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What drives Yen interventions in Tokyo?: Do off-shore foreign exchange markets matter more than Tokyo market?

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Abstract

We investigate the Bank of Japan's (BOJ) Yen interventions for the period 13 May 1991 to 16 March 2004. The previous literature has been hampered by the coarse daily data and has been unable to identify intervention determinants beyond some embodiment of the first moment of Yen returns. We consider both lagged overnight off-shore (London and New York) and intradaily on-shore (Tokyo) market developments for their heterogeneous influences on the BOJ's intervention decisions. Using a friction model to estimate the reaction function, we find that the interventions were leaning against the wind during the Tokyo hours, in general. Prior to June 1995, there were significant responses to previous day's intradaily Yen returns and volatility. Post 1995, we report a broadening in the BOJ's monitoring to include overnight off-shore Yen returns until Dec 2002 and a broader measure of market disorderliness measured as a transactions cost band in one-month covered interest rate parity condition since Jan 2003. Moreover, there is some evidence that the BOJ secretly leaned into the wind in response to Yen depreciations during the recent period of 2003-2004.

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1. Introduction

We investigate the relative importance of on-shore (Tokyo) and off-shore (London and New York) market developments in shaping the intervention reaction function of the Bank of Japan (BOJ) for the period 1991 to 2004.[1] The BOJ has been one of the most prominent central authorities to participate in the foreign exchange market with the objective of altering the underlying exchange rate dynamics. Since the release of the historical BOJ intervention data by the Japanese Ministry of Finance in July 2001, a long list of researchers have investigated various aspects of the BOJ interventions. This literature has examined intervention effectiveness by determining whether the first and second moments of the Yen/USD exchange rate returns are affected in the desired direction, or if prominent trends are reduced (Beine, 2004; Chaboud and Humpage, 2003; Fatum and Hutchison, 2003; Nagayasu, 2004). The BOJ's intervention reaction function has also been investigated (Ito, 2002; Ito and Yabu, 2007; Kim and Sheen, 2006). Various researchers have experimented with the 'usual suspects' in prompting interventions and these include different guises of first and second moments of target exchange rate movements (See Neely, 2005; Sarno and Taylor, 2001). The common finding is that the BOJ seemed to lean against the wind (LATW) in response to a deviation from some target exchange rate (or movements). In addition, there have been some attempts to examine intervention profitability and monetary policy considerations (Kim and Sheen, 2006). However, a major shortfall in the literature, in general, is the usage of coarse daily data which is incapable of capturing the time varying nature of the information content on the variables of interest.

The Bank of Japan (2000) states that Yen interventions are implemented to 'mitigate the negative influence' of exchange rate fluctuations after monitoring and analysing

[1] The investment decisions are made by Ministry of Finance and the BOJ is acting as its agent and conducts intervention transactions.

developments in the foreign exchange markets ‘day and night’. However, they have never released a categorical breakdown of when, why or even how they will intervene. The combination of the current lack of an official stance on the determinants of intervention and the need to understand these motives by the foreign exchange market participants has been the major impetus for researchers to uncover the true drivers the BOJ’s intervention. However, investigation into the extent to which the BOJ responds differently to market information coming from different segments of a 24-hour trading day is yet to be added to the literature. This is an important issue because Yen is a 24-hour trading currency and yet the BOJ’s Yen intervention is mostly confined to Tokyo trading hours (Dominguez, 2003), and so market participants need to understand the BOJ’s likely responses to market developments emanating from both on- and off-shore trading hours. In this paper, we address this shortfall and investigate the BOJ’s proclamation that it analyses market developments ‘day and night’.

Our objective is to ascertain whether the exchange rate developments during the intradaily on-shore period or the overnight off-shore period preceding the day of intervention have a greater impact on the final intervention decision of the BOJ. This is an important issue because if the BOJ is not monitoring and responding to the market developments of both segments, the intervention decision is likely to be based on an incomplete set of information. A poorly implemented intervention can be costly not only because of the transaction costs involved, but because it can potentially reduce the potency of future interventions when faced with serious market turbulences. We divide a 24-hour trading day into on- and off-shore trading hours and investigate the intervention decisions of the BOJ for the period 13 May 1991 to 16 March 2004. In addition, we also investigate different roles these determinants might play in inviting secret as opposed to publicly known interventions.

The major findings of this paper are as follows. i) Prior to June 1995, the BOJ responded only to disorderliness emanating from the previous day’s Tokyo market by LATW interventions. However, during Jun 1995 to Dec 2002, the BOJ responded to overnight Yen returns. On the days following a persistent overnight trend, however, it refrained from intervening. ii) In all samples, the BOJ responded to on-shore Tokyo market volatility, however, it refrained from intervening on the days following high levels of volatility in the post-95 samples. iii) During the recent period (Jan 2003 – Mar 2004) the BOJ also reacted to a broad measure of market uncertainty proxied by a transaction cost band (TCB) around one-month covered interest rate parity in the overnight London markets. A widening TCB led to LATW interventions in the subsequent Tokyo market. We also find that the BOJ secretly 'leaned into the wind' when Yen depreciated during the previous day's intradaily Tokyo market. iv) The BOJ tolerated Yen depreciations more than appreciations apparently to ensure external competitiveness. The post-95 samples show a much greater asymmetry which is consistent with the dominance of Yen sale interventions during the periods.

Thus, our paper significantly contributes to the literature by providing new and much richer understanding of the intervention determinants of the BOJ than the current knowledge. The rest of the paper is organized as follows. The data issues are presented in section 2 and the modeling strategies are discussed in section 3. Section 4 presents the empirical results and conclusions are offered in section 5.

2. Data issues

2.1. Intradaily vs. overnight model outline

We break down a 24 global Yen trading hours in a calendar day into two separate and distinct horizons. The intradaily horizon is between market opening and closing in Tokyo (*Intradaily (ID):* 7:00am to 5:00pm Japanese Standard Time (JST), (GMT 2200-0800)). The overnight horizon is the European and American trading period. (*Overnight (ON):* 5:00pm (day *t*) to 7:00am (day *t+1*), JST, (GMT 0800-2200))[2]. The BOJ states in their intervention

[2] The overnight horizon was further disaggregated into London/New York morning hours when both markets are operating and New York afternoon hours when only the latter is open. The disaggregated results of the two

outline (BOJ, 2000) that they conduct their interventions in the Tokyo market, and so interventions should fall within the intradaily horizon.[3] A graphical representation of the two horizons is displayed in Figure 1. The intradaily horizon has at least one hour overlap with the London morning trading. However the bulk of the trading in London and New York markets are conducted whilst the Tokyo market is closed.

