065 ***	{0.00}	-0.091 ***	{0.00}	2.747 ***	{0.00}
2		α_{vmar}			0.681 ***	{0.00}			0.951 ***	{0.00}			0.971 ***	{0.00}
3	a_{erma}	α_{erma}	-0.133 ***	{0.00}	2.138 ***	{0.00}	-0.041 **	{0.04}	2.501 ***	{0.00}	-0.072 ***	{0.00}	2.404 ***	{0.00}
4	a_{vmma}	α_{vmma}	0.004	{0.53}	-0.322 ***	{0.00}	0.002	{0.50}	-0.705 ***	{0.00}	0.002	{0.34}	-0.705 ***	{0.00}
5	a_{erh}	α_{erh}	0.056 **	{0.02}	-5.039 ***	{0.00}	0.134 ***	{0.00}	-2.978 ***	{0.00}	0.135 ***	{0.00}	-3.757 ***	{0.00}
6	a_{vmh}	α_{vmh}	-0.013 **	{0.05}	0.588 ***	{0.00}	-0.024 ***	{0.00}	-0.174 ***	{0.00}	-0.007 **	{0.01}	-0.265 ***	{0.00}
7	a_{hol}	α_{hol}	0.018 **	{0.03}	-0.664 ***	{0.00}	-0.003	{0.52}	-0.630 ***	{0.00}	0.003	{0.57}	-0.648 ***	{0.00}
8	a_{idiff}	α_{idiff}	-0.001	{0.85}			0.023 ***	{0.00}			0.012 ***	{0.00}		
9	a_{intv}	α_{intv}	-0.440 ***	{0.00}	5.464 ***	{0.00}	0.027 ***	{0.00}	0.324 ***	{0.00}	-0.097 ***	{0.00}	1.209 ***	{0.00}
10	a_{cum}	α_{cum}	0.356 ***	{0.00}	-1.963 ***	{0.00}	-0.006	{0.53}	-0.296 ***	{0.00}	-0.011	{0.24}	-0.468 ***	{0.00}
11	a_{size}	α_{size}	-0.035	{0.69}	-1.053 ***	{0.00}	0.004	{0.57}	0.200 ***	{0.00}	0.118 ***	{0.00}	-0.604 ***	{0.00}
12	a_{fed}	α_{fed}	0.562	{0.13}	0.571	{0.47}	0.866 ***	{0.01}	7.023	{0.17}	0.410 **	{0.00}	-0.924	{0.20}
13	b_c	β_c	0.045 ***	{0.00}	0.161 ***	{0.00}	0.320 ***	{0.00}	0.334 ***	{0.00}	0.213 ***	{0.00}	0.405 ***	{0.00}
14	b_h	β_h	0.692 ***	{0.00}	0.885 ***	{0.00}	0.899 ***	{0.00}	0.777 ***	{0.00}	0.860 ***	{0.00}	0.754 ***	{0.00}
15	$b_{\varepsilon_{er1}}$	$\beta_{\varepsilon_{er1}}$	0.001	{0.90}	0.179 ***	{0.00}	-0.047 ***	{0.00}	0.054 ***	{0.00}	-0.037 ***	{0.00}	0.049 ***	{0.00}
16	$b_{\varepsilon_{er2}}$	$\beta_{\varepsilon_{er2}}$	0.189 ***	{0.00}	0.063 ***	{0.00}	0.292 ***	{0.00}	0.168 ***	{0.00}	0.262 ***	{0.00}	0.267 ***	{0.00}
17	$b_{\varepsilon_{vm1}}$	$\beta_{\varepsilon_{vm1}}$	0.057 ***	{0.00}	0.007	{0.70}	0.050 ***	{0.00}	-0.025 *	{0.09}	0.041 ***	{0.00}	0.011	{0.42}
18	$b_{\varepsilon_{vm2}}$	$\beta_{\varepsilon_{vm2}}$	-0.045 *	{0.09}	-0.092 ***	{0.00}	-0.052 ***	{0.00}	0.304 ***	{0.00}	-0.073 ***	{0.00}	0.254 ***	{0.00}
19	b_{hol}	β_{hol}	-0.276 ***	{0.00}	-0.031 ***	{0.00}	-0.286 ***	{0.00}	0.069 ***	{0.00}	-0.239 ***	{0.00}	0.020 ***	{0.00}
20	b_{intv}	β_{intv}	1.015 ***	{0.00}	0.379 ***	{0.00}	0.041 ***	{0.00}	0.101 ***	{0.00}	0.100 ***	{0.00}	0.273 ***	{0.00}
21	b_{cum}	β_{cum}	-0.320 ***	{0.00}	0.064	{0.35}	-0.028 ***	{0.00}	-0.063 ***	{0.00}	-0.028 ***	{0.00}	-0.083 ***	{0.00}
22	b_{size}	β_{size}	-0.413 ***	{0.00}	-0.230 ***	{0.00}	-0.009 *	{0.09}	0.086 ***	{0.00}	-0.072 ***	{0.00}	-0.086 ***	{0.00}
23	b_{fed}	β_{fed}	0.792 ***	{0.00}	-0.706 **	{0.02}	0.322	{0.36}	3.313 ***	{0.00}	0.232 **	{0.04}	-0.245	{0.40}
	ρ		-0.011	{0.70}			-0.012	{0.56}			-0.024	{0.16}		
	d		16 ***	{0.00}			3666 **	{0.04}			35 ***	{0.00}		
	$\ln L$		-3631				-7832				-11636			
	$Q_b(10) : \chi^2(40)$		39	{0.51}			68 ***	{0.00}			60 **	{0.02}		
	$Q_b^2(10) : \chi^2(40)$		22	{0.99}			68 ***	{0.00}			14	{1.00}		

Table 3: Friction Model Estimations of BOJ's Intervention Reaction Function

	Sample 1: 13 Jan 1991 - 20 Jun 1995	Sample 2: 21 Jun 1995 - 30 Mar 2004	Full Sample: 13 May 1991 - 30 Mar 2004
α_c	-0.064 *** {0.00}	-0.544 *** {0.00}	-0.300 *** {0.00}
α_{ERsize}	0.010 *** {0.01}	-0.431 *** {0.00}	-0.044 {0.22}
β_c	-0.025 {0.81}	-1.091 {0.28}	-0.752 * {0.09}
β_{hsize}	0.009 {0.93}	1.484 {0.22}	0.636 {0.17}
γ_c	-0.040 *** {0.00}	-0.175 ** {0.05}	-0.288 * {0.09}
γ_{VMsize}	0.013 {0.29}	0.045 {0.58}	0.119 {0.50}
Ψ_{JP}	0.811 ** {0.02}	-61.468 *** {0.00}	1.202 {0.84}
Ψ_{US}	0.188 {0.36}	-7.591 {0.20}	-2.588 {0.36}
ϕ	0.067 {0.64}	-0.149 *** {0.00}	-0.068 ** {0.05}
δ	1.182 *** {0.00}	1.453 *** {0.00}	1.118 *** {0.00}
σ	0.682 *** {0.00}	7.103 *** {0.00}	4.739 *** {0.00}
θ^+	1.179 *** {0.00}	11.007 *** {0.00}	7.409 *** {0.00}
θ^-	-1.351 *** {0.00}	-23.725 *** {0.00}	-11.759 *** {0.00}
Log-L	-441	-928	-1682