2.2. Bank of Japan's intervention data

The BOJ's intervention data are freely available to the public.[4] Interventions are net market purchases of the USD assets with Yen and are measured in billions of Yen and the descriptive statistics are presented in Table 1. The first intervention in the sample occurred on 13 May 1991 and the last reported one was made on 16 March 2004. We cover the whole sample and there were 344 interventions.[5] There were 311 net market purchases of the USD assets and only 33 interventions of net sales. The average absolute intervention size over the full sample is 198.5 billion Yen. Although the majority were sales of Yen, we see some sizable purchases of Yen in 1998 as Japan was facing contagion problems from the Asian currency crisis. Another salient feature is that the interventions tended to occur in clusters. This is reflected in the high probability (62%) of the BOJ intervening given one it intervened the day before. Furthermore, the probability of a third consecutive day of intervention is 44%. On the other hand, there are long periods with no interventions. A change in intervention philosophy occurred in June of 1995 with the emergence of Dr. Sakakibara as the Director

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overnight horizon investigations were not as robust as the results reported in this paper using one overnight horizon and so they are not reported in the paper.

[3] When the BOJ feels it necessary to intervene outside the Tokyo trading hours, it can request foreign central banks to make 'entrustment interventions' using the funds of Japanese monetary authorities.

[4] The BOJ intervention data can be found at http://www.mof.go.jp/english/e1c021.htm. These intervention data are released with a time lag and were not generally known to the public at the time of intervention.

[5] We do not include the 22 interventions by the US Federal Reserve. These represent the US Federal Reserve's own foreign exchange policies and are not 'entrustment' interventions made on behalf of the BOJ.

General of the International Finance Bureau of the Ministry of Finance. Interventions became less frequent and significantly larger in magnitude. Another shift occurred under a new vice minister of Finance in Jan 2003. Interventions were mostly not well known by the market as they were conducted and the frequency increased substantially, although they remained large in magnitude. Thus, we examine three periods: Pre-Sakakibara period of 13 May 1991 to 20 Jun 1995 (Sample 1); Sakakibara period of 21 Jun 1995 to 31 Dec 2002 (Sample 2); and Recent period of 2 Jan 2003 to 16 Mar 2004 (Sample 3). Figure 2 graphically summarises the interventions as well as the Yen/USD exchange rate movements across all three periods.

Sample 1 is characterised by small but frequent interventions with a general trend of Yen appreciation. In just over four years, the BOJ recorded 166 interventions at an average absolute size of 46.8 billion Yen, and the interventions were made on 15.06% of business days. During sample 2 the BOJ only intervened 43 times in just under 7 years or only 2.49% of business days. However the average intervention size of 519.5 billion Yen is over ten times in size compared to the first sample average. The second sample contains the largest ever intervention by a central bank: a purchase of 2.62 trillion Yen on 10 April 1998 to support the currency in the face of the Asian currency crisis in that year. There was a general trend of Yen depreciation until 1998 and it hovered around 120 level since then. In sample 3, a shift in intervention philosophy resulted in a dramatic increase in intervention frequency. There were 129 interventions (all Yen sales) over 15 months and these represent 25.8% of business days. The transactions were smaller in magnitude with the average size of 271.9 billion Yen compared to sample 2, but still significantly larger than in sample 1. There was a general trend of Yen appreciation which briefly reversed towards the end of the sample.

2.3. Exchange rate data

The Yen/USD exchange rate is defined as Yen per US dollar and the Tokyo open and close spot rates are sourced from Bloomberg. The intradaily (ID) return is defined as Tokyo market's open to close: $R_t^{ID} = \ln\left(S_t^{Close} / S_t^{Open}\right) \times 100$, where S_t^{Close} and S_t^{Open} are the closing and opening spot rates in the Tokyo market on day *t*, respectively. The overnight (ON) horizon on day *t* is defined as the return from the closing rate on day *t* to the opening rate on day *t+1*: $R_t^{ON} = \ln(S_{t+1}^{Open} / S_t^{Close}) \times 100$. Descriptive statistics for both horizons are presented in Table 2. The mean return is approximately zero for both intradaily and overnight horizons in all samples. In addition, Ljung-Box Q-statistic shows no significant serial correlations in the return series at 10% in all cases, except for the intradaily returns in sample 2. However, there appears to be significant skewness and excess kurtosis in most cases.

3. Econometric modelling of intervention reaction functions

A central bank will intervene in the foreign exchange market if it believes that it can reduce short-term market disorderliness. This disorderliness could be represented by some of the following inter-related considerations: perceived trend deviations, fluctuations in exchange rates, unexpected high traded volumes, excessive exchange rate overshooting or supporting domestic monetary policy. Potential determinants of intervention vary from study to study depending not only on the monetary authority in question but also the regime under which monetary/exchange rate policy was being run. The reaction function thus allows researchers to test whether various motivations for interventions have any empirical support.

A critical modelling issue is the non-standard distribution of the intervention time series. On most days there are no interventions and when they occur, they are sporadic and are often in clusters. In the case of the BOJ, 89.9% of the days in our sample recorded no intervention. Therefore, when modelling a reaction function, one must allow for the large number of zero observations as well as the distribution pattern. Thus, a standard OLS regression model is inappropriate as the estimated coefficients will not have standard distributions and will be rendered uninterpretable. Many studies thus have instead used alternative methods. These include Logit (Frenkel, Pierdzioch and Stadtmann, 2005), Probit (Ito and Yabu, 2007; Frenkel, Pierdzioch and Stadtmann, 2004) and Friction models (Almekinders and Eijfinger, 1996; Kim and Sheen, 2006). In this paper we adopt and modify Kim and Sheen (2006)'s approach. The major enhancement in our model is that we consider overnight and intraday exchange rate returns, return volatility and a broader measure of market uncertainty as potential determinants. This allows us to make additional inference on how the BOJ responded to market disorderliness in the domestic and off-shore markets.

3.1. Determinants of intervention

3.1.1. Exchange rate deviations

The BOJ states (BOJ, 2000) that one of its intervention objectives is to mitigate negative influences on the Yen exchange rates. As such, it may respond to either raw deviations or deviations from a trend. A common measure is to use a moving average as the trend and calculate the deviations from it. In our case, we use a relatively simple definition of log exchange rate returns over each horizon instead of deviations from some trend for each horizon to avoid high correlations between overnight and intradaily return trends.

We also model those exchange rate changes that persist over a few periods. We use a dummy variable for persistent changes that is defined independently for each of the two horizons. The intradaily persistence dummy takes the value of one if either of the following two scenarios is observed: exchange rate return for the intraday horizon is positive for all three preceding intradaily horizons or the return is negative in all the aforementioned periods.[6] Otherwise it takes the value of zero. The overnight persistence dummy is similarly defined and takes the value of positive one if overnight return is positive in three consecutive overnight periods or if all returns are negative. The dummy takes the value of zero otherwise.

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[6] We tried a number of alternatives of 2, 3, 4 and 5 days, and the results obtained are fundamentally the same as the ones reported for 3 days.

This dummy is multiplied by the exchange rate return for their respective horizons. This then allows us to deduce the cumulative effect of persistence over the raw exchange rate returns.

3.1.2. Exchange rate volatility

We proxy the exchange rate volatility by a conditional volatility series for each horizon from a univariate E-GARCH(1,1) model. The GARCH family of models have been used extensively in the intervention literature as many claim that daily return volatility is predictable in most financial markets.[7] We also attach a directional dummy to the volatility series that takes the value of one if the Yen/USD exchange rate return is positive (i.e. a Yen depreciation) and negative one if the return is negative on a given day. This allows us to draw some inference on the differential reaction of the BOJ to volatility associated with a Yen appreciation or a depreciation. There is a possibility that the BOJ may withhold from intervening if volatility levels are perceived to be too high. On days following high volatility, the BOJ may feel that intervention might be impotent, and they (particularly small ones) may just add to the level of uncertainty apparent in the market rather than resolving it. To account for this, we include a volatility size dummy to test for different responses when the volatility level is in the top 25% of all observations.[8]

3.1.3. A broad measure of market disorderliness – transaction cost band of CIP

For the overnight horizon, we also use a broader measure of market disorderliness. We use a one-month covered interest arbitrage (CIP) transaction cost band (TCB) generated from bid and ask quotes of spot and one-month forward Yen/USD exchange rates and one-month bid and ask rates on eurodollar and euroyen interest rates in the London market. The TCB is

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[7] We chose to use the E-GARCH(1,1) model over the ubiquitous GARCH(1,1) model because the former is more suited to modelling wider variations in the volatility series which is the case for the overnight horizon.

[8] We also investigated various thresholds, 10, 25, 50%. The results are similar to what is reported in the paper.

essentially a measurement of the distance between the upper and lower bounds around the exact CIP condition in which no arbitrage would occur. It is defined as,

TCB = $\left(\frac{F_a}{S_b} - \frac{1+i_b}{1+i_a^*}\right) - \left(\frac{F_b}{S_a} - \frac{1+i_a}{1+i_b^*}\right)$, where S and F are spot and forward Yen/USD rates, i and i^* are one month euroyen and eurodollar interest rates, and subscripts a and b refer to ask and bid, respectively.[9] The TCB is useful for explaining the intervention decision because the parity condition incorporates the forward market risk premia and interest rate differential between foreign and domestic securities. Turbulence in the debt and forward market segments would be reflected in the TCB and can also impact on the spot exchange rate. Thus, the TCB is a more comprehensive measure of market disorderliness, encapsulating an overall measure of market uncertainty that exchange rate volatility alone can not convey. [10]

3.1.4. Lagged intervention

It is shown in Table 1 that the BOJ often intervened on successive days in order to support the initial intervention. The probability of an intervention on day *t* given there was an intervention on day *t-1* is 62% for the whole sample. We include a lagged intervention term to account for this aspect.

3.2. The friction model of intervention reaction function

Using the potential intervention determinants discussed above we write the desired intervention reaction function for the BOJ as:

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[9] The calculations of and further information on the TCB can be found in Bhar et. al. (2004).

[10] It is possible that the TCB is correlated with the overnight return volatility since they both are proxies for the level of market disorderliness. The actual correlation coefficient, however, is -0.011, and so there is no potential for multicollinearity in the estimations.

$$
\begin{aligned}
Intv_t = & \left(\alpha^{ID} + \alpha^{ID}_{Pers} \cdot I^{ID}_{Pers,t-1}\right) \cdot R^{ID}_{t-1} + \left(\alpha^{ON} + \alpha^{ON}_{Pers} \cdot I^{ON}_{Pers,t-1}\right) \cdot R^{ON}_{t-1} \\
& + \left(\beta^{ID} \cdot I^{ID}_{ds,t-1} + \beta^{ID}_{Size} \cdot I^{ID}_{ds,t-1} \cdot I^{ID}_{hsize,t-1}\right) \cdot h^{ID}_{t-1} \\
& + \left(\beta^{ON} \cdot I^{ON}_{ds,t-1} + \beta^{ON}_{Size} \cdot I^{ON}_{ds,t-1} \cdot I^{ON}_{hsize,t-1}\right) \cdot h^{ON}_{t-1} \\
& + (\phi \cdot I^{TCB}_{ds,t-1} + \phi \cdot I^{TCB}_{ds,t-1} \cdot I^{TCB}_{size,t-1}) \cdot TCB_{t-1} + \delta \cdot Intv_{t-1} + \varepsilon_t
\end{aligned}
\tag{1}
$$

Where:

$Intv_t$ = Net market purchase of USD by BOJ measured in Yen '00 billions.

ID, ON = Tokyo Intraday horizon, Overnight off-shore horizon.

$I^{ID}_{Pers,t-1}$ ($I^{ON}_{Pers,t-1}$) = An indicator variable that takes the value of one if intraday Tokyo return, R^{ID}_{t-1}, (overnight return, R^{ON}_{t-1}) is either positive or negative for the current and past three consecutive intraday (overnight) horizons.

$I^{ID}_{ds,t-1}$ ($I^{ON}_{ds,t-1}$) = An indicator variable that takes the value of positive one if R^{ID}_{t-1} (R^{ON}_{t-1}) is positive or negative one if it is negative.

$I^{ID}_{hsize,t-1}$ ($I^{ON}_{hsize,t-1}$)= An indicator variable that takes the value of one if intraday (overnight) volatility on day *t-1* is in the top 25% of all observed intraday (overnight) volatilities.

$I^{TCB}_{ds,t-1}$ = An indicator variable that takes the value of positive one if Yen/USD return in London is positive or negative one if it is negative.

$I^{TCB}_{Size,t-1}$ = An indicator variable that takes the value of one if the TCB in overnight London markets on day *t-1* is in the top 25% of all observed TCB's.

The intervention function shown in (1) represents the BOJ's desired intervention in the absence of fixed costs. Since we have a large proportion of zero observations for the dependent variable, it is reasonable to assume that there exist positive and negative thresholds of intervention which represent potential fixed costs. We denote these thresholds θ^+ and θ^-, respectively. An actual positive intervention at the desired value estimated in equation (1) will only take place if the desired value is greater than θ^+ and conversely, a negative intervention will only take place if the desired value is less than θ^-. Otherwise, no intervention takes place. The likelihood function with the three distinct distributional characteristics is shown below.

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

where Φ is the standard normal cumulative distribution function.

3.3. Expected results

The literature suggests that the BOJ intervention is largely of an LATW variety. As such, we expect both α^{ID} and α^{ON} to be negative, that is, a Yen appreciation (i.e. R_t<0) encourages a purchase of the USD (Yen sale). On the other hand, it is possible that BOJ might refrain from intervening if observed exchange rate movement has been a part of a strong trend. If so, we expect the coefficients for the persistent dummies, α^{ID}_{Pers} and α^{ON}_{Pers} to be positive and so they would offset to some extent the negative overall intervention coefficients.

When central banks intervene in response to market volatility, they often do so with the aim of calming the market turbulence mostly through the signalling channel. On the other hand, the noise trading channel of Hung (1997) posits that central banks may intervene to increase short-term volatility and force investors to second guess the on-going market momentum. However, the direction of intervention will depend on whether the currency is appreciating or depreciating at the time of high volatility. If the BOJ identifies high volatility in the foreign exchange market whilst Yen is depreciating, one would expect it to attempt to calm the market by purchasing Yen (a negative intervention). Conversely, we expect an intervention sale of Yen (a positive intervention) if volatility is high with Yen appreciating. Therefore, we again expect the coefficients for volatility in both horizons, β^{ID} and β^{ON}, to be negative. We also test for a non-linearity in the BOJ's response to volatility levels in the market. We conjecture, that in times of high volatility, the BOJ may withhold from entering the market as the intervention may either go unnoticed or may actually further confuse the market and exacerbate the market disorderliness. Kim and Sheen (2002) find such a size effect in the reaction function for the Reserve Bank of Australia. As such, we expect the coefficients for the size dummies in both horizons, β^{ID}_{Size} and β^{ON}_{Size}, to be positive to offset the negative coefficients expected for the volatility terms.

We expect a widening TCB would encourage the BOJ's LATW interventions. As we tagged the TCB with an exchange rate change dummy, $I^{TCB}_{ds,t-1}$, we expect its coefficient, ϕ, to be negative. That is, a widening TCB while Yen is depreciating would lead to a Yen purchase. Similarly, we expect the size dummy for TCB, ϕ_{Size}, to be positive for the same reason as above for the volatility. That is, on the days following an unusually large TCB in the overnight London markets, the BOJ may choose not to intervene.

4. Empirical results

Table 3 reports the estimation results of model (1). There are considerable differences in the estimated reaction functions amongst the three sub-samples. The full sample results are also included for completeness. One cannot, however, extract much meaning from the full sample estimations as the differences in policy across the three sample periods often cause the mean full sample effect to be insignificant or rendered indeterminate.

4.1. Pre-Sakakibara period: 13 May 1991 to 20 June 1995 (Sample 1)

The BOJ responded only to previous day's intradaily exchange rate returns as shown by significant and negative α^{ID} which is suggestive of LATW interventions. The BOJ was not concerned with the exchange rate developments during the preceding off-shore hours. In response to a one percent appreciation (depreciation) of Yen in Tokyo the day before, the BOJ sold 9.3 billion Yen. Although, this suggests that the BOJ responded exclusively to the developments in Tokyo market, it is consistent with other researchers who suggest that the BOJ leaned against the wind (Kim and Sheen, 2006; Frenkel *et al.,* 2004; Ito and Yabu, 2007).

The intradaily volatility coefficient, β^{ID}, is negative and significant. As the volatility values are tagged by a dummy variable to indicate whether Yen was appreciating or depreciating with volatility, the sign of the coefficient can be used to infer whether the interventions responding to high volatility were made with or against the market movements. The negative coefficient indicates that the interventions were used for market calming influences by LATW in times of high volatility. This result is in contrast to the existing literature where no strong evidence is reported on the BOJ responding to exchange rate volatility.[11] This is despite such response is recorded for the interventions of other central banks.[12] We attribute our finding to the fact that the 24 hour horizon used in the previous BOJ intervention studies is too coarse to accurately map what the BOJ was responding to. By disaggregating the low and insignificant responses to overnight volatility and the significant responses to intradaily volatility, we uncover the fact that the BOJ indeed paid attention to market volatility. It was a matter of which volatility that the BOJ was responding to.

The coefficient for the high volatility dummy, β^{ID}_{Size}, is positive but is not significant. The volatility coefficient estimated for the overnight horizon, β^{ON}, has no effect on the intervention decision. Nor is there a size effect for a different response to excessive volatility observed in the overnight horizon. In addition, the coefficient for the TCB is insignificant. Thus, it seems that the BOJ paid no attention to overnight market developments.

The coefficient for the lagged intervention term, δ, is significant as expected. It shows that given an intervention on day *t-1*, the BOJ was likely to intervene on day *t* in the same direction but at 1.5 times the size, on average, of the previous day. This may be due to two factors. First, the BOJ may feel that the initial intervention was successful and wants to ride the market in the desired direction with larger supporting interventions, particularly if the currency was greatly misaligned. Second, the initial intervention may have been unsuccessful

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[11] One exception is Frenkel et al. (2005) who report some limited influence of lagged Yen return volatility measured as the absolute return for the period 1991 to 2001. However, they do not address the significant differences between the pre-95 and the post-95 samples and so the overall sample results they report may not fully reflect the underlying relationship.

[12] The US Federal Reserve and German Bundesbank have been well documented to react to increases in volatility (Baillie and Osterberg, 1997; Almekinders and Eijffinger, 1996) along with the Reserve Bank of Australia (Kim and Sheen, 2002).

but the BOJ's need to affect the exchange rate level was such that they would make a larger intervention the next day in the hope that it would send a stronger signal to the market.

The positive and negative intervention thresholds (θ^+, θ^-) are highly significant. This is consistent with the previous research that include a loss function for intervention (Almekinders and Eijffinger 1996; Ito and Yabu 2007; Kim and Sheen 2002, 2006). The negative threshold is significantly larger (42%) in magnitude than the positive one suggesting that the BOJ was more forgiving of Yen depreciations. The economic backdrop during the first sample also accentuates why the BOJ would respond more fiercely to Yen appreciations. In the early 1990s, the Japanese stock market crashed and the economy fell into a deep recession. At the same time Yen was steadily appreciating against the USD which continued through to 1995. The stronger Yen created additional pressures on the Japanese economy as it struggled to remain competitive in the world markets. Apparently, the BOJ's intervention efforts were used to combat the effects of the recession.

In sum, the BOJ considered only the first and second moment developments in the previous day's Tokyo market ignoring the overnight off-shore market developments in making its intervention decisions.

4.2. Sakakibara period: 21 June 1995 to 31 December 2002 (Sample 2)

The average intervention is over ten times larger than in the first sample and this explains the larger coefficients in the second sample estimations. The intradaily intervention coefficient, α^{ID}, is again significant and negative. A one percent Yen appreciation led to a 253 billion Yen sale, and this is more than 25 times larger in magnitude compare to the first sample response. More importantly, we find evidence that the overnight returns had a significant influence on the intervention decision[13]. The coefficient, α^{ON}, is negative

[13] As a robustness check, we included contemporaneous intradaily returns and volatility in addition to (and in place of) the lagged counterparts in model (1). Although, lagged intradaily results are not affected (negative

implying that the interventions leaned against the overnight wind to counter any undesirable overnight developments from persisting into the domestic market. A one percent Yen appreciation during overnight hours invited a 671 billion Yen sale in the subsequent Tokyo trading hours, and this is nearly three times the size of the BOJ's response to lagged intradaily returns. This suggests that not only did the BOJ monitor overnight movements but they valued this information more than previous day's intradaily information. This is consistent with the intervention philosophy during the second sample. The BOJ not only leaned against the wind but, on occasions, it also aggressively pursued the first moment objectives. Ito (2002) states that "The intervention was conducted to change actively the level of the yen/dollar rate…". Thus, it is of vital importance to base intervention decisions on the most current Yen movements. Considering that the BOJ interventions were normally carried out in Tokyo, the most recent Yen trend to be considered is from the overnight period. Thus, our finding that the BOJ paid attention to both domestic and off-shore Yen movements and responded to both only during sample 2 reflects such a shift in intervention focus.

Furthermore, the persistence dummy, α^{ON}_{Pers} is significantly positive. On normal days (i.e. no persisting Yen trends, $I^{ON}_{Pers,t-1}$=0), the effect on the intervention decision is captured solely by α^{ON}. However, on the days following persistent overnight trends (persisting over three days, $I^{ON}_{Pers,t-1}$=1), the overall impact is the sum of α^{ON} and α^{ON}_{Pers}. Since they are in opposite signs and their absolute magnitudes are statistically indistinguishable from each other (p-value of 0.8441), the sum is not statistically different from zero. That is, on these

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coefficient), the contemporaneous intradaily Yen return is significantly positive in sample 2. However, this may be a result of simultaneity bias. There is evidence that interventions during this period were highly effective in moving the exchange rate in the desired direction (a Yen sale leading to a Yen depreciation) and hence the positive contemporaneous intradaily coefficient might simply reflect this.

days a net effect on intervention is zero. The BOJ stayed out of the market if the overnight trend was persisting since the cost of intervention would be too high and its effect minimal.

Again, we find the intradaily volatility coefficient, β^{ID}, significant and negative. The intervention coefficients are again larger due to the larger average interventions in the second sample. Therefore, even after the significant policy change in 1995, the BOJ continued its attempts at reducing exchange rate volatility through Yen interventions. This time, however, we also find a significant offsetting size effect (p-value of 0.9052 of the equality restriction of the two coefficients in absolute terms), suggesting that the BOJ refrained from intervening on the days following unusually high volatility in the Tokyo market. This result is consistent with the finding of Kim and Sheen (2002) for the Reserve Bank of Australia.

The intervention thresholds (θ^{+}, θ^{-}) are again highly significant and are much larger than those in the first sample. The BOJ was much more tolerant on the adverse market movements than in the first sample. The asymmetry between the positive and negative thresholds is also present. The BOJ was more lenient when faced with a Yen depreciation than an appreciation. In fact, during the second sample the BOJ made only six negative interventions (Yen purchases) out of a total of 49 interventions. Those six interventions were made at the time of the Asian currency crisis as a defensive measure against the contagion effects that threatened to spread from the other Asian countries.

In short, we find that the BOJ responded far more energetically to market disorderliness paying attention to both lagged overnight and intradaily market developments during the Sakakibara period.

4.3. Recent period: 2 Jan 2003 to 16 March 2004 (Sample 3)

The recent period is characterised by much more frequent but still large magnitude interventions. This time, there is no significant response to Yen return movements. Neither lagged intradaily nor overnight offshore return movements led to interventions. However, the lagged intradaily volatility still elicited LATW interventions with the BOJ staying out of the market on days with unusually high volatility. Moreover, there is now strong evidence of the BOJ responding to the TCB widening. The coefficient for the TCB is now significant and negative, however, the size effect for the TCB is insignificant. This suggests that the BOJ carried out LATW interventions in response to a widening of the TCB.

Thus, during the recent period, the BOJ seemed to have responded only to market disorderliness as measured by increasing lagged intradaily return volatility and by the overall measure of market uncertainty from the overnight offshore market. This is consistent with the change in the intervention philosophy where the BOJ concentrated on market calming instead of pursuing mean objectives.

4.4. Public vs. secret interventions

The second section of rows in Table 1 shows the break-down of interventions into those that were publicly known as they occurred (public) and those that the market was unaware (secret).[14] Public intervention dominated the Pre-sakabibara and the Sakakibara periods, whereas secret intervention dominated the recent period. Seventy four percent of interventions can be classified as secret, compared to 16% and 6% for the first two periods, respectively. We argue that the BOJ kept most of its intervention transactions under wraps during the recent period for the purpose of achieving market calming. Central banks often intervene in secrecy to induce noise traders (see Hung, 1997) in such a way as to stimulate heterogeneity in the market and hence the shorter term volatility, aiming to break bandwagon effects. Thus, the decision to intervene secretly may be influenced by a different set of fundamentals compared to publicly known interventions.

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[14] We examined press reports (via Factiva database) on the day and the day after the BOJ intervention, and classify public interventions as those that any news report clearly states that the BOJ was in the market and intervened. If an official intervention was not reported or not confirmed by any news reports, the intervention is then classified as secret.

To investigate this possibility, we estimate the BOJ reaction function (1) separately for secret and public interventions. We concentrate on the recent period as the earlier periods do not have enough observations for secret interventions to allow separate estimations. The results are reported in Table 4. The results for public interventions are identical to the overall results reported in Table 3. For secret interventions, a significant response is shown to lagged intradaily Yen returns. Since there were only Yen sale interventions during the sample, the positive and significant α^{ID} suggests that the BOJ covertly sold Yen when it was depreciating the day before. We conjecture that the aim was to stimulate heterogeneity in the market. This would discourage uninformed and liquidity traders from the market leading to a reduction in volume and an eventual fall in the volatility. However, the BOJ's responses to the lagged intradaily volatility and a persistent trend in the overnight volatility remain LATW in nature. The BOJ sold Yen in response to the higher volatilities that were associated with Yen appreciation by selling Yen (both on public and secret intervention basis). Thus, the mode of the BOJ's interventions depended on whether Yen appreciated or depreciated during the day before in the Tokyo market.

5. Conclusion

The main theme of this paper has been to explore to what extent the foreign exchange market developments during both the intradaily on-shore Tokyo and overnight off-shore horizons determined the BOJ's Yen intervention decisions for the period from 13 May 1991 to 16 March 2004. The literature has thus far utilized coarse daily data and the BOJ's reaction functions estimated provide an incomplete picture. This paper is the first research that investigates the relative importance of different market segments in the 24-hour Yen trading in relation to the BOJ's intervention reaction function. We uncovered the details of intervention determinants that the previous researchers failed to observe, and so the results we report provide an important additional layer of understanding.

Specifically, we document the shifting focus of BOJ's intervention reaction function over the three sub periods we considered. Prior to June 1995, the BOJ was responsive only to market developments during the previous day's intradaily Tokyo trading hours. However, during the period June 1995 to Dec 2002 it also responded to overnight off-shore market returns. In fact, the overnight Yen movements yielded more influence (nearly three times) than the previous day's Tokyo market movements. During the recent period of Jan 2003 to Mar 2004, the BOJ responded only to lagged intradaily volatility and to an overall measure of market uncertainty proxied by a transaction cost band around one-month covered interest rate parity condition. In addition, we show that most of the interventions during this period were not publicly known (or secret) as they occurred, and the BOJ secretly 'leaned into the wind' when Yen depreciated during the previous day's intradaily Tokyo market.

In all, our investigation yielded much richer evidence of time varying nature of intervention determinants than the current literature. The fact that we found significance for volatility (and a general measure of market disorderliness) as a major driving force of an intervention decision whilst others, in general, do not could be due to our noble approach of disaggregating holding periods. Thus, our evidence on the relative importance of off-shore vs. on-shore movements of the determinants adds significantly to the intervention literature.

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Figure 1: Trading hours of Tokyo London and New York FX markets

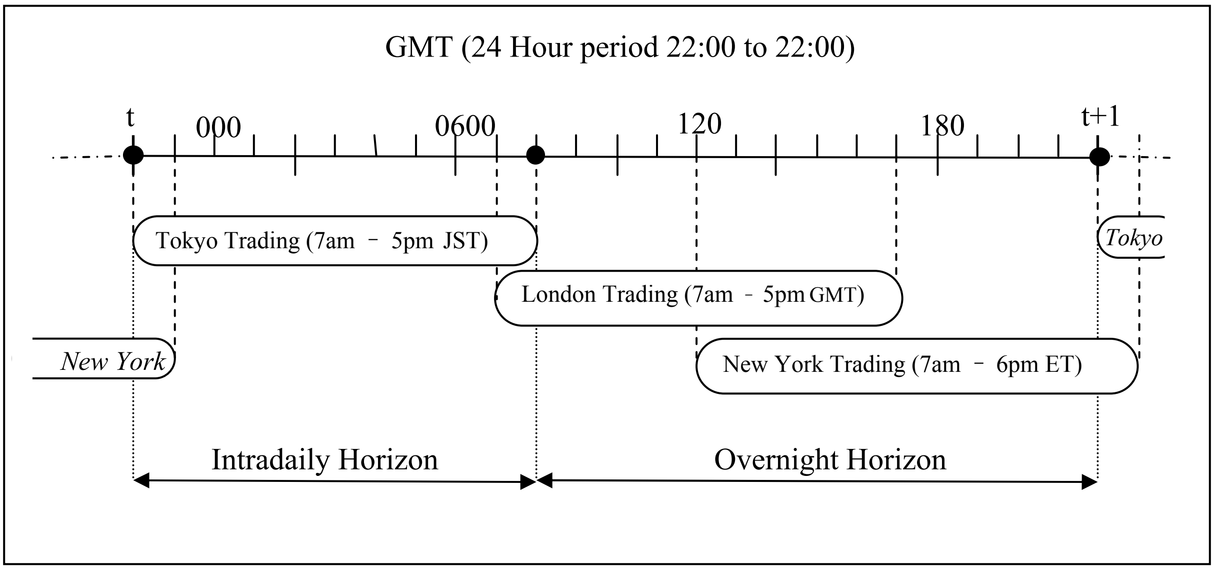

Figure 2: Tokyo closing Yen/USD rate and BOJ interventions

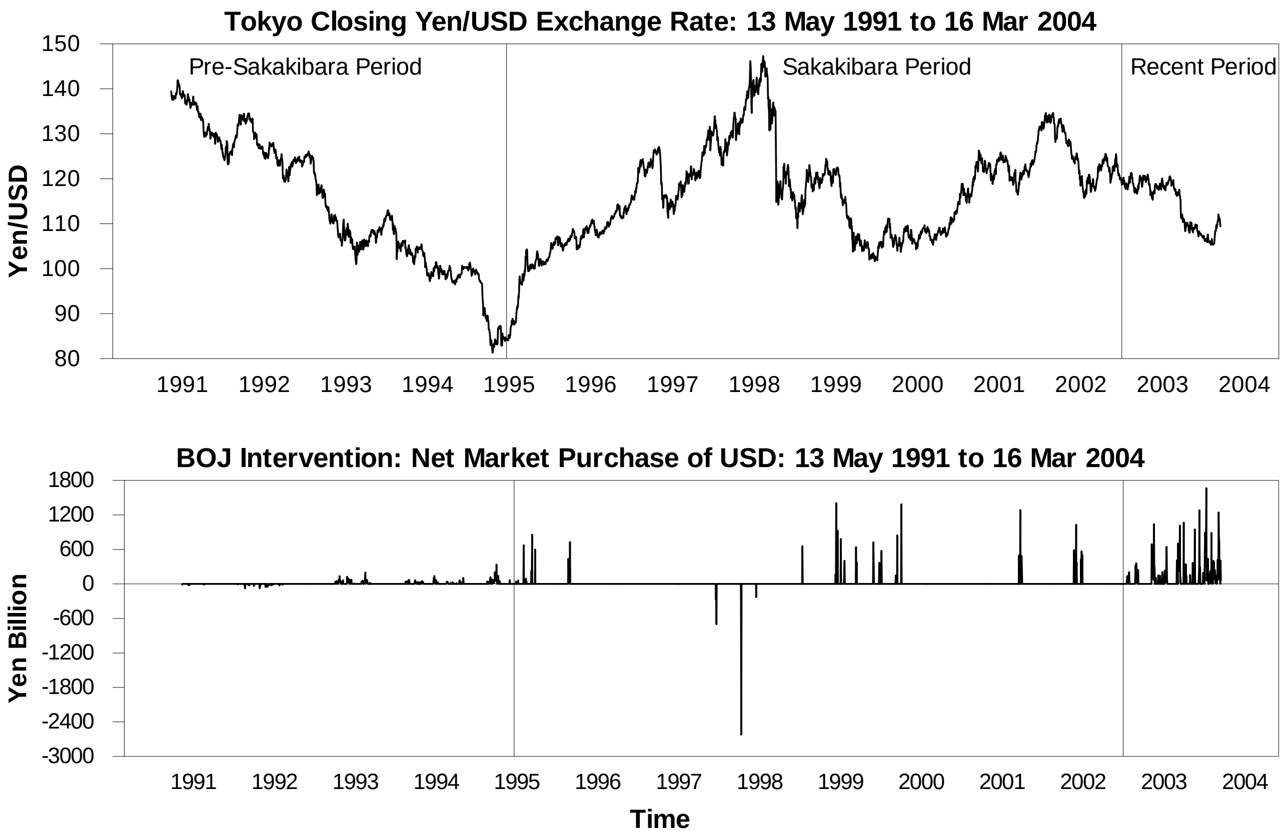

Table 1: BOJ intervention statistics

	Sample 1 Pre-Sakakibara *13 May 1991 - 20 Jun 1995*	**Sample 2** Sakakibara *21 Jun 1995 - 31 Dec 2002*	**Sample 3** Recent Period *2 Jan 2003 - 16 Mar 2004*	**Full Sample** *1 Apr 1991 - 16 Mar 2004*
Frequency of Interventions (No. of Days)				
Sale of Yen	139	43	129	311
(% of business days)	(12.61%)	(2.19%)	(25.80%)	(9.17%)
Purchase of Yen	27	6	-	33
(% of business days)	(2.45%)	(0.31%)	-	(0.97%)
Total	**166**	**49**	**129**	**344**
(% of business days)	**(15.06%)**	**(2.49%)**	**(25.80%)**	**(10.14%)**
Publicly known and secret interventions [(a)]				
Publicly known interventions	**140**	**46**	**33**	**219**
(% of total interventions)	(84.34%)	(93.88%)	(25.58%)	(63.66%)
Secret interventions	**26**	**3**	**96**	**125**
(% of total interventions)	(15.66%)	(6.12%)	(74.42%)	(36.34%)
Size of Intervention (Billions of Yen)				
Average Sale of Yen	50.2	496.5	271.9	203.9
Average Purchase of Yen	29.2	684.4	-	148.3
Average Absolute Intervention	**46.8**	**519.5**	**271.9**	**198.5**
Largest Intervention (Billions of Yen)				
Sale of Yen	338.8	1405.9	166.4	1666.4
Purchase of Yen	76.9	2620.1	-	2620.1
Smallest Intervention (Billions of Yen)				
Sale of Yen	5.1	43	0.1	0.1
Purchase of Yen	3.2	76.4	-	3.2
Cumulative Intervention Probabilities				
$P(Intv_t \neq 0 \mid Intv_{t-1} = 0)$	0.07	0.019	0.060	0.04
$P(Intv_t \neq 0 \mid Intv_{t-1} \neq 0)$	0.61	0.245	0.767	0.62
$P(Intv_t \neq 0 \mid Intv_{t-1} \neq 0 \;\&\; Intv_{t-2} \neq 0)$	0.42	0.082	0.605	0.44

(a) Publicly known interventions are defined as those that were reported by financial press (both real time and daily press). We use the online Factiva database which provides a searching tool for news reports from multiple sources, including the Reuters News, the Wall Street Journal and the Financial Times. The newswire reports provided by the Reuters News and the Dow Jones Newswires, for example, ensure that news from the foreign exchange market is transmitted into reports on a real time basis. For every official intervention day, we search for any news report which clearly states that the BOJ was in the foreign exchange market and intervened through their purchases or sales of Yen. Such an intervention is classified as a public intervention. If an official intervention was not reported or not confirmed by any news reports, the intervention is then classified as secret.

Table 2: Summary statistics of Yen/USD returns over intraday, overnight and daily horizons

Sample 1: Pre-Sakakibara Period
13 May 1991 - 20 June 1995

	Intradaily		Overnight		Daily	
Summary Statistics						
Mean	-0.0290		-0.0172		-0.0466	
Variance	0.4119		0.0511		0.4579	
Skewness	-0.1806		-3.5649		-0.4014	
Excess Kurtosis	5.0702		52.8872		4.5991	
Jarque-Bera Normality	1186		130765		1001	
Q(20)	14.0096	{0.8300}	27.9930	{0.1096}	19.4568	{0.4923}
$Q^2(20)$	78.7693 ***	{0.0000}	10.3807	{0.9607}	64.7511 ***	{0.0000}
Unit Root Tests						
ADF	-33.3392 ***		-31.4787 ***		-34.7553 ***	

Sample 2: Sakakibara Period
21 June 1995 - 31 December 2002

	Intradaily		Overnight		Daily	
Summary Statistics						
Mean	0.0066		0.0106		0.0173	
Variance	0.5408		0.0600		0.6099	
Skewness	-1.3615		-0.5491		-1.2141	
Excess Kurtosis	13.1472		31.9298		10.6767	
Jarque-Bera Normality	14766		83614		9821	
Q(20)	28.7958 *	{0.0919}	13.9500	{0.8330}	26.4952	{0.1501}
$Q^2(20)$	537.9100 ***	{0.0000}	193.9501 ***	{0.0000}	525.9347 ***	{0.0000}
Unit Root Tests						
ADF	-43.2373 ***		-44.3141 ***		-44.8247 ***	

Sample 3: Recent Period
2 January 2003 - 16 March 2004

	Intradaily		Overnight		Daily	
Summary Statistics						
Mean	-0.0373		0.0115		-0.0258	
Variance	0.2519		0.0360		0.3057	
Skewness	0.0228		0.2103		-0.4160	
Excess Kurtosis	0.5954		14.2440		3.2623	
Jarque-Bera Normality	5		2665		149	
Q(20)	18.4776	{0.5560}	20.8134	{0.4082}	22.7513	{0.3012}
$Q^2(20)$	23.2850	{0.2750}	104.2719 ***	{0.0000}	13.2039	{0.8685}
Unit Root Tests						
ADF	-18.7116 ***		-18.3548 ***		-19.1763 ***	

Full Sample
13 May 1991 - 16 March 2004

	Intradaily		Overnight		Daily	
Summary Statistics						
Mean	-0.0100		0.0017		-0.0085	
Variance	0.4720		0.0549		0.5148	
Skewness	-0.9993		-1.3837		-0.9641	
Excess Kurtosis	11.2770		37.7610		9.6285	
Jarque-Bera Normality	18538		202609		13628	
Q(20)	25.2479	{0.1921}	11.3444	{0.9368}	24.3042	{0.2294}
$Q^2(20)$	778.9390 ***	{0.0000}	153.3006 ***	{0.0000}	555.2776 ***	{0.0000}
Unit Root Tests						
ADF	-57.4078 ***		-57.2608 ***		-56.9943 ***	

The table above presents summary statistics for intradaily, overnight and daily exchange rate returns for each sample period. Q(20) and $Q^2(20)$ are the Ljung-Box Q-Tests of serial correlation of the return and squared return respectively. ADF is the Augmented Dickey-Fuller test with constant trend and appropriate lags. *, **, *** indicate significance at the 10%, 5% and 1% level respectively.

Table 3: Estimation results for the BOJ intervention reaction function

$$\begin{aligned} Intv_t = & \left(\alpha^{ID} + \alpha^{ID}_{Pers} \cdot I^{ID}_{Pers,t-1}\right) \cdot R^{ID}_{t-1} + \left(\alpha^{ON} + \alpha^{ON}_{Pers} \cdot I^{ON}_{Pers,t-1}\right) \cdot R^{ON}_{t-1} \\ & + \left(\beta^{ID} \cdot I^{ID}_{ds,t-1} + \beta^{ID}_{Size} \cdot I^{ID}_{ds,t-1} \cdot I^{ID}_{hsize,t-1}\right) \cdot h^{ID}_{t-1} \\ & + \left(\beta^{ON} \cdot I^{ON}_{ds,t-1} + \beta^{ON}_{Size} \cdot I^{ON}_{ds,t-1} \cdot I^{ON}_{hsize,t-1}\right) \cdot h^{ON}_{t-1} \\ & + (\phi \cdot I^{TCB}_{ds,t-1} + \phi \cdot I^{TCB}_{ds,t-1} \cdot I^{TCB}_{size,t-1}) \cdot TCB_{t-1} + \delta \cdot Intv_{t-1} + \varepsilon_t \end{aligned}$$

	Sample 1		**Sample 2**		**Sample 3**		**Full Sample**	
	Pre-Sakakibara period		Sakakibara period		Recent period			
	13 May 1991 - 20 June 1995		*21 June 1995 - 31 December 2002*		*2 January 2003 - 16 March 2004*		*13 May 1991 - 16 March 2004*	
	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
α^{ID}	-0.0931 ***	{0.0089}	-2.5272 ***	{0.0000}	1.1237	{0.1369}	-0.6384 ***	{0.0000}
α^{ID}_{Pers}	-0.0828	{0.1642}	0.1374	{0.9418}	0.1549	{0.9043}	-0.5308 *	{0.0968}
α^{ON}	-0.0572	{0.7284}	-6.7143 ***	{0.0003}	-0.8087	{0.4987}	-1.2441 ***	{0.0047}
α^{ON}_{Pers}	-0.2119	{0.6706}	7.2529 ***	{0.0000}	-17.5753	{0.4474}	0.4343	{0.9019}
β^{ID}	-0.3696 ***	{0.0000}	-1.3451 **	{0.0285}	-3.6403 **	{0.0151}	-1.7454 ***	{0.0000}
β^{ID}_{Size}	0.0950	{0.1717}	1.2135 **	{0.0324}	4.6286 ***	{0.0013}	1.5870 ***	{0.0000}
β^{ON}	-0.8822	{0.2420}	17.8797	{0.2002}	-3.8364	{0.7736}	-1.3276	{0.6114}
β^{ON}_{Size}	1.1762	{0.1918}	-27.5911	{0.1342}	-13.4010	{0.3852}	1.2380	{0.7158}
ϕ	0.1150	{0.4220}	1.5755	{0.6387}	-5.0057 ***	{0.0088}	-1.1566 *	{0.0710}
ϕ_{Size}	-0.0651	{0.7496}	-0.7332	{0.8997}	2.7388	{0.3779}	-0.1451	{0.9006}
σ	0.6955 ***	{0.0000}	13.6833 ***	{0.0000}	3.8590 ***	{0.0000}	4.7560 ***	{0.0000}
$\theta+$	0.9984 ***	{0.0000}	28.6733 ***	{0.0000}	2.3546 ***	{0.0000}	7.0986 ***	{0.0000}
$\theta-$	-1.4186 ***	{0.0000}	-37.9036 ***	{0.0000}	-26.6005 ***	{0.0000}	-11.4133 ***	{0.0000}
δ	1.4561 ***	{0.0000}	1.8867 ***	{0.0000}	0.8491 ***	{0.0000}	1.1645 ***	{0.0000}
Log-L	-448		-364		-447		-1715	

This table reports the friction model estimation results for the three sub-periods as well as the full sample period of 1991 – 2004. Overall interventions variable, $Intv_t$, is explained as a function of intradaily and overnight developments in the first and second moments of the exchange rate and the Transaction Cost Band that proxies the overall market disorderliness of the overnight overseas markets. The Numbers in curly braces are p-values. ***, **, * represent significance at one, five and ten percent, respectively.

Table 4: Reaction function estimations for public and secret interventions during the recent period

$$Intv_t^P, Intv_t^S = \left(\alpha^{ID} + \alpha_{Pers}^{ID} \cdot I_{Pers,t-1}^{ID}\right) \cdot R_{t-1}^{ID} + \left(\alpha^{ON} + \alpha_{Pers}^{ON} \cdot I_{Pers,t-1}^{ON}\right) \cdot R_{t-1}^{ON}$$
$$+ \left(\beta^{ID} \cdot I_{ds,t-1}^{ID} + \beta_{Size}^{ID} \cdot I_{ds,t-1}^{ID} \cdot I_{hsize,t-1}^{ID}\right) \cdot h_{t-1}^{ID}$$
$$+ \left(\beta^{ON} \cdot I_{ds,t-1}^{ON} + \beta_{Size}^{ON} \cdot I_{ds,t-1}^{ON} \cdot I_{hsize,t-1}^{ON}\right) \cdot h_{t-1}^{ON} \quad (1)$$
$$+ (\phi \cdot I_{ds,t-1}^{TCB} + \phi \cdot I_{ds,t-1}^{TCB} \cdot I_{size,t-1}^{TCB}) \cdot TCB_{t-1} + \delta \cdot Intv_{t-1} + \varepsilon_t$$

Where $Intv_t^P, Intv_t^S$ are Public and Secret interventions, respectively.

	Sample 3 - Recent period *2 January 2003 - 16 March 2004*			
	Public		Secret	
	Coefficient	P-Value	Coefficient	P-Value
α^{ID}	0.6769	{0.1722}	0.9720 ***	{0.0067}
α_{Pers}^{ID}	0.7000	{0.6546}	-0.6600	{0.4924}
α^{ON}	-1.7085	{0.1216}	0.7973	{0.2365}
α_{Pers}^{ON}	-18.3145	{0.6316}	-6.6088	{0.5598}
β^{ID}	-2.6341 ***	{0.0001}	-2.4917 ***	{0.0000}
β_{Size}^{ID}	3.1179 **	{0.0366}	2.9326 ***	{0.0017}
β^{ON}	-3.6420	{0.6442}	-2.1675	{0.5239}
β_{Size}^{ON}	-2.5117	{0.8526}	-11.2266 *	{0.0534}
ϕ	-3.2495 ***	{0.0082}	-3.5956 ***	{0.0013}
ϕ_{Size}	1.5637	{0.4774}	2.6198	{0.1403}
σ	3.3315 ***	{0.0000}	2.3057 ***	{0.0000}
θ+	2.4613 ***	{0.0000}	1.4585 ***	{0.0000}
θ-	-32.4555 ***	{0.0000}	-3086.8509 ***	{0.0000}
δ	0.6255 ***	{0.0000}	0.4449 ***	{0.0000}
Log-L	-419		-379	

This table reports the friction model estimation results for the three sub-periods as well as the full sample period of 1991 – 2004. Overall interventions variable, $Intv_t$, is partitioned into those that were reported by the Financial press the day after (public intervention, $Intv_t^P$) and those that were not detected by the market as they occur (secret intervention, $Intv_t^S$). These two types of interventions are modelled separately and the estimation results are reported in this table. Numbers in curly braces are p-values. ***, **, * represent significance at one, five and ten percent, respectively.